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

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Abstract: This paper evaluated differences between yields of no-tillage compared to conventional or reduced tillage and their associated downside risk. Six crops were evaluated along with how those yields and risks differed by various environmental factors such geographic location, precipitation, soil type and how long the practice had been used.

Introduction

In 1984, then Secretary of Agriculture John Block predicted that 95% of all U.S. cropland would be under no-tillage by 2010 (McWhorter 1984) and others predicted 65% by year 2000 (Phillips et al. 1980). However, in the United States, only 24 percent of cropland is maintained by no-tillage and this percentage declines when looking at all croplands worldwide (CTIC 2009). With a wide range of reported 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 (Javurek et al. 2007).

Yields are one of the most important factors influencing profit. Low yields could translate into low profits or worse, a loss, whereas higher yields mean higher profits. Thus, an important factor affecting risk and return and thus farmer willingness to adopt no-tillage is the yield realized after the adoption of no-tillage (Ribera et al. 2004). Many conflicting studies exist as to whether yields with no-tillage are higher (Endale et al. 2008; Smiley & Wilkins 1993; Wagger & Denton 1989), lower (Graven & Carter 1991; Halvorson et al. 2006; Hammel 1995) or equal to conventional tillage yields (Archer & Reicosky 2009; Barnett 1990; Kapusta et al. 1996). These conflicting findings may result from yields under no-tillage, reduced and conventional tillage being affected by many factors such as location of production, soil texture, rainfall and crop. DeFelice et al. (2006) evaluated the impact of growing environment factors on mean yields of corn and soybeans using experiments located primarily in the eastern United States. However, the effects of location and other growing environment factors on both mean yields and downside risk of no-tillage compared with tillage has not been studied. Our objective is to evaluate the impacts on the mean and downside risk of crop yields of switching from conventional or reduced tillage practices to no-tillage for six crops. Data from 442 published paired tillage experiments across the United States growing corn, soybeans, cotton, oats, wheat and sorghum and a wider range of potential growing environment and location factors than DeFelice et al. were used to achieve the objective of this study.

Data

A dataset of paired tillage experiments from the *Soil & Tillage Research* journal were collected by Maithilee Kunda and Tristram West of the Oak Ridge National Laboratory (Kunda and West 2006). Of those experiments only the one's pertaining to the contiguous U.S. were used in this analysis. Additional experimental data were collected from two other refereed journals, *Agronomy Journal* and *Journal of Production Agriculture*. These datasets allowed us to evaluate crop yield differences when comparing conventional and reduced tillage to no-tillage as explained by such factors as time since conversion from tillage to no-tillage, crop, precipitation, soil texture and geographic region. Data from corn, soybeans, cotton, oats, wheat and sorghum tillage experiments were incorporated in the analysis. The experiments were conducted across the United States, with data ranging from 1964 to 2005.

Methods and Procedures

Conceptual Framework

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

$$\pi_i = P \times Y_i - VC_i - FC_i, \tag{1}$$

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 yield probability distribution (Anderson, Dillon, and Hardaker 1977; Chavas, Posner, and Hedtcke 2009). The first moment is mean yield:

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

where $E[\cdot]$ is the expectation operator, $\mathbf{v}$ is a vector of the aforementioned production environment factors affecting production, and $\mathbf{x}$ 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*. Risk averse farmers 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:

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

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. 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.

Empirical Models

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

$$\begin{aligned} RR = {} & \beta_0 + \sum_{i=1}^{5} \beta_i CROP_i + \sum_{j=6}^{8} \beta_j SOIL_j + \sum_{k=9}^{16} \beta_k ERS_k + \beta_{17} TILL + \beta_{18} BEGAN + \beta_{19} LOGYR + \beta_{20} RAIN \\ & + \sum_{i=1}^{5} \sum_{j=6}^{8} \beta_{i\,j} (CROP_i)(SOIL_j) + \sum_{i=1}^{5} \beta_{i\,18} (CROP_i)(BEGAN) \\ & + \sum_{i=1}^{5} \beta_{i\,19} (CROP_i)(LOGYR) + \sum_{i=1}^{5} \beta_{i\,20} (CROP_i)(RAIN) + \varepsilon, \end{aligned} \tag{8}$$

where *CROP* represents one of five crops (*i* = sorghum, wheat, soybeans, cotton or oats); *SOIL* represents one of three soil textures (*j* = sand, silt or clay), and ERS represents one of eight USDA ERS Farm Resource Regions (*k* = 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. *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. *LOGYR* is used to test if a yield lag exists when switching from conventional tillage or reduced tillage to no-tillage as much anecdotal evidence suggests, and to see if no-tillage yields increase over time relative to tillage yields through soil improvement. 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 sand or clay textured soils; therefore no interactions were specified 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 *NTPROB* is the downside risk dependent variable equal to one if the no-tillage crop yield was less than the conventional or reduced tillage yield and a zero otherwise, and all other variables are as defined in equation (8).

Statistical Methods

Equation (8) was estimated using the mixed model procedure in SAS (SAS Institute 2004). Tests for multicollinearity and heteroskedasticity were performed using the VIF and SPEC options in PROC REG, respectively (SAS Institute 2004). Heteroskedasticity was present and corrected in the mixed model by adding a RANDOM statement that included the location of each experiment. Mutlicollinearity was an issue in the initial analysis when both USDA ERS Farm Resource Regions and latitude were included as explanatory variables. Only the USDA ERS Farm Resource Regions were used in the model because they not only capture differences in temperature and other climatic factors affected by latitude, but differences across growing regions not affected by temperature.

The logistic regression in equation (9) and the marginal effects of the explanatory variables were estimated using LIMDEP (Greene 2007). The MARGINAL EFFECTS statement was used to calculate the marginal effect each variable had on the probability of having decreased yields with no-tillage compared to conventional or reduced tillage.

Results

Mean Yield Differences

As was hypothesized, crops reacted differently to tillage methods. No-tillage sorghum and wheat had higher yields than conventional or reduced tillage sorghum and wheat. It can also be said the differences between no-tillage and conventional tillage yields of sorghum and wheat were greater than the difference between no-tillage and conventional tillage corn, because the higher the ratio of no-tillage yields over tillage yields the greater the difference in yields. However, oats grown using no-tillage yielded less than their conventional tillage counterparts and the difference between no-tillage and tillage yields of oats were less than the difference between no-tillage and tillage yields of corn. One explanation for this result could be the amount of residue left behind by each crop. Corn production leaves significantly more residue on the soil than do the other crops. Dense crop residue coverage can lead to a cool and moist soil, which can delay crop emergence and reduce seed germination, affecting yields (Halvorson et al. 2006). Corn also has a significantly higher carbon (C) to nitrogen (N) ratio (C:N) 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 decomposes. Since corn has a high C:N ratio it decomposes slower limiting the availability of nutrients, particularly nitrogen, because the microorganisms that decompose the residue compete with the plant for these nutrients (Mannering and Griffith 1985). An optimal C:N ratio for decomposition would 25:1 or lower. Oats on the other hand leave a significantly smaller amount of residue behind than corn. 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). 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 tillage yields in the same texture. The differences between no-tillage and tillage yields under a silty soil were also lower than the difference between no-tillage and tillage yields under 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 (DeFelice et al. 2006; Hairston et al. 1990). Yields under clay and sandy soils were not statistically different from those under 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 the differences in no-tillage and tillage yields of sorghum, wheat and soybeans produced on a sandy soil texture were less than the difference of no-tillage and tillage yields of corn in a loam soil. 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 amount 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. The Southern Seaboard and Mississippi Portal regions, which represent a majority of the southern United States, had positive and significant coefficients. These regions had on average higher no-tillage yields than conventional or reduced tillage yields and had greater differences between yields of no-tillage and tillage than the differences in no-tillage and tillage yields in the Heartland region. These results concur with previous research (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 tillage yields as well as smaller differences in yields compared to the Heartland region. All experiments in our dataset from 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. Wet years and cold climates have been found to cause reduced yields under no-tillage compared to conventional or reduced tillage, thus, this could be the explanation for lower no-tillage yields in these regions (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 negative, suggesting that as the year the experiment was initiated increases, the difference between no-tillage and tillage crop yields of sorghum and wheat decreases. 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, *LOGYR×COTT*; the coefficient was positive which does coincide with our hypothesis that the longer the amount of time no-tillage is used cotton yields increase as no-tillage rebuilds the soils quality.

The variable *RAIN* was significant in two interactions, *RAIN×SORG* and *RAIN×OAT*. For each millimeter increase in rainfall, no-tillage sorghum yields decreased slightly compared to conventional or reduced tillage sorghum. The difference between no-tillage and tillage yields of sorghum decreased compared to the difference between no-tillage and tillage yields of corn when rainfall increased. 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. 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 compared to tillage oat yields.

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.

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. 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 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. 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 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. 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 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, such as the ones used in this study, should be considered.

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Table 1. 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 2. 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	<0.00***

***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).