University of Tennessee, Knoxville
Trace: Tennessee Research and Creative Exchange

Masters Theses

Graduate School

8-2010

Effects of No-Tillage on Crop Yields and Net Returns Across the United States

Dustin Kevin Toliver
University of Tennessee - Knoxville, dtoliver@utk.edu

Recommended Citation

Toliver, Dustin Kevin, "Effects of No-Tillage on Crop Yields and Net Returns Across the United States. " Master's Thesis, University of Tennessee, 2010.
https://trace.tennessee.edu/utk_gradthes/754

To the Graduate Council:

I am submitting herewith a thesis written by Dustin Kevin Toliver entitled "Effects of No-Tillage on Crop Yields and Net Returns Across the United States." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Economics.

James A. Larson, Major Professor

We have read this thesis and recommend its acceptance:

Roland K. Roberts, Burton C. English, Daniel de la Torre Ugarte

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Dustin Toliver entitled "Effects of No-Tillage on Crop Yields and Net Returns Across the United States." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Economics.

James A. Larson, Major Professor

We have read this thesis
and recommend its acceptance:

Roland K. Roberts

Burton C. English

Daniel de la Torre Ugarte

Accepted for the Council:

Carolyn R. Hodges
Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

Effects of No-Tillage on Crop Yields and Net Returns Across the United States

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Dustin Kevin Toliver

August 2010

Acknowledgements

First and foremost I would like to thank my parents for always giving me the guidance and support to succeed in life and my fiancée Heather for putting up with all my moaning and groaning. I would also like to thank my brother, thinking of all the trials and tribulations he went through allows me to put everything in perspective and keep striving to be the best I can be. Everything I do is in remembrance of you; you are missed every second of every day. A thank you goes out to Dr. Larson for guiding me through this arduous process, without him this work would not have been possible. Thank you to Dr. Roberts for taking a chance on a History major and giving me the opportunity to further my education; thank you to Dr. English for locating the funding for me to attend graduate school and the valuable hands-on experience working with switchgrass, which will hopefully land me a job in the biofuels sector; and Dr. Ugarte for giving me a good laugh when I needed it. I think he will forever know me as the “soil guy.” My experience here has been a positive one; while difficult at times, I would never hesitate to recommend this program to anyone.

Abstract

Farmers are always looking for ways to increase yields and profits and no-tillage may be a way to achieve this goal. However, a comprehensive study of the performance of no-tillage yields relative to conventional tillage yields and their net returns is lacking. This study evaluated the potential factors that influence differences in conventional tillage and no-tillage yields and net returns as explained by such factors as time, crop, precipitation, soil texture and geographic region. Data were collected from 442 paired tillage experiments growing corn, soybeans, cotton, oats, wheat and sorghum published in three refereed journals. Data were evaluated using a mixed model and logit model respectively, to evaluate differences in mean yields and downside risk with no-tillage compared to tillage. Sorghum and wheat were found to have higher no-tillage yields relative to tillage. No-tillage was also found to outperform conventional tillage in the southern United States with just the opposite occurring in the northern U.S. A silty soil was also found to reduce no-tillage yields. Several factors were found to decrease the chance of downside risk with no-tillage, they were sorghum, sandy soil, Northern Crescent, Northern Great Plains, Prairie Gateway and Southern Seaboard regions. Two factors that increased the chance of lowered no-tillage yields were increased rainfall and length of use of no-tillage.

Differences in mean net returns and downside risk were evaluated using a mixed model and logit model. Results showed that no-tillage was more profitable than conventional tillage in the Mississippi Portal region, but less profitable in the Prairie Gateway. Net returns were lower for no-tillage wheat and soybeans when produced in a clay soil. Cotton grown in sand had higher no-till net returns, but increased rainfall decreased cotton net returns. A logit model showed certain factors decreased the probability of lower no-tillage net returns. There was less downside risk with wheat grown under no-tillage as well as less downside risk in the Southern Seaboard region and when no-tillage was used on a clay soil. There were factors that increased the probability of lower no-tillage net returns; increased precipitation, Northern Great Plains, Prairie Gateway and Basin & Range regions.

TABLE OF CONTENTS

LIST OF TABLES

TABLE **PAGE**

Part 2: Effects of Conservation Tillage on Crop Yields as Influenced by Crop, Region and Environmental Factors

Part 3: Effects of Conservation Tillage on a Farmer's Net Return

Part 1: Introduction

Introduction

The cultivation of land for growing crops has evolved through time. The plow was first developed in Mesopotamia around 4000-6000 BC (Lal et al. 2007). It was a simple wooden tool used for preparing the soil for crops. The next major revision of the plow came in the first century AD with the invention of the "Roman plow" which was made of metal (White 1967). This plow was used throughout the centuries with minor changes made along the way. The moldboard plow as we know it today was designed in 1784 by Thomas Jefferson. It was not until the 1830s that is was manufactured and marketed by a blacksmith named John Deere (Lal et al. 2007). With the event of the Dust Bowl, the moldboard plow came under scrutiny as it was blamed for causing the soil erosion that helped lead to the catastrophic losses of soils from farm fields (Faulker 1942). New cultivation and conservation tillage methods were developed and since the 1950s there has been a gradual transition from the moldboard plow to conservation tillage methods (Lal et al. 2007).

Conservation tillage is a practice that leaves at least 30 percent of the soil covered with crop residue (Frazee et al. 2005). Different types and forms of conservation tillage exist, such as no-tillage, strip-tillage, ridge-tillage and mulch-tillage (Frazee et al. 2005). Tillage of the land decreases soil moisture, increases soil temperature and diminishes soil organic carbon (SOC) (Lal 2004). SOC is organic carbon stored in the soil from decaying animal and plant residues (Global Terrestrial Observing System, Accessed on July 2010). The different methods of conservation tillage reduce the amount of tilling done to the soil and some forms like no-tillage, completely eliminate tillage. No-tillage is a farm management practice where seeds are planted directly into the untilled soil and weeds and competing vegetation are controlled with herbicides (Phillips et al. 1980).

No-tillage has been found to have many advantages that farmers and society as a whole may find beneficial. The residue left on the soil covers the surface helping keep soil temperatures down which is especially beneficial in warmer climates. No-tillage can also help conserve moisture which is advantageous during dry years and may also help reduce irrigation costs. Crop residues on the soil surface can drastically reduce wind and water erosion, and reduce air and water pollution. Improved soil productivity may occur from increased soil organic matter. Other potential advantages of using no-tillage include reduced fuel consumption, lower maintenance and repair costs and lower labor costs (Deen and Kataki 2003; Lankoski et al. 2004). No-tillage can increase a farm's economic performance through these reductions (Lankoski et al. 2004).

The Earth's average temperature has increased an estimated 0.7-1.4 degrees Fahrenheit since the Industrial Revolution of the late 1800s (Mastrandrea and Schneider 2005). This occurrence has commonly been called "global warming". Global warming is an increase in Earth's average surface temperature. There are many things believed to cause this warming effect. For instance, natural and human causes may have contributed to global warming. The main anthropogenic (human) causes of global warming are thought to be the burning of fossil fuels and land use changes such as deforestation and land cultivation (Mastrandrea and Schneider 2005). When fossil fuels are burned they release carbon dioxide, CO_2, into the atmosphere. CO_2 is a common greenhouse gas. A greenhouse gas is a chemical compound found in the Earth's atmosphere that absorbs the heat from the infrared radiation of sunlight (Energy Information Administration 2008).

Since the Industrial Revolution, greenhouse gases have increased by 25%. This influx of carbon dioxide is too much for the natural carbon cycle to regulate; therefore, the level of greenhouse gases has risen. The increase in the greenhouse gases causes the Earth's temperature to elevate (Energy Information Administration 2008). Tillage of the soil has been linked to global warming, given that tilling the soil releases carbon dioxide into the atmosphere (Mastrandrea and Schneider 2005).

Several suggestions have been made to help alleviate global warming. Soil carbon sequestration is one that has gained much recent attention. Soil carbon sequestration is the storage and accumulation of CO_2 from the atmosphere into the soil. Soil carbon sequestration has the possibility of reducing the global warming effect. Decreasing SOC levels have been found to be caused by tillage, erosion, leaching and mineralization of the soil (Lal and Kimble 1997). Besides having the potential to mitigate global warming, increased SOC levels may increase agricultural production, reduce sedimentation in waterways and improve water quality (Lal 2004).

No-tillage is a land management strategy that encourages soil carbon sequestration (Lal et al. 1999). No-tillage may encourage carbon sequestration by eliminating tillage, since tillage releases CO_2 into the atmosphere, and by retaining crop residues. Plants absorb CO_2 from the atmosphere through photosynthesis and form carbon compounds such as lignin and cellulose. Therefore, when the crop residues and plant roots begin to decompose, it releases that stored carbon into the soil (Follet 2001).

Soil degradation and the loss of soil organic carbon have been noted problems for a long time in the United States. In 1938, Albrecht (1938) stated in a report for the USDA that the loss of SOC soil due to intense tillage has led to decreased crop yields and lowered land value. The potential for lower production costs with no-tillage could be a critical benefit to farmers, given that farmers are price-takers in input and output markets (Cochrane 1965). Many farmers may be able to use no-tillage as a way to reduce costs. However, the majority of United States cropland is not farmed using this practice (CTIC 2009).

In the 1980s it was predicted that area cropped using no-tillage would overtake the area cropped using conventional tillage. In 1984, then Secretary of Agriculture John Block predicted that 95% of all United States' cropland would be under no-tillage by 2010 (McWhorter 1984). A study by Phillips et al. (1980) estimated that by 2000, 65% of cropland in the United States would be under no-tillage. However, in the United States, only 24 percent of crop land is maintained by no-tillage and this percentage declines when looking at all croplands worldwide (CTIC 2009). With a wide range of advantages, why has no-tillage not been more universally adopted? Past research suggests a reduction in crop yields during the period of conversion from conventional tillage to no-tillage (Larson et al. 2001), or increased costs by way of new equipment and increased use of chemicals as the reason it has not been more widely adopted (Javurek et al. 2007).

Much research has been done pertaining to the benefits of no-tillage, such as how it can reduce soil erosion and enhance soil quality; however, little has been done to look into why it is not more widely adopted. Improved knowledge concerning the reasons farmers have not converted to no-tillage practices will help policy makers develop strategies to encourage these practices.

The objective of the first portion of this research was to evaluate the impacts on the mean and risk of crop yields of switching from conventional or reduced tillage practices to no-tillage as explained by factors such as time, crop, precipitation, soil texture and geographic region and to determine which factors may increase the probability of downside risk when using no-tillage. The objective of the second portion of this research will evaluate the mean and risk of net returns for different tillage systems and how those net returns are affected by the same factors mentioned above.

References

Albrecht, W.A. 1938. “Loss of Soil Organic Matter and its Restoration. *Soils and Men. Yearbook of Agriculture.* Pp. 348-360, U.S. Government Printing Office: USDA.

Cochrane, W. 1965. *The City Man's Guide to the Farm Problem.* Minneapolis: University of Minnesota Press.

Conservation Technology Information Center-CTIC. *Conservation Tillage Facts.* Internet site: http://www.conservationinformation.org/?action=learningcenter_core4_convotill (Accessed April 2, 2009).

Deen, W. and P. K. Kataki. 2003. "Carbon Sequestration in a Long-Term Conventional Versus Conservation Tillage Experiment." *Soil and Tillage Research* 74(2):143-150.

Energy Information Adminstration. 2008. *Greenhouse Gases, Climate Change, and Energy*. Brochure No. DOE/EIA-X012. Washington DC.

Faulkner, E. 1942. *Plowman’s Folly*. University of Oklahoma Press, Norman, OK.

Follett, R. 2001. “Soil Management Concepts and Carbon Sequestration in Cropland Soils.” *Soil & Tillage Research*. 61: 77-92.

Frazee, R., D. Towery, D. Peterson, M. Hirschi. 2005. "U.S. Tillage Trends." *Land & Water.* University of Illinois Extension, University of Illinois. Bull. No. 6, January.

Global Terrestrial Observing System. Internet site: http://www.fao.org/gtos/tems/variable_show.jsp?VARIABLE_ID=34 (Accessed July 7, 2010).

Javurek, M., M. Vach, Z. Strasil. 2007. "Production, Economic and Energetic Aspects of Continuous Ten-Year Use of Conservation Soil Tillage." *Scientia Agriculturae Bohemica* 38(4):179-185.

Lal, R. 2004. “Soil Carbon Sequestration to Mitigate Climate Change.” *Geoderma*. 123: 1-22.

Lal, R. and J. Kimble. 1997. “Conservation Tillage for Carbon Sequestration.” *Nutrient Recycling in Agroecosystems*. 49: 243-253.

Lal, R., R. F. Follett, J. Kimble, and C.V. Cole. 1999. "Managing U.S. Cropland to Sequester Carbon in Soil." *Journal of Soil and Water Conservation.* 54(1):374-378.

Lal, R., D. Reicosky, and J. Hanson. 2007. “Evolution of the Plow Over 10,000 Years and the Rationale for No-till Farming.” *Soil & Tillage Research.* 93:1-12.

Lankoski, J., M. Ollikainen, P. Uusitalo. 2004. “No-Till Technology: Benefits to Farmers and the Environment?” Discussion paper 1, Helsinki, Finland. University of Helsinki. March.

Larson, J., E. Jaenicke, R. Roberts, and D. Tyler. 2001. "Risk Effects of Alternative Winter Cover Crop, Tillage, and Nitrogen Fertilization Systems in Cotton Production." *Journal of Agricultural and Applied Economics* 33(3):445-457.

Mastrandrea, M. and S. Schneider. 2005. “Global Warming”. World Book Online Reference Center. Internet Site: http://www.nasa.gov/worldbook/global_warming_worldbook.html (Accessed on July 13, 2009).

McWhorter, C. 1984. “Future Needs in Weed Science.” *Weed Science.* 32:850-855.

Phillips, R., R. Blevins, G. Thomas, W. Frye, S. Phillips. 1980. “No-Tillage Agriculture.” *Science*, June, pp.1108-1113.

White, K. 1967. *Agricultural Implements of the Roman World.* Cambridge.

Part 2: Effects of No-Tillage Production Practices on Crop Yields as Influenced by Crop and Growing Environment Factors

Abstract

A review of literature indicates that an evaluation of the performance of no-tillage yields relative to conventional tillage yields is needed. This study evaluated the potential factors that influence differences in mean yields and downside risk for no-tillage versus conventional or reduced tillage crop yields. Data from paired tillage experiments growing corn, soybeans, wheat, cotton, oats or sorghum published in three refereed journals, *Agronomy Journal*, *Soil & Tillage Research* and *Journal of Production Agriculture*, were collected to evaluate crop yield differences when comparing conventional and reduced tillage to no-tillage as explained by such factors as time since conversion from conventional tillage to no-tillage, the year the experiment was initiated, crop, precipitation, soil texture and geographic region. The experiments were conducted across the United States, with data from 1964 to 2005. The data were evaluated using a mixed model and a logit model to respectively evaluate differences in mean yields and downside risk for no-tillage compared to conventional or reduced tillage. The results showed that no-tillage yields for sorghum and wheat were greater than conventional tillage yields; however, yields for oats under no-tillage were lower than oats under conventional tillage. The results also indicated that no-tillage did not perform as well as conventional tillage under finely textured soils such as silt. No-tillage crop yields performed better relative to conventional tillage yields in the southern United States, but poorly in the northwest. No-tillage yields relative to conventional tillage were higher in warmer, southern climates. Using no-tillage to produce sorghum decreased the chance of having lower yields compared to corn. Crops grown in the Northern Crescent, Northern Great Plains, Prairie Gateway and Southern Seaboard were less likely to have lower

yields with no-tillage compared to the Heartland region. Areas of the United States that had higher rainfall increased the chance of no-tillage yields being less than conventional tillage yields and thus was relatively risky in terms of production risk. Overall, it was found that under the right conditions no-tillage could be a viable alternative to conventional tillage for farmers.

Introduction

Conservation tillage methods like no-tillage are not new. The Incas and ancient Egyptians used a form of no-tillage by using a stick to make a hole in the soil for the seed and covering the hole with dirt using their feet (Derpsch 2004). However, no-tillage as we know it today did not occur until the late 1940s with the invention of the herbicide 2,4-D and later the herbicides atrazine and paraquat (Derpsch 2004). Herbicides made it possible to substitute weed control using hand labor and mechanical tillage with weed control using chemicals. Since that time, the area under no-tillage for major crops in the United States has grown to an estimated 59 million acres in 2007 (Larson et al. 2010).

Besides the development of effective herbicides for weed control, other factors that have influenced the growing acceptance of no-tillage by farmers include improved no-tillage planter and drill technologies, the shortage of farm labor for hand weeding and mechanical tillage operations, declining real commodity prices, rising land prices, reduced machinery investment with no-tillage and increased concern about soil erosion (Young 1982). Capital investment requirements for farm land and equipment are continually rising and returns on investment in agriculture have historically been low. Thus, a reduction in machinery investment and less fuel, repair and labor costs with the use of no-tillage would result in higher net returns for the farmer c***ēterīs paribus***.

Reduced soil erosion, decreased moisture evaporation and increased land use by allowing farmers to plant on highly erodible or sloping lands are just a few of the other possible agricultural benefits of using no-tillage (Phillips et al. 1980). A few examples of the off-farm societal advantages could be reduced chemical and sediment runoff and reduced CO_2 emissions resulting in improved water quality and cleaner air (Young 1982).

Profits are what drive a farmer to produce. The potential for lower production costs with no-tillage (Young 1982; Bremer et al. 2001; Lankoski et al. 2004) could be a critical benefit to farmers, given that farmers are price-takers in input and output markets (Cochrane 1965). Farmers receive less for their products because of the “treadmill effect” described by Cochrane (1965) as a generally increasing supply of food resulting from advancing technology, subject to a highly inelastic food demand. These two effects coupled together place a downward pressure on commodity prices. To stay ahead of the treadmill effect, farmers must always look for new ways to increase production, reduce production costs and increase net revenue. The ability to manage larger acreages with the same or less equipment and labor has peaked farmers’ interest in no-tillage practices (DeFelice et al. 2006).

Notwithstanding the potential cost, labor and environmental benefits of no-tillage and the increased use of the practice in the United States, no-tillage has been estimated to have been adopted on only about one-quarter of the total area in major crops in the United States in 2007 (Larson et al., 2010). Yields are one of the most important factors influencing profit. Low yields could translate into low profits, or worse, losing money, whereas high yields usually mean higher profits. The yields realized after the adoption of no-tillage may be an important factor affecting risk and return and thus farmer willingness to adopt no-tillage (Ribera et al. 2004). The evidence on whether no-tillage yields are different from conventional tillage or reduced tillage yields is not clear. Many reports indicate higher yields with the use of no-tillage compared to conventional tillage (Endale et al. 2008; Smiley & Wilkins 1993; Wagger & Denton 1989). There are just as many reports stating the opposite (Graven & Carter 1991; Halvorson et al. 2006; Hammel

1995) as well as just as many stating there is no real significant difference in conventional tillage and no-tillage yields (Archer & Reicosky 2009; Barnett 1990; Kapusta et al. 1996).

A study performed by Anderson (1986) evaluated no-tillage effects on corn yields. In 1983 there was severe drought stress during the growing season, but the no-tillage corn did not seem to be nearly as affected by the drought as the conventional tillage corn. No-tillage corn yielded 17-24% more than the conventional tillage corn. Several other studies also found that no-tillage methods produced higher grain yields in years of drought (Belvins et al. 1971; Legg et al. 1979; Miller and Shrader 1976; Triplett et al. 1968). Different crops respond differently to no-tillage. Wilhelm and Wortmann (2004) concluded that no-tillage soybean yields were similar to conventionally tilled soybeans, whereas no-tillage corn consistently produced lower yields than corn using conventional tillage. Shapiro et al. (2001) found similar results when they discovered that no-tillage corn and sorghum produced lower yields than conventionally tilled corn and sorghum, but no-till soybeans yielded similar results to conventionally tilled soybeans. This leads one to believe that maybe yields under no-tillage, reduced and conventional tillage are affected by factors such as location of production, soil texture, rainfall and crop. Under certain conditions no-tillage may be the best choice and conventional tillage may be best for other conditions.

The economic feasibility, benefits and uncertainties of no-tillage must be understood by farmers before they are willing to convert to the practice. Such things that must be considered include yields after conversion, costs and the learning curve associated with the newly adopted tillage method (D’Emden et al. 2006). The use of no-tillage practices has often been associated with higher chemical costs and reduced yields because of increased disease, weed and insect pressure with the increase in crop residues (Caswell et al. 2001; University of Idaho 2009; Ribera et al. 2004). Crop residue also has its benefits including reduced soil erosion, increased soil organic carbon, conservation of soil moisture and cooler soils during the heat of summer (Hartman 2008). However, the central issue revolves around farmers wanting to know how no-tillage will affect crop yields. The aforementioned studies suggest that the yields associated with no-tillage vary depending on numerous factors such as crop, weather, soil type and region.

The objective of this paper is to evaluate the impacts on the mean and risk of crop yields of switching from conventional or reduced tillage practices to no-tillage as explained by factors such as the year the conversion from conventional tillage to no-tillage took place, the crop being grown, annual precipitation, soil texture and location of production. The only other analysis of tillage methods that compares to the present study is the one conducted by DeFelice et al (2006). However, their study only evaluated mean yields of corn and soybeans with most experiments that they examined located in the eastern United States. This study differs in that it incorporates six crops from across the United States evaluating differences in mean yields and the downside risk of no-tillage compared to conventional or reduced tillage. This study also evaluated a wider range of potential growing environment and location factors that may influence differences in yields.

Conceptual Framework

The profits for producing a crop using alternative tillage practices can be modeled using the following equation (Nicholson, 2005):

(1) $$\pi_i = P \times Y_i - VC_i - FC_i,$$

where π is profit; *P* is crop price; *Y* is crop yield; *VC* is the variable costs of production; *FC* is the fixed costs of production; and *i* is tillage practice (conventional tillage, no-tillage, strip-tillage, ridge-tillage or mulch-tillage). Crop yield *Y* is an important component of profit, which is the measure that can be used to rank tillage practices by their monetary outcomes. Yields for a given tillage practice *i* are uncertain due the unpredictable impacts of weather, soils, and other production environment factors and location (Graven and Carter 1991; Hairston et al. 1990; Lueschen et al. 1992; Smith et al. 1992). The influence of alternative tillage practices on crop yields can be evaluated using the moments of the probability distribution of yields (Anderson, Dillon, and Hardaker, 1977; Chavas, Posner, and Hedtcke, 2009). The first moment is mean yield:

(2) $$E[Y_i] = E[F(\mathbf{v}_i \mid \mathbf{x}_i)],$$

where $E[\cdot]$ is the expectation operator, **v** is a vector of the aforementioned production environment inputs affecting production, and **x** is a vector of production inputs used with tillage method *i*. Mean yield and thus mean profit varies with tillage practice *i* as influenced by the aforementioned production environment location factors.

Many farmers are also concerned about the riskiness of yields associated with tillage practice *i*. Farmers who are risk averse are most often concerned about deviations in yields below the mean or some other target value (Binswanger, 1981; Selley, 1984; Antle, 1987; Chavas, 2004) Downside risk below a target or comparison value can be modeled using the lower partial moment (*LPM*) (Fishburn, 1977). The equation for the LPM in the context of the tillage decision problem is given by:

(3) $$E[LPM]_i = E[\{\min(Y_i - Z), 0\}^n],$$

where Z is some yield reference point for tillage practice i to be evaluated against and n is the degree of the moment. Thus, the *LPM* is a measure of the expected deviations below the comparison or target level. The common classifications of n are: $n = 0$ is the probability of a loss, $n = 1$ is the target shortfall, $n = 2$ is the target semi-variance, and $n = 3$ is the target skewness.

Meta-analysis is a quantitative method for summarizing the results of independent studies to allow for the testing of hypotheses that cannot be addressed in a single experiment (Hedges and Olkin, 1985; Cooper and Hedges, 1994; Miguez and Bollero, 2005). For the present study, the hypothesis related to the effects of the unpredictable impacts of weather, soils and other production environment factors on mean yields and downside yield risk for no-tillage ($i = NT$) relative to tillage (conventional-, strip-, ridge-, and mulch-tillage; $i = TILL$) were evaluated using data from paired no-tillage and tillage method experiments from across the United States. The approach used in this study is through the creation of a response ratio (*RR*) that is used to evaluate relative tillage and no-tillage yields and is given by (Hedges et al. 1999):

$$RR = \left(\frac{Y_{NT}}{Y_{TILL}} \right). \tag{4}$$

Using the natural log of the response ratio (*ln(RR)*) as the dependent variable (Miguez and Bollero 2005), a mixed linear model was used to evaluate which production environmental factors affected mean crop yields:

$$\ln(RR) = X\alpha + U\beta + \varepsilon, \tag{5}$$

where α is a vector of unknown fixed effects, β is a vector of random effects, ε is a vector of random residuals and X and U are given known and incidence matrices, respectively

(Harville and Mee 1984; McLean et al. 1991). Identification of factors influencing differences in mean yields for no-tillage versus conventional tillage or reduced tillage practices was determined by the sign and significance of parameter estimates.

Using the probability of a loss below a comparison level ($n = 0$) that is embodied in equation (3) and the response ratio in equation (4), a conditional logit model was specified to evaluate the probability of no-tillage yields being lower than tillage yields as influenced by the aforementioned production environment and location factors. The dependent variable *NTPROB* was defined as follows: If the response ratio, $RR < 1$, then $NTPROB = 1$; otherwise, $NTPROB = 0$. Thus, downside risk in this case is defined as the probability of reduced yields with no-tillage when compared with yields from conventional or reduced tillage.

The logit model below specifies the probability of downside production risk when switching from conventional or reduced tillage to no-tillage:

$$NTPROB(a=1) = \frac{e^{\beta' X}}{1+e^{\beta' X}}. \tag{6}$$

Equation (7) is the probability of no downside risk when switching to no-tillage:

$$NTPROB(a=0) = 1 - P(a=1) = \frac{1}{1+e^{\beta' X}}. \tag{7}$$

Maximum likelihood was used to estimate the conditional logit model. Identification of factors influencing the probability of lower no-tillage yields was determined by the sign and significance of parameter estimates and the evaluation of probabilities. The marginal effects give the probability of no-tillage having reduced yields compared to conventional or reduced tillage.

Methods & Procedures

Data

Data from 686 paired tillage and conservation tillage experiments published in the *Soil and Tillage Research* Journal were compiled by Maithilee Kunda and Tristram West of the Oak Ridge National Laboratory (Kunda and West 2006). Of these 686 paired experiments, only the 161 paired experiments that pertained to the 48 contiguous states of the United States were analyzed. The dataset was updated to include four additional paired experiments conducted since July 2006. These paired experiments compare conventional tillage and/or reduced tillage to no-tillage. The dataset was augmented using experiments published in the *Agronomy Journal* from 1980 through 2009. The reason for only going back to 1980 in the *Agronomy Journal* is because the *Soil & Tillage Research* journal only went back to 1980, so to be consistent the same starting date was used. The *Agronomy Journal* added 173 paired experiments to the tillage database. A third dataset was created with journal articles from the *Journal of Production Agriculture* from its inception in 1988 until it was absorbed into the *Agronomy Journal* in 1999, which netted an additional 104 paired experiments. These additions augmented the dataset to a total of 442 paired tillage experiments across 92 locations. Of these experiments, 66% used a randomized complete block experimental design, 25% split-plot design, 7% other, i.e. strip plot, strip-split and unique companion plots and 2% were not given. When experiments used different fertilizer and nitrogen rates in their study the yields for each tillage method were averaged over these treatments. The data include numerous crops of which sorghum, corn, soybeans, oats, cotton and wheat will be used. Other data for all experiments include the year each experiment began, each individual year of the experiment, soil texture, geographic location and annual precipitation. The soil texture at each experiment was usually given. If only the soil texture percentages were given, a soil texture triangle was used to place it into a soil texture category (University of Missouri, Accessed online January 2010). The central theme of the identified texture, which is the most important, was used to place the soil into either a clay, silt, sand or loam soil texture (University of Missouri, Accessed online January 2010). The annual precipitation for each year of each experiment was added to the dataset through the use of the National Environmental Satellite, Data, and Information Service, a branch of the Department of Commerce (U.S. Dept. of Commerce 2009). In addition, the zip codes at which the experiments took place were used to place each experiment into one of the nine ERS Farm Resource Regions of the USDA (USDA Economic Research Service 2000). The locations for all experiments in this analysis are found in Figure (1) in the appendix. Four observations were omitted due to human error when producing the crop resulting in little-to-no yield. Three observations were omitted because of a zero yield reading from a plot digitizer. The dependent variable *RR* was created using equation (4) and the conventional-, reduced- and no-tillage yields. The total usable observations in the combined *Soil & Tillage Research*, *Agronomy Journal,* and *Journal of Production Agriculture* dataset was 1546. Appendix Table 1 has the variable names and their definitions. Also located in the appendix is a list of references used to create the dataset.

Empirical Models

The empirical models were used to evaluate mean yield differences between no-tillage and conventional tillage or reduced tillage methods using the log of the yield proportions (*RR*) as the dependent variable and were specified as follows:

(8)

$$RR = \beta_0 + \sum_{i=1}^{5} \beta_i CROP_i + \sum_{j=6}^{8} \beta_j SOIL_j + \sum_{k=9}^{16} \beta_k ERS_k + \beta_{17} TILL + \beta_{18} BEGAN$$

$$+ \beta_{19} LOGYR + \beta_{20} RAIN + \sum_{i=1}^{5} \sum_{j=6}^{8} \beta_{i\,j} (CROP_i)(SOIL_j)$$

$$+ \sum_{i=1}^{5} \beta_{i\,18} (CROP_i)(BEGAN) + \sum_{i=1}^{5} \beta_{i\,19} (CROP_i)(LOGYR)$$

$$+ \sum_{i=1}^{5} \beta_{i\,20} (CROP_i)(RAIN) + \varepsilon,$$

where *i* is the subscript for one of five crops: sorghum, wheat, soybeans, cotton or oats. Subscript *j* represents one of three soil textures: sand, silt or clay. The subscript for the ERS regions, *k*, represents one of eight USDA ERS Farm Resource Regions: Northern Crescent, Northern Great Plains, Prairie Gateway, Eastern Uplands, Southern Seaboard, Fruitful Rim, Basin & Range or Mississippi Portal. The reference categories for *CROP*, *SOIL* and *ERS* in equation (8) are corn (*CORN*), loam soil (*LOAM*) and the Heartland (*HEART*) region. *TILL* is a binary dummy variable with a value of 1 for a comparison of conventional tillage to no-tillage, and 0 for reduced tillage to no-tillage. The variable *BEGAN* is a continuous variable used to capture improvements in technology over time. It represents the year in which the experiment was initiated, with 1964=1, 1965=2,…, 2005=42; then the natural log of that number was taken. Another variable, *LOGYR*, was created to verify if there is a yield lag when switching from conventional tillage or reduced tillage to no-tillage as much anecdotal evidence suggests, and to see if no-tillage yields relative to tillage yields increase over time through soil improvement. *LOGYR* is a continuous variable which represents each year of the experiment with experiment 1: 1981=1, 1982=2,..., 1985=5; experiment 2: 1995=1, 1996=2; then the natural log of that number was taken. The continuous variable *RAIN* is annual precipitation for each location and year of each experiment. *CROP* and *ERS* were not interacted because all crops were not present in each ERS Farm Resource Region. For example the Fruitful Rim and Basin & Range regions only had observations for two and one crops, respectively. It should be noted that there are no observations for sorghum, wheat, soybeans, oats or cotton in a silt textured soil. There are also no observations for oats in a sand or clay textured soil, therefore there are no interactions between those specific crops and soil textures.

The following conditional logit model was specified to evaluate the probability of no-tillage yields being less than conventional or reduced tillage yields:

(9)

$$\begin{aligned} NTPROB = {} & \gamma_0 + \sum_{i=1}^{5} \gamma_i CROP_i + \sum_{j=6}^{8} \gamma_j SOIL_j + \sum_{k=9}^{16} \gamma_k ERS_k + \gamma_{17} TILL + \gamma_{18} BEGAN \\ & + \gamma_{19} LOGYR + \gamma_{20} RAIN + \sum_{i=1}^{5} \sum_{j=6}^{8} \gamma_{i\,j} (CROP_i)(SOIL_j) \\ & + \sum_{i=1}^{5} \gamma_{i\,18} (CROP_i)(BEGAN) + \sum_{i=1}^{5} \gamma_{i\,19} (CROP_i)(LOGYR) \\ & + \sum_{i=1}^{5} \gamma_{i\,20} (CROP_i)(RAIN) + \varepsilon, \end{aligned}$$

where *i* is the subscript for one of five crops: sorghum, wheat, soybeans, cotton or oats; subscript *j* represents one of three soil textures: sand, silt or clay; and the subscript for *k* represents one of eight USDA ERS Farm Resource Regions: Northern Crescent, Northern Great Plains, Prairie Gateway, Eastern Uplands, Southern Seaboard, Fruitful Rim, Basin & Range or Mississippi Portal. The reference categories for *CROP, SOIL* and *ERS* in equation (9) are corn (*CORN*), loam soil (*LOAM*) and the Heartland (*HEART*) region. *NTPROB* is the downside risk dependent variable and was given a value of one if the no-tillage crop yield was less than then conventional or reduced tillage yield and a zero otherwise. The same explanatory variables were used as previously stated for equation (8).

Hypotheses

Several variables that describe the characteristics of the growing environment for each experiment were hypothesized to affect mean yields in a no-tillage system relative to conventional or reduced tillage and the probability of those yields being lower than conventional or reduced tillage yields. Yields for different crops may respond differently under alternative tillage regimes. Crops with high residue may not do as well in colder climates. Too much residue in a lower average temperature growing environment can result in decreased no-tillage yields relative to reduced or conventional tillage yields due to a delay in crop emergence (Graven and Carter 1991; Halvorson et al. 2006; Lueschen et al. 1992). By the same token, a low residue crop may not produce as well under no-tillage relative to conventional or reduced tillage in a southern and dry climate. Crop residues help conserve soil moisture and protect it from extreme heat and helps keep the soil cool (Doran et al. 1984; Halvorson et al. 2006; Herbek et al. 1986). Crop yields depend on numerous factors such as farm management and environmental conditions. Wilhelm and Wortmann (2004) discovered in their experiment that different crops respond differently to no-tillage. They found that no-tillage soybean yields were similar to conventionally tilled soybeans, whereas no-tillage corn consistently produced lower yields than corn produced using conventional tillage. Shapiro et al. (2001) found similar results while studying tillage effects on yields of soybeans, corn and sorghum. Whereas other studies have found no-tillage corn to have higher or equal yields when compared to conventional tillage corn (Endale et al. 2008; Herbek et al. 1986; Wagger and Denton 1989).

Yields for no-tillage were hypothesized to be greater than yields for conventional or reduced tillage in the southern United States and lesser in the northern part of the United States (DeFelice et al. 2006). This should also translate into no-tillage being less likely to produce lower yields in the southern regions and have a higher probability of downside risk in the northern regions when compared to conventional or reduced tillage yields. One reason for this hypothesis is that the residue left on the ground with no-tillage potentially acts as insulation and the temperature of the ground may stay cooler longer in northern regions. Cooler soil temperatures in the spring have the potential to delay the emergence and growth of crops and thus negatively impact yields. The warmer temperatures in southern climates can help counteract the low soil temperatures with no-tillage in northern climates and the residues can help prevent soil moisture evaporation from the increased heat. This hypothesis was supported by DeFelice et al. (2006), who found that no-tillage yields for corn and soybeans tended to be higher than conventional tillage yields in the southeastern United States with the opposite occurring in the northern

United States. They also discovered that yield differences between the two tillage systems were negligible in the central United States.

Soil texture could have a positive or negative effect on no-tillage yields relative to conventional or reduced tillage. No-tillage has been found to have greater yields than conventional tillage on moderate to well drained soils, but lower yields on poorly drained soils (DeFelice et al. 2006). Therefore, it is hypothesized that no-tillage will perform well on sandy and some loam soils, but not fare as well on clay, silt and certain loamy soils where the texture is finer and slows drainage; or in other words that no-tillage may not perform as well in finely-textured soil (Hairston et al. 1990). A sandy textured soil is hypothesized to decrease the probability of having lower yields with no-tillage, whereas silty and clay soils will likely increase the probability of having lower no-tillage yields.

Another key factor is the year in which the experiment began. Crop yields have increased over time due to the progression in weed control technology, crop genetics, drill and planter equipment design, and other factors. It was hypothesized that the variable *BEGAN*, will have a negative sign. As the year the experiment began progresses into more recent times, the difference between conventional or reduced tillage and no-tillage yields was expected to decrease. In addition, there has been evidence that there is a lag in yields when switching from conventional to no-tillage (So et al. 2009). Several studies indicate that no-tillage yields may increase over time relative to conventional tillage yields because of increased organic matter, soil enzyme activity, microbial biomass and changes in soil porosity (So et al. 2009; DeFelice et al. 2006). Therefore, the years after the experiment began (*LOGYR*) is hypothesized to have a positive effect on no-tillage yields relative to tillage. Thus, no-tillage yields were expected to grow with time relative to conventional or reduced tillage yields after conversion to no-tillage. *LOGYR* should also show that with time after conversion to no-tillage, the probability of lower yields compared to conventional or reduced tillage yields should decrease.

Conservation practices such as no-tillage have been shown to retain moisture, in part because of the increase in residue covering the soil. Rainfall could have a positive or negative effect on no-tillage crop yields relative to conventional or reduced tillage yields. Since no-tillage conserves and retains moisture it should fare better than conventional tillage when precipitation is low or during drought conditions, but excessive amounts of rainfall could saturate no-tillage soils negatively affecting crop yields. Therefore, the more rainfall the higher the probability that no-tillage yields will be lower than conventional tillage yields. This hypothesis would coincide with the findings of Eckert (1984) who found that cooler and wetter than normal conditions favored conventional-tillage corn, whereas drier conditions favored no-tillage corn. Herbek et al. (1986) also found that no-tillage corn performed better than conventionally tilled corn during dry years.

Statistical Analysis

Equation (8) was estimated using the mixed model in SAS (SAS Institute 2004) to test the hypothesis that the yield means do not differ (Littell et al. 1996). Tests for multicollinearity and heteroskedasticity were performed using the VIF and SPEC options in PROC REG of SAS, respectively (SAS Institute 2004). The VIF option in SAS was used to report the Variance Inflation Factors for testing multicollinearity. A Variance Inflation Factor greater than 10 is an indication of multicollinearity (Chatterjee and Price 1991). Multicollinearity occurs when two or more independent variables are so highly correlated with each other that the standard errors are inflated (Chatterjee and Price 1991). If multicollinearity is present it can influence the significance and inferential power of the coefficients (Chatterjee and Price 1991). The SPEC option performed the White test for heteroskedasticity. To further the tests for heteroskedasticity, a Breusch-Pagan test was performed in SAS. Heteroskedasticity is where the variance of the regression error term is not constant (Stock and Watson 2003). If present, heteroskedasticity can influence standard errors and potentially affect the significance of tests of hypothesis.

Heteroskedasticity was present in the model as can be seen in Table 2 in the appendix. This was corrected in the mixed model by adding a RANDOM statement in PROC MIXED in SAS that included the location of each experiment. There was a mutlicollinearity issue that was corrected by using the USDA ERS Farm Resource Regions rather than the latitude of the experiment, as it was causing collinearity problems with other explanatory variables. Both latitude and ERS regions were tried separately in the model with the ERS Farm Resource Regions resulting in less collinearity problems with other variables in the model than latitude. The USDA ERS Farm Resource Region should also explain more as to how no-tillage crop yields differ in various growing regions than just by temperature and north and south, which is what latitude would explain. Test results for multicollinearity can be seen in Table 3.

A logistic regression for equation (9) was estimated using LIMDEP (Greene 2007). Statement MARGINAL EFFECTS was called in LIMDEP to evaluate the marginal effects each variable had on the probability of having decreased yields with no-tillage compared to conventional or reduced tillage. The marginal effect measures changes in the probability of no-tillage yields being lower than conventional tillage yields from changes in the explanatory variables. Marginal effects are used to quantify the effect of variables on an outcome of interest (Woolridge 2000).

Results

Mean Yield Differences

As was hypothesized, different crops reacted differently to tillage methods. No-tillage sorghum had higher yields than conventional or reduced tillage sorghum; no-tillage sorghum yields were also higher than relative conventional or reduced tillage corn yields. Wheat cultivated under no-tillage was found to result in higher yields than wheat grown using conventional or reduced tillage. No-tillage wheat also yielded more than corn grown using no-tillage relative to conventional or reduced tillage. However, oats grown using no-tillage yielded less than their conventional tillage counterparts and also yielded less than relative conventional or reduced tillage corn. One explanation for this result could be the amount of residue left behind by each crop. Sorghum and wheat leave more residue per bushel harvested than corn (McCarthy et al. 1993; Smith 1986), but corn produces significantly higher bushels per acre, therefore, more residue is left one the ground with corn compared to wheat or sorghum. Too dense a coverage of crop residues can lead to a cool and moist soil which can delay crop emergence and reduce seed germination, which can affect yields (Halvorson et al. 2006). Corn also has a significantly higher carbon (C) to nitrogen (N) ratio compared to sorghum and wheat. Corn has a C:N of 70:1 compared to sorghum at 25:1 and wheat at 22:1 (Ilukor and Oluka 1995). The lower the C:N ratio, the faster the residue will decompose. Since corn has a high C:N ratio it decomposes slower limiting the availability of nutrients, particularly nitrogen. This is because the microorganisms that decompose the residue are competing for these nutrients with the plant (Mannering and Griffith 1985). An optimal C:N ratio would 25:1 or lower. Oats on the other hand leave a lesser amount of residue at only 50 lb per bushel harvested. This could explain why its yields were less than corn (Hofman 1997). Too little residue can result in stunted growth, stress and decreased yields caused from lack of soil water, poor canopy development and high surface temperatures (Doran et al. 1984). However, too much residue can have adverse affects on crop yields. Too much residue can keep soil temperatures too cool and wet delaying crop emergence; a dense residue cover can also increase weeds and insects and keep herbicides from reaching the soil. So, there seems to be a fine line between not enough and too much residue.

As expected, the results show that no-tillage production in a silt textured soil yielded less than conventional or reduced tillage yields in the same texture. When compared to the reference, a loam soil texture, no-tillage in a silty soil produced lower crop yields relative to conventional or reduced tillage yields in a loam soil. These results coincide with previous research that no-tillage performs better in coarse, well-drained soils, but does not produce as well under fine, poor-drained soils relative conventional or reduced tillage (DeFelice et al. 2006; Hairston et al. 1990). Clay and sandy soils were not statistically different from loam soils. There were several significant interactions between soil texture and crop. The interaction *SORG×SAND*, *WHEAT×SAND* and *SOY×SAND* were all significant and all negative. In other words, the use of no-tillage on a sandy soil texture growing sorghum, wheat or soybeans yielded less than conventional or reduced tillage under the same crops and soil texture. It can also be reported sorghum, wheat and soybeans produced using no-tillage on a sandy soil texture yield less than no-tillage yields of corn in a loam soil relative to conventional and reduced tillage. A potential explanation for this result could be that usually sandy soils are lower in organic matter and nutrients when compared to loamy soils. Sandy soils also leach nutrients more readily, reducing the amounts available to the plants (North Carolina Dept. of Agriculture Accessed July 2010). With the implementation of no-tillage practices, organic matter and nutrients are increased with the use of crop residues. However, soybeans do not leave as much residue on the soil as a crop such as corn. Therefore, fewer nutrients are put back into the soil due to lesser amounts of residue, and less erosion protection is present which may lead to lower yields with no-tillage. Too little residue can also result in decreased no-tillage yields because of lack of soil moisture and protection from extreme temperatures (Doran et al. 1984). Sorghum and wheat leave more residue behind per bushel harvested (McCarthy et al. 1993; Smith 1986), than the other crops evaluated in this paper, which may have delayed crop emergence from keeping the soil too cool and moist, resulting in lower yields (Halvorson et al. 2006; Swan et al. 1987).

The hypothesis of no-tillage performing better relative to tillage in a warmer climate was confirmed for the Southern Seaboard and Mississippi Portal regions, which represent a majority of the southern United States, had positive and significant coefficients. The Southern Seaboard and Mississippi Portal regions had on average higher no-tillage yields than conventional or reduced tillage yields than the Heartland region. These results concur with previous research and the previously stated hypothesis (DeFelice et al. 2006). The Basin & Range and Fruitful Rim ERS regions, which cover much of the west and northwest part of the country, had lower mean no-tillage yields when compared to conventional or reduced tillage yields in the Heartland region. The reduction in relative yields for the two regions make sense and coincides with the previous hypothesis, because all experiments in these regions were in the upper northwest corner of the United States. The upper northwest corner of the United States is a place that receives an exceeding amount of snow and cold weather, none of which are prime conditions for no-tillage. Wet years and cold climates have been found to cause reduced yields under no-tillage compared to conventional or reduced tillage (Graven and Carter 1991; Eckert 1984; Herbek et al. 1986).

The significant interactions between *BEGAN* and sorghum and wheat, *BEGAN*×*SORG* and *BEGAN*×*WHEAT*, were both significant and both negative, suggesting that as the year the experiment was initiated increases, the difference between no-tillage and conventional tillage crop yields of sorghum and wheat decreases compared to corn. A possible explanation for these results could be because corn technology has increased faster than technology for wheat or sorghum. The corn seed industry supports a much larger breeding effort than any other crop (Egli 2008).

LOGYR was hypothesized to have a positive sign in hopes of capturing any yield lag in the first few years of switching to no-tillage. The variable was significant and surprisingly, the effect was negative. This means that with each one year increase with the use of no-tillage, corn yields decreased slightly when compared to conventional tillage. These results were not expected. One way to attempt to explain this result is that most experiments lasted between three and five years. This may not be enough time to let no-tillage fields reach their full potential in building soil tilth, porosity and organic matter. There was one significant interaction with the *LOGYR* variable in the model; in the significant interaction the coefficient was positive which does coincide with our hypothesis that the longer the amount of time no-tillage is used, yields increase as no-tillage rebuilds the soils quality. *LOGYR×COTT* was positive which means as the length of use of no-tillage increases, yields of no-tillage cotton increases relative to corn.

The amount of rainfall was hypothesized to be either beneficial or harmful to no-tillage yields. The variable *RAIN* was significant in two interactions, *RAIN×SORG* and *RAIN×OAT*. In other words, for each millimeter increase in rainfall, no-tillage sorghum yields decreased slightly compared to conventional or reduced tillage sorghum relative to corn. This has been found in other work where no-tillage performs better than conventional tillage during dry times, but yields less during wet years (Anderson 1986; Blevins et al. 1971). One reason for lower no-tillage yields with increased rainfall is that the wetter the soil, the slower it takes for the soil temperature to increase. This problem is further impacted under cold temperatures and with the use of crop residues, as is the case with no-tillage. The residues act as insulation keeping the soils cooler as well as reducing moisture evaporation (Herbek et al. 1986). The other significant interaction, *RAIN×OAT*, was positive with a coefficient of 0.0010, which means a one millimeter increase in rainfall slightly increases no-tillage oat yields relative to corn.

Results for the mixed model comparing no-tillage yields relative to conventional or reduced tillage yields can be found in Table 4 of the appendix. The following is an example calculation of relative yield differences for corn on a loam soil in the Southern Seaboard region using the estimated parameters. Given that the estimates for corn and loam are located in the intercept, the coefficient for the intercept is added to the continuous variables *BEGAN*, *LOGYR* and *RAIN*. The continuous variables are multiplied by their means and then added the coefficient for the Southern Seaboard region. The antilog of the estimate is then taken which yields the estimate for corn on a loam soil in the Southern Seaboard; i.e.

$$-0.00537 + (0.004154 \times 2.81) + (-0.02269 \times 1.41) + (-0.00002 \times 1101) + 0.071555 = 0.02383984 \qquad Antilog(0.02383984) = 1.024126$$

After the antilog is taken you are left with a simple proportion of no-tillage yields over tillage yields. Being that the proportion is greater than one it can be said that no-tillage yields of corn on a loam soil in the Southern Seaboard are higher than conventional or reduced tillage yields of corn on a loam soil in the same region. Another example for the estimate of corn on a loam soil in the Heartland region:

$$-0.00537 + (0.004154 \times 2.81) + (-0.02269 \times 1.41) + (-0.00002 \times 815) = -0.04199016$$

$$Antilog(-0.04199016) = 0.958879$$

The intercept was added to the continuous variables *BEGAN*, *LOGYR* and *RAIN*, which were multiplied by their means and added to the equation. After the estimate was calculated, the antilog for that estimate is taken to give the response ratio for corn on a loam soil in the Heartland region. This then allows the comparison of tillage methods of corn on a loam soil in the two different regions. From this you can see that no-tillage yields of corn are higher relative to conventional tillage in the Southern Seaboard, with just the opposite in the Heartland region.

Logit Results

For the logit model, 37.1% of the observations had higher no-tillage yields when compared to conventional tillage yields. The remaining 62.9% showed that conventional or reduced tillage yields were greater than no-tillage yields. The marginal effects show that sorghum is the only crop that has a smaller probability than corn of having lower no-tillage yields compared to conventional or reduced tillage yields. One explanation for this could be that sorghum leaves more residue on the ground than does corn. Sorghum on average produces 70 to 80 pounds of residue per bushel compared to 60 pounds of residue per bushel with corn (McCarthy et al. 1993). The more residue that is left means more organic matter to help build up the soils productivity, increased water conservation and more protection from possible extreme heat conditions.

No-tillage in sandy soils was found to be 17% more likely to have higher yields than conventional or reduced tillage compared to a loam soil. This coincides with our previous hypothesis that no-tillage performs better in sandy soils. Previous research has shown that no-tillage performs well under coarse-textured, well-drained soils as opposed to finely textured or poorly drained soils (DeFelice et al. 2006; Hairston et al. 1990). A sandy soil did not have as good of an outcome when wheat and soybeans were the crops grown on the soil. Wheat and soybeans grown on sandy soils increases the chance of having reduced yields with no-tillage when compared to corn in a loam soil. A logical explanation for this could be that sandy soils are usually lower in organic matter and nutrients. With no-tillage, the increase in crop residues contributes more organic matter and nutrients. However, soybeans do not leave as much residue as a crop such as corn. Therefore, fewer nutrients are put back into the soil due to lesser amounts of residue and less erosion protection is present, which leads to the higher probability of lower yields with no-tillage. Just the opposite could be the cause for no-tillage wheat yields being more likely to be lower than conventional tillage in a sandy soil when compared to corn. A high amount of residue is left when producing no-tillage wheat. This could be too much residue, causing the soil to be too moist and cool delaying crop emergence and possibly decreasing yields. This could imply that 50 pounds of residue per bushel as with soybeans could be too little residue for no-tillage and 100 pounds of residue per bushel per acre as is the case with wheat could be too much residue to productively use no-tillage. A switch from conventional tillage to no-tillage was also found to be less likely to result in decreased yields than a switch from reduced to no-tillage. A reason for that could be that such as drastic change from conventional to no-tillage could allow no-tillage to enrich the soil to a greater degree than from reduced tillage which already uses at least 30% of crop residues.

Growing location differences were a factor in affecting the possibility of no-tillage yields being lower than conventional tillage yields. Crops grown in the Northern Crescent, Northern Great Plains, Prairie Gateway and Southern Seaboard regions were less likely to produce lower no-tillage yields than conventional or reduced tillage yields compared to the Heartland region. A study by DeFelice et al. (2006) found that no-tillage corn and soybean yields were greater in warmer climates and lower in colder climates. Most experiments located in the Northern Great Plains region were in the most southern portion of that region, which would coincide with previous work that no-tillage performs well under warm, southern climates. The fact that the Northern Crescent decreased the likelihood of downside risk with no-tillage is a little surprising, but successful no-tillage does occur in that region (Barnett 1990; Pedersen & Lauer 2003).

The year each experiment was initiated (*BEGAN*), had a significant interaction with soybeans. The results show that each one year increase in the year the experiment was initiated when producing soybeans, the likelihood of having lower yields with no-tillage compared to conventional tillage decreases by 20% compared to corn. An explanation for this result could be that soybean technology, such as herbicide tolerant crops, is more readily and widely adopted than corn technology. Herbicide tolerant soybeans have been adopted by farmers at a faster and higher rate than herbicide tolerant corn (Fernandez-Cornejo 2010).

The variable *LOGYR* was significant with a marginal effect of 0.063, meaning that the longer the amount of time that no-tillage is used, the higher the probability of having lower no-tillage corn yields compared to conventional tillage. This result was not expected. Possible explanations could be increased weed, insect and disease with the use of no-tillage as a result of the increased residue. Some previous work has shown no-tillage to have reduced yields compared to conventional tillage due to weed infestations (Buhler & Mester 1991; Cardina et al. 1995). The residue could also be keeping the soil too cold and moist delaying crop emergence and diminishing yields. One study in Minnesota did report a gradual decrease in corn yields over time with the use of no-tillage. This was thought to be attributed in part to wet and cold soil (Linden et al. 2000). When *LOGYR* is interacted with different crops just the opposite occurs. When interacted with soybeans and cotton there is a lower probability of having lower yields with no-tillage relative to corn. Relative to corn, increases in the amount of time from conversion to no-tillage with the crops soybeans and cotton the probability of having lower no-tillage yields compared to conventional or reduced tillage yields decreases. Thus the production of soybeans and cotton using no-tillage becomes less risky relative to reduced or conventional tillage as time after conversion increases.

The amount of rainfall was significant in affecting the probability of corn having diminished yields with no-tillage relative to tillage. Each millimeter increase in rainfall increases the probability of having lower no-tillage corn yields than conventional tillage by half of a percent. This falls in line with our previous hypothesis. Previous research has shown that no-tillage out performs conventional tillage during dry times because no-tillage conserves water, but no-tillage yields are less when increased amounts of rainfall are present (Eckert 1984; Herbek et al. 1986). This could be caused from the decaying wet residue increasing weeds and disease; the increased residue may also make it difficult for the herbicides to reach the soil. The increased rainfall could also be keeping the soil too cool and moist, delaying crop emergence and decreasing yields (Herbek et al. 1986). However, increases in rainfall decreased the likelihood of lower relative no-tillage yields when producing soybeans when compared to corn. Since soybeans do not provide as much crop residue as corn, it may not affect soil moisture and temperature as much as corn. Therefore, crop emergence is not delayed and diminished yields are not likely to occur. When rainfall was interacted with sorghum, a high residue crop, the probability of having lower no-tillage yields compared to conventional tillage increase when compared to corn; this once again coincides with rainfall negatively affecting no-tillage yields with high amounts of crop residue.

Conclusion and Implications

The objective of this research was to evaluate the impacts on the mean and risk of crop yields of switching from conventional or reduced tillage practices to no-tillage as explained by factors such as the crop grown, the year the experiment began, time from conversion from conventional or reduced tillage to no-tillage, annual precipitation, soil texture and location of production and how those factors affected the probability of having lower no-tillage yields compared to conventional tillage. This objective was accomplished by collecting 30 years of refereed journal articles from 442 experiments at 92 locations dealing with paired conventional or reduced tillage compared with no-tillage experiments. These data included many different crops with locations across the United States. The paired experiments used in this analysis go as far back as 1964, when no-tillage was still in its infancy.

This study was able to corroborate previous work done with no-tillage. Previous studies found that different crops respond differently to no-tillage (Shapiro et al. 2001; Wilhelm and Wortmann 2004). This study found similar results with sorghum and wheat prospering under no-tillage methods, whereas oats did not. Sorghum was also found to reduce the probability of having lower no-tillage yields compared to tillage yields. This analysis was also able to show that no-tillage performed better relative to conventional or reduced tillage under coarse soil conditions in most instances and that a sandy soil texture decreased the probability of having lower no-tillage yields compared to conventional tillage yields. However, when growing wheat and soybeans on a sandy soil, the likelihood of having lower no-tillage yields compared to conventional tillage or reduced tillage increased. Thus no-tillage may have greater downside risk when wheat and soybeans are grown on sandy soils. The length of time that no-tillage was used after conversion from reduced or conventional tillage had positive effects on the mean yields for soybeans and cotton. Time after the conversion from conventional or reduced tillage to no-tillage also improved the probability of having higher no-tillage yields when sorghum, soybeans, oats and cotton were produced. The fact that it did not have a positive effect with corn is surprising. The reason could be the high amount of residue left on the soil with corn which can lead to decreased yields because too much residue can keep the soil too cool and moist delaying crop emergence and seed germination (Halvorson et al. 2006). Annual rainfall increased the probability of reduced no-tillage yields. Thus, there may be more downside risk associated with no-tillage crop production in regions where annual rainfall is higher. Finally, this research was able show no-tillage does perform better than tillage in the southern regions of the United States compared to northern regions. Where the crop is grown was found to affect the probability of decreased no-tillage yields and thus downside risk relative to reduced or conventional tillage. No-tillage crop production in the Northern Great Plains, Prairie Gateway, Northern Crescent and Southern Seaboard regions were found to decrease the likelihood of lower no-tillage yields than conventional or reduced tillage yields when compared to the Heartland region.

Since the implementation of no-tillage, much research has been done with regards to yields compared with conventional tillage and no-tillage crop production but, many of these studies have contradicting results. This study does not answer all questions about the use of no-tillage. It seems that the use of no-tillage should be on a case-by-case basis where many different factors should be considered. A few to be considered should be the crop being produced, the geographic region of the farm, soil type and climate. A limitation of the study could be that most of the data collected were either for corn, wheat or soybeans with a loam soil in the Heartland USDA ERS region. While sufficient data points were included in this study, none in quite the numbers as the aforementioned. An additional data search could be performed to try to fill in these holes, but will probably yield little more. More work and experimentation should be performed on different crops, soils and regions to verify how well no-tillage works with all crops, regions and soils. More studies evaluating crop residue effects on no-tillage yields would be beneficial in hope of finding an optimal amount that will optimize profits and yields with the use no-tillage.

References

Anderson, E. 1986. "No-Till Effects on Yield and Plant Density of Maize Hybrids." *Agronomy Journal.* 78:323-326.

Anderson, J., J. Dillon, and B. Hardaker. 1977. *Agricultural Decision Analysis.* Ames, Iowa: The Iowa State University Press.

Antle, J. 1987. "Econometric Estimation of Producers' Risk Attitudes." *American Journal of Agricultural Economics*. 69:509–522.

Archer, D. and D. Reicosky. 2009. "Economic Performance of Alternative Tillage Systems in the Northern Corn Belt." *Agronomy Journal.* 101:296-304.

Barnett, K. 1990. "No-Tillage Corn Production in an Alfalfa-Grass Sod." *Journal of Production Agriculture.* 3:71-75.

Blevins, R., D. Cook, S. Phillips, and R. Phillips. 1971. "Influence of No-Tillage on Soil Moisture." *Agronomy Journal.* 63:593-596.

Binswanger, H.P. 1981. "Attitudes toward Risk: Theoretical Implications of an Experiment in Rural India." *Econ. J.* 91:867–890.

Bremer, J., S. Livingston, R. Parker, and C. Stichler. 2001. "Conservation Tillage Applications." Texas Coop. Ext., Texas A&M University, College Station.

Buhler, D. and T. Mester. 1991. "Effect of Tillage Systems on the Emergence Depth of Giant and Green Foxtail." *Weed Science.* 39:200-203.

Cardina, J., E. Regnier, and D. Sparrow. 1995. "Velvetleaf Competition and Economic Threshold in Conventional and No-Tillage Corn." *Weed Science.* 43:81-87.

Caswell, M., K. Fuglie, C. Ingram,S. Jans, and C. Kascak. 2001. *Adoption of Agricultural Production Practices: Lessons Learned from the U.S. Department of Agriculture Area Studies Project*. Washington, DC: USDA.

Chatterjee, S. and P. Price. 1991. *Regression Analysis by Example.* Wiley-Interscience Publication. New York, NY.

Chavas, J.P. 2004. *Risk Analysis in Theory and Practice*. New York: Elsevier.

Chavas, J.P., J. Posner, and J. Hedtcke. 2009. "Organic and Conventional Production Systems in the Wisconsin Integrated Cropping Systems Trial: II. Economic and Risk Analysis 1993-2006." *Agronomy Journal.* 101:288-295.

Cochrane, W. 1965. *The City Man's Guide to the Farm Problem.* Minneapolis: University of Minnesota Press.

Cooper, H., and L.V. Hedges. 1994. The *Handbook of Research Synthesis*. New York: Russell Sage Foundation.

D'Emden, F., R. Llewellyn, and M. Burton. 2006. "Adoption of Conservation Tillage in Australian Cropping Regions: An Application of Duration Analysis." *Techonological Forecasting & Social Change.* 73: 630-647.

DeFelice, M, P. Carter, and S. Mitchell. 2006. "Influence of Tillage on Corn and Soybean Yield in the United States and Canada." *Plant Management Network.*

Derpsch, Rolf. 2004. "History of Crop Production, With and Without Tillage." *Journal of No-Till Agriculture*. 3(1):150-154.

Dick, W., and D. Van Doren Jr. 1985. "Continuous Tillage and Rotation Combinations Effects on Corn, Soybean, and Oat Yields." *Agronomy Journal.* 77:459-465.

Doran, J., W. Wilhelm, and J. Power. 1984. "Crop Residue Removal and Soil Productivity with No-Till Corn, Sorghum and Soybean." *Soil Sci. Soc. Am. Journal*. 48:640-645.

Eckert, D. 1984. "Tillage System X Planting Date Interactions in Corn Production." *Agronomy Journal.* 76:580-582.

Egli, D. 2008. "Comparison of Corn and Soybean Yields in the United States: Historical Trends and Future Prospects." *Agronomy Journal*. 100:S-79-S88.

Endale, D., H. Schomberg, D. Fisher, M. Jenkins, R. Sharpe, and M. Cabrera. 2008. "No-Till Corn Productivity in a Southeastern United States Ulitsol Amended with Poultry Litter." *Agronomy Journal.* 100:1401-1408.

Fernandez-Cornejo, J. 2010. "Adoption of Genetically Engineered Crops in the U.S.: Extent of Adoption." Online site: http://www.ers.usda.gov/data/biotechcrops/adoption.htm Accessed July 2010.

Fishburn, P. 1977. "Mean-Risk Analysis with Risk Associated with Below-Target Returns." *The American Economic Review.* 67:116-126.

Graven, L. and P. Carter. 1991. "Seed Quality Effect on Corn Performance Under Conventional and No-Tillage Systems." *Journal of Production Agriculture.* 4:366-373.

Greene, W. 2007. *LIMDEP Version 9.0 Reference Guide.* New York: Econometric Software, Inc.

Hairston, J., W. Jones, P. McConnaughey, L. Marshall, and K. Gill. 1990. "Tillage and Fertilizer Management Effects on Soybean Growth and Yield on Three Mississippi Soils." *Journal of Production Agriculture.* 3:317-323.

Halvorson, A., A. Mosier, C. Reule and W. Bausch. 2006. "Nitrogen and Tillage Effects on Irrigated Continuous Corn Yields." *Agronomy Journal*. 98:63-71.

Hammel, J. 1995. "Long-Term Tillage and Crop Rotation Effects on Winter Wheat Production in Northern Idaho." *Agronomy Journal*. 87:16-22.

Hartman, Murray. 2008. "Estimating the Value of Crop Residue." Alberta Reduced Tillage Linkages. Internet site: http://www.reducedtillage.ca/article76.aspx (Accessed on July 23, 2009).

Harville, D. and R. Mee. 1984. "A Mixed-Model Procedure for Analyzing Ordered Categorical Data." *Biometrics*. 40:393-408.

Hedges, L.V., and I. Olkin. 1985. *Statistical Methods for Meta-Analysis.* New York: Academic Press.

Hedges, L.V., J. Gurevitch, and P.S. Curtis. 1999. "The Meta-Analysis of Response Ratios in Experimental Ecology." *Ecology*. 80:1150–1156.

Herbek, J., L. Murdock, and R. Blevins. 1986. "Tillage System and Date of Planting Effects on Yield of Corn on Soils with Restricted Drainage." *Agronomy Journal.* 78:824-826.

Hofman, Vernon.1997. *Residue Management for Erosion Control.* Fargo, North Dakota: North Dakota State University-Extension Service, No. DS-22-97.

Ilukor, J and S. Oluka. 1995. "Carbon-To-Nitrogen Ratios in Agricultural Residues." *Environmental Monitoring and Assessment.* 38:271-275.

Kapusta, G., R. Krausz, and J. Matthews. 1996. "Corn Yield is Equal in Conventional, Reduced and No-Tillage After 20 Years." *Agronomy Journal.* 88:812-816.

Kunda, M., and T. West. 2006. "Tillage & Yield Study." Working paper, Oak Ridge National Laboratory.

Lankoski, J., M. Ollikainen, and P. Uusitalo. 2004. "No-Till Technology: Benefits to Farmers and the Environment?" Discussion paper 1, Helsinki, Finland. University of Helsinki. March.

Larson, J.A., B.C English, D.G. De La Torre Ugarte, R. Menard, C. Hellwinckel, and T.O. West. 2010. “Economic and Environmental Impacts of the Corn Grain Ethanol Industry on the United States Agricultural Sector.” *Journal of Soil and Water Conservation* 65: Forthcoming.

Legg, J., G. Stanford, and O. Bennett. 1979. “Utilization of Labeled-N Fertilizer by Silage Corn Under Conventional and No-till Culture.” *Agronomy Journal.* 71:1009-1015.

Linden, D., C. Clapp, and R. Dowdy. 2000. “Long-Term Corn Grain and Stover Yields as a Function of Tillage and Residue Removal in East Central Minnesota.” *Soil & Tillage Research*. 56:167-174.

Littell, R.C., W. Stroup, G. Milliken, and R. Wolfinger. 1996. *SAS System for Mixed Models*. SAS publishing, North Carolina.

Lueschen, W., J. Ford, S. Evans, B. Kanne, T. Hoverstad, G. Randall, J. Orf, and D. Hicks. 1992. “Tillage, Row Spacing and Planting Date Effects on Soybean Following Corn or Wheat.” *Journal of Production Agriculture.* 5:254-260.

Mannering, J and D. Griffith. 1985. “Value of Crop Rotaion Under Various Tillage Systems.” Purdue University Agronomy Guide. No. AY-230.

McCarthy, J., D. Pfost, and H. Currence. 1993. “Conservation Tillage and Residue Management to Reduce Soil Erosion.” University of Missouri-Extension. No. G1650.

McLean, R., W. Sanders, and W. Stroup. 1991. “A Unified Approach to Mixed Linear Models.” *The American Statistician*. 45:54-64.

Miguez, F., and G. Bollero. 2005. “Review of Corn Yield Response Under Winter Cover Cropping Systems Using Meta-Analytic Methods.” *Crop Science Society of America*. 45(6):2318-2329.

Miller, E. and W. Shrader. 1976. “Moisture Conservation Potential with Conservation Tillage Treatments in the Thick Loess Area of Western Iowa.” *Agronomy Journal*. 68:374-378.

Nicholson, W. 2005. *Microeconomic Theory: Basic Principles and Extensions*. Mason, OH: Thomson/South-Western.

North Carolina Dept. of Agriculture. Plant Nutrients. Online site: http://www.agr.state.nc.us/cyber/kidswrld/plant/nutrient.htm (Accessed July 2010).

Pedersen, P. and J. Lauer. 2003. “Corn and Soybean Response to Rotation Sequence, Row Spacing and Tillage System. *Agronomy Journal*. 95:965-971.

Phillips, R., R. Blevins, G. Thomas, W. Frye, and S. Phillips. 1980. “No-Tillage Agriculture.” *Science*, June, pp.1108-1113.

Ribera, L., F. Hons, and J. Richardson. 2004. “An Economic Comparison Between Conventional and No-Tillage Farming Systems in Burleson County, Texas.” *Agronomy Journal*. 96: 415-424.

SAS Institute. 1988. *SAS/STAT user’s guide*. 6.03 edition. Cary, NC: SAS Institute.

SAS Institute Inc. 2004. *SAS 9.1.3 Help and Documentation*. Cary, NC: SAS Institute Inc., 2000-2004.

Selley, R. 1984. “Decision Rules in Risk Analysis.” In (P.J Barry, ed.), *Risk Management in Agriculture*. Ames, IA: Iowa state University Press.

Shapiro, C., D. Holshouser, W. Kranz, D. Shelton, J. Witkowski, K. Jarvi, G. Echtenkamp, L. Lunz, R. Frerichs, R. Brentlinger, M. Lubberstedt, M. McVey McCluskey, and W. Stroup. 2001. “Tillage and Management Alternatives for Returning Conservation Reserve Program Land to Crops.” *Agronomy Journal*. 93:850-862.

Smiley, R. and D. Wilkins. 1993. “Annual Spring Barley Growth, Yield, and Root Rot in High- and Low-Residue Tillage Systems.” *Journal of Production Agriculture*. 6:270-275.

Smith, John. *Distribution of Crop Residue A Requirement for Conservation Tillage*. Lincoln, Nebraska: University of Nebraska-Lincoln Extension, No. G86-782, 1987.

Smith, M., P. Carter, and A. Imholte. 1992. “No-till vs. Conventional Tillage for Late-Planted Corn Following Hay Harvest.” *Journal of Production Agriculture*. 5:261-264.

So, H., A. Grabski, and P. Desborough. 2009. “The Impact of 14 Years of Conventional and No-Till Cultivation on the Physical and Crop Yields of a Loam Soil at Grafton NSW, Australia.” *Soil & Tillage Research*. 104(1): 180-184.

Stock, J. and M. Watson. 2003. *Introduction to Econometrics*. Boston, MA: Pearson Education, Inc.

Swan, J., E. Schneider, J. Moncrief, W. Paulson, and A. Peterson. 1987. “Estimating Corn Growth, Yield and Grain Moisture from Air Growing Degree Days and Residue Cover.” *Agronomy Journal*. 79:53-60.

Triplett Jr., G., D. Van Doren Jr., and B. Schmidt. 1968. "Effect of Corn Stove Mulch on No-Tillage Corn Yield and Water Infiltration." *Agronomy Journal*. 60:236-239.

University of Idaho. "Crop Management Decisions Move Toward Precision, Sustainable Agriculture." Department of Plant, Soil and Entomological Sciences. Internet site: http://www.cals.uidaho.edu/pses/Research/r_hort_cropmanagement.htm (Accessed on July 23, 2009).

University of Missouri-The Cooperative Soil Survey. Internet site: http://soils.missouri.edu/tutorial/page8.asp#c (Accessed January 28, 2010).

University of Missouri-The Cooperative Soil Survey. Internet site: http://soils.missouri.edu/tutorial/page5.asp# (Accessed January 28, 2010).

USDA. Economic Research Service. 2000. "Farm Resource Regions." Agricultural Information Bulletin No. 760, September 2000.

U.S. Department of Commerce-National Climatic Data Center-NESDIS. Internet site: http://www.ncdc.noaa.gov/oa/climate/stationlocator.html (Accessed November 2009).

Wagger, M. and H. Denton. 1989. "Tillage Effects on Grain Yields in a Wheat, Double-Crop Soybean, and Corn Rotation." *Agronomy Journal*. 81:493-498.

West, T.D., D. Griffith, G. Steinhardt, E. Kladivko, and S. Parsons. 1996. "Effect of Tillage and Rotation on Agronomic Performance of Corn and Soybean: Twenty-Year Study on Dark Silty Clay Loam Soil." *Journal of Production Agriculture*. 9:241-248.

Wilhelm, W., J. Doran, and J. Power. 1986. "Corn and Soybean Yield Response to Crop Residue Management Under No-Tillage Production Systems." *Agronomy Journal*. 78:184-189.

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

Woolridge, Jeffrey. 2000. *Introductory Econometrics: A Modern Approach*. Boston: South-Western College Publishing.

Young Jr., H. M. 1982. *No-Tillage Farming*. Brookfield, WI: No-Till Farmer, Inc.

Appendix

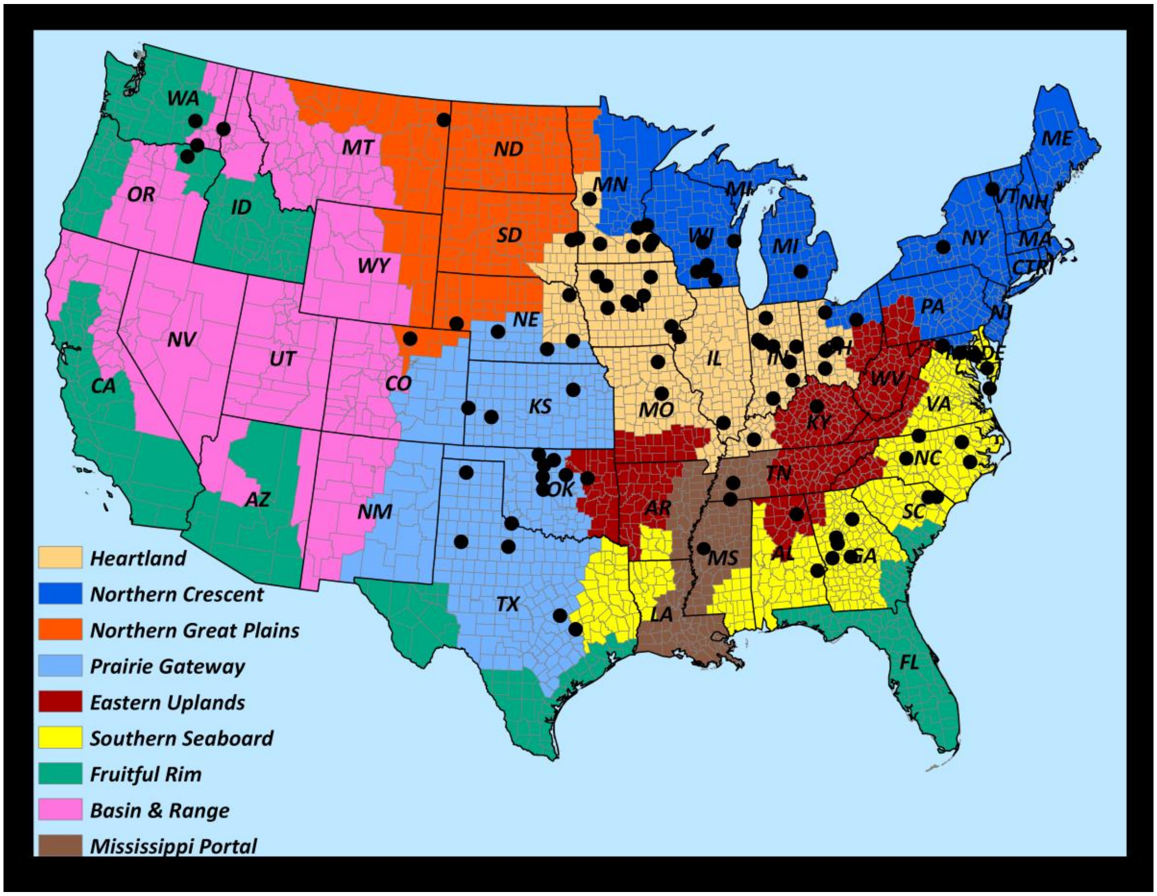


Figure 1. Experiment Locations by USDA ERS Farm Resource Region

Table 1. Variable Names and Definitions for the Statistical Models Comparing No-tillage Yields with Conventional Tillage or Reduced Tillage

Variable Name	Variable Definition	Hypothesized Sign
BEGAN	Natural log of the year the experiment began	−
LOGYR	Natural log of each year of experiment	+
RAIN	Annual rainfall(mm) at experiment location	+/−
Crop		
SORG	= 1 if sorghum; 0 otherwise.	+/−
WHEAT	= 1 if wheat; 0 otherwise.	+/−
*CORN**	= 1 if corn; 0 otherwise.	+/−
SOY	= 1 if soybeans; 0 otherwise.	+/−
OAT	= 1 if oats; 0 otherwise.	+/−
COTT	= 1 if cotton; 0 otherwise.	+/−
Tillage		
TILL	= 1 if comparing conventional tillage to no-tillage; = 0 for comparing reduced tillage to no-tillage.	+/−
Soil Texture		
SAND	= 1 if sandy soil; 0 otherwise.	+
SILT	= 1 if silty soil; 0 otherwise.	−
CLAY	= 1 if clay soil; 0 otherwise.	−
*LOAM**	= 1 if loamy soil; 0 otherwise.	−
USDA ERS Region		
*HEART**	= 1 if Heartland region; 0 otherwise.	+/−
NCRES	= 1 if Northern Crescent region; 0 otherwise.	−
NGP	= 1 if Northern Great Plains region; 0 otherwise.	−
PGATE	= 1 if Prairie Gateway region; 0 otherwise.	+/−
EASTU	= 1 if Eastern Uplands region; 0 otherwise.	+/−
SOSEA	= 1 if Southern Seaboard region; 0 otherwise.	+
FRIM	= 1 if Fruitful Rim region; 0 otherwise.	+/−
BANDR	= 1 if Basin & Range region; 0 otherwise.	+/−
MISS	= 1 if Mississippi Portal region; 0 otherwise.	+

* Variable dropped for the purpose of estimating the statistical models for the analysis.

Table 2. Test for Heteroskedasticity for PROC MIXED Mean Yield Model Comparing No-tillage Yields with Conventional Tillage or Reduced Tillage Yields

	White's Test			Breusch-Pagan		
Model	DF	Statistic	Pr > ChiSq.	DF	Statistic	Pr > ChiSq.
CTRTNT	114	191.10	<.0001	20	54.26	<.0001

Table 3. Variance Inflation Factors for PROC MIXED Mean Yield Model Comparing No-tillage Yields with Conventional or Reduced Tillage Yields

Variable	CTRTNT
INTERCEPT	0.00
SORG	1.63
WHEAT	2.86
SOY	1.23
OAT	1.05
COTT	1.91
TILL	1.08
BEGAN	1.58
LOGYR	1.32
RAIN	2.01
SAND	2.13
SILT	1.15
CLAY	1.08
NCRES	1.32
NGP	2.46
PGATE	2.22
EASTU	1.07
SOSEA	2.77
FRIM	1.28
BANDR	2.33
MISS	1.95

Table 4. Estimated Mixed Mean Yield Model Comparing No-tillage Yields with Conventional or Reduced Tillage Yields

Variable	Coefficient	t-Value
INTERCEPT	−0.01	−0.11
SORG	0.44***	5.33
WHEAT	0.22***	2.62
SOY	−0.17	−1.01
OAT	−0.52**	−2.47
COTT	−1.02	−1.59
SAND	0.00	0.07
SILT	−0.12*	−1.83
CLAY	0.01	0.20
TILL	−0.00	−0.28
BEGAN	0.00	0.34
LOGYR	−0.02***	−2.67
RAIN	−0.00	−0.92
NCRES	−0.01	−0.39
NGP	−0.04	−1.13
PGATE	0.00	0.18
EASTU	0.04	1.19
SOSEA	0.07***	2.72
FRIM	−0.10***	−2.77
BANDR	−0.11**	−2.46
MISS	0.09*	1.68
SORG×SAND	−0.22**	−2.57
SORG×CLAY	0.02	0.29
SORG×BEGAN	−0.07***	−3.60
SORG×LOGYR	0.03	1.06
SORG×RAIN	−0.00***	−4.62
WHEAT×SAND	−0.21***	−4.49
WHEAT×CLAY	−0.10	−1.08
WHEAT×BEGAN	−0.05**	−2.21
WHEAT×LOGYR	−0.00	−0.08
WHEAT×RAIN	−0.00	−1.48
SOY×SAND	−0.21***	−4.16
SOY×CLAY	0.00	0.03
SOY×BEGAN	0.05	0.98
SOY×LOGYR	0.02	1.36
SOY×RAIN	0.00	0.65
OAT×LOGYR	0.15	1.48
OAT×RAIN	0.00**	2.58
COTT×SAND	0.16	1.43
COTT×CLAY	0.01	0.10
COTT×BEGAN	0.25	1.26
COTT×LOGYR	0.17***	3.40
COTT×RAIN	0.00	0.65
n	1546	
−2 Res. Log. Likelihood	−811.1	
AIC	−807.1	
AICC	−807.1	
BIC	−811.1	

****Denotes significance at the 99% confidence level.*
***Denotes significance at the 95% confidence level.*
**Denotes significance at the 90% confidence level.*
(Reference Category: CORN, LOAM, and HEART).

Table 5. Estimated Logit Model for the Probability of No-tillage Yields Lower than Conventional or Reduced Tillage Yields

Explanatory Variable	Coefficient	Marginal Effect
CONSTANT	−0.60	−0.13
SORG	−5.10***	−0.75
WHEAT	−1.53	−0.35
SOY	3.10	0.38
OATS	6.01	0.31
COTT	10.96	0.39
SAND	−0.74**	−0.17
SILT	30.75	0.33
CLAY	−0.11	−0.02
TILL	−0.31*	−0.06
BEGAN	0.26	0.06
LOGYR	0.31***	0.06
RAIN	0.00***	0.00
MISS	−0.39	−0.09
NCRES	−0.35*	−0.08
NGP	−0.93**	−0.22
PGATE	−0.59***	−0.13
EASTU	−0.25	−0.05
SOSEA	−0.90***	−0.21
FRIM	0.73	0.13
BANDR	−0.25	−0.05
SORG×SAND	30.77	0.32
SORG×CLAY	−0.34	−0.08
SORG×BEGAN	0.30	0.06
SORG×LOGYR	−0.11	−0.02
SORG×RAIN	0.01***	0.00
WHEAT×SAND	2.70***	0.28
WHEAT×CLAY	0.60	0.11
WHEAT×BEGAN	0.40	0.08
WHEAT×LOGYR	0.17	0.04
WHEAT×RAIN	−0.00	−0.00
SOY×SAND	3.44***	0.30
SOY×CLAY	0.40	0.08
SOY×BEGAN	−0.96*	−0.20
SOY×LOGYR	−0.40*	−0.08
SOY×RAIN	−0.00**	−0.00
OAT×LOGYR	−2.26	−0.47
OAT×RAIN	−0.01	−0.00
COTT×SAND	−30.22	−0.72
COTT×CLAY	30.79	0.31
COTT×BEGAN	−2.50	−0.52
COTT×LOGYR	−1.55**	−0.32
COTT×RAIN	−0.00	−0.00
n	1546	
Log Likelihood	-872.15	
AIC	1.19	
BIC	1.36	
Chi-Squared	295.29	<.00000***

****Denotes significance at the 99% confidence level*
***Denotes significance at the 95% confidence level*
**Denotes significance at the 90% confidence level*
(Reference Category: CORN, LOAM, and HEART)

Journal Article References Used in Database

Soil & Tillage Research

Aase, J., G. Schaefer, and J. Pikul Jr. 1997. "Hayland Conversion to Wheat Production in Semiarid Eastern Montana: Tillage, Yield and Hay Production Comparisons." *Soil & Tillage Research.* 44:225-234.

Al-Darby, A., B. Lowery, and T. Daniel. 1987. "Corn Leaf Water Potential and Water Use Efficiency Under Three Conservation Tillage Systems." *Soil & Tillage Research.* 9:241-254.

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

Bauer, P., J. Frederick, and W. Busscher. 2002. "Tillage Effect on Nutrient Stratification in Narrow- and Wide-Row Cropping Systems." *Soil & Tillage Research.* 66:175-182.

Baumhardt, R. and O. Jones. 2002. "Residue Management and Tillage Effects on Soil-Water Storage and Grain Yield of Dryland Wheat and Sorghum for a Clay Loam in Texas." *Soil & Tillage Research.* 68:71-82.

Beck, D. and D. DeBoer. 1992. "Post-Emergence, Inter-Row Tillage to Enhance Infiltration Under Sprinkler Irrigation." *Soil & Tillage Research.* 23:111-123.

Blevins, R., G. Thomas, M. Smith, W. Frye, and P. Cornelius. 1983. "Changes in Soil Properties After 10 Years Continuous Non-tilled and Conventionally Tilled Corn." *Soil & Tillage Research.* 3:135-146.

Busscher, W., P. Bauer, and J. Frederick. 2006. "Deep Tillage Management for High Strength Southeastern USA Coastal Plain Soils." *Soil & Tillage Research.* 85:178-185.

Campbell, R., D. Karlen, and R. Sojka. 1984. "Conservation Tillage for Maize Production in the U.S. Southeastern Coastal Plain." *Soil & Tillage Research.* 4:511-529.

Cox, W., R. Zobel, H. van Es, and D. Otis. 1990. "Growth Development and Yield of Maize Under Three Tillage Systems in the Northeastern USA." *Soil & Tillage Research.* 18:295-310.

Eckert, D. 1990. "Ridge Planting for Row Crops on a Poorly Drained Soil. I. Rotation and Drainage Effects." *Soil & Tillage Research.* 18:181-188.

Endale, D., M. Cabrera, J. Steiner, D. Radcliffe, W. Vencill, H. Schomberg, and L. Lohr. 2002. “Impact of Conservation Tillage and Nutrient Management on Soil Water and Yield of Cotton Fertilized with Poultry Litter or Ammonium Nitrate in the Georgia Piedmont.” *Soil & Tillage Research.* 66:55-68.

Evans, S., M. Lindstrom, W. Voorhees, J. Moncrief, and G. Nelson. 1996. “Effect of Subsoiling and Subsequent Tillage on Bulk Density, Soil Moisture and Corn Yield.” *Soil & Tillage Research.* 38:35-46.

Fausey, N. 1990. “Experience with Ridge-till on Slowly Permeable Soils in Ohio.” *Soil & Tillage*. 18:195-205.

Heatherly, L., C. Elmore, and R. Wesley. 1990. “Weed Control and Soybean Response to Preplant Tillage and Planting Time.” *Soil & Tillage Research.* 17:199-210.

Heer, W. and E. Krenzer Jr. 1989. “Soil Water Availability for Spring Growth of Winter Wheat as Influenced by Early Growth and Tillage.” *Soil & Tillage Research.* 14:185-196.

Hilfiker, R. and B. Lowery. 1988. “Effect of Conservation Tillage Systems on Corn Root Growth.” *Soil & Tillage Research.* 12:269-283.

Hussain, I., K. Olson, and S. Ebelhar. 1999. “Impacts of Tillage and No-till on Production of Maize and Soybean on an Eroded Illinois Silt Loam Soil.” *Soil & Tillage Research.* 52:37-49.

Iragavarapu, T. and G. Randall. 1995. “Yield and Nitrogen Uptake of Monocropped Maize from a Long-Term Tillage Experiment on a Poorly Drained Soil.” *Soil & Tillage Research.* 34:145-156.

Joshi, J., J. Moncrief, J. Swan, and O. Burford. 1994. “Long-Term Conservation Tillage and Liquid Dairy Manure Effects on Corn. I. Nitrogen Availability.” *Soil & Tillage Research.* 31:211-224.

Karunatilake, U., H. van Es, and R. Schindelbeck. 2000. “Soil and Maize Response to Plow and No-tillage After Alfalfa-to-Maize Conversion on a Clay Loam Soil in New York.” *Soil & Tillage Research.* 55:31-42.

Kladivko, E., D. Griffith, and J. Mannering. 1986. “Conservation Tillage Effects on Soil Properties and Yield of Corn and Soybeans in Indiana.” *Soil & Tillage Research.* 8:277-287.

Lal, R. 1996. “Axle Load and Tillage Effects on Crop Yields on a Mollic Ochraqualf in Northwest Ohio.” *Soil & Tillage Research.* 37:143-160.

Lal, R. 1984. “Mechanized Tillage Systems Effects on Soil Erosion from an Alfisol in Watersheds Cropped to Maize.” *Soil & Tillage Research.* 4:349-360.

Lal, R. and M. Ahmadi. 2000. “Axle Load and Tillage Effects on Crop Yield for Two Soils in Central Ohio.” *Soil & Tillage Research.* 54:111-119.

Lal, R., T. Logan, and N. Fausey. 1989. “Long-Term Tillage and Wheel Traffic Effects on a Poorly Drained Mollic Ochraqualf in Northwest Ohio. I. Soil Physical Properties, Root Distribution and Grain Yield of Corn and Soybean.” *Soil & Tillage Research.* 14:341-358.

Linden, D., C. Clapp, and R. Dowdy. 2000. “Long-Term Corn Grain and Stover Yields as a Function of Tillage and Residue Removal in East Central Minnesota.” *Soil & Tillage Research.* 56:167-174.

Logan, T., D. Eckert, and D. Beak. 1994. “Tillage, Crop and Climatic Effects on Runoff and Tile Drainage Losses of Nitrate and Four Herbicides.” *Soil & Tillage Research.* 30:75-103.

Lowery, B., R. Hartwig, D. Stoltenberg, K. Fermanich, and K. McSweeney. 1998. “Groundwater Quality and Crop-Yield Responses to Tillage Management on a Sparta Sand.” *Soil & Tillage Research.* 48:225-237.

Lyon, D., W. Stroup, and R. Brown. 1998. “Crop Production and Soil Water Storage in Long-Term Winter Wheat-Fallow Tillage Experiments.” *Soil & Tillage Research.* 49:19-27.

Machado, Stephen, Steve Petrie, Karl Rhinhart, and Annie Qu. 2007. “Long-Term Continuous Cropping in the Pacific Northwest: Tillage and Fertilizer Effects on Winter Wheat, Spring Wheat, and Spring Barley Production”. *Soil & Tillage Research*. 94:473-481.

McMaster, G., D. Palic, and G. Dunn. 2002. “Soil Management Alters Seedling Emergence and Subsequent Autumn Growth and Yield in Dryland Winter Wheat-Fallow Systems in the Central Great Plains on a Clay Loam Soil.” *Soil & Tillage Research.* 65:193-206.

Mullins, G., C. Burmester, and D. Reeves. 1997. “Cotton Response to In-Row Subsoiling and Potassium Fertilizer Placement in Alabama.” *Soil & Tillage Research.* 40:145-154.

Nail, Elizabeth, Douglas Young, and William Schillinger. 2007. “Diesel and Glyphosate Price Changes Benefit the Economics of Conservation Tillage Versus Traditional Tillage”. *Soil & Tillage Research*. 94:321-327.

Pierce, F., M. Fortin, and M. Staton. 1992. “Immediate and Residual Effects of Zone-tillage in Rotation with No-tillage on Soil Physical Properties and Corn Performance.” *Soil & Tillage Research.* 24:149-165.

Pikul, J. Jr., L. Carpenter-Boggs, M. Vigil, T. Schumacher, M. Lindstrom, and W. Riedell. 2001. “Crop Yield and Soil Condition Under Ridge and Chisel-Plow Tillage in the Northern Corn Belt, USA.” *Soil & Tillage Research.* 60:21-33.

Pikul, J. Jr., R. Ramig, and D. Wilkins. 1993. “Soil Properties and Crop Yield Among Four Tillage Systems in a Wheat-Pea Rotation.” *Soil & Tillage Research.* 26:151-162.

Unger, P. 1994. “Ridge Tillage for Continuous Grain Sorghum Production with Limited Irrigation.” *Soil & Tillage Research.* 31:11-22.

Varsa, E., S. Chong, J. Abolaji, D. Farquhar, and F. Olsen. 1997. “Effect of Deep Tillage on Soil Physical Characteristics and Corn Root Growth and Production.” *Soil & Tillage Research.* 43:219-228.

Wilhelm, W. J. Schepers, L. Mielke, J. Doran, J. Ellis, and W. Stroup. 1987. “Dryland Maize Development and Yield Resulting from Tillage and Nitrogen Fertilization Practices.” *Soil & Tillage Research.* 10:167-179.

Agronomy Journal

Al-Darby, A.M. and B. Lowery. 1986. “Evaluation of Corn Growth and Productivity with Three Conservation Tillage Systems”. *Agronomy Journal.* 78:901-907.

Anderson, E.L. 1986. “No-Till Effects on Yield and Plant Density of Maize Hybrids”. *Agronomy Journal.* 78: 323-326.

Archer, D. and D. Reicosky. 2009. “Economic Performance of Alternative Tillage Systems in the Northern Corn Belt.” *Agronomy Journal.* 101:296-304.

Bermudez, M. and A. Mallarino. 2004. “Corn Response to Starter Fertilizer and Tillage Across and Within Fields Having No-Till Management Histories”. *Agronomy Journal.* 96:776-785.

Bordovsky, D., M. Choudhary, and C. Gerard. 1998. “Tillage Effects on Grain Sorghum and Wheat Yields in the Texas Rolling Plains”. *Agronomy Journal.* 90:638-643.

Cochrane, R., R. Roberts, J. Larson, and D. Tyler. 2007. “Cotton Profitability with Alternative Lime Application Rates, Cover Crops, Nitrogen Rates and Tillage Methods.” *Agronomy Journal.* 99:1085-1092.

Crabtree, R.J. and R.N. Rupp. 1980. “Double and Monocropped Wheat and Soybeans Under Different Tillage and Row Spacing”. *Agronomy Journal.* 72:445-448.

Dao, T. and H.T. Nguyen. 1989. “Growth Response of Cultivars to Conservation Tillage in a Continuous Wheat Cropping System”. *Agronomy Journal.* 81: 923-929.

Decker, J., F. Epplin, D. Morley, and T. Peeper. 2009. “Economics of Five Wheat Production Systems with No-Till and Conventional Tillage”. *Agronomy Journal.* 101: 364-372.

Dick, W. and D. Van Doren Jr. 1985. “Continuous Tillage and Rotation Combinations Effects on Corn, Soybean, and Oat Yields”. *Agronomy Journal.* 77: 459-465.

Douglas, C.L. Jr., D.E. Wilkins, and D.B. Churchill. 1994. “Tillage, Seed Size, and Seed Density Effects on Performance of Soft White Winter Wheat”. *Agronomy Journal.* 86: 707-711.

Eckert, D.J. 1984. “Tillage System X Planting Date Interactions in Corn Production”. *Agronomy Journal.* 76:580-582.

Edwards, J.H., D.L. Thurlow, and J.T. Eason. 1988. “Influence of Tillage and Crop Rotation on Yields of Corn, Soybean, and Wheat”. *Agronomy Journal.* 80: 76-80.

Elmore, R. 1991. “Soybean Cultivar Response to Planting Rate and Tillage”. *Agronomy Journal.* 83:829-832.

Elmore, R. 1987. “Soybean Cultivar Response to Tillage Systems”. *Agronomy Journal.* 79:114-119.

Endale, D., H. Schomberg, D. Fisher, M. Jenkins, R. Sharpe, and M. Cabrera. 2008. “No-Till Corn Productivity in a Southeastern United States Ultisol Amended with Poultry Litter”. *Agronomy Journal.* 100: 1401-1408.

Gerik, T. and J. Morrison Jr. 1984. “No-Tillage of Grain Sorghum on a Shrinking Clay Soil”. *Agronomy Journal.* 76: 71-76.

Griffith, D.R., E.J. Kladivko, J.V. Mannering, T.D. West, and S.D. Parsons. 1988. “Long-Term Tillage and Rotation Effects on Corn Growth and Yield on High and Low Organic Matter, Poorly Drained Soils”. *Agronomy Journal.* 80:599-605.

Hallauer, A.R. and T.S. Colvin. 1985. “Corn Hybrids Response to Four Methods of Tillage”. *Agronomy Journal.* 77: 547-550.

Hammel, J. 1995. “Long-Term Tillage and Crop Rotation Effects on Winter Wheat Production in Northern Idaho”. *Agronomy Journal.* 87:16-22.

Hargrove, W.L. 1985. “Influence of Tillage on Nutrient Uptake and Yield of Corn”. *Agronomy Journal.* 77: 763-768.

Herbek, J.H., L.W. Murdock, and R.L. Blevins. 1986. “Tillage System and Date of Planting Effects on Yield of Corn on Soils with Restricted Drainage”. *Agronomy Journal.* 78: 824-826.

Imholte, A.A. and P.R. Carter. 1987. “Planting Date and Tillage Effects on Corn Following Corn”. *Agronomy Journal.* 79:746-751.

Janosky, J., D. Young, and W. Schillinger. 2002. “Economics of Conservation Tillage in a Wheat-Fallow Rotation”. *Agronomy Journal.* 94:527-531.

Karlen, D.L. and R.E. Sojka. 1985. “Hybrid and Irrigation Effects on Conservation Tillage Corn in the Coastal Plain”. *Agronomy Journal.* 77:561-567.

Katsvairo, T. and W. Cox. 2000. “Tillage X Rotation X Management Interactions in Corn”. *Agronomy Journal.* 92:493-500.

Licht, M. and M. Al-Kaisi. 2005. “Corn Response, Nitrogen Uptake, and Water Use in Strip-Tillage Compared with No-Tillage and Chisel Plow”. *Agronomy Journal.* 97:705-710.

Meisinger, J.J., V.A. Bandel, G. Stanford, and J.O. Legg. 1985. “Nitrogen Utilization of Corn Under Minimal Tillage and Moldboard Plow Tillage. I. Four-Year Results Using Labeled N Fertilizer on an Atlantic Coastal Plain Soil”. *Agronomy Journal.* 77: 602-611.

Mengel, D.B., D.W. Nelson, and D.M. Huber. 1982. “Placement of Nitrogen Fertilizers for No-Till and Conventional Till Corn”. *Agronomy Journal.* 74:515-518.

Payne, W., P. Pasmussen, C. Chen, R. Goller, and R. Ramig. 2000. “Precipiation,Temperature and Tillage Effects Upon Productivity of a Winter Wheat-Dry Pea Rotation”. *Agronomy Journal.* 92: 933-937.

Payne, W., P. Rasmussen, C. Chen, and R. Ramig. 2001. “Assessing Simple Wheat and Pea Models Using Data from a Long-Term Tillage Experiment”. *AgronomyJournal.* 93: 250-260.

Pedersen, P. and J. Lauer. 2003. “Corn and Soybean Response to Rotation Sequence, Row Spacing, and Tillage System”. *Agronomy Journal.* 95: 965-971.

Pedersen, P. and J. Lauer. 2004. “Soybean Growth and Development Response to Rotation Sequence and Tillage System”. *Agronomy Journal.* 96: 1005-1012.

Ribera, L., F.M. Hons, and J. Richardson. 2004. “An Economic Comparison between Conventional and No-Tillage Farming Systems in Burleson County, Texas”. *Agronomy Journal.* 96: 415-424.

Sainju, U. and B. Singh. 2001. “Tillage, Cover Crop, and Kill-Planting Date Effects on Corn Yield and Soil Nitrogen”. *Agronomy Journal.* 93:878-886.

Shapiro, C., D. Holshouser, W. Kranz, D. Shelton, J. Witkowski, K. Jarvi, G. Echtenkamp, L. Lunz, R. Frerichs, R. Brentlinger, M. Lubberstedt, M. McVey McCluskey, and W. Stroup. 2001. “Tillage and Management Alternatives for Returning Conservation Reserve Program Land Land to Crops”. *Agronomy Journal.* 93:850-862.

Singer, J., S. Logsdon, and D. Meek. 2007. “Tillage and Compost Effects on Corn Growth, Nutrient Accumulation, and Grain Yield”. *Agronomy Journal.* 99: 80-87.

Singer, J., S. Logsdon, and D. Meek. 2008. “Soybean Growth and Seed Yield Response to Tillage and Compost”. *Agronomy Journal.* 100:1039-1046.

Stecker, J., D. Buchholz, R. Hanson, N. Wollenhaupt, and K. McVay. 1995. “Tillage and Rotation Effects on Corn Yield Response to Fertilizer Nitrogen on Aqualf Soils”. *Agronomy Journal.* 87:409-415.

Tarkalson, D., G. Hergert, and K. Cassman. 2006. “Long-Term Effects of Tillage on Soil Chemical Properties and Grain Yields of a Dryland Winter Wheat-Sorghum/Corn-Fallow Rotation in the Great Plains”. *Agronomy Journal.* 98: 26-33.

Torbert, H. Allen, K. Potter, and J. Morrison Jr. 2001. “Tillage System, Fertilizer Nitrogen Rate, and Timing Effect on Corn Yields in the Texas Blackland Prairie”. *Agronomy Journal.* 93: 1119-1124.

Touchton, J.T. and J.W. Johnson. 1982. “Soybean Tillage and Planting Method Effects on Yield of Double-Cropped Wheat and Soybeans”. *Agronomy Journal.* 74:57-59.

Tyler, D. and J. Overton. 1982. “No-Tillage Advantages for Soybean Seed Quality During Drought Stress”. *Agronomy Journal.* 74:344-347.

Vetsch, J. and G. Randall. 2002. “Corn Production as Affected by Tillage System and Starter Fertilizer”. *Agronomy Journal.* 94: 532-540.

Vetsch, J., G. Randall, and J. Lamb. 2007. “Corn and Soybean Production as Affected by Tillage Systems”. *Agronomy Journal.* 99: 952-959.

Wagger, M.G. and H.P. Denton. 1989. “Tillage Effects on Grain Yields in a Wheat, Double-Crop Soybean, and Corn Rotation”. *Agronomy Journal.* 81: 493-498.

Webber, C.L. III, M.R. Gebhart, and H.D. Kerr. 1987. Effect of Tillage on Soybean Growth and Seed Production”. *Agronomy Journal.* 79: 952-956.

Wilhelm, W.W. and Charles Wortmann. 2004. “Tillage and Rotation Interactions for Corn and Soybean Grain Yield as Affected by Precipitation and Air Temperature”. *Agronomy Journal.* 96:425-432.

Winter, S. and P. Unger. 2001. “Irrigated Wheat Grazing and Tillage Effects on Subsequent Dryland Grain Sorghum Production”. *Agronomy Journal.* 93:504-510.

Journal of Production Agriculture

Barnett, K. 1990. “No-tillage Corn Production in an Alfalfa-Grass Sod.” *Journal of Production Agriculture.* 3:71-75.

Bundy, L., T. Andraski, and T. Daniel. 1992. “Placement and Timing of Nitrogen Fertilizers for Conventional and Conservation Tillage Corn Production.” *Journal of Production Agriculture.* 5:214-221.

Cahoon, J., D. Eisenhauer, R. Elmore, F. Roeth, B. Doupnik Jr., R. Selley, K. Frank, R. Ferguson, M. Lorenz, and L. Young. 1999. “Corn Yield Response to Tillage with Furrow Irrigation.” *Journal of Production Agriculture.* 12:269-275.

Clark, L., T. Moore, and J. Barnett. 1996. “Response of Cotton to Cropping and Tillage Systems in the Texas Rolling Plains.” *Journal of Production Agriculture.* 9:55-60.

Ditsch, D. and J. Grove. 1991. “Influence of Tillage on Plant Populations, Disease Incidence and Grain Yield of Two Soft Red Winter Wheat Cultivars.” *Journal of Production Agriculture.* 4:360-365.

Epplin, F., D. Beck, E. Krenzer Jr., and W. Heer. 1993. “Effects of Planting Dates and Tillage Systems on the Economics of Hard Red Winter Wheat Production.” *Journal of Production Agriculture.* 6:57-62.

Evanylo, G. 1991. “Potassium Fertilization of Doublecropped Wheat and Soybeans Under Two Tillage Systems.” *Journal of Production Agriculture.* 4:555-562.

Graven, L. and R. Carter. 1990. Seed Size/Shape and Tillage System Effect on Corn Growth and Grain Yield.” *Journal of Production Agriculture.* 3:445-452.

Graven, L. and P. Carter. 1991. “Seed Quality Effect on Corn Performance Under Conventional and No-tillage Systems.” *Journal of Production Agriculture.* 4:366-373.

Heatherly, L., C. Elmore, R. Wesley, and S. Spurlock. 1996. “Net Returns from No-till Doublecrop Winter Wheat and Irrigated Soybean on a Clay Soil.” *Journal of Production Agriculture.* 9:554-558.

Howard, D., C. Gwathmey, R. Roberts, and G. Lessman. 1998. “Potassium Fertilization of Cotton Produced on a Low K Soil with Contrasting Tillage Systems.” *Journal of Production Agriculture.* 11:74-79.

Hunt, P., P. Bauer, and T. Matheny. 1997. “Crop Production in a Wheat-Cotton Doublecrop Rotation with Conservation Tillage.” *Journal of Production Agriculture.* 10:462-465.

Kanwar, R., T. Colvin, and D. Karlen. 1997. “Ridge, Moldboard, Chisel and No-till Effects on Tile Water Quality Beneath Two Cropping Systems.” *Journal of Production Agriculture.* 10:227-234.

Karlen, D., J. Edwards, W. Busscher, and D. Reeves. 1991. “Grain Sorghum Response to Slit-tillage on Norfolk Loamy Sand.” *Journal of Production Agriculture.* 4:80-85.

Lueschen, W., J. Ford, S. Evans, B. Kanne, T. Hoverstad, G. Randall, J. Orf, and D. Hick. 1992. “Tillage, Row Spacing and Planting Date Effects on Soybean following Corn or Wheat.” *Journal of Production Agriculture.* 5:254-260.

Lueschen, W., S. Evans, J. Ford, T. Hoverstad, B. Kanne, J. Orf, J. Staricka, W. Stienstra, D. Warnes, and D. Hicks. 1991. “Soybean Production as Affected by Tillage in a Corn and Soybean Management System: I. Cultivar Response.” *Journal of Production Agriculture.* 4:571-579.

Lund, M., P. Carter, and E. Oplinger. 1993. “Tillage and Crop Rotation Affect Corn, Soybean and Winter Wheat Yields.” *Journal of Production Agriculture.* 6:207-213.

Matowo, P., G. Pierzynski, D. Whitney, and R. Lamond. 1997. “Long Term Effects of Tillage and Nitrogen Source, Rate and Placement on Grain Sorghum Production.” *Journal of Production Agriculture.* 10:141-146.

Miller, D. and J. Aarstad. 1990. “Preplant Tillage Effects on Irrigated Corn Grown on a Sandy Soil.” *Journal of Production Agriculture.* 3:606-609.

Morrison, Jr., J., T. Gerik, F. Chichester, J. Martin, and J. Chandler. 1990. “A No-tillage Farming System for Clay Soils.” *Journal of Production Agriculture.* 3:219-227.

Norwood, C. 1992. “Tillage and Cropping System Effects on Winter Wheat and Grain Sorghum.” *Journal of Production Agriculture.* 5:120-126.

Norwood, C., A. Schlegel, D. Morishita, and R. Gwin. 1990. “Cropping System and Tillage Effects on Available Soil Water and Yield of Grain Sorghum and Winter Wheat.” *Journal of Production Agriculture.* 3:356-362.

Norwood, C. and R. Currie. 1996. “Tillage, Planting Date and Plant Population Effects on Dryland Corn.” *Journal of Production Agriculture.* 9:119-122.

Philbrook, B., E. Oplinger, and B. Freed. 1991. “Solid-Seeded Soybean Cultivar Response in Three Tillage Systems.” *Journal of Production Agriculture.* 4:86-91.

Potter, K., J. Morrison Jr., and H. Torbert. 1996. “Tillage Intensity Effects on Corn and Grain Sorghum Growth and Productivity on a Vertisol.” *Journal of Production Agriculture.* 9:385-390.

Roberts, R., D. Gerloff, and D. Howard. 1997. “Economics of Foliar-Applied Potassium for Conventional and No-till Cotton.” *Journal of Production Agriculture.* 10:585-589.

Segarra, E., J. Keeling, and J. Abernathy. 1991. “Tillage and Cropping System Effects on Cotton Yield and Profitability on the Texas Southern High Plains.” *Journal of Production Agriculture.* 4:566-571.

Smiley, R. and D. Wilkins. 1993. “Annual Spring Barley Growth, Yield and Root Rot in High- and Low-Residue Tillage Systems.” *Journal of Production Agriculture.* 6:270-275.

Smith, M., P. Carter, and A. Imholte. 1992. “No-till vs. Conventional Tillage for Late-Planned Corn Following Hay Harvest.” *Journal of Production Agriculture.* 5:261-264.

Stevens, W., J. Johnson, J. Varco, and J. Parkman. 1992. “Tillage and Winter Cover Management Effects on Fruiting and Yield of Cotton.” *Journal of Production Agriculture.* 5:570-575.

Vepraskas, M., W. Busscher, and J. Edwards. 1995. “Residual Effects of Deep Tillage vs. No-till on Corn Root Growth and Grain Yield.” *Journal of Production Agriculture.* 8:401-405.

Weisz, R. and D. Bowman. 1999. “Influence of Tillage System on Soft Red Winter Wheat Cultivar Selection.” *Journal of Production Agriculture.* 12:415-418.

West, T., D. Griffith, and G. Steinhardt. 1996. “Effect of Paraplowing on Crop Yields with No-till Planting.” *Journal of Production Agriculture.* 9:233-237.

West, T., D. Griffith, G. Steinhardt, E. Kladivko, and S. Parsons. 1996. "Effect of Tillage and Rotation on Agronomic Performance of Corn and Soybean: Twenty-Year Study on Dark Silty Clay Loam Soil." *Journal of Production Agriculture.* 9:241-248.

Wheeler, T., J. Gannaway, H. Kaufman, J. Dever, J. Mertley, and J. Keeling. 1997. "Influence of Tillage, Seed Quality, and Fungicide Seed Treatments on Cotton Emergence and Yield." *Journal of Production Agriculture.* 10:394-400.

Wiese, A., T. Marek, and W. Harman. 1998. "No-tillage Increases Profit in a Limited Irrigation-Dryland System." *Journal of Production Agriculture.* 11:247-252.

Chapter 3: Effects of No-Tillage on a Farmer's Net Return

Abstract

Farmers are constantly looking for ways to increase their profits. One possible way of obtaining this goal is with the use of no-tillage. This study evaluated and compared net returns for conventional or reduced tillage versus no-tillage. The study also evaluated different factors that may affect a farmer's net return such as crop, location of production, soil texture, time since conversion from conventional or reduced tillage to no-tillage, tillage and precipitation. Data for six different crops across the United States from 442 paired tillage experiments published in three refereed journals; *Agronomy Journal*, *Soil & Tillage Research* and *Journal of Production Agriculture* were analyzed. Yields were detrended and inflated to 2009 levels. Crop prices were obtained from USDA NASS and reflected average 2009 prices for each state and crop represented. Budgets for each location were gathered from a large-scale agricultural simulator, POLYSYS. Net returns were evaluated using a mixed model and a logit model to evaluate differences in mean net returns and downside risk, respectively. Results showed that no-tillage was more profitable than tillage in the Mississippi Portal, but was less profitable in the Prairie Gateway. Net returns were lower for no-tillage wheat and soybeans when produced on clay soils. Cotton grown on sandy soils had higher no-tillage net returns, but increased annual rainfall decreased net returns for crops produced using no-tillage. Results indicate that wheat grown under no-tillage had less downside risk relative to corn and the other crops analyzed in this study. Crops grown using no-tillage on clay soils also had a lower probability of low net returns when compared to crops grown using tillage on clay soils. Regional differences in the riskiness of no-tillage relative to tillage were also identified in the analysis. Crop production using no-tillage

was less risky in the Southern Seaboard but more risky in the Northern Great Plains, the Prairie Gateway and the Basin & Range regions. These results appear to be consistent with no-tillage performing better in terms or risk in warmer climates than in colder climates.

Introduction

Crop yields and inputs are two of the main driving factors affecting a farmer's net return. Thus, farmers are constantly looking to adopt farm management practices that increase yields and decrease input costs. One management practice with promising results of accomplishing this task is no-tillage. No-tillage has been shown to reduce fuel, labor and machinery repair costs (Bremer et al. 2001; Deen and Kataki 2003; Lankoski et al. 2004). However, more herbicides are needed to help control weeds when using no-tillage. Herbicide resistant crops, such as Roundup Ready crops, that allow glyphosate to be sprayed over the top to control weeds during the growing season have facilitated the adoption of no-tillage (Roberts et al. 2006). The cost of glyphosate has declined due to the expiration of the patent for RoundUp (glyphosate), which can now be generically made, but as of the last few years this cost has increased once again due to increased demand (Johnston 2007).

There are many advantages to using no-tillage that may result in decreased costs to the farmer. Planting with no-tillage is accomplished in one pass, whereas with conventional tillage the soil is tilled, disked and then planted. Thus, overall fuel usage is decreased, because equipment for tillage is not required for crops grown using no-tillage; a lower overall investment in machinery and equipment is required by farmers adopting no-tillage. With the use of no-tillage, less labor is needed, and erosion is reduced because of more residue on the soil surface (Harper 1996). Improved soil moisture conservation with no-tillage may allow a farmer to use less irrigation (Harper 1996).

No-tillage of today is more economically efficient than in years past because of cheaper chemical costs and improved equipment designs, which could influence farmers to more readily convert to the practice. Epplin et al. (2005) found two changes over the past decade that justified the reevaluation of no-tillage efficiency in wheat production. One justification is the improved design of no-tillage grain drills and air seeders, which in the past have been partially blamed for lower wheat yields with the use of no-tillage (Epplin et al. 2005). Poor crop stands with no-tillage has also been problematic for other crops in the past (Triplett and Dick 2008). The other justification is the decrease in the price of glyphosate, which has declined from $45.50/gallon (RoundUp price) in 1999 to $20/gallon in 2004 (Epplin et al. 2005). Epplin et al. (2005) reported that for a farm in Oklahoma producing continuous wheat, no-tillage was found to have higher total operating costs than conventional tillage. But when evaluating total operating costs plus machinery fixed costs, a 320 acre farm accumulates costs of $109/acre for conventional tillage and $119/acre for no-tillage, a 640 acre farm has costs of $103/acre for conventional tillage and $113/acre for no-tillage, a 1,280 acre farm has costs of $99/acre for conventional tillage and $96/acre for no-tillage, and a 2,560 acre farm has costs of $103/acre for conventional tillage and $100/acre for no-tillage (Epplin et al. 2005). This information suggests that no-tillage is more profitable than conventional tillage on larger farms (+1,280 acres). Epplin et al. (2005) conclude that if yields for no-tillage and conventional tillage are the same, no-tillage is more economical on larger farms (+1,280 acres) than on smaller farms. With the potential for improved equipment design, declining chemical costs and increasing diesel prices in the future, no-tillage may become even more economical relative to conventional tillage.

As indicated previously, another perceived advantage for farmers who adopt no-tillage is the invention of RoundUp Ready crops. These genetically modified crops

(GMO) crops are herbicide resistant. Herbicide resistant crops that allow chemicals to be sprayed over the top of the crop have become a potential bonus for farmers implementing no-tillage. Herbicide resistant soybeans became available in 1996 and by 2001 68% of all U.S. soybean acreage was planted with herbicide resistant soybeans (Fernandez-Cornejo and McBride 2005). These bioengineered crops were developed to survive applications of glyphosate, which beforehand would have killed or weakened the plant if it were to come in contact with it. This technology gives farmers more options for herbicide application. Herbicide tolerant crops allow farmers to spray post-emergence and use a single product to control weeds instead of multiple herbicides used to control broadleaf and grass weeds that won't harm the crop. The adoption of GMO crops has been found to be correlated to the farmer's education and experience. The more experience and education the farmer has, the more likely he/she will adopt a GMO crop (Fernandez-Cornejo and McBride 2005), and the more likely the farmer is to adopt no-tillage practices (Roberts et al. 2006).

Just as with no-tillage versus conventional tillage crop yields, there are many conflicting findings as to which tillage system resulted in the highest net return. Previous studies show that different tillage regimes have different levels of profitability depending on the location of production, the crop and other factors such as precipitation and soil texture. In addition, net returns and input costs can vary from farm to farm because of types and ages of farm machinery, a farmer's management skill and weed and insect problems (USDA 2006). Heatherly et al. (1996) found that net returns for winter wheat grown under no-tillage in Mississippi were similar in 1988. However, no-tillage winter wheat had higher net returns in 1989 and lower returns in 1990 when compared to conventional tillage. They also found that no-tillage soybean net returns were not statistically different from conventional tillage soybeans in the experiment.

Some crops were found to be more profitable under no-tillage than others. Net returns in Manhattan, KS, differed by crop and tillage method (Williams et al. 2009). No-tillage soybeans had higher net returns than reduced or conventional tillage soybeans. Reduced tillage sorghum and wheat at the same location yielded higher returns when compared to conventional tillage and no-tillage (Williams et al. 2009).

Net returns have been found to differ by location when growing the same crop. Corn produced in Pennsylvania was found to be more profitable under no-tillage when compared to reduced and conventional tillage (Harper 1996), whereas no-tillage corn in Minnesota had higher returns than corn cultivated with moldboard plow, but no-tillage returns were similar when compared to chisel plow (Archer and Reicosky 2009). Net returns on reduced tillage wheat were found to be higher in Kansas when compared to conventional and no-tillage wheat (Williams et al. 2009). Similar results in Washington were found when comparing reduced tillage wheat to conventional tillage wheat (Nail et al. 2007). However, Janosky et al. (2002) found that reduced tillage wheat net returns in Washington were not statistically different from conventional tillage wheat net returns. Epplin et al. (1993) in Oklahoma found that conventional tillage wheat had higher net returns than no-tillage wheat (Epplin et al. 1993). Some studies from different locations for the same crop coincide with one another. For example, Cochran et al. (2007) found that no-tillage cotton net returns in Jackson, TN were higher than conventional tillage cotton net returns. The same was true for cotton grown in Stoneville, MS, using the same tillage systems (Hanks and Martin 2007). Both of these studies also stated that no-tillage cotton net returns were higher without the use of a cover crop because of the extra costs of establishing the cover crops.

Net returns for different tillage methods may also be affected by farm size. Decker et al. (2009) found that on a 642 acre (260 ha) farm, conventional tillage had higher net returns when producing wheat for grain or forage. When the size of the farm increased to a size of 2,560 acres (1,036 ha), no-tillage was more profitable when producing wheat for forage, but wheat cultivated for grain using conventional tillage still provided higher net returns. Epplin et al. (2005) discovered a similar result where they found that if wheat yields are equivalent for conventional tillage and no-tillage, then no-tillage is more economical on larger farms (+1,280 acres) and conventional tillage more economical on smaller farms.

With the many potential benefits, it begs the question why is no-tillage only utilized on 38% of U.S. cropland (CTIC 2009)? Farmers may be uncertain about the benefits of no-tillage both agronomically and economically and farmers who switch to no-tillage could face a huge learning curve. Kurkalova et al. (2001) discovered that farmers who do not adopt conservation tillage do not do so because the expected profit gain does not fully compensate for the perceived increased risks with conservation tillage and the inability to recover lost profits associated with the switch from a conventional tillage method. To overcome this risk, they found that a government subsidy between \$2.40/acre per year and \$3.50/acre per year would be needed to entice soybean farmers to adopt a conservation tillage method (Kurkalova et al. 2001).

Much research has been done evaluating no-tillage crop yields, but far less has been done on the economics of using no-tillage. The objective of this research is to evaluate mean net returns and the potential of downside risk of no-tillage compared to conventional or reduced tillage from data pertaining to six crops from a wide array of conditions and locations across the United States.

Conceptual Framework

Assuming farmers are profit maximizers and price-takers for their inputs and outputs (Nicholson 2005), profits for no-tillage ($\prod_{NT}$) and conventional tillage ($\prod_{CT}$) can be modeled using the following profit equation:

1) $E(\pi_{NT}) = Price \times E(Yield_{NT}) - VC_{NT} - FC_{NT}$, and

2) $E(\pi_{CT}) = Price \times E(Yield_{CT}) - VC_{CT} - FC_{CT}$,

where *E* is the expectation operator, *Price* is the price received by the farmer, *Yield* is the yield for each tillage practice, *VC* is the variable costs of production and *FC* is the fixed costs of production for each tillage method. Variable costs for each tillage method typically include fuel, seed, fertilizer and most notably for no-tillage, herbicides. Fixed costs for each tillage practice include machinery, self-employed labor and land. However, labor and machinery requirements differ between the two tillage methods. No-tillage tends to use less machinery because tillage operations are foregone, thus reducing fuel and labor costs. Variable costs increase when the use of variable inputs rises to increase output, but fixed costs remain unchanged no matter the production level (Massey 1997). If variable costs and/or fixed costs are higher, profits will be lower; therefore, if farmers are to maximize profit, they would want to choose a practice that reduces costs and/or increases yields.

Many farmers are also concerned about the riskiness of net returns associated with a no-tillage practice. Farmers who are risk averse are most often concerned about deviations in net returns below the mean or some other target value (Binswanger, 1981; Selley, 1984; Antle, 1987; Chavas, 2004) Downside risk below a target or comparison value can be modeled using the lower partial moment (*LPM*) (Fishburn, 1977). The equation for the LPM in the context of the tillage decision problem is given by:

$$E[LPM]_i = E[\{\min(Y_i - Z),0\}^n], \quad (3)$$

where E is the expectations operator, Z is some net return reference point for tillage practice i to be evaluated against and n is the degree of the moment. Thus, the *LPM* is a measure of the expected deviations below the comparison or target level. The common classifications of n are: $n = 0$ is the probability of a loss, $n = 1$ is the target shortfall, $n = 2$ is the target semi-variance, and $n = 3$ is the target skewness.

Meta-analysis is a quantitative method for summarizing the results of independent studies to allow for the testing of hypotheses that cannot be addressed in a single experiment (Hedges and Olkin, 1985; Cooper and Hedges, 1994; Miguez and Bollero, 2005). For the present study, the hypothesis related to the effects of the unpredictable impacts of weather, soils and other production environment factors on net returns and downside net return risk for no-tillage ($i = NT$) relative to tillage (conventional-, strip-, ridge-, and mulch-tillage; $i = TILL$) were evaluated using data from paired no-tillage and tillage method experiments from across the United States. Because yields are a large factor in determining profit, yields are assumed to be random while other input and output prices and quantities are assumed to not vary in this analysis. The approach used in this study is through the creation of a response ratio (*RR*) that is used to evaluate relative tillage and no-tillage net returns and is given by (Hedges et al. 1999):

(4) $$RR = \left(\frac{NR_{NT}}{NR_{TILL}} \right).$$

Using the response ratio (*RR*) as the dependent variable, a mixed linear model was used to evaluate which production environmental factors affected mean net revenues:

(5) $$RR = X\alpha + U\beta + \varepsilon,$$

where α is a vector of unknown fixed effects, β is a vector of random effects, ε is a vector of random residuals and X and U are given known and incidence matrices, respectively (Harville and Mee 1984; McLean et al. 1991). Identification of factors influencing differences in net revenues for no-tillage versus conventional tillage practices was determined by the sign and significance of parameter estimates.

Using the probability of a loss below a comparison level ($n = 0$) that is embodied in equation (3) and the response ratio in equation (4), a conditional logit model was specified to evaluate the probability of no-tillage net revenues being lower than tillage net revenues as influenced by the aforementioned production environment factors. The dependent variable *NTPROB* was defined as follows: If the response ratio, $RR < 1$, then $NTPROB = 1$; otherwise, $NTPROB = 0$. Thus, downside risk in this case is defined as the probability of reduced net revenues with no-tillage when compared with net revenues from conventional tillage.

The logit model below specifies the probability of downside production risk when switching from conventional or reduced tillage to no-tillage:

(6) $$NTPROB(a = 1) = \frac{e^{\beta' X}}{1 + e^{\beta' X}}.$$

Equation (7) is the probability of no downside risk when switching to no-tillage:

(7) $$NTPROB(a=0)=1-P(a=1)=\frac{1}{1+e^{\beta' X}}.$$

Maximum likelihood was used to estimate the conditional logit model. Identification of factors influencing the probability of lower no-tillage net revenues was determined by the sign and significance of parameter estimates and the evaluation of probabilities. The marginal effects give the probability of no-tillage having reduced net revenues compared to conventional tillage.

Methods & Procedures

Data

Data from 686 paired tillage and conservation tillage experiments published in the *Soil and Tillage Research* Journal were compiled by Maithilee Kunda and Tristram West of the Oak Ridge National Laboratory (Kunda and West 2006). Of these 686 paired experiments, only the 161 paired experiments that pertained to the 48 contiguous states of the United States were analyzed. The dataset was updated to include four additional paired experiments appearing in that journal since July 2006. These paired experiments compare conventional tillage and/or reduced tillage to no-tillage. The dataset was augmented using the *Agronomy Journal* from the years 1980 through 2009. The reason for only going back to 1980 in the *Agronomy Journal* is because the *Soil & Tillage Research* journal only went back to 1980, so to be consistent the same starting date was used. The *Agronomy Journal* added 173 paired experiments to the tillage database. A third dataset was created with journal articles from the *Journal of Production Agriculture* from its inception in 1988 until it was absorbed into the *Agronomy Journal* in 1999, which netted an additional 104 paired experiments. These additions augmented the dataset to a total of 442 paired tillage experiments across 92 locations. Of these experiments, 66% used a randomized complete block experimental design, 25% split-plot design, 7% other, i.e. strip plot, strip-split and unique companion plots and 2% were not given. The data include numerous crops of which sorghum, corn, soybeans, oats, cotton and wheat will be used. Other data for all experiments include the year each experiment began, each individual year of the experiment, soil texture, geographic location and annual precipitation. The soil texture at each experimental site was usually given. If only the soil texture percentages were given, a soil texture triangle was used to place it into a soil texture category (University of Missouri, Accessed online January 2010). The central theme of the identified texture, which is the most important, was used to place the soil either a clay, silt, sand or loam soil texture (University of Missouri, Accessed online January 2010). The annual precipitation for each year of each experiment was added to the dataset through the use of the National Environmental Satellite, Data, and Information Service, a branch of the Department of Commerce (U.S. Dept. of Commerce 2009). In addition, the zip codes at which the experiments took place were used to place each experiment into one of the nine ERS Farm Resource Regions of the USDA (USDA Economic Research Service 2000). Crop prices were obtained through NASS and crop budgets were retrieved from POLYSYS. Variable names and definitions can be found in Table 6 in the appendix.

Conventional tillage and reduced tillage data were grouped together for comparison with no-tillage. Hereafter the grouping of conventional and reduced tillage will be referred to as conventional tillage. Yield data from the compiled datasets were detrended and inflated to 2009 crop yield levels following procedures used by the Food and Agriculture Organization of the United Nations (Gommes and Hoefsloot 2006). Yields are detrended to remove upward trends caused from factors such as improvements in technology, weather and extreme factors like policies and laws affecting farm management. Prices for each crop were obtained through NASS and reflect average 2009 prices for each respective state in which data from the crop experiments were gathered for the analysis (USDA-NASS 2010). Crop budgets used to analyze net returns were from the large-scale agriculture simulation model, POLYSYS (Tiller et al. 1997). POLYSYS has a set of budgets for all U.S. counties and each crop and each respective tillage method used; conventional, reduced and no-tillage practices. Budget data for each crop and tillage practice were estimated using a consistent set of assumptions, methods and data following ASAE standards and AAEA commodity cost and return guidelines (AAEA 2000; ASAE 2006). The budgets reflect best management practices for each crop, tillage practice and region. The information gathered from POLYSYS reflects the costs per acre of labor, seed, fuel, lubrication, repairs, nitrogen, phosphorus, potassium, lime, herbicides, insecticides, other chemicals, irrigation, housing, insurance, farm machinery depreciation, interest and an “other” category entailing custom costs such as scouting and irrigation water costs. Government transition, supplemental and/or loan deficiency payments were not included in the analysis.

Empirical Models

The following net return equation was created to determine a farmer’s net return when using different tillage methods.

5)

$$\begin{aligned} Net\ Revenue_{ijk} \\ &= \left(Price_{jk} \times Yield_{ijk}\right) - Labor_{ijk} - Seed_{ijk} - Fuel_{ijk} - Lube_{ijk} \\ &- Repairs_{ijk} - Nitrogen_{ijk} - Phosphorus_{ijk} - Potassium_{ijk} \\ &- Lime_{ijk} - Herbicide_{ijk} - Insecticide_{ijk} - OtherChemicals_{ijk} \\ &- Irrigation_{ijk} - Other_{ijk} - Housing_{ijk} - Insurance_{ijk} \\ &- Depreciation_{ijk} - Interest_{ijk}, \end{aligned}$$

where *i* represents the tillage method; conventional or no-tillage, *j* represents the crop grown; corn, sorghum, oats, soybeans, cotton or wheat and *k* denotes experiment location. Using the net revenues estimated in equation (5), an empirical model was created, (Equation 6), to evaluate how different tillage methods affects mean net revenues across different variables such as crop, time, precipitation, soil texture and geographic region.

6)

$$\begin{aligned} NR = \alpha_0 + \sum_{i=1}^{5} \alpha_i CROP_i + \sum_{j=6}^{8} \alpha_j SOIL_j + \sum_{k=9}^{16} \alpha_k ERS_k + \alpha_{17} NT + \alpha_{18} BEGAN \\ + \alpha_{19} LOGYR + \alpha_{20} RAIN + \sum_{i=1}^{5} \alpha_{i\,17} (CROP_i)(NT) \\ + \sum_{k=9}^{16} \alpha_{k\,17} (ERS_k)(NT) + \sum_{j=6}^{8} \alpha_{j\,17} \left(SOIL_j\right)(NT) + \alpha_{21}(NT)(BEGAN) \\ + \alpha_{22}(NT)(LOGYR) + \alpha_{23}(NT)(RAIN) + \varepsilon, \end{aligned}$$

where *i* is the subscript for one of five crops: sorghum, wheat, soybeans, cotton or oats. Subscript *j* represents one of three soil textures: sand, silt or clay. The subscript for the ERS regions, *k*, represents one of eight USDA ERS Farm Resource Regions: Northern Crescent, Northern Great Plains, Prairie Gateway, Eastern Uplands, Southern Seaboard, Fruitful Rim, Basin & Range or Mississippi Portal. The reference categories for *CROP*, *SOIL* and *ERS* are corn (*CORN*), loam soil (*LOAM*) and the Heartland (*HEART*) region, respectively. These three variables were dropped to facilitate the estimation of the statistical. These variables were dropped because each had the most observations for their respective category. The dependent variable, *NR*, is the associated net returns for each observation. *NT* is a binary dummy variable with a value of 1 representing no-tillage and 0 for conventional tillage. The variable *BEGAN*, is a continuous variable used to capture improvements in technology over time. It represents the year in which the experiment was initiated, with 1964=1, 1965=2,…, 2005=42; then the natural log of that number was taken. Another variable, *LOGYR*, was created to verify if there is a yield lag when switching from conventional tillage or reduced tillage to no-tillage as much anecdotal evidence suggests, and to see if no-tillage yields relative to tillage yields increase over time through soil improvement. *LOGYR* is a continuous variable which represents each year of the experiment with experiment 1: 1981=1, 1982=2,..., 1985=5; experiment 2: 1995=1, 1996=2; then the natural log of that number was taken. The continuous variable *RAIN* is annual precipitation for each location and year of each experiment. It should be noted that there are no observations for sorghum, wheat, soybeans, oats or cotton in a silt textured soil. There are also no observations for oats in a sand or clay textured soil, therefore there are no interactions between those specific crops and soil textures.

The empirical models below were used to evaluate net return risk and differences between no-tillage and conventional tillage methods using the net revenue proportions (*RR*) as the dependent variable and were specified as follows:

7)

$$RR = \beta_0 + \sum_{i=1}^{5} \beta_i CROP_i + \sum_{j=6}^{8} \beta_j SOIL_j + \sum_{k=9}^{16} \beta_k ERS_k + \beta_{17} BEGAN + \beta_{18} LOGYR$$

$$+ \beta_{19} RAIN + \sum_{i=1}^{5} \quad \sum_{j=6}^{8} \beta_{i\,j} (CROP_i)(SOIL_j)$$

$$+ \sum_{i=1}^{5} \beta_{i\,17} (CROP_i)(BEGAN) + \sum_{i=1}^{5} \beta_{i\,18} (CROP_i)(LOGYR)$$

$$+ \sum_{i=1}^{5} \beta_{i\,19} (CROP_i)(RAIN) + \varepsilon,$$

where *i* is the subscript for one of five crops: sorghum, wheat, soybeans, cotton or oats. Subscript *j* represents one of three soil textures: sand, silt or clay. The subscript for the ERS regions, *k*, represents one of eight USDA ERS Farm Resource Regions: Northern Crescent, Northern Great Plains, Prairie Gateway, Eastern Uplands, Southern Seaboard, Fruitful Rim, Basin & Range or Mississippi Portal. The reference categories for *CROP*, *SOIL* and *ERS* are corn (*CORN*), loam soil (*LOAM*) and the Heartland (*HEART*) region. The variable *BEGAN*, is a continuous variable used to capture improvements in technology over time. It represents the year in which the experiment was initiated, with 1964=1, 1965=2,…, 2005=42; then the natural log of that number was taken. Another variable, *LOGYR*, was created to verify if net returns increase over time when switching from conventional tillage or reduced tillage to no-tillage. *LOGYR* is a continuous variable which represents each year of the experiment with experiment 1: 1981=1, 1982=2,..., 1985=5; experiment 2: 1995=1, 1996=2; then the natural log of that number was taken. The continuous variable *RAIN* is annual precipitation for each location and year of each experiment. *CROP* and *ERS* were not interacted because all crops were not present in each ERS Farm Resource Region. For example the Fruitful Rim and Basin & Range regions only had observations for two and one crops, respectively. It should be noted that there are no observations for sorghum, wheat, soybeans, oats or cotton in a silt textured soil. There are also no observations for oats in a sand or clay textured soil, therefore there are no interactions between those specific crops and soil textures.

The following conditional logit model was specified to evaluate the probability of no-tillage net returns being less than conventional tillage net returns:

8)

$$\begin{aligned} NTPROB = {} & \gamma_0 + \sum_{i=1}^{5} \gamma_i CROP_i + \sum_{j=6}^{8} \gamma_j SOIL_j + \sum_{k=9}^{16} \gamma_k ERS_k + \gamma_{17} BEGAN + \gamma_{18} LOGYR \\ & + \gamma_{19} RAIN + \sum_{i=1}^{5} \sum_{j=6}^{8} \gamma_{i\,j} (CROP_i)(SOIL_j) \\ & + \sum_{i=1}^{5} \gamma_{i\,17} (CROP_i)(BEGAN) + \sum_{i=1}^{5} \gamma_{i\,18} (CROP_i)(LOGYR) \\ & + \sum_{i=1}^{5} \gamma_{i\,19} (CROP_i)(RAIN) + \varepsilon, \end{aligned}$$

where *i* is the subscript for one of five crops: sorghum, wheat, soybeans, cotton or oats; subscript *j* represents one of three soil textures: sand, silt or clay; and the subscript for *k* represents one of eight USDA ERS Farm Resource Regions: Northern Crescent, Northern Great Plains, Prairie Gateway, Eastern Uplands, Southern Seaboard, Fruitful Rim, Basin & Range or Mississippi Portal. As with the other two statistical models, the reference categories for *CROP*, *SOIL* and *ERS* are corn (*CORN*), loam soil (*LOAM*) and the Heartland (*HEART*) region, respectively. *NTPROB* is the downside risk dependent variable and was given a value of one if the no-tillage crop net returns were less than conventional or reduced tillage net revenues and a zero otherwise. The same explanatory variables were used as previously stated for equation (7).

Hypotheses

There are many conflicting findings as to which system results in the highest net revenues. Previous studies show different tillage regimes have different levels of profitability for different locations, crops and years. Net revenues will most likely vary for many different reasons. Net revenues and input costs can vary from farm to farm because of many different factors such as location of production, soil type, different types and ages of farm machinery, a farmer’s management skill and weed and insect complications (USDA 2006). No-tillage is hypothesized to have increased net returns over conventional tillage, due to its documented machinery, fuel and labor costs reductions (Deen and Kataki 2003; Lankoski et al. 2004).

It is hypothesized that different crops in different tillage systems may have very different net returns. It is hard to say which will be more profitable due to the fact that net revenues vary for many different reasons in each location. Net revenues have been found to differ by location when growing the same crop. However, it is hypothesized that net returns for no-tillage will likely be higher in the southern warmer climates. Previous work by DeFelice et al. (2006) has shown no-tillage to produce higher yields than conventional tillage in the southern United States. Higher yields coupled with evidence of reduced costs, should result in higher net revenues (Deen and Kataki 2003; Lankoski et al. 2004).

Previous evidence has shown no-tillage performs better than conventional tillage for crops grown on coarse-textured, well drained soils (DeFelice et al. 2006; Hairston et al. 1990). Therefore, it is hypothesized that a crop grown on a sandy textured soil using no-tillage will have higher net returns than a crop produced using tillage practices. However, this could turn out not to be true because sandy soils may not be as nutrient rich as other soil texture types. Each year of the experiment, *LOGYR*, should have a positive effect on no-tillage net revenues. With each passing year, the crop residues should increase the soil productivity through increased organic matter and improved soil tilth. Likewise, the year the experiment was initiated, represented by the variable *BEGAN,* should cause the difference between no-tillage and conventional tillage net revenues to decrease through improvement in technology over time. Growing environments with higher annual precipitation are expected to favor crops grown using tillage relative to no-tillage (D.J. Eckert 1984; Herbek et al. 1986). Thus, the net revenues for crops grown using tillage practices should have less downside risk relative to no-tillage when rainfall increases.

Statistical Analysis

Equation (6) was estimated using mixed model procedures in SAS (SAS Institute 2004) to test the hypothesis that the net revenue means do not differ (Littell et al. 1996). Tests for multicollinearity and heteroskedasticity were performed using the VIF and SPEC options in PROC REG of SAS, respectively (SAS Institute 2004). The VIF option in SAS was used to report the Variance Inflation Factors for testing multicollinearity. A Variance Inflation Factor greater than 10 is an indication of multicollinearity (Chatterjee and Price 1991). Multicollinearity occurs when two or more independent variables are so highly correlated with each other that the standard errors are inflated (Chatterjee and Price 1991). If multicollinearity is present it can influence the significance and inferential power of the coefficients (Chatterjee and Price 1991). The SPEC option performed the White test for heteroskedasticity. To further the tests for heteroskedasticity, a Breusch-Pagan test was performed in SAS. Heteroskedasticity is where the variance of the regression error term is not constant (Stock and Watson 2003). If present, heteroskedasticity can influence standard errors and potentially affect the significance of tests of hypothesis.

If heteroskedasticity was present in the model, this was corrected in the mixed model by adding a RANDOM statement that included the location of each experiment. There was a mutlicollinearity issue that was corrected by using the USDA ERS Farm Resource Regions rather than the latitude of the experiment, as it was causing collinearity problems with other explanatory variables. Both latitude and ERS regions were tried separately in the model with the ERS Farm Resource Regions resulting in less collinearity problems with other variables in the model than latitude. The USDA ERS Farm Resource Region should also explain more as to how no-tillage crop yields differ in various growing regions than just by temperature and north and south, which is what latitude would explain. When testing for multicollinearity no issues were found. Test results for heteroskedasticity and mulitcollinearity can be found in the appendix in Tables 8 and 9.

Results

Mean Net Return Results

Results for the simple means and mean differences statistical models comparing no-tillage and conventional or reduced tillage net return can be found in Tables 7 and 10, respectively, of the appendix. Mean net returns by tillage and crop across all locations and conditions were calculated using PROC MEANS procedures with no-tillage resulting in the highest mean net returns per acre for sorghum, cotton and oats at \$122.82, \$178.43 and \$45.75, respectively. Conventional tillage was found to have the highest average net returns for wheat, soybeans and corn at \$69.54, \$325.08, and \$346.10, respectively.

Different tillage regimes were found to affect farm net returns. Overall, no-tillage was found to have higher net returns per acre than conventional tillage. There were many significant interactions with no-tillage; all crops evaluated, except oats, were significant when interacted with no-tillage. All the significant interactions between no-tillage and crops were positive. No-tillage sorghum, wheat, soybeans and cotton all yielded higher net returns when compared to conventional tillage corn. Conventional tillage net returns for corn was found to be the highest of all the crops evaluated. The next highest net return was for soybeans, followed by sorghum, cotton, oats and wheat.

Soil texture played an important role when looking across all crops and tillage methods in net returns. Sandy and silty textured soils increased net returns compared to loam textured soils. However, a clay textured soil resulted in decreased net returns compared to loamy soils. When no-tillage was interacted with each soil texture, only one was observed as significant, *SAND×NT*. This interaction had a negative coefficient which means that net returns when using no-tillage in a sandy textured soil are less than conventional tillage net returns on a loam soil. This is not what was expected, a possible explanation could be that a sandy soil texture does not have as many nutrients as a loam soil and sandy soils tend to leach nutrients (North Carolina Dept. of Agriculture Accessed July 2010).

No-tillage did not perform as well in the Northern Great Plains, Prairie Gateway and Mississippi Portal regions when compared to conventional tillage net returns in the Heartland region. Each of the three significant interactions resulted in lower net returns. The fact that the Heartland region seems to be one of the more profitable regions does not come as a surprise since it is the region with the most farms in the United States at 22%, highest value of production at 23% and most cropland at 27%; most of the observations in the dataset also come from this region (USDA-ERS 2000). Net returns were found to vary by geographic region when looking at net returns over all tillage methods and crops. Three regions were significant, Northern Crescent, Northern Great Plains and Mississippi Portal; the Northern Crescent and Mississippi Portal regions produced lower net returns when compared to the Heartland region and the Northern Great Plains resulted in higher net returns compared to the Heartland region. Crop net returns for each ERS Farm Resource Region can be found in the appendix.

The variable *BEGAN*, which represents the year each experiment was initiated, was significant when interacted with no-tillage. This suggests that as the year the experiment was initiated increases, the difference between no-tillage and conventional tillage net returns decreased. This result indicates that technology improvement may be an important factor in net revenues for different tillage methods over time.

Overall, precipitation was found to play a significant role in increasing a farmer's net return. The variable *RAIN* was significant at the <0.0001 level with a coefficient of 0.1440. In other words, a one millimeter increase in annual precipitation increased net revenues by $0.14 per acre. The $RAIN \times NT$ interaction was also significant with a coefficient of -0.049. This means that a one millimeter increase in annual precipitation decreases net revenues with the use of no-tillage by about $0.05 per acre. This coincides with the previous paper's results and other work on how precipitation affects no-tillage; increases in the amount of annual precipitation can decrease no-tillage yields and lower yields can transfer into lower profits (Eckert 1984; Herbek et al. 1986).

Proc Mixed Response Ratio Net Return Comparison Model

A meta-analytic approach was used to compare tillage net returns with a response ratio of those net returns as the dependent variable. Results can be found on Table 11 in the appendix. The following is an example of how to estimate net revenues for corn on a loam soil in the Southern Seaboard region relative to the Heartland region. Given that the estimated coefficients for corn and loam are embodied in the intercept you would take the coefficient for the intercept term, the estimated coefficients for the continuous variables *BEGAN*, *LOGYR* and *RAIN* are multiplied by their respective means and added to the intercept and the estimated coefficient for the Southern Seaboard region; i.e.

$$1.1005 + (0.0654 \times 2.81) + (0.04713 \times 1.41) + (-0.00029 \times 1101) + 0.3025$$
$$= 1.3339373$$

Another example, to obtain the estimate for corn on a loam soil in the Heartland region:

$$1.1005 + (0.0654 \times 2.81) + (0.04713 \times 1.41) + (-0.00029 \times 815) = 1.1143773$$

The intercept was added to the coefficients for the continuous variables *BEGAN*, *LOGYR* and *RAIN* which were multiplied by their respective means and this give the response ratio for corn on a loam soil in the Heartland region. This then allows a comparison of corn on a loam soil in the Heartland and Southern Seaboard region. Both have ratios greater than one meaning they both have higher no-tillage net returns than conventional tillage, but the Southern Seaboard region has an even higher relative no-tillage net revenue compared to conventional tillage.

In the mixed model comparing tillage net returns using a meta-analytic approach resulted in only six variables being significant. Two ERS Farm Resource Regions were significant, the Mississippi Portal and Prairie Gateway. The Prairie Gateway had lower no-tillage net returns when compared to conventional tillage net returns. No-tillage net returns were also lower relative to conventional tillage in the Heartland region. Net returns for no-tillage were higher than conventional tillage net returns in the Mississippi Portal region and also higher returns relative to conventional tillage in the Heartland region. One explanation for this result could be that no-tillage yields have been found to be higher than conventional tillage yields in warmer climates (DeFelice et al. 2006). Yields are a substantial component of net revenues in the analysis.

When a clay soil texture was interacted with wheat and soybeans it resulted in both having lower no-tillage net returns relative conventional tillage and also lower no-tillage net returns relative to conventional tillage corn in a loam soil texture. One explanation for this is that a clay soils are very slow to drain. With the residue left on the ground with no-tillage soybeans and wheat this may lead to a moist and low temperature soil which can negatively affect yields through delaying emergence of the crop and reduced seed germination compared to conventional tillage (Agriculture and Agri-Food Canada, Accessed July 2010; Hairston et al. 1990; Herbek et al. 1986). Cotton grown on a sandy soil resulted in higher no-tillage net revenues relative to conventional or reduced tillage. Net revenues for no-tillage cotton in a sandy soil texture were also higher relative to conventional tillage net returns of corn on a loam soil texture. This is likely due to higher yields with no-tillage in a sandy soil texture (DeFelice et al. 2006; Hairston et al. 1990) and corn having a much higher carbon to nitrogen ratio than cotton. A high carbon to nitrogen ratio means the slower the crop residue will break down, which depletes available nitrogen to the plant and may reduce yields (Mannering and Griffith 1985).

Increasing amounts of annual precipitation resulted in lower no-tillage net revenues compared to conventional or reduced tillage relative to corn. This result has been found in previous work where increases in precipitation has negative effects on no-tillage yields compared to conventional tillage (Eckert 1984; Herbek et al. 1986). Lower yields reduce profit margins.

Logit Results

In the conditional logit model 44.8% of observations had higher no-tillage net returns compared to conventional tillage, with 55.2% resulting in higher conventional tillage net returns. Results can be found in Table 12 in the appendix. Wheat was the only crop with a lower probability than corn of having lower no-tillage net revenues compared to conventional tillage net revenues. When compared to corn, as the year the experiment was initiated increased with the crops wheat and sorghum the probability of having lower no-tillage net returns compared to conventional tillage increases. This result could be because corn is a much higher valued crop with higher yields per acre than sorghum or wheat and corn yields per acre have increased over time (Egli 2008). It was also discovered that as the length of use of no-tillage increases when growing cotton the likelihood of having decreased no-tillage net returns compared to conventional tillage net returns decreases compared to corn. An explanation for this result could be that corn is a much higher residue crop than cotton which can keep the soil too cool and moist for ideal growing conditions. Corn also has a higher carbon to nitrogen ratio. Both of these factors can reduce yields over time which in turn could translate into lower net revenues (Graven and Carter 1991; Halvorson et al. 2006; Mannering and Griffith 1985).

A clay soil texture was found to reduce the probability of having lower no-tillage net revenues compared to conventional tillage relative to a loam soil texture. This could be due to the residues left behind with no-tillage. The residues keep clay soils from crusting. When a clay soils crusts it limits water infiltration and increases runoff which can decrease yields and therefore net returns (Agriculture and Agri-Food Canada, Accessed July 2010). When soybeans are grown under a clay texture the probability of reduced no-tillage net revenues compared to conventional tillage increases relative to corn. On explanation for this result is that soybeans are a much lower residue crop than corn. The amount of residue left behind with soybeans may be too little to keep the soil from crusting. Similar results were found when producing sorghum under a sandy soil texture.

Relative to the Heartland region, three regions were found to increase the probability of lower no-tillage net revenue compared to conventional tillage. Those three were the Northern Great Plains, Prairie Gateway and Basin & Range regions. Crop production in the Southern Seaboard region decreased the likelihood of having lower no-tillage net returns than conventional or reduced tillage when compared to the Heartland region. An explanation for these results could be that no-tillage yields have been found to be higher than conventional tillage yields in the southern United States (DeFelice et al. 2006). These higher yields in the southern United States would likely decrease the chance of lower no-tillage net returns.

Increases in the amount of annual precipitation increased the probability of lower no-tillage net returns compared to conventional tillage net returns relative to corn. Thus, crop production using no-tillage in higher precipitation environments had more downside risk relative to a low precipitation environment. Previous research has shown that too much precipitation can negatively affect no-tillage yields relative to conventional tillage (Anderson et al 1986; Blevin et al. 1971), which would likely increase the probability of lower no-tillage net revenues. The same effect was found when growing wheat with no-tillage. However, when rainfall increases when growing sorghum, the likelihood of reduced no-tillage net returns decreases relative to corn. This is likely due to corn leaving more residue on the soil surface than sorghum because of its higher yields. The reduced amount of residue with sorghum may allow the soil to dry and warm up quicker than corn. This could help prevent a delay in crop emergence and poor seed germination by allowing the soil to come to an ideal temperature and moisture balance for planting.

In this analysis there were not much differences in mean net returns, however, there were several factors influencing downside risk. The crop being grown, annual precipitation, soil texture and location of production all influenced the likelihood of decreased net returns with no-tillage. Overall, a warm climate with moderate amounts of precipitation were found to decrease the chance of downside risk of net returns with no-tillage compared to conventional or reduced tillage.

Conclusion and Implications

This paper evaluated the differences in net returns between conventional or reduced tillage and no-tillage. This analysis covered six crops with experiment data from across the United States. The factors considered in the analysis were the crop being grown, annual precipitation, soil texture, the year the experiment began, time since conversion from conventional tillage to no-tillage, and location of crop production.

When looking at mean net returns with a mixed model, no-tillage was found overall to be more profitable than conventional tillage. When evaluating each crop separately, no-tillage sorghum, wheat, soybeans and cotton were found, on average, to yield higher net revenues when compared to conventional or reduced tillage corn. Geographic region also played an important role in net revenues; when compared to the Heartland region, no-tillage net revenues were lower in the Northern Great Plains, Prairie Gateway and Mississippi Portal regions. Conventional tillage in the Heartland region had higher net revenues than any region with no-tillage.

Across all tillage methods, crops grown on sandy and silty soils were the most profitable when compared to a loam soil and a clay soil was found to yield significantly lower net returns. When interacting no-tillage with each soil texture, only sand was found to be statistically significant. Net returns for no-tillage on sandy soil were lower when compared to conventional or reduced tillage on a loam soil. Increases in the amount of annual precipitation were found to decrease a farmer's net return when using no-tillage compared to conventional tillage. The year the experiment was initiated showed that the difference between no-tillage and conventional tillage net returns decreases over time. This is likely due to no-tillage technology progressing over time through advancements in planting, seed and chemical technologies. Also, farmers and extension agents have become more knowledgeable about no-tillage and can better their techniques on how to better manage no-tillage to maximize profits and yields.

When evaluating net revenues with a response ratio very few things were significant; leaving one to believe there is not much statistical difference in net returns between no-tillage and conventional tillage. However, when evaluating the risk of no-tillage net returns being lower than conventional tillage net return there were many significant factors affecting the probability of reduced net returns with no-tillage. Several factors were found to decrease the probability of reduced no-tillage net returns such as producing wheat, a clay soil texture, the Southern Seaboard region, increased amounts of rainfall when growing sorghum and increased years of use of no-tillage when growing cotton. There were also many factors increasing the likelihood of reduced no-tillage net returns: increases in the amount of rainfall, the Northern Great Plains, Prairie Gateway and Basin & Range regions. So while net returns between the two tillage methods may not differ much there is still risk involved.

This research shows that no-tillage could be a viable option to conventional tillage in some environments. A farmer may be able to switch to no-tillage as a way to increase his or her bottom line under the right conditions. However, as with all studies, there are limitations and improvements to be made. To give a more accurate picture of a farmer’s net return, government payments and programs need to be incorporated into the analysis. Also, these yields are from paired experiments on experiment stations. Typically, no-till yields are higher relative to conventional tillage and may not fully represent what can be expected on public farms. Experiment stations often have better knowledge of certain cropping systems and likely more funds and technology to help produce the best possible yield. Still, these data should give a fairly accurate depiction of what to expect when examining the possibility of using no-tillage.

References

Agriculture and Agri-Food Canada. "Soil Texture and Water Quality." Internet site: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1197483793077&lang=eng (Accessed on July 2010).

American Agricultural Economics Association. 2000. *Commodity Costs and Returns Estimation Handbook*. AAEA, Ames, IA.

American Society of Agricultural Engineers. 2006. *Agricultural Machinery Management.* ASAE Standard EP496.3. ASAE, St. Joseph, MI.

Anderson, E. 1986. "No-Till Effects on Yield and Plant Density of Maize Hybrids." *Agronomy Journal.* 78:323-326.

Antle, J. 1987. "Econometric Estimation of Producers' Risk Attitudes." *American Journal of Agricultural Economics*. 69:509–522.

Archer, D. and D. Reicosky. 2009. "Economic Performance of Alternative Tillage Systems in the Northern Corn Belt." *Agronomy Journal.* 101:296-304.

Binswanger, H.P. 1981. "Attitudes toward Risk: Theoretical Implications of an Experiment in Rural India." *Econ. J*. 91:867–890.

Blevins, R., D. Cook, S. Phillips, and R. Phillips. 1971. "Influence of No-Tillage on Soil Moisture." *Agronomy Journal.* 63:593-596.

Bremer, J., S. Livingston, R. Parker, and C. Stichler. 2001. "Conservation Tillage Applications." Texas Coop. Ext., Texas A&M University, College Station.

Chatterjee, S. and P. Price. *Regression Analysis by Example.* Wiley-Interscience Publication. New York, NY 1991.

Chavas, J.P. 2004. *Risk Analysis in Theory and Practice*. New York: Elsevier.

Clemen, R. and T. Reilly. 2001. *Making Hard Decisions*. Pacific Grove, CA: Duxbury/Thomson Learning.

Cochran, R., R. Roberts, J. Larson, and D. Tyler. 2007. "Cotton Profitability with Alternative Lime Application Rates, Cover Crops, Nitrogen Rates and Tillage Methods." *Agronomy Journal*. 99:1085-1092.

Conservation Technology Information Center-CTIC. *Conservation Tillage Facts.* Internet site: http://www.conservationinformation.org/?action=learningcenter_core4_convotill (Accessed April 2, 2009).

Cooper, H., and L.V. Hedges. 1994. The *Handbook of Research Synthesis*. New York: Russell Sage Foundation.

Decker, J., F. Epplin, D. Morley, and T. Peeper. 2009. "Economics of Five Wheat Production Systems with No-till and Conventional Tillage." *Agronomy Journal.* 101:364-372.

Deen, W. and P. K. Kataki. 2003. "Carbon Sequestration in a Long-Term Conventional Versus Conservation Tillage Experiment." *Soil and Tillage Research.* 74(2):143-150.

DeFelice, M, P. Carter, and S. Mitchell. 2006. "Influence of Tillage on Corn and Soybean Yield in the United States and Canada." *Plant Management Network.*

Eckert, D. 1984. "Tillage System X Planting Date Interactions in Corn Production." *Agronomy Journal.* 76:580-582.

Epplin, F., D. Beck, E. Krenzer Jr., and W. Heer. 1993. "Effects of Planting Dates and Tillage Systems on the Economics of Hard Red Winter Wheat Production." *Journal of Production Agriculture.* 6:57-62.

Epplin, F., C. Stock., D. Kletke., and T. Peeper. 2005. "Cost of Conventional Tillage and No-till Continuous Wheat Production for Four Farm Sizes." *2005 Journal of the ASFMRA*. Pp. 69-76.

Fernandez-Cornejo, J., and W. McBride. 2002. "Adoption of Bioengineered Crops." Economic Research Service, USDA, Agricultural Economics Report No. 810.

Fishburn, P. 1977. "Mean-Risk Analysis with Risk Associated with Below-Target Returns." *The American Economic Review.* 67:116-126.

Gommes, R. and P. Hoefsloot. 2006. FAO. Internet site: http://80.69.76.153/wiki/index.php?title=Chapter14 (Accessed April 28, 2010).

Hairston, J., W. Jones, P. McConnaughey, L. Marshall, and K. Gill. 1990. "Tillage and Fertilizer Management Effects on Soybean Growth and Yield on Three Mississippi Soils." *Journal of Production Agriculture.* 3:317-323.

Hanks, J. and S. Martin. 2007. "Economic Analysis of Cotton Conservation Tillage Practices in the Mississippi Delta." *Journal of Cotton Science.* 11:75-78.

Harper, Jayson. 1996. "Economics of Conservation Tillage." *Conservation Tillage Series*. No. 6. Penn State College of Agricultural Sciences.

Harville, D. and R. Mee. 1984. "A Mixed-Model Procedure for Analyzing Ordered Categorical Data." *Biometrics*. 40:393-408.

Heatherly, L., C. Elmore, R. Wesley, and S. Spurlock. 1996. “Net Returns from No-Till Doublecrop Winter Wheat and Irrigated Soybean on a Clay Soil.” *Journal of Production Agriculture.* 9:554-558.

Hedges, L.V., and I. Olkin. 1985. *Statistical Methods for Meta-Analysis.* New York: Academic Press.

Hedges, L.V., J. Gurevitch, and P.S. Curtis. 1999. “The Meta-Analysis of Response Ratios in Experimental Ecology.” *Ecology*. 80:1150–1156.

Herbek, J., L. Murdock, and R. Blevins. 1986. “Tillage System and Date of Planting Effects on Yield of Corn on Soils with Restricted Drainage.” *Agronomy Journal.* 78:824-826.

Janosky, J., D. Young, and W. Schillinger. 2002. “Economics of Conservation Tillage in a Wheat-Fallow Rotation.” *Agronomy Journal.* 94:527-531.

Johnston, K. 2007. “Global Demand Drives Increasing Pressure on Glyphosate Costs.” Nufarm Media Release.

Kunda, M. and T. West. 2006. “Tillage & Yield Study.” Working paper, Oak Ridge National Laboratory.

Kurkalova, L., C. Kling, and J. Zhao. 2001. “The Subsidy for Adopting Conservation Tillage: Estimation from Observed Behavior.” Working paper, Center for Agricultural and Rural Development, Iowa State University, 2001.

Lankoski, J., M. Ollikainen, and P. Uusitalo. 2004. “No-Till Technology: Benefits to Farmers and the Environment?” Discussion paper 1, Helsinki, Finland. University of Helsinki. March.

Littell, R.C., W. Stroup, G. Milliken, and R. Wolfinger. 1996. *SAS System for Mixed Models*. SAS publishing, North Carolina.

Mannering, J and D. Griffith. 1985. “Value of Crop Rotaion Under Various Tillage Systems.” Purdue University Agronomy Guide. No. AY-230.

McLean, R., W. Sanders, and W. Stroup. 1991. “A Unified Approach to Mixed Linear Models.” *The American Statistician*. 45:54-64.

Miguez, F., and G. Bollero. 2005. “Review of Corn Yield Response Under Winter Cover Cropping Systems Using Meta-Analytic Methods.” *Crop Science Society of America*. 45(6):2318-2329.

Nail, E., D. Young, and W. Schillinger. 2007. "Diesel and Glyphosate Price Changes Benefit the Economics of Conservation Tillage Versus Traditional Tillage." *Soil & Tillage Research.* 94:321-327.

Nicholson, W. 2005. *Microeconomic Theory: Basic Principles and Extensions*. Mason, OH: Thomson/South-Western.

Roberts, R., B. English, Q. Gao, and J. Larson. 2006. "Simultaneous Adoption of Herbicide-Resistant and Conseration-Tillage Cotton Technologies." *Journal of Agricultural and Applied Economics*. 38:629-643.

SAS Institute Inc. 2004. *SAS 9.1.3 Help and Documentation*. Cary, NC: SAS Institute Inc., 2000-2004.

Selley, R. 1984. "Decision Rules in Risk Analysis." In (P.J Barry, ed.), *Risk Management in Agriculture*. Ames, IA: Iowa state University Press.

Stock, J. and M. Watson. 2003. *Introduction to Econometrics*. Boston, MA: Pearson Education, Inc.

Tiller, Kelly H., Daniel G. De La Torre Ugarte, and Daryll Ray. 1997. "The POLYSYS Modeling Framework: A Guide for Users." Agricultural Policy Analysis Center, The University of Tennessee-Knoxville.

Triplett Jr., G. and W. Dick. 2008. "No-tillage Crop Production: A Revolution in Agriculture." *Agronomy Journal.* S-153-S-165.

USDA. Economic Research Service. 2000. "Farm Resource Regions." Agricultural Information Bulletin No. 760, September 2000.

U.S. Department of Agriculture-National Agricultural Statistics Service. Internet site: http://www.nass.usda.gov (Accessed April 28, 2010).

U.S. Department of Agriculture-Natural Resources Conservation Service. *Enterprise Costs and Returns for Different Cropping and Tillage Systems in Northeast Montana*. Economics Technical Note No. MT-7. January 2006.

U.S. Department of Commerce-National Climatic Data Center-NESDIS. Internet site: http://www.ncdc.noaa.gov/oa/climate/stationlocator.html (Accessed November 2009).

Williams, J., D. Pendell, R. Llewelyn, D. Peterson, and R. Nelson. 2009. "Returns to Tillage Systems Under Changing Input and Output Market Conditions." *2009 Journal of the ASFMRA*. Pp. 78-93.

Appendix

Appendix

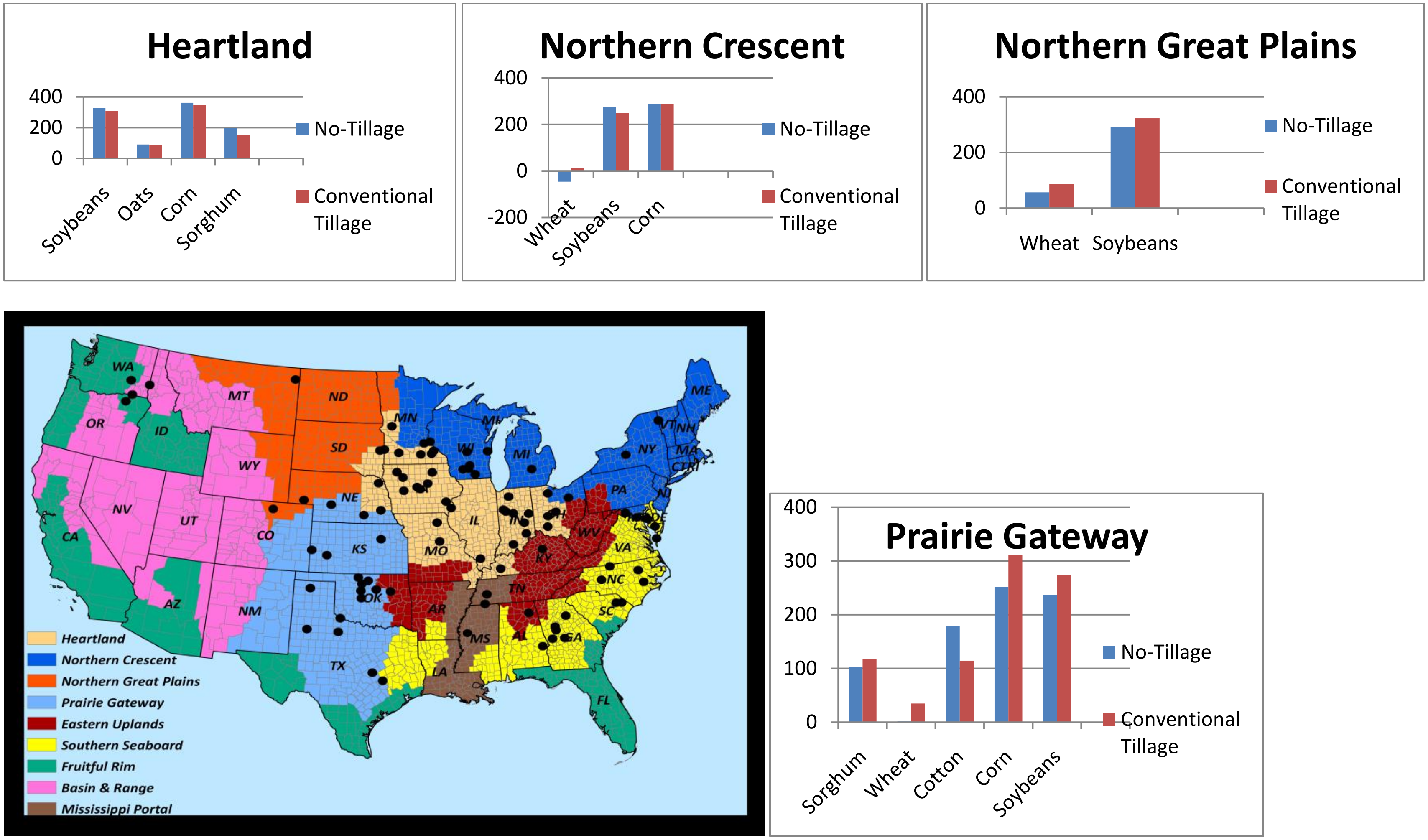


Figure 2. Net Revenues for the Heartland, Northern Crescent, Northern Great Plains and Prairie Gateway regions.

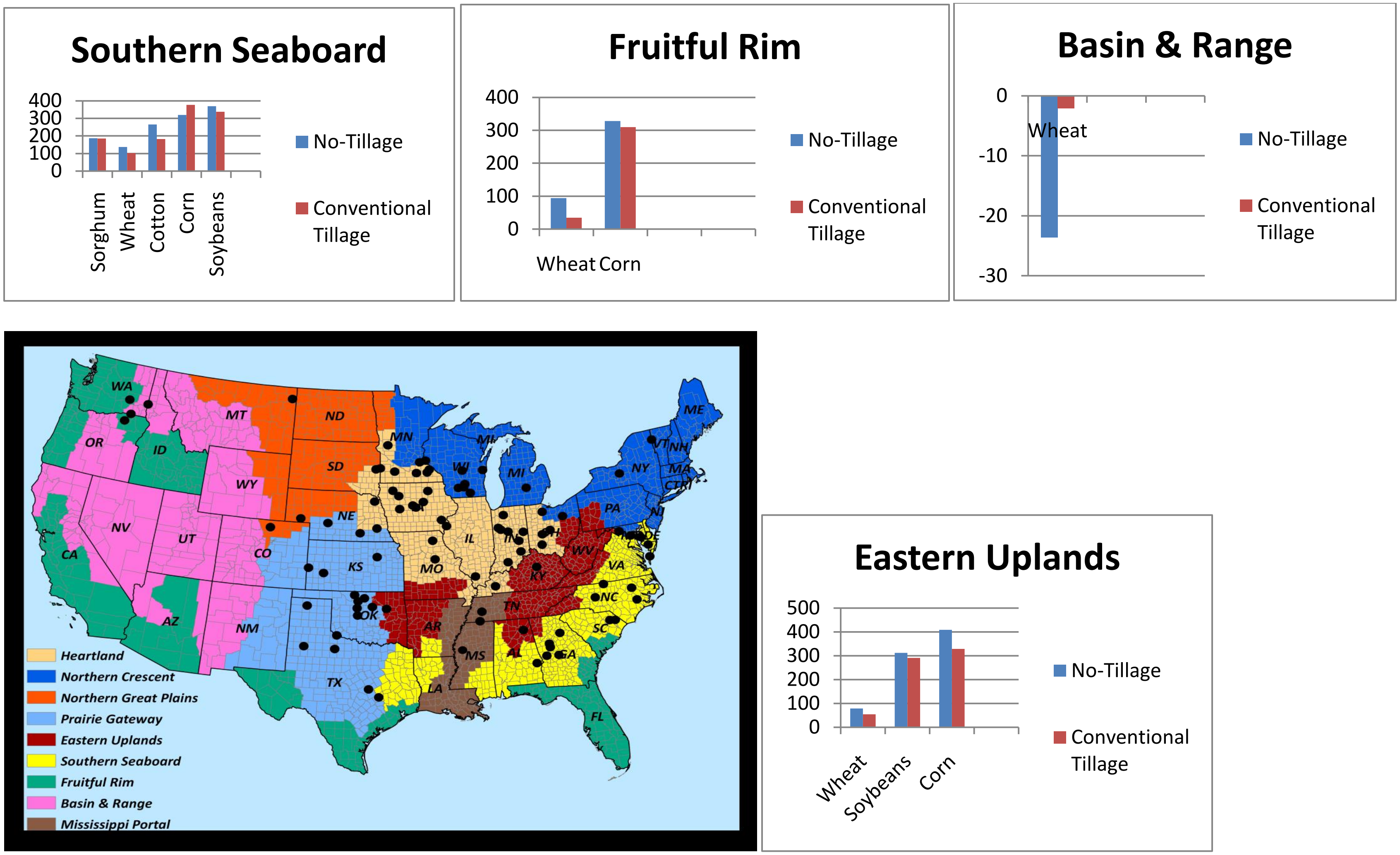
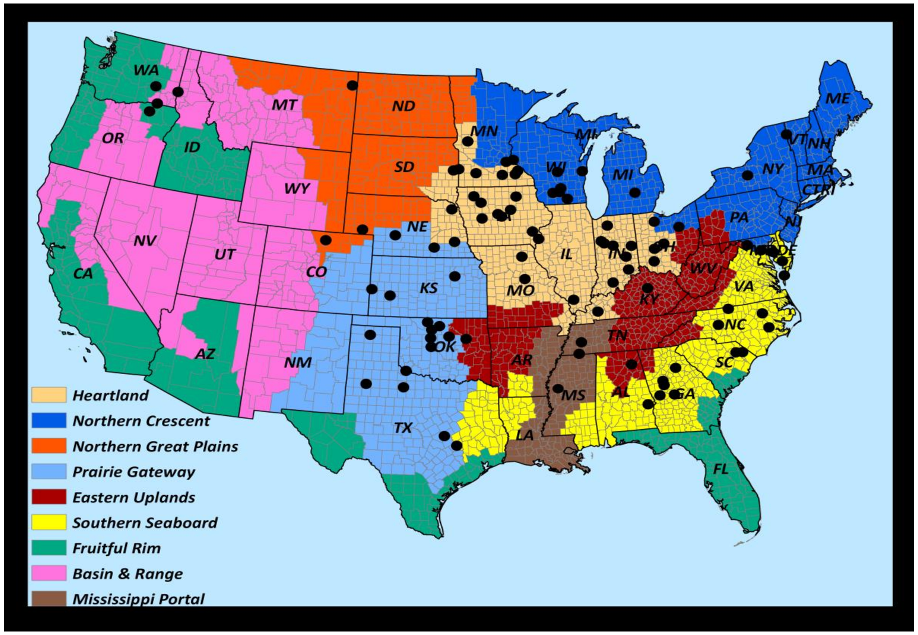


Figure 3. Net Returns for the Southern Seaboard, Fruitful Rim, Basin & Range and Eastern Uplands regions.



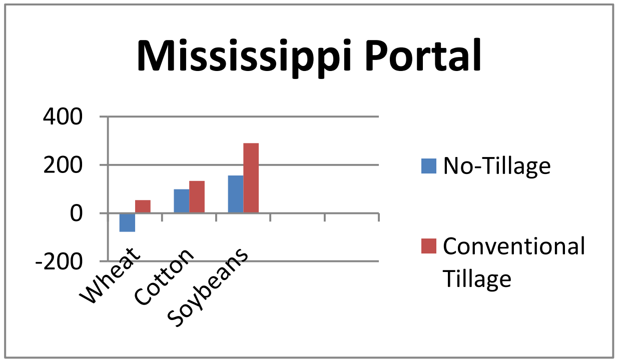


Figure 4. Net Returns for the Mississippi Portal region.

Table 6. Variable Names and Definitions for the Statistical Models Comparing No-tillage Net Returns with Conventional Tillage Net Returns

Variable Name	Variable Definition	Hypothesized Sign
BEGAN	Natural log of the year the experiment began	−
LOGYR	Natural log of each year of experiment	+
RAIN	Annual rainfall(mm) at experiment location	+/−
Crop		
SORG	= 1 if sorghum; 0 otherwise.	+/−
WHEAT	= 1 if wheat; 0 otherwise.	+/−
CORN	= 1 if corn; 0 otherwise.	+/−
SOY	= 1 if soybeans; 0 otherwise.	+/−
OAT	= 1 if oats; 0 otherwise.	+/−
COTT	= 1 if cotton; 0 otherwise.	+/−
Tillage		
NT	= 1 if no-tillage; 0= conventional tillage.	+/−
Soil Texture		
SAND	= 1 if sandy soil; 0 otherwise.	+
SILT	= 1 if silty soil; 0 otherwise.	−
CLAY	= 1 if clay soil; 0 otherwise.	−
LOAM	= 1 if loamy soil; 0 otherwise.	−
USDA ERS Region		
HEART	= 1 if Heartland; 0 otherwise.	+/−
NCRES	= 1 if Northern Crescent; 0 otherwise.	−
NGP	= 1 if Northern Great Plains; 0 otherwise.	−
PGATE	= 1 if Prairie Gateway; 0 otherwise.	+/−
EASTU	= 1 if Eastern Uplands; 0 otherwise.	+/−
SOSEA	= 1 if Southern Seaboard; 0 otherwise.	+
FRIM	= 1 if Fruitful Rim; 0 otherwise.	+/−
BANDR	= 1 if Basin & Range; 0 otherwise.	+/−
MISS	= 1 if Mississippi Portal; 0 otherwise.	+

Table 7. Average Net Returns by Tillage and Crop

Tillage Method	Crop	Observations	Mean	Std Dev.	Min	Max
No-Tillage						
	Sorghum	83	122.82	112.08	−257.46	304.61
	Wheat	200	45.06	99.70	−145.08	493.45
	Cotton	52	178.43	166.77	−44.70	576.49
	Soybeans	147	301.36	174.22	−58.48	1138.09
	Oats	7	45.75	49.42	−38.58	97.57
	Corn	446	316.68	143.32	−136.78	938.58
Conventional Tillage						
	Sorghum	172	109.47	82.41	−120.69	311.75
	Wheat	468	69.54	137.71	−164.93	714.71
	Cotton	71	154.97	113.68	−83.84	424.05
	Soybeans	292	325.08	274.88	−59.80	1637.91
	Oats	14	32.52	54.38	−63.10	101.84
	Corn	885	346.10	177.83	−120.06	1247.34

Table 8. Test for Heteroskedasticity for PROC MIXED Net Return Model Comparing No-tillage Net Returns with Conventional Tillage Net Returns

	White's Test			Breusch-Pagan		
Model	DF	Statistic	Pr > ChiSq.	DF	Statistic	Pr > ChiSq.
NR	113	1643.00	<.0001	20	964.30	<.0001

Table 9. Variance Inflation Factors for PROC MIXED Net Return Model Comparing No-tillage Net Returns with Conventional Tillage Net Returns

Variable	NR
INTERCEPT	0.00
SORG	1.78
WHEAT	2.85
SOY	1.21
OAT	1.04
COTT	1.74
SAND	1.80
SILT	1.17
CLAY	1.08
NT	1.02
BEGAN	1.45
LOGYR	1.32
RAIN	1.88
NCRES	1.28
NGP	2.10
PGATE	2.45
EASTU	1.07
SOSEA	2.31
FRIM	1.62
BANDR	1.94
MISS	1.78

Table 10. Estimated Mixed Net Return Model Comparing Mean No-tillage Net Returns with Conventional Tillage and Reduced Tillage Net Returns

Variable	Coefficient	t-Value
INTERCEPT	247.71***	9.49
SORG	−191.99***	−11.84
WHEAT	−274.78***	−19.77
SOY	−38.57***	−3.62
OAT	−261.86***	−6.34
COTT	−194.69***	−8.33
SAND	213.87***	11.52
SILT	242.42***	4.22
CLAY	−41.20**	−2.04
BEGAN	−3.55	−0.54
LOGYR	−5.93	−1.22
RAIN	0.14***	9.79
NT	101.62**	2.39
NCRES	−45.11***	−3.60
NGP	76.82***	3.43
PGATE	−13.45	−1.08
EASTU	−39.72	−1.47
SOSEA	−10.98	−0.58
FRIM	30.94	1.40
BANDR	11.64	0.43
MISS	−92.39***	−3.04
SORG×NT	59.1**	2.09
WHEAT×NT	40.63*	1.69
SOY×NT	37.58**	2.05
OAT×NT	31.41	0.32
COTT×NT	137.61***	3.62
NT×NCRES	14.44	0.68
NT×NGP	−73.94*	−1.91
NT×PGATE	−64.20***	−2.96
NT×EASTU	10.05	0.24
NT×SOSEA	−25.89	−0.86
NT×FRIM	12.73	0.27
NT×BANDR	−73.87	−1.44
NT×MISS	−128.82***	−2.65
NT×SAND	−14.97***	−4.48
NT×SILT	−50.64	−0.50
NT×CLAY	50.08	1.51
NT×BEGAN	−21.94**	−2.02
NT×LOGYR	−12.29	−1.46
NT×RAIN	−0.05*	−1.96
n	2837	
-2 Res. Log Likelihood	36215.9	
AIC	36217.9	
AICC	36217.9	
BIC	36215.9	

****Denotes significance at the 99% confidence level.*

***Denotes significance at the 95% confidence level.*

**Denotes significance at the 90% confidence level.*

(Reference Category: CORN, CT, LOAM, and HEART).

Table 11. Estimated Mixed Net Return Model Comparing No-tillage Net Returns with Conventional Tillage Net Returns with a Response Ratio

Variable	Coefficient	t-Value
INTERCEPT	1.10	0.80
SORG	0.21	0.11
WHEAT	−1.48	−0.72
SOY	0.55	0.14
OAT	0.61	0.11
COTT	−16.46	−1.14
SAND	−0.33	−0.44
SILT	0.15	0.08
CLAY	1.02	0.97
BEGAN	0.07	0.18
LOGYR	0.05	0.20
RAIN	−0.00	−0.42
NCRES	0.27	0.64
NGP	0.92	1.03
PGATE	−0.92**	−1.99
EASTU	0.08	0.11
SOSEA	0.30	0.52
FRIM	−0.22	−0.20
BANDR	−0.02	−0.02
MISS	4.78***	3.66
SORG×SAND	−1.02	−0.46
SORG×CLAY	0.24	0.14
SORG×BEGAN	−0.38	−0.76
SORG×LOGYR	0.30	0.55
SORG×RAIN	0.00	1.12
WHEAT×SAND	−0.45	−0.34
WHEAT×CLAY	−14.90***	−7.87
WHEAT×BEGAN	−0.05	−0.09
WHEAT×LOGYR	0.11	0.25
WHEAT×RAIN	0.00	1.43
SOY×SAND	0.24	0.15
SOY×CLAY	−3.32*	−1.91
SOY×BEGAN	−0.12	−0.11
SOY×LOGYR	0.51	1.15
SOY×RAIN	−0.00	−0.56
OAT×LOGYR	1.05	0.37
OAT×RAIN	−0.01	−0.72
COTT×SAND	5.28**	2.23
COTT×CLAY	2.48	0.85
COTT×BEGAN	6.59	1.47
COTT×LOGYR	−0.63	−0.56
COTT×RAIN	−0.01***	−3.22
−2 Res. Log. Likelihood	4333.1	
AIC	4337.1	
AICC	4337.2	
BIC	4333.1	

****Denotes significance at the 99% confidence level.*
***Denotes significance at the 95% confidence level.*
**Denotes significance at the 90% confidence level.*
(Reference Category: CORN, LOAM, and HEART).

Table 12. Estimated Logit Model for the Probability of No-tillage Net Returns being Lower than Conventional Tillage Net Returns

Explanatory Variable	Coefficient	Marginal Effect
CONSTANT	0.40	0.10
SORG	−2.54	−0.47
WHEAT	−6.19***	−0.80
SOY	1.11	0.26
OATS	3.87	0.49
COTT	0.38	0.09
SAND	−0.24	−0.06
SILT	30.19	0.53
CLAY	−1.78**	−0.37
BEGAN	−0.33	−0.08
LOGYR	0.23	0.06
RAIN	0.00**	0.00
MISS	0.11	0.03
NCRES	0.02	0.00
NGP	2.39***	0.44
PGATE	0.55*	0.14
EASTU	−0.23	−0.06
SOSEA	−1.15***	−0.27
FRIM	−0.13	−0.03
BANDR	2.76***	0.45
SORG×SAND	2.96**	0.45
SORG×CLAY	−29.37	−0.57
SORG×BEGAN	1.48***	0.37
SORG×LOGYR	−0.45	−0.11
SORG×RAIN	−0.00***	−0.00
WHEAT×SAND	0.14	0.03
WHEAT×CLAY	0.13	0.03
WHEAT×BEGAN	1.07***	0.27
WHEAT×LOGYR	0.18	0.05
WHEAT×RAIN	0.00***	0.00
SOY×SAND	1.56	0.33
SOY×CLAY	2.69**	0.44
SOY×BEGAN	−0.37	−0.10
SOY×LOGYR	−0.45	−0.11
SOY×RAIN	−0.00	−0.00
OAT×LOGYR	−1.82	−0.46
OAT×RAIN	−0.00	−0.00
COTT×SAND	−31.17	−0.53
COTT×CLAY	3.05	0.46
COTT×BEGAN	−0.56	−0.14
COTT×LOGYR	−3.25	−0.81
COTT×RAIN	0.00**	0.00
Log Likelihood	−570.85	
AIC	1.25	
BIC	1.48	
Chi-Squared	191.96	<0.0000

****Denotes significance at the 99% confidence level*
***Denotes significance at the 95% confidence level*
**Denotes significance at the 90% confidence level*
(Reference Category: CORN, LOAM, and HEART)

Chapter 4: Summary

Summary

This study evaluated the factors affecting crop yields and net returns. These factors included the type of tillage method used, crop, soil texture, geographic region, precipitation and time. Two tillage methods were evaluated, conventional tillage and no-tillage, along with six crops from across the United States. The six crops were corn, cotton, soybeans, oats, sorghum and wheat. This research was done to help determine the profitability and agronomic effectiveness of no-tillage compared to conventional tillage. This information could be useful for a farmer thinking of switching to no-tillage to increase their bottom line.

The first portion of this research focused on how different factors affected mean no-tillage crop yields compared to conventional tillage crop yields. A risk analysis was also performed to determine the probability of downside risk when using no-tillage. Certain factors were found to decrease the chance of downside risk when using no-tillage. Those factors include growing sorghum, a sandy soil texture and using no-tillage in the Northern Crescent, Northern Great Plains and Southern Seaboard regions. Chances of downside risk were also decreased with each year of use of no-tillage when producing soybeans and cotton. Other factors increased the probability of downside risk with no-tillage. Among those was rainfall, the more the rainfall the higher likelihood of decreased yields, and growing wheat or soybeans in a sandy textured soil.

No-tillage yields were higher than conventional tillage yields on average for sorghum and wheat when compared to corn; however, no-tillage oat yields were lower. A silty soil texture was found to decrease no-tillage yields. An increase in rainfall was also found to affect no-tillage crop yields. No-tillage performed better than conventional tillage in the Southern Seaboard and Mississippi Portal regions, but yielded less in the Basin & Range and Fruitful Rim regions when both were compared to the Heartland region. Each year of use of no-tillage was discovered to increase yields of soybeans and cotton compared to corn. However, growing wheat or soybeans in a sandy textured soil resulted in lower yields with no-tillage.

The second portion of this research dealt with mean net returns, along with a risk and net returns evaluation of no-tillage relative to conventional tillage using a response ratio. For the mean net returns model no-tillage was found to be more profitable than conventional tillage. No-tillage sorghum, wheat, soybeans and cotton all resulted in higher net returns on average than conventional tillage corn. When net returns of conventional tillage in the Heartland region were compared to no-tillage yields of other regions, the Northern Great Plains, Prairie Gateway and Mississippi Portal regions all obtained significantly lower net returns. Net returns for no-tillage were also found to be lower than conventional tillage as rainfall increased.

When evaluating net returns with a response ratio there were few significant factors that affected the difference between no-tillage and conventional tillage net returns. When evaluating the risk of no-tillage net returns being lower than conventional tillage net returns there were several significant factors that affected the probability of net returns for no-tillage being lower than conventional tillage. Several factors were found to decrease the probability of reduced no-tillage net returns such as producing wheat, a clay soil texture, the Southern Seaboard region, increased amounts of rainfall when growing sorghum and increased years of use of no-tillage when growing cotton. There were also many factors increasing the likelihood of reduced no-tillage net returns: increases in the amount of rainfall, the Northern Great Plains, Prairie Gateway and Basin & Range regions. So while net returns between the two tillage methods may not differ much there is still risk involved.

In conclusion, it was found that crop yields and net returns by tillage method differ by various factors. The risk factors associated with lower net returns or yields with no-tillage relative to conventional tillage were also found to vary. Farmers should evaluate the different factors relative to their farms to help determine if no-tillage is viable for them. There are a few possible guidelines to consider when evaluating a possible implementation of no-tillage. A warm climate with conditions similar to the southern United States would likely be a good location for the use of no-tillage. A sandy textured soil seems to produce better yields with no-tillage compared to conventional tillage. Areas that receive little rainfall are likely to give better results under no-tillage, considering its moisture conserving abilities. No-tillage in some cases may increase a farmer's net return because of the reduced labor, fuel, and machinery costs and in some cases increased yields. No-tillage could be a viable option for farmers under certain circumstances to increase their yields and net revenue compared to a conventional tillage method. These two papers in conjunction with one another can be used as a guideline when evaluating a decision to swap from a conventional or reduced tillage method to no-tillage.

Vita

Dustin Kevin Toliver was born on October 24, 1984 in Tallahassee, FL to Jessie and Teresa Toliver. He was raised in the small South Georgia town of Bainbridge. Dustin graduated with honors from Bainbridge High School in 2003. He then attended the University of Georgia where he received a B.A. in History. After completion of his undergraduate degree, Dustin was accepted into the University of Tennessee where he graduated with an M.S. in Agricultural Economics. Dustin hopes to pursue a career in biofuels.