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ECONOMICS AND MARKETING

Influence of Cover Crop and Tillage Systems on Optimal Nitrogen Rate for Tennessee Cotton Considering Risk

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ABSTRACT

Upland cotton fields have minimal amounts of crop residue after harvest to cover the soil surface, which exposes the soil and increases the risk of soil erosion. This is especially challenging in the Mid-South U.S. where cotton is commonly grown on sandy or silty soils that are naturally prone to soil erosion. Winter cover crops and no-till planting are two practices that can mitigate soil erosion by increasing soil surface biomass. However, there is uncertainty on how these practices can impact producers' profits and risk. We determine the influence of four winter cover crops and two tillage systems on the optimal nitrogen rates, cotton yields, and net returns for risk-neutral to risk-averse cotton producers. Data came from a long-term nitrogen (N), tillage, and cover crop experiment in Tennessee. A flexible moment model was used to estimate the impact of risk on the decision to plant cover crops and tillage system. Planting cover crops on till planted cotton decreased optimal N fertilizer rate as well as optimal yields. However, the impact of cover crops on optimal N rate, yields, net returns for no-till planting depends on the cover crop species. A risk-neutral producer would select a till and no cover crop system, but as risk aversion increases, no-till planting with no cover crop system was optimal. Results improve the understanding into the profitability and risk of using cover crops and no-till, which will assist producers in making optimal production systems.

The amount of crop residue that remains on soil surface after upland cotton (*Gossypium hirsutum* L.) harvest is small relative to other row crops (Nyakatawa et al., 2001). This means that cotton fields have higher levels of bare soil remaining after harvest, which can increase the likelihood of water-induced soil erosion (Nyakatawa et al., 2001). This issue is especially relevant in the Mid-South U.S. where cotton is typically grown on sandy and silty soils that are naturally prone to soil erosion (Boquet et al., 2004; Bradley and Tyler, 1996). Thus, using best management practices to reduce soil erosion in Mid-South cotton production while not reducing profitability or increasing risk exposure is a major challenge.

Winter cover crops and no-tillage planting (referred to as no-till hereafter) are practices that can reduce soil erosion in cotton production by increasing plant residue on soil surface (Boquet et al., 2004; Foote et al., 2015; Hanks and Martin, 2007; Kornecki and Price, 2010; Kornecki et al., 2015; Mbuthia et al., 2015; Richter et al., 2007; Tewolde et al., 2015; Zablotowicz et al., 2011). Research has shown that these practices also can increase organic matter, provide nutrients, improve moisture holding capacity, and reduce water evaporation of soil (Karlen et al., 2013; Mbuthia et al., 2015; Richter et al., 2007; Snapp et al., 2005; Triplett and Dick, 2008). However, adoption of cover crops and no-till remains limited across the U.S. (Wade et al., 2015). Less than 2% of all U.S. cropland (2.75 million ha) was planted with cover crops in 2011, and no-till planting was reported on 40% of U.S. cropland (36 million ha) in 2011 (Wade et al., 2015). A possible explanation for the limited use of cover crops and no-till might result from the inconsistency in findings on the profitability and risk-management benefits from adopting these practices (Boquet et al., 2004; Dunn et al., 2016; Snapp et al., 2005; Triplett and Dick, 2008).

Studies have found that legume cover crops can reduce nitrogen (N) fertilizer costs relative to not using cover crop or non-legume cover crops (Foote et al., 2015; Hanks and Martin, 2007; Larson et al., 2001b; Varco et al., 1999). However, net returns from planting legume and non-legume cover crops have been reported to be lower (Hanks and Martin, 2007; Larson et al., 2001b), higher (Varco et al., 1999), or equivalent (Foote et al., 2015) to net returns without cover crops. Similarly, no-till can generate higher net returns than conventional tillage (referred to as till here-

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after) planting (Hanks and Martin, 2007) and lower net returns than till planting (Larson et al., 2001b). Several meta-analyses of no-till studies have been conducted and concluded the profitability of no-till to be unclear (Toliver et al., 2012; Triplett and Dick, 2008).

Additionally, there have been studies that report planting cover crops and no-till planting can reduce yield variability or production risk in cotton production (Jaenicke et al., 2003; Larson et al., 2001a). Larson et al. (2001a) considered yield variance in determining optimal N fertilizer rates, yields, and net returns for cotton production under different cover crop and tillage systems. They found optimal N rates and yields varied across cover crop and till systems and by risk preferences. Not planting a cover crop was risk efficient under till planting, but if the producer used no-till planting, using hairy vetch as the cover crop was risk efficient when the producer was highly risk averse. Overall, till planting with no cover crop was preferred across all risk-preference levels, showing no risk-management benefits from using cover crops or no-till. However, Allen and Borchers (2016) concluded that higher rental rates for no-till land than till land indicated no-till planting could reduce risk, making land more valuable. Thus, impacts of cover crops and no-till on risk are unclear.

Although these studies provide insights into the profitability and risk associated with cover crops and no-till, a shortcoming of these studies is the use of short-term experiment data. Long-term experiments are vital for measuring the effects of cover crops and no-till on soils, crop yields, input use, and profitability, because most of the benefits of these practices such as increased soil organic matter are realized after many years of continuous use (Boquet et al., 2004; Karlen et al., 2013; Richter et al., 2007). Thus, analyzing the profitability and risk associated with cover crops and no-till production using a long-term experiment would make a unique contribution to the literature.

The objective of this research was to determine the impact of four winter cover crop treatments (no cover crop, hairy vetch, winter wheat, and crimson clover) and two tillage (no-till and till) systems on optimal N rates, yield, and certainty equivalents (CE) for risk-neutral and risk-averse cotton producers in Tennessee. Data are from a long-term (29-yr) cotton fertilizer, tillage, and cover crop experiment in West Tennessee. The aim of this research is to help producers improve production decisions, by first selecting the risk-efficient N application rate for different cover crops and tillage systems, and then identifying the risk-efficient production practice of different cover crops and tillage systems.

MATERIALS AND METHODS

Data. Data on cotton lint yield response to N from 1981 to 2012 were obtained from the West Tennessee Research and Education Center in Jackson, TN (35.63°N; 88.85°W). Cotton was grown on a Memphis silt loam (fine-silty, mixed, active, thermic Typic Hapluadalf), which is a deep, well-drained, moderately permeable soil formed in thick (1.5 m) loess deposits (USDA-National Resource Conservation Service, 2002). The Memphis series soils are typical soil conditions for cotton production in Tennessee.

The experimental design was a randomized complete block with split-plots and four replications. N fertilization treatment varied in the main plots, whereas cover crop treatment and tillage treatment varied in the split plots. N fertilizer treatment of 0, 34, 67, or 101 kg N ha^{-1} were randomly assigned to plots. Ammonium nitrate (340 g N kg^{-1}) was hand broadcasted at planting. The N plots were split vertically and randomly assigned no cover (native vegetation), winter wheat, hairy vetch, or crimson clover. The cover crop plots were vertically split again and randomly assigned no-till or till treatments. Final plot size for each treatment combination was 4-m wide and 9-m long. The same N application rate, cover crop, and tillage treatment was applied annually to each plot in each year (Zhou et al., 2017). The annual phosphate rate was 101 kg ha^{-1} and the annual potassium rate was 101 kg ha^{-1}.

Continuous cotton was planted middle-to-late May each year. No-till plots received a burn-down application of generic glyphosate [*N*-(phosphonomethyl) glycine] and pyrithiobac sodium (sodium 2-chloro-6-[(4, 6-dimethoxy pyrimidin-2yl) thio] benzoate) to terminate the cover crops and weeds before planting. Till plots were disked twice before planting cotton. Average cotton population density ranged from 9 to 10 plants m^{-2} annually with 17.8-cm row spacing. Several cultivars were planted on the plots: 'Stoneville 825', 1984 to 1993; 'Deltapine 50', 1994 to 1995; 'Stoneville 132', 1996; 'Deltapine 50', 1997; 'Stoneville 474', 1998; 'Deltapine 425', 1999 to 2000; 'Deltapine 451', 2001 to 2006; and 'Phytogen', 2007 to 2012. The same cultivar was planted on all plots in each year.

Seed cotton was mechanically harvested from the two inside rows of each plot and ginned using a 1/5-scale gin at the West Tennessee Research and Education Center. Winter cover crops were established in October after each harvest. The seeding rates were 101 kg ha^{-1} for winter wheat, 22 kg ha^{-1} for hairy vetch, and 17 kg ha^{-1} for crimson clover. Previous studies have reported subsets of these data collected from 1984 to 2001 (Cochran et al., 2007; Jaenicke et al., 2003; Larson et al., 2001a, b). This study extends these studies by including a long-term dataset and conducts a risk analysis considering skewness or downside risk, which is unanticipated low outcomes such as crop failure (Antle, 1987).

Increasing trends in yield over time might have occurred due to changes in management practices or improved technology. For example, weeds were problematic early in the experiment and pH levels declined until 1995 (Cochran et al., 2007). This resulted in yields decreasing from 1984 to 1995. However, after 1995, lint yields began to increase most likely due to improved weed management and the use of glyphosate-resistant cotton varieties. Failure to control for this trend in the data would results in biased results. Therefore, cotton lint yields were tested for a deterministic time trend using a quadratic time-response function. A time trend was present in the data and was corrected using the M estimator (Huber, 1973), an accepted approach to adjust for the effects of time trends in yield (Boyer et al., 2015a; Woodard et al., 2011; Zhou et al., 2017). We note that detrending these yield data could mask yield gains from soil health improvements due to cover crops and tillage system. Table 1 displays the detrended average cotton yield by N fertilizer rate, cover crop, and tillage system.

Table 1. Average Cotton Lint Yields (kg ha^{-1}) by Winter Cover Crop, Tillage System, and N Application Rate (kg ha^{-1}) from 1984 to 2012

N Rate (kg ha^{-1})	No Cover	Winter Wheat	Hairy Vetch	Crimson Clover
		Till		
0	**813**	**742**	**959**	**912**
34	**952**	**921**	**1056**	**965**
67	**1040**	**1024**	**1030**	**920**
101	**1092**	**994**	**1001**	**1038**
		No-Till		
0	**688**	**694**	**971**	**939**
34	**894**	**926**	**1050**	**1008**
67	**1035**	**1039**	**1012**	**1013**
101	**992**	**1037**	**945**	**1000**

Economic Model. Partial budgeting was used to calculate the net returns of different cover crop and tillage systems for upland cotton. Machinery, chemical, and cover-crop seed costs vary across these systems along with optimal N fertilizer rates. Reduction in the cost of N fertilizer resulting from using a cover crop is an important factor in determining the profitability of covers crops. Expected net returns are defined as

$$E(\pi_{ij}) = p^c E(y_{ij}) - p^N N_{ij} - c_i - w_j \qquad \text{(Eq. 1)}$$

where $E(\pi_{ij})$ is the producers' expected returns (\$ ha^{-1}) for cotton grown following cover crop i under tillage system j; p^c is the price of cotton lint (\$ kg^{-1}); $E(y_{ij})$ is the expected lint yield (kg ha^{-1}); p^N is the cost of N fertilizer (\$ kg^{-1}); N is the amount of N fertilizer applied to cotton (kg ha^{-1}); c_i is the cost of establishing the cover crop (\$ ha^{-1}); and w_j is the fixed production cost for each tillage practice (\$ ha^{-1}). A risk-neutral producer would select the tillage system, cover crop species, and N fertilizer rate to maximize expected returns (Nicholson, 2005).

Average annual prices of N (\$ kg^{-1}) and cotton lint (\$ kg^{-1}) from 1981 to 2012 were used in a partial budget to calculate net returns. Nominal prices were converted to reflect real 2012 prices using the Federal Reserve implicit price deflator (U.S. Bureau of Economic Analysis, 2015). From 1981 to 2012, the average annual real N price was \$1.08 kg^{-1} (USDA ERS, 2013), and the average annual real cotton lint price was \$1.82 kg^{-1} (USDA ERS, 2014).

Production costs for each combination of cover crop and tillage system was separated into the cost of establishing a cover crop and the production costs associated with preparing the field using no-till or till planting. Cover-crop seed prices were collected from 2006 to 2012 through personal communication with the Tennessee Farmer Cooperative and adjusted to 2012 dollars. The real average price of cover-crop seed was \$0.50 kg^{-1} for winter wheat, \$3.56 kg^{-1} for hairy vetch, and \$2.58 kg^{-1} for crimson clover. The total cost of seed, machinery, inputs, and labor costs for establishing the cover crop were estimated to be \$106.27 ha^{-1} for winter wheat, \$130.02 ha^{-1} for hairy vetch, and \$92.87 ha^{-1} for crimson clover. For no-tillage, the cost of a burn-down herbicide application was \$47.45 ha^{-1} and the cost of preparing the seedbed for till cotton was \$93.17 ha^{-1} (University of Tennessee Agricultural and Resource Economics Department, 2016).

Therefore, cover crops increase production costs through seed, machinery, labor, and other costs incurred to establish and then kill the cover crop. To recuperate the cover-crop costs, additional revenue through higher cash-crop yields are needed or the use of a legume cover crop that reduces N fertilizer costs by adding N in the soil. No-till can reduce machinery and fuel costs but can increase chemical costs for producers relative to till. Changes in expected yields determine the profitability of no-till because the cost of production for no-till and till are often similar (Toliver et al., 2012; Triplett and Dick, 2008).

Weather, management practices, diseases, and other unobserved factors introduce variability in expected net returns. To introduce this risk into the producer's decision-making framework, we applied a standard risk-modeling framework for agricultural producers (Antle, 1987). This framework assumes that the preferences for a risk-averse producer are characterized by a utility function $U(\pi_{ij}, r)$, where r is the producer's risk-aversion level. Utility measures an individual's preference for a cover crop and tillage production system. The utility a producer receives from maximizing profit is converted to monetary terms by inverting the utility function into a certainty equivalent (CE). The CE is the guaranteed return that would make a producer indifferent between the risk-free return and a risky decision. For each cover crop and tillage system, the CE was calculated as the expected net returns (Equation 1) less the amount the producer would pay to eliminate risk (i.e., risk premium).

Risk-averse producers apply N fertilizer at a rate that maximizes their CE:

$$\max_{N_{ij}} \mathrm{CE}_{ij} = E(\pi_{ij}) - \mathrm{RP}_{ij} \qquad \text{(Eq. 2)}$$

where CE_{ij} is the producers' anticipated CE (\$ ha^{-1}); and RP_{ij} is the producer's risk premium (\$ ha^{-1}) (Nicholson, 2005). If a producer is risk neutral, the risk premium is zero and the maximum CE (Equation 2) equals maximum net returns (Equation 1) (Nicholson, 2005).

Previous research on the effects of risk on optimal N rates for cotton under various cover crop and tillage practices incorporated yield variance in the economic framework, but did not consider the effects of the third moment, skewness (or downside risk) (Larson et al., 2001a). Antle (1987) proposed an empirical model that included variance and skewness into risk analysis. Applying Antle's (1987) approach to determine optimal N rates for cotton production under various cover crop and tillage systems is a novel application of this model and extends our knowledge on the effectiveness of using cover crops and no-tillage for managing production risk.

Following Antle (1987), the risk premium was calculated considering the variance and skewness of the distribution of net returns, $f(\pi_{ij}, \varepsilon_{ij})$, where ε_{ij} is random error. Higher order moments of the net returns distribution are the variance, $\varepsilon_{ij}^2(\pi_{ij}) = E\{[f(\pi_{ij}, \varepsilon_{ij}) - E(\pi_{ij})]^2\}$, and skewness $\varepsilon_{ij}^3(\pi_{ij}) = E\{[f(\pi_{ij}, \varepsilon_{ij}) - E(\pi_{ij})]^3\}$. A power utility function was used to characterize cotton producer risk preferences, which has been used in the literature to simultaneously consider variance and skewness in calculating risk premiums (Di Falco and Chavas, 2006, 2009). The power utility function is expressed as:

$$U(\pi_{ij}) = \frac{\pi_{ij}^{1-r}}{1-r} \qquad \text{(Eq. 3)}$$

This form of utility is favorable because its third differentiation (with respect to net returns) implies aversion to downside risk ($\partial^3 U/\partial^3 \pi_{ij} > 0$) (Menezes et al., 1980). Following Antle (1987), the producer's risk premium is derived from the power utility function using a third-degree Taylor series expansion:

$$\mathrm{RP}_{ij} = \frac{\delta_{1ij}\varepsilon^2(\pi_{ij})}{2} + \frac{\delta_{2ij}\varepsilon^3(\pi_{ij})}{6} \qquad \text{(Eq. 4)}$$

where δ_{1ij} is the Arrow-Pratt measure of absolute risk-aversion coefficient, which is calculated as $\delta_{1ij} = -[\partial^2 U(\pi_{ij})/\partial^2 \pi_{ij}]/[\partial U(\pi_{ij})/\partial \pi_{ij}] = r/\pi_{ij}$; and δ_{2ij} is the downside risk-aversion coefficient, calculated as $\delta_{2ij} = -[\partial^3 U(\pi_{ij})/\partial^3 \pi_{ij}]/[\partial U(\pi_{ij})/\partial \pi_{ij}] = -(r^2 - r)/\pi_{ij}^2$ (Di Falco and Chavas, 2006, 2009). The Arrow-Pratt and downside risk-aversion coefficient characterizes the producer's aversion to variance and skewness, respectively (Antle, 1987). Equation 4 indicates that the risk premium will increase as variance increases and skewness decreases (increase in downside risk).

Optimal N rates were determined for each combination of the winter cover crop and tillage systems at different risk-preferences levels, $N_{ij}^*(r)$. As suggested in previous studies (Di Falco and Chavas, 2006, 2009; Finger, 2013), optimal N application rates, $N_{ij}^*(r)$, were calculated for risk-preference levels of $r = 0$, $r = 1$, $r = 2$, and $r = 3$, where $r = 0$ represents a risk-neutral producer, $r = 1$ represents a somewhat risk-averse producer, $r = 2$ represents a fairly risk-averse producer, and $r = 3$ represents a very risk-averse producer (Di Falco and Chavas, 2006, 2009; Finger, 2013).

Once optimal N rates were determined for the cover crop and tillage systems at each risk-preference level, optimal CEs, $CE_{ij}^{*}(r)$, were calculated by revising Equation 2 with optimal N rates. For a given risk-preference level, a producer would choose the cover crop and tillage system with the highest CE. Therefore, we can determine risk-efficient cover crop and tillage systems at different risk-preference levels while considering skewness.

Statistical Analysis. The first three moments of net returns distributions were estimated as a function of the N application rate. This study assumes a quadratic relationship between mean returns and N, and a linear relationship between both the variance and skewness of returns and the N application rate, which are similar to previous studies (Boyer et al., 2015b; Di Falco and Chavas, 2006). Expected net returns were estimated as:

$$\pi_{ijkt} = a_0 + a_1 N_{ijkt} + a_2 N_{ijkt}^2 + \varepsilon_{ijkt} \qquad \text{(Eq. 5)}$$

where π_{ijkt} is the net return (\$ ha^{-1}) for the kth (k = 1,…,4) N fertilizer rate in time t (t = 1,…,29); a_0, a_1, and a_2 are the parameters; N_{ijkt} is the N application rate (kg ha^{-1}); and $\varepsilon_{ijkt} \sim \left(0, \sigma_{\varepsilon_{ijkt}}^2\right)$ is an independent and identically distributed error term. Squaring the residuals of Equation 5, we obtain the variance equation:

$$\hat{\varepsilon}^2\left(\pi_{ijkt}\right) = \beta_0 + \beta_1 N_{ijkt} + \tau_{ijkt} \qquad \text{(Eq. 6)}$$

where β_0 and β_1 are parameters for the variance equation; and $\tau_{ijkt} \sim \left(0, \sigma_{\tau_{ijkt}}^2\right)$ is an independent and identically distributed error term. Similarly, the cube of the residuals from Equation 5 is the dependent variable of the skewness response to N:

$$\hat{\varepsilon}^3\left(\pi_{ijkt}\right) = c_0 + c_1 N_{ijkt} + v_{ijkt} \qquad \text{(Eq. 7)}$$

where c_0 and c_1 are parameters; and $v_{ijkt} \sim \left(0, \sigma_{v_{ijkt}}^2\right)$ is an independent and identically distributed error term. Both estimated variance and skewness are substituted into Equation 4 to estimate the risk premium. Equations 3 and 4 are used to find CE using Equation 2.

Feasible generalized least squares (FGLS) was used to obtain unbiased and efficient parameter estimates of the mean, variance, and skewness response to applied N rates (Boyer et al., 2015b; Di Falco and Chavas, 2009). The FGLS approach corrects for heteroskedasticity by reweighting the variance of Equations 5 to 7 to downweight the influence of outliers (Wooldridge, 2013). The models were estimated using the REG procedure in SAS 9.2 (SAS Institute, 2004).

In this study, we held prices constant. Any changes in the variance or skewness of net returns across N rates (Equations 6 and 7) are due to variation in cotton yields. Researchers have found that increasing N fertilizer rates increased downside risk (Boyer et al., 2015b; Di Falco and Chavas, 2006; Finger, 2013). Thus, we hypothesize the slope of Equation 6 will be positive, and the slope of Equation 7 will be negative.

RESULTS AND DISCUSSION

Parameter Estimates. Parameter estimates for the estimated mean net-return equations were significant with the expected signs for all cover crop and tillage systems, except for till cotton after crimson clover (Table 2). The positive linear and negative quadratic estimates suggest diminishing marginal returns to N fertilizer for all cover crop and tillage systems except till planting with crimson clover. Expected net returns for till cotton after crimson clover did not respond to N application.

Intercepts of the estimated variance equations were positive and significant at the 0.01 level. The slope coefficient in the variance equations was positive for all cover crop and tillage systems, and was significant for till cotton with no cover crop, till cotton with winter wheat cover crop, no-till cotton with no cover crop, no-till cotton with winter wheat cover crop, and no-till cotton with hairy vetch cover crop. The positive coefficient indicates that as N fertilizer increases the producers' risk exposure also increases, which matches with what Larson et al. (2001b) observed. N application did not have a significant effect on the variance of net returns for crimson clover under either tillage system or till cotton after hairy vetch.

Slope estimates for the estimated skewness equation were not significant for hairy vetch or crimson clover under both tillage systems, but their intercepts were significant. Thus, net returns for cotton grown after hairy vetch or crimson clover were negatively skewed, but skewness was unaffected by the N application rate. Conversely, estimated skewness slopes for cotton following no cover or winter wheat were negative and significant for both tillage systems, implying that exposure to downside risk increased as the N application rate increased. This is consistent with Boyer et al.'s (2015b) finding for corn production in Tennessee. They found that increased N fertilizer for corn production increased producers' downside risk.

Table 2. Parameter Estimates of the Mean, Variance, and Skewness Regression Equations by Winter Cover Crop and Tillage System

Parameter[Z, Y]	Till				No-Till			
	No Cover (n[X] = 920)	Winter Wheat (n= 584)	Hairy Vetch (n = 583)	Crimson Clover (n = 640)	No Cover (n = 538)	Winter Wheat (n = 584)	Hairy Vetch (n = 584)	Crimson Clover (n = 639)
					Mean			
Intercept (a_0)	1,295*** (27.659)[W]	1,170*** (29.721)	1,566*** (46.50)	1,501*** (39.87)	1,069*** (35.97)	1,085*** (31.13)	1,585*** (44.39)	1,522.48*** (39.79)
Slope (a_1)	7.545*** (1.673)	11.98*** (1.651)	4.52** (2.106)	-1.65 (1.936)	14.49*** (1.79)	14.67*** (1.64)	4.43** (2.11)	3.38* (1.93)
Quadratic (a_2)	-0.036** (0.016)	-0.083*** (0.016)	-0.051** (0.019)	0.023 (0.018)	-0.097*** (0.018)	-0.094*** (0.017)	-0.062*** (0.021)	-0.034* (0.019)
R-squared	0.10	0.14	0.02	0.03	0.17	0.21	0.02	0.01
					Variance			
Intercept (β_0)	232,169*** (18,803)	137,725*** (16,118)	271,261*** (27,646)	257,554*** (23,878)	175,913*** (17,106)	149,124*** (18,513)	269,615*** (28,788)	260879*** (23,939)
Slope (β_1)	1,022.3*** (358)	1590.39*** (335)	351.60 (461)	639.34 (418.67)	1,246.58*** (346.41)	1,257*** (348.54)	837* (459.76)	641 (451.20)
R-squared	0.08	0.04	0.01	0.03	0.02	0.02	0.01	0.01
					Skewness			
Intercept (c_0)	33,030,219 (24,412,623)	-25,023,818 (17,208,468)	-64,754,641* (34,034,303)	-51,613,612* (29,058,441)	-4,612,862 (14,272,237)	-6,248,520 (14,416,194)	-59,444,422* (32,560,810)	-88,146,373*** (33,638,446)
Slope (c_1)	-1,714,419** (750,657)	-740,689* (403,907)	-423,531 (628,132)	-584,534 (591,878)	-1,573,917*** (457,893)	-1,588,418*** (447,046)	-751,831 (661,193)	-348,488 (664,025)
R-squared	0.06	0.05	0.01	0.01	0.02	0.02	0.01	0.01

[Z] Parameter estimates were corrected for heteroscedasticity using Feasible Generalized Least Squares.

[Y] Values followed by ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

[X] n is the number of observations used in the regression.

[W] standard errors are in parentheses.

Table 3. Optimal Nitrogen Application (kg ha^{-1}) and Lint Yield (kg ha^{-1}) by Winter Cover Crop and Tillage System

Risk Level[Z]	Till				No-Till			
	No Cover	Winter Wheat	Hairy Vetch	Crimson Clover	No Cover	Winter Wheat	Hairy Vetch	Crimson Clover
					Optimal Nitrogen Rate[Y]			
r **= 0**	106	73	44	0	74	77	36	50
r **= 1**	100	69	44	0	73	75	35	50
r **= 2**	93	66	44	0	69	72	33	50
r **= 3**	84	62	44	0	66	68	31	50
					Cotton Lint Yield			
r **= 0**	1095	1020	1048	926	1026	1051	1041	1018
r **= 1**	1091	1018	1048	926	1023	1049	1040	1018
r **= 2**	1084	1014	1048	926	1021	1046	1039	1018
r **= 3**	1073	1009	1048	926	1015	1041	1038	1018

[Z] *r* = 0 represents a risk-neutral producer, *r* = 1 represents a somewhat risk-averse producer, *r* = 2 represents a fairly risk-averse producer, and *r* = 3 represents a very risk-averse producer.

[Y] The price of cotton was assumed to be $1.82 kg^{-1} and the price of N was assumed to be $1.08 kg^{-1}.

Optimal N and Cotton Yield. Optimal N fertilizer rate was the highest for till cotton with no cover crop (Table 3). Planting a cover crop with till planting reduced the optimal N fertilizer rate, and the optimal N rate for till cotton after crimson clover was zero, indicating that the legume cover crop was able to capture enough N into the soil to meet the N needs for the cotton. Optimal N fertilizer rates decreased as risk aversion increased for cotton after no cover or winter wheat, demonstrating N fertilizer is a risk-increasing input. However, producer risk preferences had no effect on optimal N for cotton after hairy vetch and crimson clover under till planting. For all risk-preference levels, optimal till lint yields were highest for cotton after no cover crop and lowest for till cotton after crimson clover. We observed that optimal yields also decreased when cover crops were planted with till cotton. If the reduction in N fertilizer costs from planting a cover crop must be greater than the cost of planting a cover crop, then the cover crop provided a return in reduced N fertilizer savings that is greater than the cost of planting the cover crop.

For no-till, the highest optimal yields were realized for cotton after winter wheat and lowest for cotton followed by crimson clover. Legume cover crops reduced the optimal N rates relative to cotton after no cover crop with no-till, but optimal N rates for cotton after winter wheat were higher than no cover crop with no-till. Optimal N rates for no-till cotton after no cover crop, hairy vetch, and winter wheat decreased as risk-aversion increased. Optimal N rates for no-till cotton after crimson clover were not affected by producer risk preferences.

Overall, optimal lint yield and N rate was greatest for till cotton following no cover crop. Planting cover crops on till planted cotton resulted in a lower optimal N fertilizer rate as well as a decreased optimal yield. However, the impact of cover crops on no-till planting appears to depend on the cover crop species.

Certainty Equivalents. Till cotton after no cover crop maximized CE for risk-neutral (r = 0), somewhat risk-averse (r = 1), and fairly risk-averse (r = 2) preferences (Table 4). However, no-till cotton following no cover was preferred for producers with very risk-averse preferences (r = 3). This is different from Larson et al.'s (2001a) findings that till planting with no cover crop was preferred for all risk-aversion levels, which analyzed a 13-yr subset of the data used in this manuscript. We find from the 29-yr dataset that benefits from using no-till are available to producers but might take a long period of continuous no-till planting before the producers incur these benefits. Boquet et al. (2004) stated that inconsistent economic results likely are caused by studies using short-term datasets, and long-term datasets are needed to provide producers with robust conclusions on the profitability of using winter cover crops and no-till planting, which is confirmed by these findings. Assuming 30 to 40 harvests in a producer's career, the long-term use of no-till might be optimal on average for risk-averse producers; however, if producers switch to till planting, they might be better off using till planting the remainder of their career.

Table 4. Expected Returns, Certainty Equivalent, and Risk Premium (\$ ha^{-1}) by Winter Cover Crop and Tillage System

Risk Level[Z]	Till				No-Till			
	No Cover	Winter Wheat	Hairy Vetch	Crimson Clover	No Cover	Winter Wheat	Hairy Vetch	Crimson Clover
				Net Returns[Y]				
r = 0	1806	1611	1658	1522	1737	1685	1678	1658
r = 1	1806	1609	1658	1522	1735	1683	1678	1658
r = 2	1801	1606	1658	1522	1732	1680	1678	1658
r = 3	1789	1601	1658	1522	1727	1675	1678	1658
				Certainty Equivalent				
r = 0	1806	1611	1658	1522	1737	1685	1678	1658
r = 1	1695	1527	1569	1431	1648	1599	1581	1569
r = 2	1569	1438	1473	1332	1552	1497	1478	1470
r = 3	1433	1344	1366	1223	1446	1389	1369	1359
				Risk Premium				
r = 0	0	0	0	0	0	0	0	0
r = 1	111	84	89	91	86	86	96	89
r = 2	230	171	188	190	183	183	198	190
r = 3	358	257	292	299	284	287	306	299

[Z] **r = 0 represents a risk-neutral producer, r = 1 represents a somewhat risk-averse producer, r = 2 represents a fairly risk-averse producer, and r = 3 represents a very risk-averse producer.**

[Y] **The price of cotton was assumed to be \$1.82 kg^{-1} and the price of N was assumed to be \$1.08 kg^{-1}.**

Using a cover crop produced a lower CE than no cover for both no-till and till. The finding of an unfavorable risk and return tradeoff with cover crops is consistent with data indicating limited adoption of cover crops in Mid-South crop production (Wade et al., 2015). This also matches results from surveys showing producers are reluctant to use cover crops due to the perceived risk that these practices decrease yields (Arbuckle Jr. and Roesch-McNally, 2015; Baumgart-Gertz et al., 2012). Without financial assistance, producers could achieve a higher guaranteed return by not planting a winter cover crop. Of the cover crops examined in this study, we conclude that hairy vetch would be the preferred cover crop under till for all risk-preference levels and winter wheat would be the preferred cover crop under no-till for all risk-preference levels.

CONCLUSION

We determined the impact of four winter cover crop treatments and two tillage systems on optimal N rates, yields, and certainty equivalents for risk-neutral and risk-averse cotton producers in Tennessee. Expected net returns were calculated using partial budgeting, and a flexible moment-based model was used to estimate the impact of risk on the decision to plant cover crops and tillage system. Data on cotton lint yield response to N fertilizer were obtained from a long-term till and winter cover-crop experiment in Jackson, TN.

Economic research on cover crops and no-till production commonly use short-term datasets to determine the profitability and risk from using these practices. This has resulted in inconsistent economic findings. Therefore, analyzing the profitability and risk associated with cover crops and no-till production using a long-term dataset extends the literature. Results provide robust insight into the profitability and risk of using cover crops and no-till, which will assist producers in choosing the optimal production system.

Under till, using cover crops reduced the optimal N rate relative to not using a cover crop at all risk-preference levels. However, optimal yields were lower for till cotton with cover crops than when no cover crop was planted. Under no-till, legume cover crops reduced the optimal N rates relative to cotton after no cover crop, whereas optimal N rates for cotton after winter wheat were higher than no cover crop. A risk-neutral to fairly risk-averse producer maximized CEs by not planting cover crops and using till planting, but very risk-averse producers preferred no-till cotton following no winter cover crop. Thus, a risk-averse producer would prefer using no-till planting if they expect to use this practice continuously for many years. However, if they stop using no-till planting, till planting with no cover crop would be their optimal production. The economics benefits from using no-till appear to take many years of continuous use for a producer to receive them.

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