The Adoption of Conservation Tillage Practices in Oklahoma: Findings from a Producer Survey

J.D. Vitale*, C. Godsey**, J. Edwards**, and R. Taylor***.

*Contact author and Assistant Professor, Oklahoma State University.
jeffrey.vitale@okstae.edu
** Assistant Professor, Oklahoma State University.
*** Associate Professor, Oklahoma State University.

"Attachment C"

Abstract

A major advancement in American agriculture was the introduction of the moldboard plow. The Dust Bowl of the 1930's highlighted the devastating effect of soil erosion in the Great Plains, which gave impetus to the soil conservation movement. Stubble-mulch farming, an early form of conservation tillage, was promoted by the Soil Conservation Service beginning in the late 1930's as an alternative to the moldboard plow and as a means to mitigate soil erosion in the Great Plains. Stubble mulching, and conservation tillage in general, remained isolated practices until the 1960's when the introduction of modern herbicides, and advances in no-till planting equipment, started the no-till revolution. Although conservation tillage had initial roots in the Great Plains, the current adoption of conservation tillage, especially no-till, lags behind the rest of the U.S.. This paper documents the results of a 2007 survey of Oklahoma producers, which was conducted to assess the current status of conservation tillage in the state. Based on a survey of 1,189 producers, statistical analysis was used to identify factors explaining the adoption of conservation tillage practices in Oklahoma. The survey found that conventional tillage remains the most common tillage practice among Oklahoma producers. According to the survey, conventional tillage is used on 38% of the total acreage, conservation tillage, including no-till, accounts for 33% of total acreage, and the remaining 29% is in reduced till. The analysis found that eleven of the thirteen response variables from the survey were statistically significant based on cross-tabulation. In particular, operator age, farm size, crop rotation, perceived knowledge, and the perceived benefits of conservation tillage were highly significant in explaining adoption. Two unique variables were included in the survey analysis, livestock grazing practices and crop rotation. Livestock was found to have a negative effect on the adoption of conservation tillage, indicating that mixed farming systems are less likely to adopt conservation tillage. Rotation was also significant, as producers in a wheat monoculture were found to be significantly less likely to adopt than producers practicing some sort of crop rotation. Future policy should consider addressing the needs of Oklahoma producers, particularly crop producers heavily engaged in livestock activities as well as finding alternative crops to the wheat monoculture. Over the long run, conservation tillage remains one of the primary means to control erosion in Oklahoma.

Key words: tillage-conventional-conservation-adoption-cross-tabulation

Introduction

A major advancement in American agriculture was the introduction of the moldboard plow (Nelson 1999). The westward expansion of U.S. agriculture in the late 19th century was achieved in large measure by the moldboard plow, which enabled farmers to push back the frontier and produce on the tough prairie sods of the Great Plains (Knobloch 1996). Plowing is an intensive land preparation technique that turns over soil, buries weeds and pests, and enables a smooth, uniform seedbed for planting. A major drawback to plowing, however, is that soils are stripped of vegetative cover, leaving them exposed and vulnerable to wind and water erosion. The dust bowl of the 1930's highlighted the devastating effect of soil erosion and the environmental consequences that can be wrought from the plow, as millions of tons of topsoil were lost throughout the Great Plains (Bailey 1963). The Dust Bowl gave impetus to the soil conservation movement and led to the founding of the Soil Conservation Service[1] (SCS) in 1935 (Helms 1990; Trautman and Porter 2008; Cain and Lovejoy 2004).

Stubble-mulch farming, an early form of conservation tillage, was promoted by the SCS beginning in the late 1930's as an alternative to the moldboard plow and as a means to mitigate soil erosion in the Great Plains (Gebhardt et al. 1985; Faulkner 1974; Nelson 1997;Coughenour and Chamala 2000). Stubble mulching was a new approach to tillage that emphasized maintaining crop residue on the soil surface rather than burying it under the soil with a moldboard plow[2]. In highly erodible areas such as the Great Plains, crop residue is considered most valuable when left on the soil surface where it provides a

---

[1] The Soil Conservation Service was founded in 1935 as part of the Soil Conservation Act of 1935, PL 74-46 (Cain and Lovejoy, 2004).

[2] Stubble mulching uses a sweep plow (i.e. Noble blade) that shears stubble and weeds a few inches below the soil surface while providing minimal disturbance to the soil compared to the moldboard plow.

protective barrier against wind and water erosion and also aids in soil moisture conservation. Research was conducted by the SCS at several locations throughout the Great Plains to demonstrate the beneficial effects of maintaining crop residue on the soil surface rather than plowing it under (Bennett 1942). These early studies found that soil erosion could be reduced by as much as 95 percent compared to the moldboard plow (Bennett 1942).

Stubble mulching gained popularity in the drier parts of the Great Plains, where adoption reached 18.3 million acres by the end of the 1950's (McCalla and Army 1961). Elsewhere, however, stubble mulching struggled to make significant in roads with producers, even though there was a growing awareness among producers of the benefits in maintaining crop residue on the soil surface (Bromfield 1950; Faulkner 1943). The early attempts at conservation tillage had difficulties in controlling weeds, maintaining soil fertility, and planting though crop stubble that left producers without any economic rationale to change their practices (Helms 1990; Coughenour and Chamala 2000).

A major breakthrough in conservation tillage occurred in the 1960's with the introduction of atrazine and other modern herbicides, which provided an alternative approach to controlling weeds using chemicals instead of the plow (Thomas and Blevins 1996; Blevins et al. 1998).Atrazine led to the development of no-till farming, a cultivation technique that plants seeds directly into the soil without any prior plowing or tillage. No-till farming maintains the greatest quantity of crop residue on the soil surface, typically 95% or greater, and is the most soil conserving cultivation practice available to producers. The first no-till planting is credited to a Kentucky farmer, Harry Young, who successfully planted 0.7 acres of no-till corn in 1962. A modified corn planter was used to direct seed corn into soybean stubble, with atrazine used to control weeds (Coughenour and Chamala 2000).The initial success in Kentucky quickly spread enthusiasm for no-till into other states and regions, including successful no-till plantings in North Carolina and Illinois. Another major advancement in no-till farming was the introduction of the Allis-Chalmers no-till corn planter in 1966, which provided producers with an improved mechanism to direct seed corn and soybeans into crop residue. By the late 1960's, farmers in the Midwest were planting no-till soybeans following wheat in a corn-wheat rotation that gave them three crops in two years.

With the development of improved planting and weed control technology, the adoption of conservation tillage began an upward trend starting in the late 1960's that has continued ever since (Figure 1). The adoption of conservation tillage grew at an average rate of 0.82% per year, increasing from 6.6 to 41.0% between 1962 and 2004. The growth of no-till adoption has been somewhat slower, with an average growth rate of 0.54% per year, reaching 22.4% by 2004 (Figure 1). Over the past two decades, the adoption of no-till has been influenced by farm bill legislation. The 1985 farm bill (Food Security Act of 1985) was the first farm bill to directly address soil conservation issues. Provisions contained in the 1985 Farm Bill mandated producers farming on highly erodible cropland develop a farm conservation plan (FCP) by 1995. This included cross-compliance measures that linked the FCP to participation in the price support and other programs of the Commodity Credit Corporation (CCC). No-till was adopted by many farmers as part of their FCP, which explains the sharp increase in no-till farming that has occurred since 1988 (Figure 1). Subsequent farm bills in 1990, 1996, and 2002 have maintained similar cross-compliance linkages between CCC participation and conservation planning.

Although the adoption of conservation tillage in the U.S. remains below 50 percent, adoption rates are significantly higher in some regions than others (Table 1). In general, in regions where corn and soybean are the major crops the adoption of conservation tillage has been significantly higher than in regions where wheat, particularly winter wheat, is the major crop. The adoption of conservation tillage is concentrated in the Corn Belt and the Appalachian regions, where the adoption of conservation tillage is 10.8 and 17% higher than the national average of 40.7% (Table 1). In wheat dominated regions there is less adoption. The lowest adoption of conservation tillage is in the Southern Plains, where adoption is 16.1%, less than one-half of the national average of 40.7% (Table 1). In the Northern Great Plains, a mix of spring and winter wheat, adoption is 45.9%, slightly higher than the national average but still 5.6% lower than in the Corn Belt.

The higher adoption rates of corn and soybean are partly explained by the introduction of genetically modified (GM) corn and soybeans, i.e. Roundup Ready varieties, which have improved weed control in no-till farming[3] (Carpenter and Gianessi 1999). Although GM wheat varieties (e.g. Roundup Ready) have been developed, they have not been released commercially, leaving wheat producers at a relative disadvantage compared to corn and soybean producers. The lack of a viable rotation crop in many of the winter wheat producing regions can also be a constraint to the adoption of conservation tillage. Conservation tillage, particularly no-till, is difficult to implement under a monoculture due to the buildup of weed and pest pressure. The corn-soybean

---

[3] GM varieties are resistant to the active ingredient (glyphosate) in herbicides and are unharmed by post emergent applications.

rotation breaks cycles of weed and insect pressure resulting in more cost effective crop protection, particularly when planted with GM corn and soybean crops.

Choosing amongst alternative tillage practices is one of the more complex and difficult choices that a producer must make, particularly with respect to conservation tillage. Studies conducted over the past few decades provide no general conclusion on whether the economic returns from conservation tillage provide a positive economic rationale for adoption. Results indicate that economic returns are highly site specific, vary depending upon crop type, and often are negative. Using producer surveys, adoption studies have identified several variables that explain patterns of conservation tillage adoption, i.e. why certain types of producers have been observed to adopt conservation tillage while others have not. The findings suggest that the adoption of conservation tillage generally depends on several factors, including age (Gould et al., 1989); education (Rahm and Huffman 1984); farm size (Wu and Babcock 1998); farm income (Gould et al. 1989); off-farm income; field slope; and cropping intensity.

Adoption studies have focused primarily on corn and soybean producers in the Corn Belt (Gould et al. 1989; Wu and Babcock 1998), with only a limited number of adoption studies conducted in other regions. In particular, there is a void of information regarding the adoption patterns of conservation tillage within the Great Plains, where the adoption of conservation tillage is significantly lower than in the Corn Belt (Table 1). Wheat is the dominant crop in the Great Plains. Because of the importance of livestock in the region, most of the wheat is produced for both livestock grazing and grain production, i.e. dual purpose wheat. Management practices and timing of activities are different for wheat, especially winter wheat, which is planted and harvested under a different range of agronomic conditions, several months apart from corn and soybean. Hence, winter wheat is likely to have a distinct pattern of adoption that is explained by different factors than previously determined for other crops.

Oklahoma's adoption of conservation tillage has lagged behind the national average, typical for a Great Plains state with winter wheat as its primary crop (Figure 2). In 2004, Oklahoma ranked 35th in conservation tillage adoption with a 20.8% adoption rate, and 32nd in no-till adoption with a 10.1% adoption rate (CTIC 2004). Despite the importance of safeguarding and maintaining soil quality in Oklahoma, there is only limited information regarding conservation tillage practices in the state. While adoption rates have been estimated biennially by the NRCS as part of their Crop Residue Management (CRM) survey, the surveys are descriptive in nature and do not contain adequate information for a more in-depth investigation of conservation tillage adoption (Corak et al.; Morrison et al.). Moreover, it's likely that since the last survey was conducted the use of conservation tillage has increased in Oklahoma. Since the late 1990's, Oklahoma's adoption of conservation tillage has been on the rise, particularly no-till, which increased at an average rate of 2% (Figure I.2). Conservation tillage appears to have become a more technically and economically attractive option for Oklahoma producers, given the rising energy costs over the past few years, the continued advances in the development of conservation tillage equipment, and farm bill legislation that has maintained incentives for adopting soil conservation practices, including conservation tillage.

A survey of Oklahoma agricultural producers was recently conducted to gain a more complete understanding of conservation tillage practices in the state. The purpose of this paper is to document the findings of the conservation tillage survey, and in particular to conduct an adoption study of conservation tillage practices in Oklahoma. The survey data is analyzed using the cross-tabulation method (i.e. contingency analysis) to identify variables that can explain, in a statistically significant manner, the adoption of conservation tillage. The analysis is considered useful since the results provide a list of variables, such as age, education, farm size, etc., which are associated with the adoption of conservation tillage. Future policy initiatives can be targeted to alleviate the constraints and hence increase the adoption of conservation tillage.

This paper is organized as follows. The next section describes the methods used in gathering and analyzing the survey data, including a brief discussion of the survey instrument and cross-tabulation methodology. The results of the survey are then presented. Summary statistics are provided as well as the findings from the cross-tabulation analysis. A discussion of the implications of the results is then given. The paper closes with a conclusions section that summarizes the research findings.

Methodology

A survey of 9,500 Oklahoma agricultural producers was conducted to elicit adoption characteristics and preferences of conservation tillage practices (NASS 2007).The producers were randomly selected from an existing database of Oklahoma agricultural producers. The random sample was limited to producers with at least 80 acres of cultivated land to remove producers considered unlikely to till land, such as small hobby farmers. This resulted in a sample size of slightly over 25,000 farms. From the 9,500 surveys mailed out, 1,189 usable surveys were returned.

The survey instrument contained a total of 25 questions, with 4 of the questions containing multiple parts. Producers were asked some background information on their age, education, and employment. This included a question on the number of hours worked per week as well as the share of income earned from off-farm employment. Seven of the 25 questions were related to farm operations. Producers were asked to list their: (1) tillage practices; (2) acres farmed; (3) crop rotation; (4) winter wheat livestock grazing practices (i.e. dual purpose, grain only, or graze-out); (5) farm machinery complement; (6) perceived benefits of conservation tillage; and (7) perceived knowledge of conservation tillage.

Producers were asked to follow the CTIC definitions of tillage practices, which classify tillage practices on the basis of crop residue (CTIC 2006). Conventional tillage is defined as any operation that maintains 15 percent or less of the crop residue on the soil surface. Reduced, or minimum till, are tillage practices that leave between 15-30 percent of crop residue on soil surface. Conservation tillage, which includes no-till as its extreme, leaves at least 30 percent of the crop residue on the soil surface. Examples of conservation tillage include strip-till, ridge-till, vertical-till, mulch till, and no-till. The question on perceived benefits used a ranking to elicit producers' opinion on the perceived benefits of conservation tillage. A short statement of potential benefits was provided, such as increases yields, increases profits, etc. For each statement a numerical scale between 1 and 8 was used to gauge the strength of agreement, from Strongly Agree (8) to Strongly Disagree (1). A scale from 1 to 10 was used to assess their overall perceived knowledge of conservation tillage.

Cross-Tabulation Analysis

In this paper, the adoption patterns of Oklahoma producers were analyzed using the cross-tabulation method, sometimes referred to as contingency analysis (Westra and Olson 1997). Cross-tabulation summarizes the responses from two or more survey questions in a table, listing the joint effects that each one has on the other. Using statistical tests, cross tabulation can empirically validate (or reject) that one of the responses has a significant effect on the other.

Cross-tabulation is considered an appropriate approach since most of the tillage survey questions were defined as category variables, which conform directly to the tabular format. Advantages of cross-tabulation are its simplicity and ease of understanding. The results of cross-tabulation analysis are listed in a table, where patterns of adoption between factors can be visually identified. Econometric methods, e.g. logistic models, have been used in other tillage adoption studies to explain adoption patterns. These are more complicated to construct and require more in-depth knowledge of regression techniques to be interpreted. Moreover, it's likely that there would be a high degree of correlation among the independent variables within an econometric model, which would further complicate the analysis and potentially weaken the explanatory power of the model.

In this study, cross-tabulation was used to test whether a response variable from the survey has a statistically significant effect on the choice of tillage practices. If such an effect is found, then the response variable has explanatory power and it is valid to further interpret the cross-tabulation to identify adoption patterns. To test for a statistical relationship, cross-tabulation determines a joint probability distribution, P_{ij}, between the observed tillage practices, Y_i, and one of the survey response variables, X_j. If there is no statistical relationship between Y_i and X_j then the two variables are statistically independent, which is tested using the using the following hypothesis test:

$$H_{0:}\ P_{ij} = P_i{*}P_j \qquad \text{(Independent)} \qquad (1)$$

$$H_1\text{: } P_{ij} \neq P_i{*}P_j \qquad \text{(Dependent)} \qquad (2)$$

where P_i is the probability that $Y=Y_i$ and P_j is the probability that $X=X_j$. The null hypothesis, H_0, tests for independence by requiring that that the joint probability of Y and X is equal to the product of their marginal probabilities. Otherwise, under H_1, there is a dependent relationship between Y and X, i.e. one of the variables has an effect on the other. In this case, the joint probability of Y and X is given by the conditional probability:

$$P_{ij} = (P_i|X=X_j)P(X_j) \qquad (3)$$

The probabilities are calculated using response rates from the survey, including the observed adoption of tillage practices. The probability of the ith tillage practice is given by:

$$P_i = N_i/N \qquad (4)$$

where N_i is the observed number of adopters of the ith tillage practice and N is the total number of survey responses. Likewise, the probability of the jth category in the response variable X is given by:

$$P_j = N_j/N \qquad (5)$$

where N_i is the observed number of adopters of the ith tillage practice and N is the total number of survey responses.

Independence between the tillage practice variable, Y_i, and each response variable, X_j, is tested using the chi-square statistic, χ^2. This statistic measures the difference between the observed number of responses that fall into the joint category where Y_i and X_j intersect, N_{ij}, and the expected number of occurrences where Y_i and X_j intersect, E_{ij}. Under the null hypothesis of independence, H_0, the expected number of occurrences is given by:

$$E_{ij} = N^*P_i^*P_j \qquad (6)$$

Using Equations (4) and (5) this can be simplified to:

$$E_{ij} = N_i^*N_j / N \qquad (7)$$

The statistical significance of H_0 is tested using the Chi-square statistic with $(N_Y-1)^*(N_X-1)$ degrees of freedom:

$$\chi^2 = \sum_{i=1}^{r}\sum_{j=1}^{c} \frac{(n_{ij} - E_{ij})^2}{E_{ij}} \qquad (8)$$

Cramer's V statistic is used as a measure of the strength of association between tillage practice and adoption factors. This statistic is particularly useful when the sample size is large since the chi-square statistic can report high significance even when the relationship is very weak.

The cross-tabulation is constructed using a response variable, X_j, as the rows and the observed tillage practices, Y_i, as columns. By listing the observed frequency, each cell of the cross tabulation indicates the adoption rate within a particular category of the response variable. Providing that the chi-square test is significant, the cross-tabulation yields a visual interpretation of the relationship between the response variable and tillage practices. For instance, if tillage practice is statistically dependent on a response variable, then the frequency (i.e. adoption rate) will display a noticeable trend from one response category to the next. Statistical significance of each cell is tested using the chi-square statistic, χ^2, at the 95% confidence interval. This investigates whether deviations within each cell are statistical outliers, highlighting regions within the cross-tabulation where the effects are statistically significant.

Results

The summary statistics compare reasonably well to expectations based on findings from other surveys. The Oklahoma tillage survey found an average farm size of 865 acres, which compares favorably with the 795 acres reported in a previous Oklahoma survey (NASS 2006). The average age of the farm operator was 58.8 years, which is consistent with the average operator age of 56.0 years found from a previous survey (NASS 2006). According to the Oklahoma tillage survey, conventional tillage with some type of plowing implement (moldboard, disk, etc.) is the most commonly used tillage practice. Conventional tillage was used on 364,249 of the 856,123 acres in the survey, corresponding to 38% of the total acreage. Conservation tillage, including no-till acres, accounted for 227,265 acres in the survey, corresponding to a 33% adoption rate. Reduced tillage was found on the remaining 29% of the land in the survey.

Findings from the Oklahoma tillage survey agree to some extent with the 2004 NRCS CRM survey, which estimated 21% of Oklahoma's farmland is in conservation tillage. Since the Oklahoma survey was conducted three years after the NRCS survey, it's likely that conservation tillage has increased significantly since then. As illustrated in Figure I.2, conservation tillage has been on the rise in Oklahoma over the past few years, increasing at a rate of about 1.5% per year. Extrapolating, this would place conservation tillage at 25.5% of total acreage in 2007. Given that the sampling error rates of both surveys are somewhere in the range of +/-10%, it's likely that the CTIC survey underestimated the adoption of conservation tillage whereas the Oklahoma survey overestimated the adoption of conservation tillage.

Conventional tillage remains the most common tillage practice among Oklahoma producers, as about one-third of the producers (33.6%) in the survey responded that all of their planted acres are in conventional tillage. The adoption rate of conservation tillage was found to be 13.2%, than one-half of conventional tillage usage. The survey found 16.5% of the producers have adopted some form of reduced till. The survey also found a significant number of producers, 36.7%, who have partially adopted some type of reduced tillage or conservation tillage practice. In this paper, partial adopters are separated into four categories. Producers with at least 50% of their planted acres are placed into one of the following three categories: CT50+, RT50+, or CST50+. The remaining category contains the other tillage practices, OT, a mixture of practices with less than 50% of planted acres in each tillage type.

Cross-Tabulation Analysis. In all, eleven of the thirteen response variables from the survey were found to be significant (Table 2). In general, the statistical significance of χ^2 was very high ($P<0.001$). This was somewhat expected since the size of cross tabulations was large in most of the cases. To account for this, Cramer's V statistic was calculated to assess the strength of the relationship. The Cramer's V statistic was found to be fairly low in general, indicating only modestly strong relationships between variables. However, even though the overall relationship between variables may not be very strong, it's still possible that significant and meaningful effects are present in smaller areas of the cross-tabulation.

Operator Characteristics. According to the survey, most of the farm operators are aged 65 and over. About one-third (34.9%) of the farm operators were in the 65+ category. Young farmers, under the age of 45, comprised only 10.5% of the surveyed producers. The age of the remaining 54.7% of the producers fell somewhere between 46 and 65 years. The effect of operator age (AGE) on tillage practice is given by the cross-tabulation listed in Table 3, which lists frequency of observed adoption within each category. The results of the cross-tabulation analysis found that AGE has a statistically significant effect on tillage practice (χ^2=76.0;P<0.001). This provides empirical support that the relationships contained in the cross-tabulation are from the effects of AGE on tillage and not from random chance, justifying further interpretation of the cross-tabulation. While the overall effect of AGE on tillage practice is rather weak (Cramer's V = 0.146), it's still possible for AGE to have highly significant and meaningful effects on tillage in limited areas of the cross-tabulation.

According to the cross-tabulation, AGE has a negative effect on conservation tillage adoption. The negative effect is consistent with prior expectations and results from other studies that also found younger operators more likely to adopt conservation tillage than older operators. The negative effect of AGE is visually evident, as the adoption of conservation tillage falls from 16.8 to 11.1% between the youngest and oldest age categories[4] in Table 3. The cross-tabulation found a similar adoption pattern among the partial adopters of conservation tillage, CST50+, with AGE having a negative effect on

---

[4] The negative effect of AGE can also be visually identified by noting that 13.2% of the producers in the survey adopted conservation tillage. If AGE had no effect on adoption, then each AGE category should also have an adoption rate of 13.2%. The cross-tabulation reports, however, that younger producers had a higher than expected adoption of 16.8%, whereas the oldest AGE category had a lower than expected adoption rate of 11.7%.

adoption. Among the partial adopters AGE had a stronger effect, with adoption falling from 16.0 to 4.6% between the youngest and oldest age categories in Table 3. AGE had a positive effect on the use of conventional tillage, as older producers were more likely to be in conventional tillage than younger ones. The effect of AGE on conventional tillage is apparent from the cross-tabulation, where the use of conventional tillage increases from 25.6 to 37.5% between the youngest and oldest age categories in Table 3.

The adopters of conservation tillage were also the youngest producers in the survey, with an average age of 57.6 years. Conventional till operators averaged 60.8 years of age, 3.2 years older than adopters of conservation tillage. The youngest were the partial adopters of conservation tillage (CST_{50+}), with an average age of 53.9 years.

The survey found that about an equal proportion of operators responded they have a High degree of perceived knowledge (KNOWLEDGE) of conservation tillage as those with a Low perceived degree of knowledge. Specifically, 29.3% of operators rated their perceived knowledge of conservation tillage as High whereas 26.9% of the operators rated their perceived knowledge as Low. The remaining 43.8% of operators rated their perceived knowledge of conservation tillage between 5 and 7 in roughly equal proportions that ranged between 12.7 and 16.3%.

According to the cross-tabulation analysis, the KNOWLEDGE variable has a significant effect on tillage practice (χ^2=212.2;P<0.001). The overall association is not very strong, however, with a Cramer's V value of 0.209. A further investigation of the cross-tabulation reveals that KNOWLEDGE has a positive effect on the adoption of conservation tillage, CST, implying that operators with higher KNOWLEDGE ratings are more likely to adopt conservation tillage than operators with lower ratings. The positive effect of KNOWLEDGE is visually evident, as adoption of conservation tillage increases from 5.5 to 23.9% between the Low and High categories of the KNOWLEDGE variable. The effect of KNOWLEDGE is quite strong as indicated by the large number of statistically significant cells in the cross-tabulation. KNOWLEDGE also has a positive effect on the partial adoption of conservation tillage, CST50+, but the effect is not quite as strong. The cross-tabulation found a strong negative effect of KNOWLEDGE on conventional tillage, as the use of conventional tillage falls from 53.8 to 21.1% between the Low and High categories. The strong effect of KNOWLEDGE is also apparent from the statistically significant cells found within the CT column in Table 3. Among the other tillage categories had no discernable pattern on adoption.

The adopters of conservation tillage had the highest average knowledge rating, 6.5, whereas the lowest rating was found among conventional tillage operators, 4.6. The same effect was found among partial adopters. Partial adopters of conservation tillage, CST50+, had an average knowledge rating of 6.3, which was 1.3 units higher than the ratings found for partial adopters of conventional tillage, CT.

The perceived benefits of conservation tillage, BENEFITS, have a fairly broad distribution across farm operators according to the survey. About equal proportions of producers consider the benefits of conservation tillage to be in low, 25.1%, as those that consider benefits to be high, 19.8%. Intermediate ratings of 5 and 6 also had similar proportions of 26.0 and 29.1%, respectively (Table 3). The effect BENEFITS on tillage practice is given by the cross-tabulation listed in Table 3. According to the cross-tabulation analysis, BENEFITS has a significant effect on tillage practices

(χ^2=293.0;P<0.001) and the overall association is modestly strong with a Cramer's V value of 0.283.

The cross-tabulation indicates that BENEFITS has a positive effect on the adoption of conservation tillage, CST, implying that operators with higher BENEFITS ratings are more likely to adopt conservation tillage than operators with lower ratings and consistent with other studies. The positive effect of BENEFITS is visually evident in Table 3 as the adoption of conservation tillage increase from 2.0 to 31.5% between the Low and High categories. Both the low and high category cells are statistically significant, indicating that the effect of BENEFITS is particularly strong in these two cells. There is also a positive effect of BENEFITS on the partial adoption of conservation tillage, CST50+, which is even more significant than its effect on CST adoption. The cross-tabulation also reveals a strong negative association between BENEFITS and conventional tillage, CT.

The effect that perceived benefits have on CST adoption is also evident in the average BENEFITS rating found for each tillage practice. The highest average rating of no-till benefits was found among CST adopters, 6.5, whereas CT users had the lowest average benefit rating, 4.6 (Table 3). The positive effect of no-till benefits on tillage choices was also found among the partial adopters. Among this group, producers partially adopting conservation tillage, CST50+, had an average benefit rating of 6.3, compared to the lower rating of 5.0 for partial users of CT50+.

The survey indicates that a slight majority of operators consider that livestock grazing does not have any negative effects on conservation tillage. The cross-tabulation of LIVESTOCK reports 57.7% of the operators in the No category and 42.2% in the Yes category (livestock has some negative effect on CST). The effect of LIVESTOCK on tillage practice is given by the cross-tabulation listed in Table 3. The results found that LIVESTOCK has a statistically significant effect on tillage practices (χ^2=45.6;P<0.001). The overall relationship is only modestly strong, however, as indicated by a Cramer's V value of 0.209.

The cross-tab analysis found that LIVESTOCK variable has a negative and statistically significant effect on CST adoption. This implies that operators who reported negative impacts from grazing (i.e. Yes respondents) were less likely to adopt CST than operators who consider that grazing does not have any effect on conservation tillage (i.e. No respondents). The negative effect is visually evident in the cross-tabulation of LIVESTOCK with tillage practices. Operators who responded Yes adopted CST at a rate of only 8.6% compared to the much higher adoption rate of 17.8% among the No respondents (Table 3). The LIVESTOCK variable also had a statistically significant effect among the partial adopters of conservation tillage. The effect of LIVESTOCK on conventional tillage was positive, but the effect was not significantly significant (Table 3).

The result of the LIVESTOCK cross-tabulation is consistent with expectations since operators reporting negative effects of livestock grazing on conservation tillage perceive lower benefits. According to the survey, the negative effect of livestock was significant enough to result in lower than expected adoption of conservation tillage. In particular, problems associated with soil compaction on fields that have been grazed by livestock have been reported in other studies, making it more difficult to use for conservation tillage.

Farm Characteristics. The cross-tabulation categorized farm size into four categories, using a section (640 acres) as a standard size (Table 4). The largest proportion of farms in the survey was between 160 and 640 acres in size, as 42.7% of the farms fell into this category. The remaining categories have nearly equal proportions, ranging from 18.7 to 19.6 percent. Hence there are nearly as many small farms, less than 160 acres in size, as there are large farms greater than two sections (1,280 acres) in size.

Table 4 describes the effect of the farm size (SIZE) variable on tillage practice using cross-tabulation. The SIZE variable was found to have a significant on the choice of tillage practices (χ^2=144.4;P<0.001). This establishes that adoption patterns contained in the cross-tabulation are from the effects of SIZE, justifying further analysis of the cross-tabulation. The value of the Cramer's V statistic was calculated at 0.199, indicating that the overall association between SIZE and tillage practices is only modestly strong. However, SIZE was found to have nine significant effects in 9 of the 27 cells contained in the cross-tabulation, indicating that there were several instances where SIZE had a significant effect on tillage choices even though the overall association isn't very strong.

The cross-tabulation analysis found that SIZE had a positive effect on conservation tillage, implying that larger farms are more likely to adopt CST than smaller farms. The effect of SIZE on the adoption of CST is visibly evident in the cross-tabulation. The adoption of CST increases steadily as SIZE is increased. For instance, small farms (≤160 acres) adopt at a rate of only 9.7% whereas the largest farms (>1,280 acres) have an adoption rate of 19.1%, which is 5.9% higher greater than expected (Table 4). The cross-tabulation also reveals that SIZE has a negative effect on conventional tillage, CT, as the use of CT falls dramatically from 57.9 to 15.2% between the smallest and largest farms in the survey (Table 4). Among the partial adopters of tillage SIZE maintained a positive effect on each tillage practice, including CT50+.

The effect of size is visible in the average farm size within each tillage category. Among complete adopters, farms adopting conservation tillage were found to have the largest average farm size, 944 acres. This is nearly twice as large as farms using conventional tillage, which had an average farm size of 490 acres. The partial adopters of conservation tillage had the largest farm sizes. For instance, the partial adopters of conservation tillage, CST50+, had an average farm size of 1,098 acres, 154 acres larger than the complete adopters of conservation tillage (Table 4).

The survey found that most Oklahoma wheat producers, 63.9% of them, manage wheat under a dual purpose system where wheat is used for both grazing and grain production (Table 4). Grain-only production is practiced by 22.8% of the producers surveyed, and the remaining 13.3% of producers grow wheat for grazing purposes only. Table 4 contains the cross-tabulation of wheat management (GRAZE) and tillage practice, which describes the effect of GRAZE on the adoption and use of each tillage practice. The cross-tabulation analysis found that GRAZE has a significant overall effect on tillage practice (χ^2=31.3;P<0.0018), hence it's valid to discuss relationships between GRAZE and tillage practice even though the association between them isn't very strong (Cramer's V=0.115).

According to the cross-tabulation of GRAZE and tillage practice, there are three relationships that are visibly evident (Table 4). First, grain-only wheat was found to have a positive effect on conservation tillage. Grain-only producers adopted CST at a rate of 18.0%, which is 5.3% higher than the expected adoption rate of 12.7%. Second, dual purpose wheat was found to have a negative effect on conservation tillage, although the effect wasn't statistically significant. Only 10.4% of dual purpose producers adopted CST, which is 2.4% lower than expected. Third, graze-only producers had a higher than expected use of conventional tillage. The survey found 38.6% of the graze-only producers using CT, which is 5.0% higher than expected, although the difference wasn't statistically significant (Table 4). Among the partial adopters of conservation tillage there were no significant effects, although the patterns of adoption between complete and partial adopters were generally similar.

The effects of GRAZE on tillage practice are consistent with expectations. For instance, grain-only producers are typically the larger farms, which are focused more heavily on crop production and are likely to be better positioned to invest their resources (time, capital) in conservation tillage. Alternatively, dual purpose wheat producers are typically more concentrated on livestock production with smaller sized farms, and are less likely to invest the time or financial resources in no-till.

According to the survey, 40.8% of the producers practice a crop rotation (ROTATE) of some type (Table 4). The most popular rotation crop with wheat was sorghum, used by 45% of the producers in the survey. Other crops included in the wheat rotation were corn, cotton, and various hays. The remaining 59.2% of the producers responded that they did not practice a rotation. The cross-tabulation analysis in Table 4 found that ROTATE had a significant overall effect on tillage practice (χ^2=110.9;P<0.001). The significance indicates that it's valid to discuss relationships between ROTATE and tillage practice since they are systematic, not random. The value of Cramer's V was 0.309, implying a modestly strong association between ROTATE and tillage practice.

According to the cross-tabulation, ROTATE had a positive and statistically significant effect (P=0.05) on conservation tillage adoption, implying that producers practicing a crop rotation were more likely to adopt conservation tillage than producers in a monoculture. Producers using a crop rotation adopted CST at a rate of 21.3%, 13.7% higher than the 7.6% adoption rate among producers in a monoculture (Table 4). Among partial adopters the effect was more modest, as crop rotation increased the adoption of CST50+ from 4.7% under a monoculture to 13.7% under a crop rotation (Table 4). Alternatively, ROTATE had a negative effect on conventional tillage. The use of conventional tillage increased from 21.5 to 42.1% between producers who rotate their crops and those in a monoculture (Table 4).

According to the survey, a substantial majority of producers in Oklahoma, 73.7%, rent at least some quantity of land (Table 4). The largest proportion of producers in the survey, 30.1%, rent somewhere between one and two sections of land (161-640 acres). Another 20% of the producers rent less than one section of land (<640 acres), and the remaining 10.5% of the producers rent two sections or more. About one-fourth of the producers, 26.3%, do not rent land (Table 4).

The effect of land rental (RENT) on tillage adoption is described in Table 4 and was found have a significant effect on the choice of tillage practices (χ^2=125.6;P<0.001) with a corresponding Cramer's V value of 0.164. In particular, RENT was found to have a positive effect on the adoption of conservation tillage, with four of the effects statistically significant. For renters of two sections or more (>1,280 acres), the adoption of both CST and CST50+ were found to be significant, with adoption rates of 20.3 and 19.5%, respectively. The RENT effect was also statistically significant on the adoption of CST50+ for producers who do not rent any land, where the adoption rate was 5.1% lower than the expected rate of 8.3% (Table 4). Alternatively, the RENT was found to have a negative effect on the use of conventional tillage (Table 4). Among producers who do not rent any land, conventional tillage was used at a significantly higher rate than expected, 47.1%, which is 14.5% higher than the expected use of 33.6% (Table 4). The reverse was found for producers renting the largest quantity of land (>1,280 acres), where the use of conventional tillage was 15.7% lower than the expected rate of 33.6%.

Financial Characteristics. The cross-tabulation of farm sales (SALES) is reported in Table 5, describing the effect of SALES on tillage practices. The survey found that the just over one-half, 50.9%, of the producers generate farm sales under $100,000 in an average year. Another 27.0% of the producers surveyed reported farm sales between $101,000 and $250,000 in an average year. The remaining 22.2% had farm sales over $250,000, including 10.5% with sales over $500,000. According to the cross-tabulation analysis, SALES has a statistically significant effect on tillage practices (χ^2=133.0;P<0.001). The value of Cramer's V statistic was somewhat low, 0.197, indicating that the overall association between total farm sales and tillage practice is somewhat weak.

From visual interpretation of the cross-tabulation, it's apparent that SALES has a positive effect on conservation tillage and correspondingly, a negative effect on conventional tillage. The adoption of conservation tillage, CST, increased from 9.5 to 19.2% between the lowest (≤$100,000) and highest (>$500,000) categories of farm sales.

For conventional tillage, CT, the use of CT fell from 43.5 to 11.7% between the lowest and highest categories of farm sales. In 10 of the 28 categories the effects of SALES was statistically significant, with 5 occurring in both the lowest and highest income categories. The cross-tabulation also indicates that the partial adopters of conservation tillage are more likely to be producers with higher farm sales. The adoption rates of CT50+, RT50+, and CST50+ were all higher than expected for SALES greater than $100,000. In particular, for farms with sales over $500,000 the adoption rates of CT50+, RT50+, and CST50+ were all highly significant, including CST50+ that had an adoption rate 12.5% higher than expected.

The results suggest that in terms of both conservation and conventional tillage adoption, a critical value for SALES is $100,000 (Table 5). Farm sales below $100,000 per year appear to be too low for some producers to adopt conservation tillage. The survey found a lower than expected adoption rate of conservation tillage for producers with sales under $100,000, 9.5%, which is 3.7% less than expected. Above $100,000 in farm sales, however, the trend is reversed. The adoption of conservation tillage is greater than expected, with producers in the highest SALES category adopting CST at a rate of 19.2%, 5.9% above the expected level of adoption. Alternatively, the number of conventional till producers was 9.7% higher than expected in the lowest SALES category and 21.9% lower than expected in the highest sales category (>$500,000).

The effect of the farm income share (SHARE) on tillage practice is given by the cross-tabulation listed in Table 5. The survey found that the division of farm income between crop and livestock revenue is fairly uniform. In particular, the survey contains roughly equal proportions of Ranchers, 30.2%, and Crop Farmers, 23.0% (Table 5). The mixed producers, who generate anywhere between 26 and 75% of their income from crops, account for the remaining 46.9% of the producers in the survey. The results of the cross-tabulation indicate that SHARE has a statistically significant effect on tillage practices (χ^2=56.4;P<0.001) justifying further analysis of the cross-tabulation. The overall association is rather weak, however, given the low Cramer's V value of 0.124.

The results suggest that SHARE has a positive effect on conservation tillage adoption, implying that crop farmers are more likely to adopt conservation tillage than ranchers. The effect of SHARE is visually apparent from the cross-tabulation, even though only four of the cells are statistically significant (Table 5). For instance, the adoption of conservation tillage, CST, increases from 10.6% among Ranchers to 16.4% among Crop Farmers. Moreover, the adoption of CST is 2.6% lower than expected for ranchers and 3.2% higher than expected for crop farms (Table 5). Alternatively, the SHARE variable was found to have a negative effect on conventional tillage, CT. This association is also visually apparent from the cross-tabulation. For instance, CT adoption fell from 38.4 to 32.1% between the rancher and crop farm categories. In particular, the use of CT among ranchers (<25% of farm income from crops) was significantly higher than expected, with an observed adoption rate of 38.4%, which was 4.8% higher than expected.

The effect of the off-farm income (OFF-FARM) on tillage practice is given by the cross-tabulation listed in Table 5. According to the survey, one-third (33.3%) of the producers are full time operators who earn all of their income on-farm (Table 5). Another 10.9% of the producers earn nearly all of their income on-farm, with only 1 to 25 % of their income coming from off-farm sources. Part-time operators, earning at least 75% of their income off-farm, make up 22.2% of the producers in the survey. The remaining 33.6% of the producers in the survey lie somewhere between full and part time operators, earning in the range of 26 to 75% of their income off-farm. The results of the cross-tabulation indicate that OFF_FARM is significantly associated with tillage practices (χ^2=51.1;P=0.001), establishing that associations contained in the cross-tabulation are from the systematic effects of OFF-FARM on tillage practice and not from random chance. The overall association between OFF-FARM and tillage practice is fairly weak, however, given the low Cramer's V value, 0.105.

The results of the cross-tabulation suggest that there is a negative effect of OFF-FARM on conservation tillage, implying that full time operators are more likely to adopt conservation tillage than part-time operators. This association is visually apparent from the cross-tabulation, even though only 4 of the cells in the cross-tabulation are statistically significant (Table 5). For instance, the partial adoption of conservation tillage, CST50+, falls from 11.6% among full time operators to 5.0% among part time operators. Given that 8.3% of operators were found to adopt CST50+, the adoption rate shifts from 3.3% above the expected value to 3.3% below the expected rate. Among complete adopters of conservation tillage, the effect of OFF-FARM is weaker as CST adoption is fairly close to the expected rate of 13.2%, with only a 2.4% difference in adoption between full and part time operators.

Alternatively, the association between OFF-FARM and conventional tillage is positive, and is a much stronger association than those found with conservation tillage. In particular, only 26.6% of full time operators were found in conventional tillage, a highly significant difference from the expected rate of 33.6% that was found among all producers in the survey. Similarly, part-time operators were found to be much more likely to be in conventional tillage than expected. The cross-tabulation reports that 42.6% of the part-time producers adopt CT, a highly significant difference of 9.0% from the expected adoption rate of 33.6%.

Discussion of Results. The significant effect of AGE on conservation tillage adoption is consistent with other adoption studies. Age has been found to have a negative and significant effect on the adoption of new technology since generally speaking older operators are more resistant to change, having invested in and grown accustomed to existing technology (Norris and Batie, 1983;Gould et al., 1989;Kurkalova et al., 2006). New technology such as conservation tillage requires a new approach to cultivation and the acquisition of new management skills (Bultena and Hoiberg, 1983). Since many of the old farmers are nearing retirement, such investments make less economic sense to them than younger producers. This is especially true regarding the long-term benefits from continuous no-till that can take up to ten years or longer to be fully realized.

Operator education was not found to have a significant effect in the cross-tabulation analysis, similar to the findings in other adoption studies (D'Emden et al., 2007;Banerjee et al., 2007). This is somewhat unexpected since seemingly most other adoption studies have found education to be a significant factor explaining adoption (Wu and Babcock, 1998; Ervin and Ervin, 1982;Fuglie and Kascak, 2001). The results found in this study suggest that education could be too general to predict with any significant level of confidence which type of tillage practice a producer would use. Extension information was also not found to be associated with tillage practices, even though it was found significant in another study (D'Emden et al., 2007). It's likely that in Oklahoma extension information on conservation tillage is used and available in equal proportions by producers of various tillage practices.

The strong association between KNOWLEDGE and tillage practice is expected and consistent with other studies since farmers with greater perceived knowledge of no-till are more likely to adopt conservation tillage than producers with less knowledge of no-till (Westra and Olsen, 1997). Conservation tillage requires increased management skills and knowledge to successfully adopt, and producers with limited knowledge of conservation tillage are less likely to adopt. Hence the results suggest that lack of knowledge could be a potential constraint to adoption among conventional tillage producers.

Crop rotation had a significant effect on the adoption of conservation tillage practices. The significance of crop rotation on no-till adoption is expected for a couple of reasons. First, practicing no-till on a wheat monocropping system can be a challenge to the operator. The buildup of weed and pest pressure is difficult to control in a profitable manner, and requires a great degree of management. Conventional tillage can provide a more cost-effective approach to controlling weeds and pests in a wheat monocrop, and at least initially is better understood by the operator than the control required under no-till. Second, many no-till producers adopt no-till since it provides them the ability to intensify their operations, including the use of crop rotations. Some no-till producers double-crop soybeans and other crops along with wheat, which is typically not feasible under conventional tillage due to the increased labor requirements.

The positive and significant effect of farm size on the adoption of conservation tillage is consistent with previous studies (Rahm and Huffman.1984; Erenstein and

Cadena.1997; Iqbal, Azeem and Munir. 2002; D'Emden, Llewellyn and Burton. 2007; Gould, Saupe and Klemme. 1989). In the previous studies, the effect of farm size on conservation tillage adoption was been explained through labor savings, arguing that larger farms have higher labor demands and face more critical labor bottlenecks during planting. It's more likely, however, that operators keep their labor fixed and use no-till to expand their farm size. Since farm size is correlated to farm income, larger farms are also better equipped to purchase no-till equipment and can more easily pay off the fixed costs of no-till adoption.

The results found that there was a significant difference in the no-till adoption characteristics of producers primarily engaged in crop production compared to producers with a larger concentration in livestock. This is similar in some ways to the findings by Goueld et al., 1989 that dairy farms in Wisconsin had a negative effect on the adoption of conservation tillage. Fall grazing of livestock on winter wheat is a common practice in Oklahoma and the survey suggests that grazing livestock on wheat fields discourages the adoption of no-till. The survey results are consistent with expectations since crop oriented producers are more likely than ranchers to invest in conservation tillage, including the time required to develop the management skills as well as the purchase of new equipment. Ranchers often produce crops, i.e. winter wheat, more as a source of livestock feed than as a cash enterprise and are less likely to realize the benefits of conservation tillage than crop farmers.

The significant and positive effect of RENT on conservation tillage adoption is consistent with previous findings by Lee and Stewart (1983) that land owners adopt less conservation tillage than land renters. Other studies, however, have found no effect of rent on the adoption of conservation tillage (Banerjee et al., 2007). A major benefit of adopting conservation is labor savings, which in addition to saving operating costs also provides producers with an opportunity to increase farm size. The results suggest that many operators face land constraints and increase farm size by both adopting conservation tillage and renting additional land. Most likely it is the full time operators who rent the land since they have more time to take advantage of no-till's labor savings since the effect was strongest amongst producers who rented the most land, two sections or more. Alternatively, part time operators with presumably greater time constraints appear less likely to adopt this strategy of packaging the adoption of conservation tillage with renting land. The results refute somewhat the claim, often put forth, that CST discourages land rental. Some have argued that landlords dislike no-till, calling it "trash farming". The results of this survey don't support this claim since rental increased with CST adoption.

Off-farm income earnings had a significant effect on the adoption of conservation tillage practices, even though the number of hours worked off-farm was not found to be significant. Full-time operators, those earning all of their income from agriculture, had a greater tendency to adopt no-till than producers who worked mainly off-farm. The results from this study are different from previous research that found off-farm work encouraged no-till adoption (Gould et al., 1989;Korsching 1983;Fuglie, 1999; Kurkalova et al., 2006). Producers solely involved in agriculture have higher turnover of equipment and typically have greater financial leverage. Part-time and "hobby" farmers have more difficulty investing in new equipment, are more likely to wait until their conventional equipment wears before they consider purchasing no-till equipment, and moreover conservation tillage requires more management skills and has a learning curve that smaller, hobby farms might find difficult to acquire.

Other studies reasoned that the opportunity cost of operator's time would encourage no-till adoption since labor requirements and reduced under no-till (Gould et al., 1989). This explanation ignores, however, that full time operators are likely to leverage labor savings from no-till to farm more acres and expand their farm size. Adopting no-till also enables full time operators the opportunity to produce more intensively, including double cropping, consistent with findings from Dhuyvetter et al. (1996) that report an increase in returns from conservation tillage primarily when it enables more intensive cropping systems. Conservation tillage, by saving land preparation time and conserving soil moisture, enables Oklahoma wheat farmers the opportunity to double crop soybeans in the summer months. More intensive cropping helps increase acres farmed, effectively lowering fixed costs, including expensive farm implements such as combines. Hence the results from this study suggest that full time farm operators may be adopting no-till not because it saves them time and labor, but rather that it enables them to increase profits by increasing their farm size.

The positive effect of SALES on the adoption of conservation tillage is consistent with expectations and results from previous studies (Gould et al., 1989; Davey and Furtan, 2007). Farms with higher sales are more likely to be willing and/or able to invest in new equipment and farm practices such as conservation tillage than farms with lower sales. Producers with higher income have greater access to credit and are better equipped financially to purchase no-till implements. There is also likely to be correlation among the SALES, SIZE, and OFF-FARM variables. Hence producers with larger sales volumes are also likely to be operators of bigger farms given the high correlation between farm size and sales. Bigger farms were also found to be more likely adopters of no-till since they often face more severe labor bottlenecks and they also are better able to spread fixed costs of adoption. Producers with larger farm sales are also more likely to derive their income primarily from agriculture with little off-farm employment. As discussed above, full time farm operators are more likely to adopt no-till since no-till enables them to increase their income by farming more acres.

Conclusions

The adoption of conservation tillage in the wheat producing regions has lagged behind other regions such as the Corn Belt. In this paper, the adoption characteristics of 1,189 Oklahoma producers were analyzed. Using cross-tabulation, a total of 13 variables from the survey were analyzed to determine their effect on the adoption of conservation tillage. Eleven of the thirteen variables were found to have a significant overall effect on the choice of tillage practices. In particular, operator age, perceived knowledge of conservation tillage, perceived benefits of conservation tillage, livestock grazing, farm size, rotation practices, and land tenure were all found to have significant individual effects on the adoption of conservation tillage.

The results find that in general the mixed farming systems in Oklahoma play a significant role in shaping the adoption patterns of conservation tillage. Livestock grazing practices, the importance of livestock in the farm operation, and the perceived impacts of livestock on conservation tillage were all significant. Future policy should consider producers with more of a livestock orientation as this group appears to be adopting at low rate. It's likely that through improved information and research that improved techniques could be developed to assist them in adopting more aggressive forms of conservation tillage.

The wheat monoculture also appears to be a significant constraint to the adoption of conservation tillage. The climate and agronomic conditions have made it difficult for most Oklahoma producers to find a crop to rotate with wheat. Where the wheat monoculture has economic dominance, conservation tillage has a difficult economic hurdle to jump since it must either overcome the higher costs associated with pest and weed control in a monoculture, or incur and opportunity cost in switching to a rotation system that is in inherently less profitable than the wheat monoculture.

TABLES

Table 1 U.S. adoption rates of conservation tillage practices in 2004

Regions[a]	Conventional till	Reduced till	Conservation Tillage	No-till
Southern Plains	64.1	19.8	16.1	5.6
Mountain	35.0	25.9	39.1	16.2
Pacific	51.5	27.2	21.3	5.8
Northern Plains	31.0	23.1	45.9	23.9
Delta States	52.0	23.1	25.0	17.6
Southeast	51.1	12.3	36.6	32.6
Appalachian	30.4	11.9	57.7	50.9
Corn Belt	28.3	20.2	51.5	31.4
Lake States	40.3	25.2	34.5	10.6
Northeast	47.7	15.6	36.7	24.8
U.S. Average	**37.7**	**21.5**	**40.7**	**22.6**

Source: CTIC (2004).

Southern Plains: OK, TX.
Mountain: CO, MT, NV, UT, WY, AZ, ID, NM.
Pacific: OR, CA, WA.
Northern Plains: NE, ND, SD, KS.
Delta States: LA, MS, AR.
Southeast: FL, AI, GA, SC.
Appalachian: NC, KY, TN, VA, WV.
Corn Belt: IL, IN, IA, MO, OH.
Lake States: MI, MN, WI.
Northeast: DE, CT, ME, MA, NH, NJ, NY, PA, RI, VT, MD.

Table 2 Summary statistics of the conservation tillage survey and results of contingency table analysis

Factor	Mean/Mode*	DF	χ^2	P Value	Cramer's V
Operator Background and Perceptions					
Age (years)	55-65	25	76.0	<0.001	0.146
Education	High School	20	35.1	0.067	0.086
Understanding of no-till	5.1	65	212.1	<0.001	0.209
Perceived Benefits of no-till	5.5	35	293.0	<0.001	0.283
Extension Information	4.7	35	28.7	0.052	0.089
Impact of Livestock on no-till	No	5	45.6	<0.001	0.209
Farm Characteristics					
Farm Size (acres)	160-640	50	144.0	<0.001	0.199
Small Grain Mgmt.	Dual Purpose		31.3	0.0018	0.115
Crop Rotation	No	10	110.9	<0.001	0.30
Land Rent (acres)	0	15	125.6	<0.001	0.164
Financial Characteristics					
Farm Sales	$0-$100,000	25	133.0	<0.001	0.197
Income Split: Crop/Livestock	25-50% crop	15	56.4	<0.001	0.124
Off-Farm Income (% of total)	Zero	25	51.1	0.001	0.105

* Means are calculated for category variables with a numeric basis. Modes are listed for qualitative variables.

Table 3 Cross-tabulation results explaining adoption patterns of conservation and other tillage practices across selected (significant) farm operator variables

		Tillage Practices (% of producers)							
		Complete Adopters			Partial Adopters				
Variable	Description	CT*	RT	CST	CT_{50+}	RT_{50+}	CST_{50+}	OT	Expected Freq. (%)
AGE	Operator age (yrs)								
	18-45	$25.6^{\dagger}$	13.6	16.8	18.4^{+}	6.4	16.0^{+}	3.2^{-}	10.5
	46-55	31.2	12.6	14.4	17.2^{+}	8.4	10.5	5.6^{-}	23.9
	56-65	36.0	15.8	12.5	7.9^{-}	9.8	7.9	10.1	30.8
	65+	37.5	20.7^{+}	11.1	8.4	5.1	4.6	12.7^{+}	34.9
	Ave. age (yrs) ‡	*60.8*	61.6^{+}	*57.6*	*55.1*	*58.2*	53.9^{-}	64.0^{+}	
	Effect on tillage	+	NE	-	-	NE	-	+	
KNOWLEDGE	No-till knowledge of operator (perceived)								
	≤4 (low)	53.8^{+}	13.8	5.5^{-}	8.0	3.7^{-}	2.8^{-}	12.5	26.9
	5	37.9	19.7	5.6^{-}	14.7	8.6	3.0^{-}	10.6	16.3
	6	32.5	14.3	9.7	22.1	10.4	5.2	5.8	12.7
	7	23.6^{-}	20.3	15.4	9.9	12.1^{+}	12.6^{+}	6.0	15.0
	≥8 (high)	21.1^{-}	16.6	23.9^{+}	8.7	6.5	14.6^{+}	8.7	29.3
	Ave. knowledge	*5.4*	*6.1*	*7.0*	*6.0*	*6.3*	*7.1*	*5.7*	-
	Effect on tillage	-	NE	+	NE	NE	+	NE	
BENEFITS	No-till benefits (perceived)								
	≤4 (low)	56.9^{+}	17.0	2.0^{-}	11.8	3.9^{-}	0.7^{-}	7.8	25.1
	5	43.0^{+}	17.4	5.4^{-}	14.9	8.2	4.8^{-}	6.3	26.0
	6	20.3^{-}	18.4	16.4	12.7	9.6	13.0^{+}	9.6	29.1
	≥7 (high)	15.4^{-}	12.5	31.5^{+}	4.2^{-}	7.5	14.5^{+}	14.5^{+}	19.8
	Ave. benefits	*4.6*	*5.2*	*6.5*	*5.0*	*5.6*	*6.3*	*5.7*	-
	Effect on tillage	-	NE	+	NE	NE	+	NE	
LIVESTOCK	Negative effect of livestock grazing on no-till?								
	Yes	35.2	19.3	8.6^{-}	16.8^{+}	8.2	5.7^{-}	6.4	42.2
	No	28.0	16.0	17.8^{+}	9.2^{-}	8.0	10.8	10.3	57.7
	Total Producers	391	192	153	136	87	97	107	1163
	Obs. Frequency	33.6	16.5	13.2	11.7	7.5	8.3	9.2	100.0

Source: Oklahoma State University Conservation Tillage Survey (2008).

[a] CT=Conventional till, RT = reduced till, CST = conservation till, CT_{50+} = conventional tillage on at least 50% of acreage, RT_{50+} = reduced tillage on at least 50% of acreage, CST_{50+} = conservation tillage on at least 50% of acreage, OT = remaining tillage practices, a mix of CT, RT, and CST that has under 50% acreage of each type.

† Superscripts "+" and "-" refer to cells in the cross-tab table that are outliers, either above "+" or below the expected value, based on the value of the cell's chi-square. Expected values in each cell are calculated based on hypothesized independence between tillage practices and a particular adoption factor.

‡Average values are calculated using the value of each category and where appropriate at the midpoint of each category. Averages are listed for reference and are not used in the contingency analysis.

Table 4 Cross-tabulation results explaining adoption patterns of conservation and other tillage practices across selected (significant) farm variables

		Tillage Practices (% of producers in each tillage practice)							
		Complete Adopters			Partial Adopters				Observed
Variable	Description	CT*	RT	CST	CT_{50+}	RT_{50+}	CST_{50+}	OT	Frequency (%)
SIZE	Farm Size(acres)								
	≤160	57.9^{+}	17.5	9.7	3.1^{-}	1.8^{-}	3.5^{-}	6.6	18.7
	161-640	35.3†	19.5	11.0	11.2	7.1	6.4	9.6	42.7
	641-1,280	28.9	13.8	14.2	13.4	9.2	9.6	10.9	19.6
	>1,280	15.2^{-}	12.1	19.1^{+}	17.8^{+}	11.7^{+}	14.7^{+}	9.5	18.9
	Ave. size (acres) ‡	*490*	*624*	*944*	*1,004*	*1,018*	*1,098*	*782*	-
	Effect on tillage	-	NE	+	+	+	+	NE	
GRAZE	Grazing practice on wheat								
	Grain only	33.1	11.4^{-}	18.0^{+}	8.8	8.5	11.0	9.2	22.8
	Graze only	38.6	17.1	14.6	8.9	3.2^{-}	5.7	12.0	13.3
	Dual Purpose	34.1	18.4	10.4	12.9	8.2	7.5	8.5	63.9
	Effect on tillage	NE	+	-	+	NE	NE	NE	
ROTATE	Crop rotation practiced?								
	Yes	21.5^{-}	13.7	21.3^{+}	12.6	9.1	13.7^{+}	8.2	40.8
	No	42.1^{+}	18.5	7.6	10.9	6.4	4.7^{-}	9.9	59.2
RENT	Land rented (acres)								
	0	47.1^{+}	17.9	12.0	4.2^{-}	4.9	4.2^{-}	9.7	26.3
	≤160	37.3	20.2	11.6	9.9	6.4	5.2	9.4	19.9
	161-640	33.4	15.0	9.6	18.1^{+}	7.1	7.4	9.4	30.1
	641-1,280	19.2^{-}	17.3	16.7	10.9	12.2^{+}	14.7^{+}	9.0	13.3
	>1,280	17.9^{-}	11.4	20.3^{+}	13.8	10.6	19.5^{+}	6.5	10.5
	Ave. rent (acres)	*303*	*421*	*717*	*564*	*763*	*972*	*444*	-
	Effect on tillage	-	NE	+	NE	NE	+	NE	
	Total Producers	391	192	153	136	87	97	107	1163
	Obs. Frequency	33.6	16.5	13.2	11.7	7.5	8.3	9.2	100.0

Source: Oklahoma State University Conservation Tillage Survey (2008).

*CT=Conventional till, RT = reduced till, CST = conservation till, CT_{50+} = conventional tillage on at least 50% of acreage, RT_{50+} = reduced tillage on at least 50% of acreage, CST_{50+} = conservation tillage on at least 50% of acreage, OT = remaining tillage practices, a mix of CT, RT, and CST that has under 50% acreage of each type.

†Superscripts "+" and "-" refer to cells in the cross-tab table that are outliers, either above "+" or below the expected value, based on the value of the cell's chi-square. Expected values in each cell are calculated based on hypothesized independence between tillage practices and a particular adoption factor.

‡Average values are calculated using the value of each category and where appropriate at the midpoint of each category. Averages are listed for reference and are not used in the contingency analysis.

Table 5 Cross-tabulation results explaining adoption patterns of conservation and other tillage practices across selected (significant) financial characteristics

		Tillage Practices (% of producers in each tillage practice)							
		Complete Adopters			Partial Adopters				Observed
Variable	Description	CT*	RT	CST	CT_{50+}	RT_{50+}	CST_{50+}	OT	Frequency (%)
SALES	Farm Sales ($1,000)								
	≤100	43.5^{+}	18.8	9.5^{-}	8.5^{-}	4.8^{-}	3.8^{-}	11.2	50.9
	101-250	28.0†	14.7	15.6	13.7	8.8	11.4	7.8	27.0
	251-500	27.3	18.2	15.9	12.1	9.9	11.4	5.3	11.6
	>500	11.7^{-}	10.0	19.2^{+}	19.2	15.0^{+}	20.8^{+}	4.2	10.5
	Ave. sales ($1,000) ‡	*303*	*421*	*717*	*563*	*763*	*972*	*444*	-
	Effect on tillage	-	NE	+	+	+	+	-	
SHARE	Crop share of farm income (%)								
	0-25 (Ranchers)	38.4	20.7	10.6	6.8^{-}	4.6	6.8	12.0	30.2
	26-50 (Mixed)	34.6	14.0	12.7	14.3	7.4	7.7	9.3	31.1
	51-75 (Mixed)	29.7	15.6	12.5	18.8^{+}	11.5	5.2	6.8	15.8
	76-100 (Crop Farms)	32.1	15.4	16.4	8.2	8.2	12.1^{+}	7.5	23.0
	Effect on tillage	-	NE	+	+	+	+	-	
OFF-FARM	Share of income earned off-farm (%)								
	0 (Full-time)	26.6^{-}	16.0	14.0	11.9	10.9^{+}	11.6^{+}	9.0	33.3
	1-25	30.1	16.7	13.5	12.7	6.4	11.1	8.7	10.9
	26-50	30.4	21.1	8.7	13.0	8.7	7.5	10.6	13.9
	51-75	40.6	11.8	15.3	11.8	5.2	5.7	9.6	19.7
	76-100 (Part-time)	42.6^{+}	19.0	11.6	9.7	4.3	5.0	7.8	22.2
	Effect on tillage	+	NE	NE	-	NE	-	NE	
	Total Producers	391	192	153	136	87	97	107	1,163
	Obs. Frequency	33.6	16.5	13.2	11.7	7.5	8.3	9.2	100.0

Source: Oklahoma State University Conservation Tillage Survey (2008).

[a] CT=Conventional till, RT = reduced till, CST = conservation till, CT_{50+} = conventional tillage on at least 50% of acreage, RT_{50+} = reduced tillage on at least 50% of acreage, CST_{50+} = conservation tillage on at least 50% of acreage, OT = remaining tillage practices, a mix of CT, RT, and CST that has under 50% acreage of each type.

†Superscripts "+" and "-" refer to cells in the cross-tab table that are outliers, either above "+" or below the expected value, based on the value of the cell's chi-square. Expected values in each cell are calculated based on hypothesized independence between tillage practices and a particular adoption factor.

‡Average values are calculated using the value of each category and where appropriate at the midpoint of each category. Averages are listed for reference and are not used in the contingency analysis.

Figures

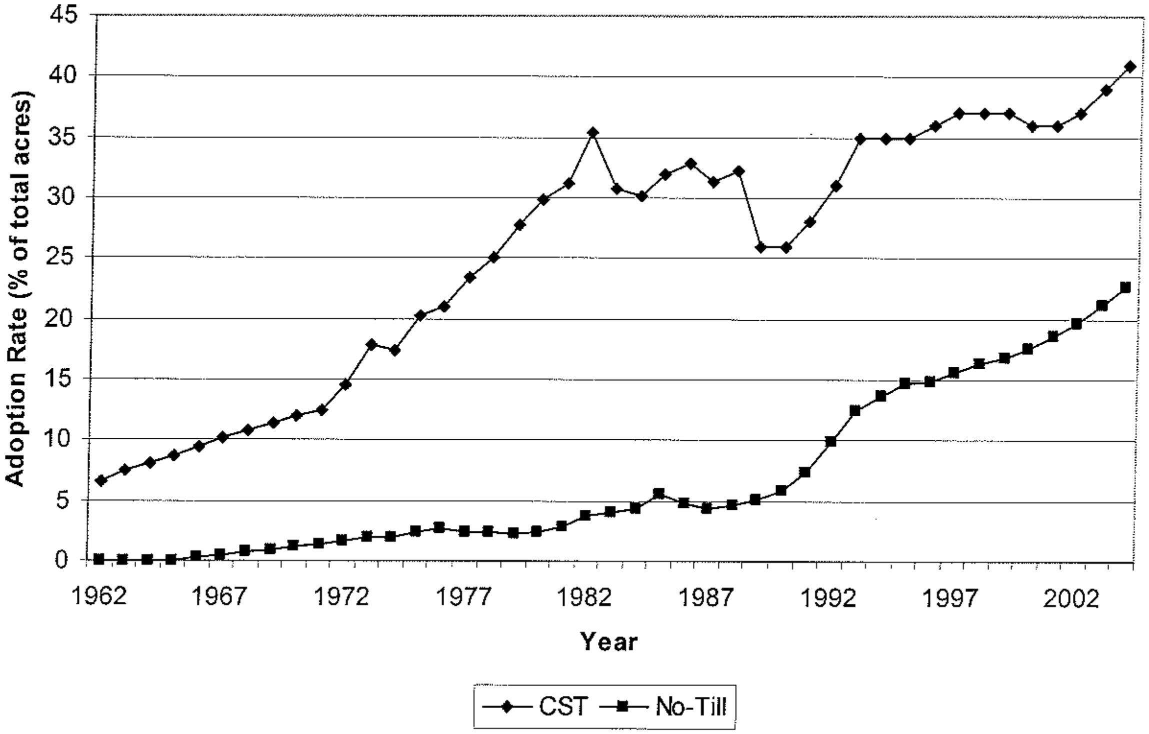

Figure 1 Trends in the Adoption of No-till and Conservation Tillage Practices in the U.S.: 1962-2004.

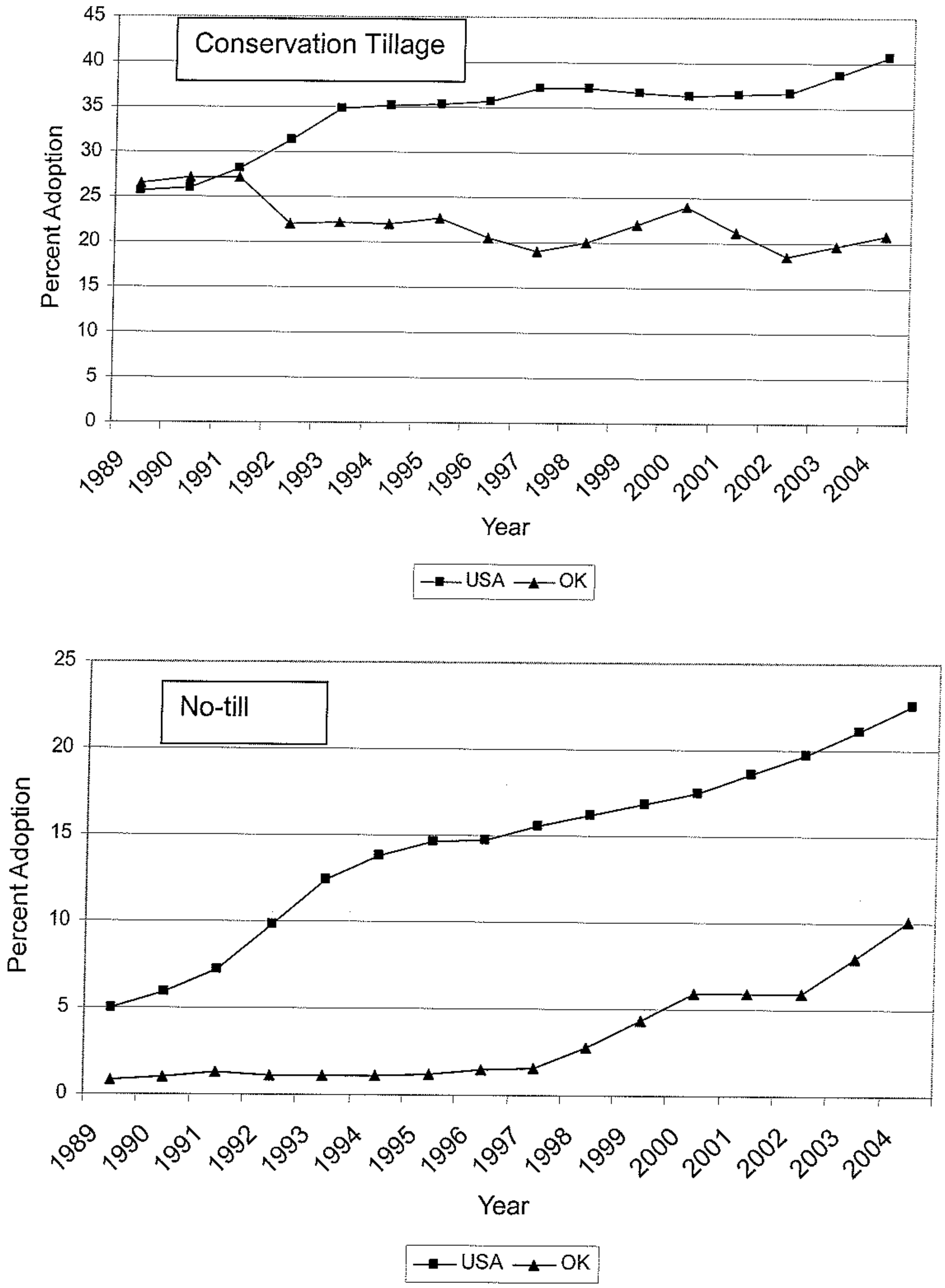

Figure 2 The Adoption of Conservation Tillage and No-Till in the U.S. and Oklahoma.

REFERENCES

Allmaras, R.R., H.H. Schomberg, C.L.J. Douglas, and T.H. Dao. 2000. Soil organic carbon sequestration potential of adopting conservation tillage in U.S. croplands. Journal of Soil and Water Conservation 55:365–373.

Amado, T.J.C., C. Bayer, P.C. Conceiçao, E. Spagnollo, B.H. Costa de Campos, and M. da Veiga. 2006. Potential of carbon accumulation in no-till soils with intensive use and cover crops in southern Brazil. Soil Science Society of America Journal 35:1599–1607.

Bailey, W.R. 1963. The great plains in retrospect with a view to the future. Journal of Farm Economics 45(5):1092-1099.

Banerjee, S., Martin, S., Roberts, R., Larson, J., Hogan, R., Johnson, J., Paxton, K. and Reeves, J., 2007. Adoption of Conservation-Tillage Practices in Cotton Production. Selected Paper presented at the Southern Agricultural Economics Association annual meeting, Mobile, Alabama, February 4-7, 2007.

Blevins, R.L., R. Lal, J.W. Doran, G.W. Langdale, and W.W. Frye. 1998. Conservation tillage for erosion control and soil quality. *In* Advances in Soil and Water Conservation, ed. F.J. Pierce, and W.W. Frye. Chelsea: Ann Arbor Press.

Carpenter, J. and L. Gianessi. 1999. Herbicide Tolerant Soybeans: Why Growers are Adopting Roundup Ready Varieties. AgBioForum (2):65-72.

Cain, Z., and Lovejoy S. 2004. History and outlook for farm bill conservation programs. http://www.choicesmagazine.org/2004-4/policy/2004-4-09.htm

Corak, S.J., T.C. Kaspar, and D.W. Meek. 1993. Evaluating methods for measuring residue cover. Journal of Soil and Water Conservation 48: 70-74.

CTIC .Cropland roadside transect survey: Procedures for using the cropland roadside transect survey for obtaining tillage/crop residue data. Conservation Technology Information Center. West Lafayette, IN: Purdue University. http://www.mo.nrcs.usda.gov/technical/agronomy/out/TransectF1.doc

Davey, K. and Furtan, W., 2007. Factors that affect the adoption decision of conservation tillage in the Prairie Region of Canada. Canadian Wheat Board. http://www.ag-innovation.usask.ca/publications2.php.

David, W., D. Daniel L., and J. Douglas J. 1999. Kansas no-till handbook. http://www.oznet.ksu.edu/library/crpsl2/s126.pdf

D'Emden, Francis H., Rick S. Llewellyn and Michael P. Burton. 2007. Adoption of conservation tillage in Australian cropping regions: an application of duration analysis.

Dick, W.A. 1983. Organic carbon, nitrogen, and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. Soil Science Society of America Journal 47:102–107.

Eghball, B., L.N. Mielke, D.L. McCallister, and J.W. Doran. 1994. Distribution of organic carbon and inorganic nitrogen in a soil under various tillage and crop sequences. Journal of Soil and Water Conservation 49:201–205.

Faulkner, E.H. 1974. Plowman's folly. University of Oklahoma Press, Norman, Oklahoma.

Fuglie, K. O. 1999. Conservation tillage and pesticide use in the cornbelt. Journal of Agricultural and Applied Economics 31 (1): 133–47.

Fuglie, Keith O., C. A. Kascak. 2001. Adoption and Diffusion of Natural-Resource-Conserving Agricultural Technology. Review of Agricultural Economics Volume 23, Issue 2, Page 386-403.

Gebhardt, M.R., T.C. Daniel, E.E. Schweizer, and R.R. Allmaras. 1985. Conservation tillage. American Association for the Advancement of *Science* 230 (4726):625-630.

Gould, Brian W., William E. Saupe,and Richard M. Klemme. May., 1989.Conservation Tillage: The Role of Farm and Operator Characteristics and the Perception of Soil Erosion. Land Economics, Vol. 65(2):167-182.

Hammel, J.E. 1995. Long term tillage and crop rotation effects on winter wheat production in northern Idaho. Agronomy Journal 87:16-22.

Helms, D. 1990. Conserving the great plains: The soil conservation service in the great plains. Agricultural History 64(2):58-73.

Horning, T.R., and M.M. Oveson.1962. Stubble Mulching in the north west. Oregon Agricultural Experiment Information Bulletin 253. Corvallis, OR: USDA ARS (USDA Agricultural Research Service) and Oregon State University.

Janosky, J., Douglas L.Y., and William F.S. 2002. Economics of conservation tillage in a wheat–fallow rotation. Agronomy Journal 94:527-531.

Kettler, T.A., D.J. Lyon, J.W. Doran, W.L. Powers, and W.W. Stroup. 2000. Soil quality assessment after weed-control tillage in a no-till wheat-fallow cropping system. Soil Science Society of America Journal 64:339–346.

Korsching, P. F., C. W. Stofferahn, P. J. Nowak and D. J. Wagener. 1983. Adopter characteristics and adoption patterns of minimum tillage: Implications for soil conservation programs. Journal of Soil and Water Conservation 38:428–30.

Knobloch, F. 1996. The Culture of Wilderness: Agriculture as Colonization in the American West. Chapel Hill: University of North Carolina Press.

Kraft, J.M., D.W. Wilkens, A.G. Ogg, L. Williams, and G.S. Willet. 1991. Integrated pest management for green peas in the blue mountain region. Washington State University Cooperative Extension Bulletin 1599. Washington State University.

Kravchenko, A.G., and K.D. Thelen. 2007. Effect of winter wheat crop residue on no-till corn growth and development. Agronomy Journal 99:549-555.

Kurkalova, L., Kling, C., Zhao, J., 2006. Green Subsidies in Agriculture: Estimating the Adoption Costs of Conservation Tillage from Observed Behavior. Canadian Journal of Agricultural Economics. 54:247–267.

Lal, R., M. Griffin, J. Apt, L. Lave, and M.G. Morgan. 2004. Managing soil carbon. Soil Science Society of America Journal 304:393.

Lee, L. and Stewart, W., 1983. Landownership and the Adoption of Minimum Tillage. American Journal of Agricultural Economics, 65(2): 256-264.

McCalla, T. M. and T.T. Army. 1961. Stubble mulch farming. Advances in Agronomy 13:125- 196.

Morrison , J.E., C.Jr. Huang, D.T. Lightle, and C.S.T. Daughtry. 1993. Residue cover measurement techniques. Journal of Soil and Water Conservation 48: 479-483.

Nelson, P. J. 1997. To hold the land: soil erosion, agricultural scientists, and the development of conservation tillage techniques. Agricultural History 71(1):71-90.

Omonode, R.A., A. Gal, D.E. Stott, T.S. Abney, and T.J. Vyn. 2006. Short-term versus continuous chisel and no-till effects on soil carbon and nitrogen. Soil Science Society of America Journal 70: 419–425.

Payne, W., P.E. Rasmussen, C. Chen, and R.E. Ramig. 2001. Assessing simple wheat and pea models using data from a long-term tillage experiment. Agronomy Journal 93:250–260.

Schillinger, W. F. 2001. Minimum and delayed conservation tillage for wheat–fallow farming. Soil Science Society of America Journal 65:1203–1209 .

Smith, E.G., T.L. Peters, R.E. Blackshaw, C.W. Lindwal, and F.J. Larney. 1996. Economics of reduced tillage in crop-fallow systems. Candian Journal of Soil Science 76:411-416.

Thomas, G.W., Blevins, R.L. 1996. The development and importance of no- tillage crop production in Kentucky. Kentucky Agricultural Experiment Station Bulletin 385.

Trautmann, N.M., K.S. Porter, and R.J. Wagenet. Modern agriculture: Its effects on the environment. Natural Resources Cornell Cooperative Extension. Ithaca, NY: Cornell University.
http://pmep.cce.cornell.edu/facts-slides-self/facts/mod-ag-grw85.html#top

USDA. 1975. Minimum tillage: A preliminary technology assessment. Office of Planning and Evaluation.

USDA. 1985. Conservation tillage: Things to consider. Agriculture Information Bulletin 46. Washington.

Westra, J., Olson, K., 1997. Farmers' decision processes and adoption of conservation tillage. Staff Paper P97-9. Department of Applied Economics, University of Minnesota.

Yin, X., and M.M. Al-Kaisi. 2004. Periodic response of soybean yields and economic returns to long-term no-tillage. Agrononmy Journal 96:723–733.