1-2020

An analysis of yield variation under soil conservation practices

Andrew E. Anderson
Purdue University

W. Ashley Hammac
USDA-ARS, Ashley.Hammac@ars.usda.gov

Diane E. Stott
USDA-ARS, diane.stott@ars.usda.gov

Wallace E. Tyner
Purdue University

doi:10.2489/jswc.75.1.103

An analysis of yield variation under soil conservation practices

A.E. Anderson, W.A. Hammac, D.E. Stott, and W.E. Tyner

Abstract: Much attention has been paid to the effects of multiple soil conservation and soil health practices on the mean yield of the subsequent crop. Much less research has focused on the variability of crop yields over time or space. Yield stability reported in standard deviation, mean absolute deviation, or coefficient of variation can be an important measure of risk for producers. Risk reduction has economic value, and understanding the effect of tillage and other soil conservation practices on yield risk is relevant to farm financial management and crop insurance risk assessment. We used data from test plots in a corn (*Zea mays* L.)–soybean (*Glycine max* L.) rotation, spanning from 2003 to 2011 to assess differences in yield stability over time and space. In this experiment, each plot was randomly assigned to a treatment of no-till with no cover crop (NTNC), no-till with an annual ryegrass (*Lolium multiflorum* Lam.) cover crop (NTCC), or a control group using conventional tillage with no cover crop (CTNC). The statistical analysis made three relevant comparisons: (1) NTCC versus NTNC, (2) NTNC versus CTNC, and (3) NTCC versus CTNC. The analysis also included separating temporal and spatial variation using a time-first approach from the literature, followed by testing for differences between groups. We employed a standard deviation ratio test, Levene's test, and coefficient of variation *t*-test. Additionally, analysis of temporal volatility was conducted using ordinary least squares regression and associated *t*-tests in a method similar to a stock beta, a technique commonly accepted in finance to measure the volatility of an investment. We propose this as a new method in analyzing the temporal volatility in crop yields. We found that no-till reduced average temporal yield variation in corn, and that cover crops reduced average spatial variation in corn. These results were robust over multiple statistical tests. Using the beta coefficient methodology proposed in this paper, we found in both corn and soybeans that NTNC and NTCC had lower temporal yield volatility relative to a benchmark yield from the CTNC group. However, the beta coefficients were, in most cases, not statistically significant. The results of this study suggest that both no-till and cover crops may help reduce yield risk for Midwestern farmers while reducing soil and nutrient loss.

Key words: corn—cover crops—no-till—risk—soybeans—yield stability

Soil conservation practices such as no-till and cover crops have been shown to decrease nitrate (NO_3^-) runoff and leaching, reduce erosion, improve soil structure, increase soil nutrient status, and enhance water-holding capacity among other agronomic benefits; however, the private economic benefits of these practices have been more difficult to establish (Wilson et al. 1982; McVay et al. 1989; Zhu et al. 1989; McCracken et al. 1994; Dabney et al. 2001; Doane et al. 2009; Chen and Weil 2010, 2011). Research on the impact of cover crops on average yield has generated mixed results. Some studies found little or no evidence of any effect (Burgess 2014; Leslie et al. 2017; Lira and Tyner 2018), while others found a positive impact (Koger and Reddy 2005; Muñoz et al. 2014; Nkongolo and Haruna 2015; Belfry et al. 2017). Still, other research found that cover crops reduced the yield in the subsequent cash crop (Reddy 2001; Kaspar and Bakker 2015). In a meta-analysis of the impact of cover crops on corn (*Zea mays* L.) yield, Tonitto et al. (2006) found no observable yield impact of cover crops. Additionally, in a more recent meta-analysis of 65 previous studies, Marcillo and Miguez (2017) found a neutral to positive effect of winter cover crops on corn yields. On average, grass cover crops had no detectable positive or negative effect on corn yields. However, they did observe a positive yield effect from legume cover crops when no nitrogen (N) fertilizer was applied, but it diminished with increased N application. In general, yield increases were attributed to improved soil physical properties and fertility status, including increased rooting depth and access to water, soil organic carbon (C), and N fixing or scavenging (Chen and Weil 2011; Marcillo and Miguez 2017).

Much analysis on mean yields as affected by no-till has been completed. In a meta-analysis of 678 studies conducted in 63 countries using 50 different crops, Pittelkow et al. (2015) showed a 5.1% yield decline across all observations. However, cotton (*Gossypium* L.), oilseeds (*Brassica* L.), and legumes (*Fabaceae*)—including soybeans (*Glycine max* L.)—did not show a statistically significant reduction in yields. Cereal crops had an average 5% drop in yields, including corn, which had 7.6% lower yields. No-till had the largest yield reductions in the most tropical climates, while more arid climates experienced smaller declines. In dry climates under rainfed cropping systems, no-till matched or exceeded conventional yields. However, for most crops in other conditions, reductions in yields were observed. Decreases in yields were most pronounced in the first one to two years following the implementation of no-till. However, the negative effect decreased over time and began to match conventional yields after several years (Pittelkow et al. 2015). Another study examined the effects of long-term tillage practices on yields in a corn–soybean rotation. It compared chisel plow tillage to no-till on eight research farms across five Midwestern states. All of the sites had previously been cultivated using each of the respective tillage practices for 8 to 50 years. The study determined that

Andrew E. Anderson is a research assistant in the Department of Agricultural Economics, Purdue University, West Lafayette, Indiana. **W. Ashley Hammac** is a senior soil scientist at Solum Lab, Ames, Iowa. **Diane E. Stott** is the national soil health specialist at the USDA Natural Resources Conservation Service, West Lafayette, Indiana. **Wallace E. Tyner** is the James and Lois Ackerman professor in the Department of Agricultural Economics, Purdue University, West Lafayette, Indiana.

tillage practices had little effect on corn yields, although the chisel plow groups typically yielded slightly more than no-till when there was a difference. Drought years were an exception during which no-till generally had a higher yield. For soybeans, the research found no evidence for differences in yields between chisel plow and no-till for any site-year or when aggregated across site years (Daigh et al. 2018).

The impact of cover crops on average yields has been well studied. The impact of cover crops on yield stability, on the other hand, has not been so thoroughly investigated. Yet, there is research that indicates that increasing crop diversity has the potential to improve yield stability over time. A study using data from a long-term crop rotation and tillage trial in Ontario, Canada, examined the impact of crop diversity on temporal yield stability over 31 years. The analysis concluded that more diverse crop rotations reduced yield variation for corn and soybeans and decreased the probability of crop failure (Gaudin et al. 2015). Several other studies have come to similar conclusions (Varvel 2000; Grover et al. 2009). While these findings were not directly related to cover crops, cover crops may offer similar benefits because they provide additional rotational diversity. Other research has also suggested that cover crops may directly enhance yield stability (Knapp and van der Heijden 2018).

Yield variability for other management practices—including no-till—has been examined, but the body of research is small. Several studies have been unable to discover any significant evidence for differences in yield stability across tillage practices (Pedersen and Lauer 2003; Daigh et al. 2018). In a 12-year field trial, Smith et al. (2007) studied the temporal yield variability of corn, soybeans, and wheat (*Triticum aestivum* L.) under four different management systems. The management systems included conventional, no-till, low-input, and organic. Yield variability was measured using the coefficient of variation (CV), which provided a measure of relative variation over time. Results showed that the no-till management system had comparable variation with conventional practices in corn. In soybeans, however, no-till had significantly lower variation than conventional management.

The hypothesis of this study is that no-till and cover crops reduce variability (increase stability) in cash crop yield by improving soil qualities. The literature has demonstrated many agronomic benefits of such systems. This study investigated to what extent the benefits of soil conservation may reduce yield stability and thus provide economic advantages. Yield variance is a basic component of production risk, a significant source of risk to individual producers. It is possible that including cover crops and/or no-till practices in their cropping system would help farmers reduce yield risk. This could be an additional internal economic benefit to growers that has not been well established in the previous literature. The effect of soil conservation practices on yield variation could also be very informative to the analysis performed to set crop insurance premiums. If cover crops or tillage practices could be shown to reduce yield variability, then lower crop insurance premiums might be justified. Not only could a reduced premium make sense as an actuarially fair practice, but it also could double as an incentive for the adoption of environmentally friendly management practices.

Materials and Methods

The data for this research came from a field trial conducted at the Purdue University Agronomy Center for Research and Education (ACRE) spanning from 2003 to 2011. The study site was dominated by three soil series: Chalmers silty clay loam (fine-silty, mixed, superactive, mesic Typic Endoaquolls), Toronto silt loam (fine-silty, mixed, superactive, mesic Udollic Epiaqualfs), and Millbrook silt loam (fine-silty, mixed, superactive, mesic Udollic Endoaqualfs). The field was separated into 9.1 m by 15.2 m plots, and each plot was cultivated using a corn–soybean rotation. Grain was harvested using a plot combine. Plots were also randomly assigned a treatment of no-till with no cover crop (NTNC), no-till with cover crops (NTCC), or they were assigned to the control of conventional till with no cover crop (CTNC). The NTNC treatment originally was two separate treatments using two different planters and having twice the number of replications as the other treatments. The planter was determined not to make a difference, and this was validated statistically. For this reason, the four replications for one of the NTNC treatments were moved to the CTNC group and treated with conventional tillage beginning in 2008. Because of concerns that the CTNC plots that had switched from NTNC would be different from the plots that had been in CTNC the whole time, the mean and variance of these observations were compared to the rest of the CTNC group. The absolute differences were extremely small and far from statistically significant. For the NTCC treatment, cover crops were seeded in the fall immediately following grain harvest and chemically terminated in the spring at least three weeks prior to cash crop planting. The cover crop that was used in this experiment was annual ryegrass (*Lolium multiflorum* Lam.). The CTNC group was cultivated using fall chisel and spring disk. For each cash crop in each year there were four replications for the NTCC treatment, eight for the NTNC treatment from 2003 to 2008 and four from 2008 to 2011, and four for the CTNC control group from 2003 to 2008 and eight from 2008 to 2011. All other farming practices, including fertilizer and herbicide application, were consistent across the plots and years. The yields were recorded in kilograms per hectare.

The following are the three separate effects that were considered in this analysis:

1. The effect of adding cover crops to no-till. This was done by comparing the NTCC group with the NTNC group. The NTNC group acts as a control since the only management difference was the addition of cover crops. This isolated the effect of adding cover crops to a no-till system.
2. The effects of no-till alone. This was done by comparing the NTNC treatment to the control group of CTNC.
3. The effects of no-till and cover crops together. This was done by comparing the NTCC with the CTNC control group.

The first question that was investigated using this data was the effect of no-till and cover crops on corn and soybean mean yield in the following season. The data showed no statistically significant difference in the average yields of the plots for any of the relevant comparisons. We then turned our attention to yield stability.

Yield variation can be expressed in terms of spatial (interplot) variability, temporal variability (intraplot), or pooled (combination of both) variability. We used a time-first approach to partition spatial and temporal variation (Sun et al. 2010). Spatial variation was calculated by measuring the variation among the temporal means from each plot. On the other hand, temporal variation was calculated by averaging the temporal variation from each plot. The pooled variability was calculated as the variation among all plots in all years. It was the total variability among all of the individual observations in each group.

There are many methods to analyze the yield variation and make comparisons between groups. The following four methods were selected for this study:

- Standard deviation ratio test
- Levene's test
- CV and chi-square test for differenceses
- Regression beta coefficient and *t*-test for statistical significance

Standard Deviation Ratio Test. The standard deviation ratio test is the simplest method to statistically test the difference in variability between groups. The test statistic is simply the standard deviation of one group divided by the standard deviation of the other. Typically, variance is used to calculate this statistic. However, the standard deviation is the square root of the variance so it is mathematically equivalent in calculating this test statistic. We used standard deviation because averages over space or time are impacted by extreme values, and variance amplifies the extremity of these outliers because it squares the deviations. The standard deviation ratio test uses an F distribution and assumes the data come from a normal population. We tested for normality using the sample skewness and kurtosis to calculate a chi-squared statistic (D'Agostino et al. 1990). Since the null hypothesis under this test was normality, the only strong statement that could be made was rejection of normality with sufficient evidence. All of the group distributions for corn showed evidence of being non-normal, and moderately negatively skewed with slightly thin tails. The group distributions for soybeans showed little evidence of being non-normal, although they were all somewhat negatively skewed with slightly thinner tails than the normal distribution. For these reasons, additional tests seemed appropriate to determine the robustness of the results obtained.

Levene's Test. Because the standard deviation ratio test is sensitive to the normality assumption (Box 1953; Markowski and Markowski 1990), we applied Levene's test to determine the robustness of the results of the standard deviation ratio test (Levene 1960). There are three ways to calculate the Levene's test statistic, each using a different measure of central tendency. Originally, the test was done only using the mean. Later Brown and Forsythe (1974) proposed using the median or trimmed mean. They showed through Monte Carlo simulation that using the trimmed mean was best when the underlying distribution was heavily tailed, while the median performed well for heavily right-skewed distributions. The original test statistic performed well with symmetric and moderately tailed distributions. For our purposes, we used the mean because none of the distributions showed heavy tails or strong positive skewness.

Coefficient of Variation. To understand the yield variability relative to the mean for each group, the CV was calculated and compared between groups. This measure captured a different picture than simple comparisons of variance because it used a relative and not an absolute measure of variation. The CV is the ratio of the standard deviation and the mean; it has been used by many disciplines to test volitility (Banik et al. 2012). To calculate temporal CV, we used the overall mean yield and the average of the temporal standard deviations from each plot. For the spatial analysis, the standard deviation of the temporal means and overall mean yield was used. The statistical test for the difference between the CV for each comparison uses a chi-square distribution with as many degrees of freedom as there are CVs to compare (Feltz and Miller 1996).

Regression Beta Coefficient. Relative volatility over time was also of interest. We compared the volatility in each group using ordinary least squares (OLS) regression analysis. This technique is commonly used in financial markets to assess some particular stock's contribution of risk to a well-diversified portfolio (Blume and Friend 1973; Black 1972). The same idea was extended to crop yields in this research. The crop yield, like the stock price, changes from time period to time period, and increases are desirable. However, risk relates to the nature of the variability of the stock price or crop yield in this case. The idea behind using regression coefficients for a measure of risk in finance is to use the variance of the portfolio rate of return as the benchmark measure of risk. In the stock market, an index is usually used as the standard for a well-diversified portfolio. We assumed that the benchmark measure of risk for a particular crop was the yield variance of the cash crop under a "conventional" farming system. This was analogous to a market index in the stock market because it provided a baseline for comparison. By regressing the percentage change in yields of the treatment group on the percentage change in yields of the control group, we could calculate the relative yield volatility using conservation practices:

$$\%\Delta \mathit{Treatment\,Yield} = \beta_0 + \beta_1 \%\Delta \mathit{Control\,Yield}\,. \quad (1)$$

If the regression coefficient was less than one, the treatment reduced yield volatility. However, if the coefficient was greater than one, the treatment increased volatility in yields. The idea was to show how much each treatment changed yield risk. As a result, the hypothesis tests needed to determine whether the resulting coefficients were equal to one. Because of this, our hypothesis tests used a null hypothesis of equality to one and an alternative hypothesis that the coefficient was less than one. For the regression input, we used percentage change in yields from year to year, just as a stock's returns are used in the finance application of this method. Using percentage changes also removes time trends and corrects for the possibility of a highly persistent time series (Wooldridge 2016).

Although both relate to a form of relative variation, this analysis is fundamentally different from the tests for differences in CV. When calculating CV, variation is compared to an overall average. On the other hand, percentage changes compare yearly yield changes to the average yield from the previous year. This difference makes the percentage changes from year to year a more precise measure of relative temporal volatility. While other studies have used CV to measure yield variability, to our knowledge none have employed Levene's test or the use of regression coefficients. The latter represents a new and innovative way to analyze yield variability. The present research also provides a more comprehensive analysis of the different types of yield variability (i.e., spatial versus temporal).

Results and Discussion

Discussion of Descriptive Statistics. The cash crop yield data summarized in the next few paragraphs by descriptive statistics and plots were segmented by treatment and not by time nor space. The summary statistics for the yield data are presented in tables 1 for corn and 2 for soybeans. The means from each treatment did not differ significantly between groups for either corn or soybeans.

For corn, the mean yields were 11,570 kg ha^{-1} for the CTNC group, 11,434 kg ha^{-1} for the NTNC treatment, and 11,685 kg ha^{-1} for the NTCC treatment. For soybeans, the means were 3,232 kg ha^{-1} for the CTNC group, 3,231 kg ha^{-1} for the NTNC treatment, and 3,306 kg ha^{-1} for the NTCC treatment. In each case, the treatment of NTCC had slightly higher mean cash crop yields. However, the differences in mean yields were not statistically significant.

For corn, the yield variabilities within the NTNC and NTCC groups were smaller than the CTNC yield variability, with standard deviations of 1,685 kg ha^{-1}, 1,644 kg ha^{-1}, and 2,083 kg ha^{-1} respectively. In soybeans, the opposite appeared to be true, where the CTNC yield variability was smaller than both treatments, although the differences were relatively small in this case. The standard deviations for soybeans were 624 kg ha^{-1} for CTNC, 649 kg ha^{-1} for NTNC, and 661 kg ha^{-1} for NTCC.

The range for each distribution provided yet another measure of dispersion; it was calculated by subtracting the minimum value from the maximum value. The ranges for the distributions in corn were 7,522 kg ha^{-1} for CTNC, 6,371 kg ha^{-1} for NTNC, and 5,793 kg ha^{-1} for NTCC. These metrics also suggest that NTNC and NTCC may reduce the variability of cash crop yield, particularly for NTCC. On the other hand, the ranges of the distributions in soybeans were 2,603 kg ha^{-1} for CTNC, 2,983 kg ha^{-1} for NTNC, and 2,847 kg ha^{-1} for NTCC. The ranges for soybeans also suggest that NTNC and NTCC had little effect on the variability of cash crop yield.

By directly observing descriptive statistics, such as standard deviation and range, it appears that soil conservation practices may help to reduce yield variability in corn, while they do not seem to have a substantial impact in soybeans. We now turn our attention to the results of formal statistical tests to evaluate the statistical significance of the observed differences in variance. For every test, each of the three relevant comparisons were made.

Table 1
Corn yield summary statistics (kg ha^{-1}).

Statistic	CTNC	NTNC	NTCC
Mean	11,570	11,434	11,685
Standard deviation	2,083	1,685	1,644
Skewness	−0.879	−0.378	−0.548
Kurtosis	2.638	2.212	2.156
Mean absolute deviation	1,671	1,405	1,380
Range	7,522	6,371	5,793
Count	52	56	36

Notes: CTNC is conventional tillage and no cover crop. NTNC is no-till and no cover crop. NTCC is no-till with a cover crop treatment.

Table 2
Soybean yield summary statistics (kg ha^{-1}).

Statistic	CTNC	NTNC	NTCC
Mean	3,232	3,231	3,306
Standard deviation	624	649	661
Skewness	−0.350	−0.007	−0.269
Kurtosis	2.373	2.751	2.946
Mean absolute deviation	519	518	518
Range	2,603	2,983	2,847
Count	52	56	36

Notes: CTNC is conventional tillage and no cover crop. NTNC is no-till and no cover crop. NTCC is no-till with a cover crop treatment.

Standard Deviation Ratio Test. The yield standard deviations presented for corn in table 3 have an apparent reduction in standard deviation for most of the comparisons across the different types of variability. The exceptions to this were temporal variation in the NTCC versus NTNC comparison and spatial variation in the NTNC versus CTNC comparison. However, the only statistically significant reductions were the temporal variation in the NTNC versus CTNC comparison and spatial variation in both the NTCC versus NTNC as well as NTCC versus CTNC. The difference in temporal yield variation between NTNC and CTNC in terms of standard deviation is 721 kg ha^{-1} (p = 0.062). The yields in the NTCC group had lower spatial variation than both NTNC and CTNC groups by 700 kg ha^{-1} (p = 0.002) and 429 kg ha^{-1} (p = 0.019), respectively. For soybeans, the group standard deviations in yield were very similar for nearly all of the comparisons. The standard deviation ratio test showed no statistically significant difference in the variation between any of the groups in any of the relevant comparisons. These results are also presented in table 3.

Levene's Test. To test the robustness of the above results, Levene's test was applied. The results for this test are presented in table 4. Levene's test uses mean absolute deviation instead of the standard deviation to test for differences in variability. In corn this test confirmed that the results of the standard deviation test were robust. When NTNC was compared to CTNC, temporal mean absolute deviation was 792 kg ha^{-1} (p = 0.070) lower in the NTNC group. NTCC reduced spatial variation by 669 kg ha^{-1} (p = 0.002) in mean absolute deviation when compared to NTNC and by 404 kg ha^{-1} (p = 0.028) when compared to CTNC. Confirming the results of the ratio test, Levene's test was inconclusive for all types of variation and all comparisons in soybeans.

Coefficient of Variation. The results of the analysis of CV are displayed in table 5. They indicated that NTCC reduced relative spatial variation in corn by 6.2 percentage points (p = 0.017) when compared to NTNC and by 3.7 percentage points (p = 0.067) when compared to CTNC. When NTNC was compared to CTNC, temporal CV was 6.1 percentage points lower, although it was insignificant at the 10% level (p = 0.119). Additionally, it is worth noting that pooled relative variation was reduced when NTNC and NTCC were compared to CTNC, although these differences were not statistically significant at the 10% level. These group pooled CVs were different by 3.3 (p = 0.156) and 3.9 (p = 0.132) percentage points, respectively. For soybeans, on the other hand,

Table 3
Standard deviation ratio test results.

Crop	Statistic	Cover crops*	No-till without cover crops†	No-till with cover crops‡
Corn		Temporal		
	SD of control group	1,344	2,065	2,065
	SD of treatment group	1,795	1,344	1,795
	F statistic	0.749	1.536	1.150
	p-value	0.832	0.062	0.337
		Spatial		
	SD of control group	1,138	867	867
	SD of treatment group	438	1,138	438
	F statistic	2.598	0.762	1.980
	p-value	0.002	0.833	0.019
		Pooled		
	SD of control group	1,685	2,083	2,083
	SD of treatment group	1,644	1,685	1,644
	F statistic	1.025	1.236	1.267
	p-value	0.477	0.220	0.232
Soybeans		Temporal		
	SD of control group	671	537	537
	SD of treatment group	638	671	638
	F statistic	1.051	0.800	0.841
	p-value	0.446	0.786	0.715
		Spatial		
	SD of control group	313	386	386
	SD of treatment group	283	313	283
	F statistic	1.106	1.231	1.361
	p-value	0.383	0.227	0.173
		Pooled		
	SD of control group	649	624	624
	SD of treatment group	661	649	661
	F statistic	0.982	0.962	0.944
	p-value	0.533	0.555	0.581

Note: H_0: F = 1; H_a : F > 1

*No-till with cover crop (NTCC) is considered the treatment and is compared to no-till without cover crop (NTNC), which is considered to be a control.

†NTNC is considered the treatment and is compared to the control of conventional tillage without cover crop (CTNC).

‡NTCC is considered the treatment and is compared to the control of CTNC.

there were no statistically significant changes in relative variation.

Regression Beta Coefficient. The analysis of relative volatility using OLS coefficients yielded interesting results, which are presented in table 6. Additionally, relative volatility is plotted over time in figures 1 and 2. For corn, the NTCC versus NTNC comparison (NTCC regressed on NTNC) yielded a coefficient of 0.952 (p = 0.363). For the NTNC versus CTNC comparison (NTNC regressed on CTNC) the coefficient was 0.702 (p = 0.135). Finally, the NTCC versus CTNC (NTCC regressed on CTNC) resulted in a coefficient of 0.846 (p = 0.125). While none of these coefficients were statistically different from 1 at the 10% level, the two comparisons involving CTNC as a control had relatively low p-values. The lack of statistical significance may have been due to the small number of observations used in the regressions. The data covered nine years, but because we used first differences, only eight observations were available to use.

For soybeans, the NTCC versus NTNC comparison (NTCC regressed on NTNC) yielded a coefficient of 0.785 (p = 0.161). For the NTNC versus CTNC comparison (NTNC regressed on CTNC), the coefficient was 0.684 (p = 0.142). Neither of these coefficients was statistically significant at the 10% level. However, the p-values were low enough to take notice. Finally, the NTCC versus CTNC (NTCC regressed on CTNC) resulted in a coefficient of 0.736 (p = 0.023). This coefficient implied that NTCC had only 73.6% of the yield volatility of the CTNC group, and the result was significant at the 5% level. The results of this analysis confirmed that there may have been differences in yield variability that were not shown in simple measures like standard deviation.

Discussion of the Results. There was evidence in our data that no-till may have had a beneficial impact on temporal average yield stability for corn in a corn–soybean rotation. This result was robust across multiple statistical tests. Cover crops were also consistently associated with lower spatial variation in corn, across multiple statistical tests. This result was true for NTCC compared to NTNC as well as when compared to CTNC. It is important to note that this particular result is specifically for corn yields in a corn–soybean rotation, using a no-till system with cover crops.

The analysis of relative changes using OLS regression showed that NTNC and NTCC reduced temporal yield volatility in corn, although the coefficients were not statistically significant. In soybeans, NTCC was less volatile than NTNC, NTNC was less volatile than CTNC, and NTCC was also less volatile than CTNC. However, only the last comparison was statistically significant. These results were in contrast to the results of the earlier tests for differences in variation. We consider year over year changes to be more representative of the uncertainty faced by farmers than the more broad measures on variation such as standard deviation or CV. This underlying difference makes the regression beta coefficient methodology unique and useful in analyses of yield risk. However, this method may be better suited for studies with data over relatively long periods of time, to provide more yearly observations and thus more statistical power. Because it essentially measures correlation, this method also lends itself to controlled trials rather than observational yield data.

The specific mechanisms by which soil conservation practices such as no-till and

Table 4
Levene's test results.

Crop	Statistic	Cover crops*	No-till without cover crops†	No-till with cover crops‡
Corn		Temporal		
	Mean abs. dev. of control group	1,004	1,796	1,796
	Mean abs. dev. of treatment group	1,341	1,004	1,341
	Levene's statistic	2.324	3.521	0.638
	p-value	0.142	0.070	0.433
		Spatial		
	Mean abs. dev. of control group	989	723	723
	Mean abs. dev. of treatment group	319	989	319
	Levene's statistic	12.220	2.532	5.558
	p-value	0.002	0.122	0.028
		Pooled		
	Mean abs. dev. of control group	1,405	1,671	1,671
	Mean abs. dev. of treatment group	1,380	1,405	1,380
	Levene's statistic	0.017	1.670	1.524
	p-value	0.896	0.199	0.220
Soybeans		Temporal		
	Mean abs. dev. of control group	500	397	397
	Mean abs. dev. of treatment group	487	500	487
	Levene's statistic	0.020	1.798	1.188
	p-value	0.888	0.190	0.288
		Spatial		
	Mean abs. dev. of control group	244	300	300
	Mean abs. dev. of treatment group	222	244	222
	Levene's statistic	0.079	0.569	0.731
	p-value	0.781	0.457	0.402
		Pooled		
	Mean abs. dev. of control group	518	519	519
	Mean abs. dev. of treatment group	518	518	518
	Levene's statistic	0.000	0.000	0.000
	p-value	0.996	0.998	0.994

Note: H_0: mean abs. dev. equal; H_a: mean abs. dev. not equal.

*No-till with cover crop (NTCC) is considered the treatment and is compared to no-till without cover crop (NTNC), which is considered to be a control.

†NTNC is considered the treatment and is compared to the control of conventional tillage without cover crop (CTNC).

‡NTCC is considered the treatment and is compared to the control of CTNC.

cover crops may impact yield variance are somewhat uncertain. However, soil health can help crops be more resilient to adverse weather conditions. Both no-till and cover crops provide numerous soil health benefits including managing and conserving soil moisture as well as moderating soil temperature (Blanco-Canqui et al. 2015; Gozubuyuk et al. 2015). Water availability in the soil, as well as temperature stress during flowering, explains a large proportion of yield variation (Hammac et al. 2017). Thus, soil conservation practices such as no-till and cover crops may help reduce the impact of extreme weather on crop yields.

Economic Significance of the Results. From the results of this study, the soil conservation practice of no-till reduced temporal variability while not having a significant impact on the mean corn yield. Further, including cover crops with no-till in the NTCC group reduced the spatial variation of corn yields when compared to both NTNC and CTNC, with no significant effect on the mean. This combination of reduced variability and constant mean implies that these conservation cropping systems may be risk-dominant over conventional systems under certain conditions. Risk dominance means one investment is comparatively more attractive than another if it has an equal or higher average return, but less variability (Barry and Ellinger 2012). If one farming system is risk-dominant over another, then the decision maker should choose the first so long as they have risk-averse preferences.

The results of this study may also be of interest to those who perform the analysis to set crop insurance premiums. Based on the results of this analysis, lower crop insurance premiums might be justified for those who use soil conservation practices. Policy makers may also be interested in these results and similar future research since lower crop insurance premiums could also be used as an incentive for the adoption of soil conservation practices.

Summary and Conclusions

In this study, temporal yield variability in corn was reduced in NTNC plots, while mean yields remained the same. This was likely due to improved soil qualities that help corn be more resilient to yearly adverse weather conditions. Spatial yield variation in corn was reduced within the NTCC group when compared to NTNC and CTNC groups. Reductions in spatial variation (i.e., yield uniformity across the field) may be a result of improved resiliency of crops to adverse soil, drainage, or other site-specific issues.

The analysis of volatility using regression beta coefficients showed that plots treated with NTNC and NTCC reduced temporal yield volatility in corn, although the coefficients were not statistically significant. In soybeans, the NTCC plots were less volatile than NTNC, NTNC was less volatile than CTNC, and accordingly, NTCC was also less volatile than CTNC. However, only the last comparison was statistically significant. Year-to-year changes used in this analysis may be more representative of the uncertainty faced by farmers compared to other metrics, like standard deviation or CV. Consequently, the regression beta coefficient methodology is both unique and useful in analyses of yield risk. This method should be considered for use when analyzing long-term crop yield data in controlled studies.

Based on the results of this research, we conclude that no-till and cover crops may provide value in terms of risk management.

Table 5
Coefficients of variation and difference test results.

Crop	Statistic	Cover crops*	No-till without cover crops†	No-till with cover crops‡
Corn		Temporal		
	CV control (%)	11.8	17.8	17.8
	CV treatment (%)	15.4	11.8	15.4
	Chi-square statistic	0.721	2.433	0.191
	p-value	0.396	0.119	0.662
		Spatial		
	CV control (%)	9.9	7.5	7.5
	CV treatment (%)	3.7	9.9	3.7
	Chi-square statistic	5.700	1.171	3.348
	p-value	0.017	0.279	0.067
		Pooled		
	CV control (%)	14.7	18.0	18.0
	CV treatment (%)	14.1	14.7	14.1
	Chi-square statistic	0.087	2.014	2.265
	p-value	0.767	0.156	0.132
Soybeans		Temporal		
	CV control (%)	20.8	16.6	16.6
	CV treatment (%)	19.3	20.8	19.3
	Chi-square statistic	0.046	0.692	0.214
	p-value	0.831	0.405	0.644
		Spatial		
	CV control (%)	9.7	11.9	11.9
	CV treatment (%)	8.6	9.7	8.6
	Chi-square statistic	0.136	0.627	0.893
	p-value	0.712	0.429	0.345
		Pooled		
	CV control (%)	20.1	19.3	19.3
	CV treatment (%)	20.0	20.1	20.0
	Chi-square statistic	0.001	0.076	0.047
	p-value	0.976	0.783	0.829

Note: H_0: CV equal; H_a: CV not equal.

*No-till with cover crop (NTCC) is considered the treatment and is compared to no-till without cover crop (NTNC), which is considered to be a control.

†NTNC is considered the treatment and is compared to the control of conventional till without cover crop (CTNC).

‡NTCC is considered the treatment and is compared to the control of CTNC.

These findings are pertinent to farmers for management purposes, crop insurance providers to set premiums, and policy makers to structure conservation incentive programs.

We recognize that this research is on a limited set of data. However, since we are not aware of similar work, we believe the methods and results should be in the literature and available to other researchers. Perhaps this analysis will encourage longer-term studies using our beta coefficient methodology. Other researchers may wish to use our approach in separating spatial and temporal variation on larger samples. Additional research is also needed to determine the mechanisms by which conservation practices may affect yield variability.

Acknowledgements

The authors are grateful for funding from the USDA Natural Resources Conservation grant "Service Soil Health Economics: Measuring and Validating the Economic Benefits and Costs of Soil Health Practices," 69-3A75-16-007, which provided partial funding for this research. The authors are solely responsible for the contents. Co-author Dr. Wallace E. "Wally" Tyner passed away on August 17, 2019. In recognition of his passing, the remaining authors gratefully acknowledge Dr. Tyner's contribution to this paper in addition to his many contributions toward sustainable agriculture systems.

References

Banik, S.K., B.M. Golam, and D. Sharma. 2012. Testing the population coefficient of variation. Journal of Modern Applied Statistical Methods 11:325-335.

Barry, P.J., and P.N. Ellinger. 2012. Risk Management. *In* Financial Management in Agriculture, ed V. Anthony. Upper Saddle River, NJ: Prentice Hall.

Belfry, K.D., C. Trueman, and R.J. Vyn. 2017. Winter cover crops on processing tomato yield, quality, pest pressure, nitrogen availability, and profit margins. PLoS One 12(7):e0180500.

Black, F. 1972. Capital market rquilibrium with testricted borrowing. The Journal of Business 45(3):444-455.

Blanco-Canqui, H., T.M. Shaver, J. Lindquist, C. Shapiro, R.W. Elmore, C. Francis, and G. Hergert. 2015. Cover crops and ecosystem services: Insights from studies in temperate soils. Agronomy Journal 107:2449-2474.

Blume, M.E., and I. Friend. 1973. A new look at the capital asset pricing model. The Journal of Finance 28:19-34.

Box, G.E.P. 1953. Non-normality and tests on variances. Biometrika 40(3/4):318-335.

Brown, M.B., and A.B. Forsythe. 1974. Robust tests for the equality of variances. Journal of the American Statistical Association 69:364-367.

Burgess, M. 2014. Tillage of cover crops affects soil water, nitrogen, and wheat yield components. Agronomy Journal 106:1497-1509.

Chen, G.C., and R.R. Weil. 2010. Penetration of cover crop roots through compacted soils. Plant & Soil 331(1-2):31-44.

Chen, G.C., and R.R. Weil. 2011. Root growth and yield of maize as affected by soil compaction and cover crops. Soil & Tillage Research 117:17-27.

Dabney, S.M., J.A. Delgado, and D.W. Reeves. 2001. Using winter cover crops to improve soil and water quality. Communications in Soil Science and Plant Analysis 32:1221-1250.

D'Agostino, R.B., A. Belanger, and R.B. D'Agostino. 1990. A suggestion for using powerful and informative tests of normality. The American Statistician 44:316-321.

Daigh, A.L.M., W.A. Dick, M.J. Helmers, R. Lal, J.G. Lauer, E. Nafzigere, C.H. Pederson, J. Strock, M. Villamil, A. Mukherjee, and R.M. Cruse. 2018. Yields and yield stability of no-till and chisel-plow fields in the Midwestern US Corn Belt. Field Crops Research 218:243-253.

Doane, T.A., W.R. Horwath, J.P. Mitchell, J. Jackson, G. Miyao, and K. Brittan. 2009. Nitrogen supply from fertilizer and legume cover crop in the transition to no-tillage for irrigated row crops. Nutrient Cycling in Agroecosystems 85:253-262.

Feltz, C.J., and G.E. Miller. 1996. An asymptotic test for the equality of coefficients of variation from *k* populations. Statistics in Medicine 15(6):647-658.

Gaudin, A.C.M., T.N. Tolhurst, A.P. Ker, K. Janovicek, C. Tortora, R.C. Martin, and W. Deen 2015. Increasing crop diversity mitigates weather variations and improves yield stability. PLoS One 10:1-21.

Gozubuyuk, Z., U. Sahin, M.C. Adiguzel, I. Ozturk, and A. Celik. 2015. The influence of different tillage practices on water content of soil and crop yield in vetch–winter wheat rotation compared to fallow–winter wheat rotation in a high altitude and cool climate. Agricultural Water Management 160:84-97.

Table 6
Volatility beta coefficients and *t*-test results.

Crop	Statistic	Cover crops*	No-till without cover crops†	No-till with cover crops‡
Corn				
	Beta	0.952	0.702	0.846
	Standard error	0.152	0.205	0.102
	T statistic	−0.319	−1.451	−1.511
	p-value	0.363	0.135	0.125
Soybeans				
	Beta	0.785	0.684	0.736
	Standard error	0.165	0.225	0.098
	T statistic	−1.305	−1.407	−2.680
	p-value	0.161	0.142	0.023

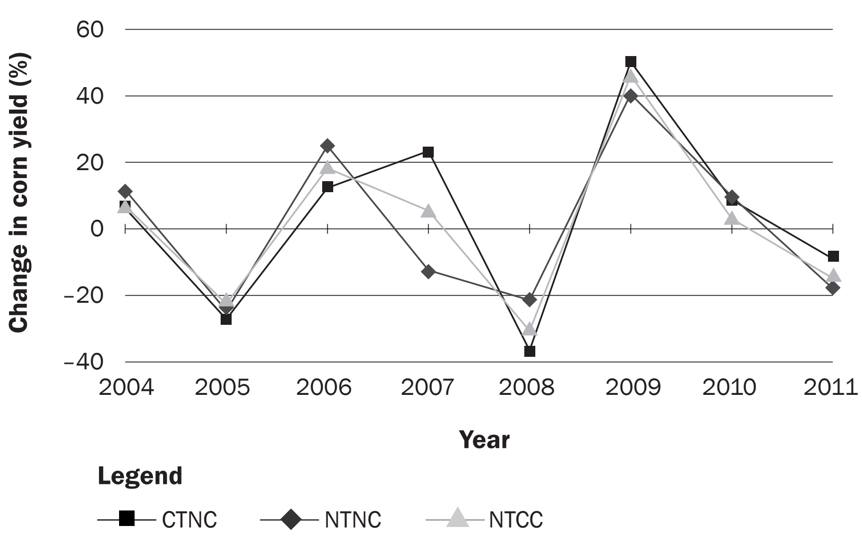
Notes: H_0: b = 1; H_a: b < 1

*No-till with cover crop (NTCC) is considered the treatment and is compared to no-till without cover crop (NTNC), which is considered to be a control.

†NTNC is considered the treatment and is compared to the control of conventional tillage without cover crop (CTNC).

‡NTCC is considered the treatment and is compared to the control of CTNC.

Figure 1
Relative yield volatility in corn. CTNC is conventional tillage and no cover crop, NTNC is no-till and no cover crop, and NTCC is no-till with a cover crop treatment.



Grover, K.K., H.D. Karsten, and G.W. Roth. 2009. Corn grain yields and yield stability in four long-term cropping systems. Agronomy Journal 101(4):940-946.

Hammac, W.A., T.M. Maaz, R.T. Koenig, I.C. Burke, and W.L. Pan. 2017. Water and temperature stresses impact Canola (*Brassica napus* L.) fatty acid, protein, and yield over nitrogen and sulfur. Journal of Agricultural and Food Chemistry 65(48):10429-10438.

Kaspar, T.C., and M.G. Bakker. 2015. Biomass production of 12 winter cereal cover crop cultivars and their effect on subsequent no-till corn yield. Journal of Soil and Water Conservation 70(6):353-364, doi: 10.2489/jswc.70.6.353.

Knapp, S., and M.G.A. van der Heijden. 2018. A global meta-analysis of yield stability in organic and conservation agriculture. Nature Communications 9:3632.

Koger, C.H., and K.N. Reddy. 2005. Effects of hairy vetch (*Vicia villosa*) cover crop and banded herbicides on weeds, grain yield, and economic returns in corn (*Zea mays*). Journal of Sustainable Agriculture 26(3):107-124.

Leslie, A.W., K.H. Wang, S.L.F. Meyer, S. Marahatta, and C.R.R. Hooks. 2017. Influence of cover crops on arthropods, free-living nematodes, and yield in a succeeding no-till soybean crop. Applied Soil Ecology 117:21-31.

Levene, H. 1960. Robust tests for equality of variances. *In* Contributions to Probability and Statistics: Essays in Honor of Harold Hotelling, ed. I. Olkin, 278–292. Palo Alto, CA: Stanford University Press.

Lira, S.M., and W.E. Tyner. 2018. Patterns of cover crop use, adoption, and impacts among Indiana farmers. Journal of Crop Improvement 32:373-386.

Marcillo, G.S., and F.E. Miguez. 2017. Corn yield response to winter cover crops: An updated meta-analysis. Journal of Soil and Water Conservation 72(3):226-240, doi: 10.2489/jswc.72.3.226.

Markowski, C.A., and E.P. Markowski. 1990. Conditions for the effectiveness of a preliminary test of variance. The American Statistician 44:322-326.

McCracken, D.V., M.S. Smith, J.H. Grove, C.T. MacKown, and R.L. Blevins. 1994. Nitrate leaching as influenced by cover cropping and nitrogen source. Soil Science Society of America Journal 58(5):1476-1483.

McVay, K.A., D.E. Radcliffe, and W.L. Hargrove. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. Soil Science Society of America Journal 53(6):1856-1862.

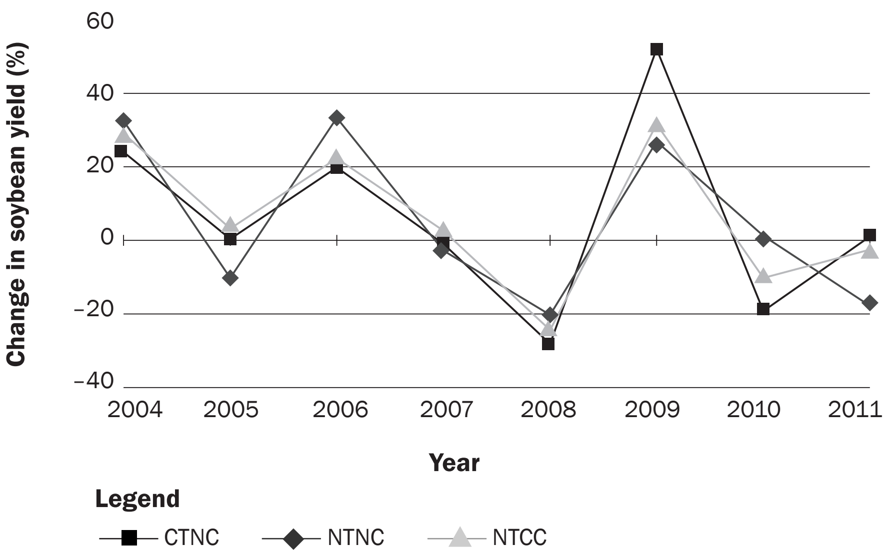
Muñoz, J.D., J.P. Steibel, S. Snapp, and A.N. Kravchenko. 2014. Cover crop effect on corn growth and yield as influenced by topography. Agriculture, Ecosystems and Environment 189:229-239.

Nkongolo, N.V., and S.I. Haruna. 2015. Effect of tillage and cover crop on corn and soybean yields in a silt loam soil. Procedia Environmental Sciences 29:15-16.

Pedersen, P., and J.G. Lauer. 2003. Soybean agronomic response to management systems in the upper Midwest. Agronomy Journal 95(5):1146-1151.

Figure 2

Relative yield volatility in soybeans. CTNC is conventional tillage and no cover crop, NTNC is no-till and no cover crop, and NTCC is no-till with a cover crop treatment.



Pittelkow, C.M., B.A. Linquist, M.E. Lundy, X.Q. Liang, K.J. van Groenigen, J. Lee, N. van Gestel, J. Six, R.T. Venterea, and C. van Kessel. 2015. When does no-till yield more? A global meta-analysis. Field Crops Research 183:156-168.

Reddy, K.N. 2001. Effects of cereal and legume cover crop residues on weeds, yield, and net return in soybean (*Glycine max*). Weed Technology 15(4):660-668.

Smith, R.G., F.D. Menalled, and G.P. Robertson. 2007. Temporal yield variability under conventional and alternative management systems. Agronomy Journal 99(6):1629-1635.

Sun, F., M.L. Roderick, G.D. Farquhar, W.H. Lim, Y.Q. Zhang, N. Bennett, and S.H. Roxburgh. 2010. Partitioning the variance between space and time. Geophysical Research Letters 37:L12704.

Tonitto, C., M.B. David, and L.E. Drinkwater. 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. Agriculture, Ecosystems and Environment 112(1):58-72.

Varvel, G.E. 2000. Crop rotation and nitrogen effects on normalized grain yields in a long term study. Agronomy Journal 92(5):938-941.

Wilson, G.F., R. Lal, and B.N. Okigbo. 1982. Effects of cover crops on soil structure and on yield of subsequent arable crops grown under strip tillage on an eroded Alfisol. Soil & Tillage Research 2:233-250.

Wooldridge, J.M. 2016. Basic regression analysis with time series data. *In* Introductory Econometrics: A Modern Approach, 3rd ed., 342-379. Boston, MA: Cengage Learning.

Zhu, J.C., C.J. Gantzer, S.H. Anderson, E.E. Alberts, and P.R. Beuselinck. 1989. Runoff, soil, and dissolved nutrient losses from no-till soybean with winter cover crops. Soil Science Society of America Journal 53:1210-1214.