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Risk Effects of Alternative Winter Cover Crop, Tillage, and Nitrogen Fertilization Systems in Cotton Production

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ABSTRACT

A Just-Pope model was developed to assess tillage, nitrogen, weather, and pest effects on risk for cotton grown after alternative winter cover crops. Yield risk for cotton after hairy vetch was less than for cotton with no winter cover when no nitrogen fertilizer was used to supplement the vetch nitrogen. However, because cotton after vetch has a higher production cost, farmers growing conventionally tilled cotton may be slow to adopt because risk-return tradeoffs may be unacceptable under risk neutrality and risk aversion. For risk-averse farmers who have already adopted no tillage, cotton grown after hairy vetch is risk efficient.

Key Words: *cover crops, Just-Pope production function, risk, tillage.*

Many of the soils on which cotton is row-cropped in West Tennessee are highly erodible and subject to surface water and groundwater pollution (Bradley and Tyler). Tilled conventionally, cotton leaves minimal crop residue on the soil surface, thereby exacerbating soil erosion and nutrient runoff on erodible soils. For example, crop residues after planting averages 3 percent for cotton compared with 29 percent for corn (U.S. Department of Agriculture). To mitigate soil erosion and runoff problems, researchers at the University of Tennessee recommend farmers use winter cover crops and no tillage practices (Duck and Tyler). Cover crops and no tillage can benefit soils by reducing erosion, improving soil characteristics, and conserving soil nutrients (Meisinger et al.). Legume covers can provide nitrogen to the next crop and reduce nitrogen fertilizer requirements. Grass covers can immobilize excess nitrogen in the soil during winter and prevent nitrogen leaching into groundwater. Conservation practices such as no tillage and winter covers have not been as widely adopted in cotton as in other crops. In 1999, about 40 percent of cotton in Tennessee was managed using conservation tillage compared with 73 percent for soybeans and 82 percent for corn (Tennessee Department of Agriculture).

A number of management considerations may make no tillage and winter covers more risky for cotton production, thereby impeding their adoption by farmers (Meisinger et al.; Triplet, Dabney, and Siefker). Planting a winter cover crop increases cost of production because of outlays to establish the cover in the

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fall and kill it in the spring and because of changes in nitrogen fertilizer requirements. Cool and wet springs combined with no tillage and heavy crop residues may negatively impact cotton yields because of lower germination, slower plant growth, and reduced nutrient uptake. Winter cover crops also may reduce soil water reserves for the next crop. On the other hand, by increasing surface residue and improving soil water holding capacity over time, winter covers and no tillage may help preserve moisture during droughts.

Additionally, no tillage may cause stratification of nutrients near the soil surface, a problem that may decrease nutrient availability. Soil acidity may also stratify under no tillage, especially at high nitrogen fertilizer levels. Decaying winter cover crop residues can also tie up nutrients, making them less available to the growing crop. For the nitrogen-fixing winter covers, the release of legume nitrogen through decay of the cover is influenced by weather and may not be synchronized with peak nitrogen demand by the growing cotton crop. Finally, weed control is more difficult with no tillage and winter covers. These and other potential consequences of conservation practices on cotton may increase yield and net revenue variability.

Giesler, Paxton, and Millhollon found that a hairy vetch winter cover followed by cotton with no nitrogen fertilizer was risk efficient for a wide range of absolute risk aversion. However, the data for their study did not contain information on alternative tillage practices and had a limited number of nitrogen fertilizer levels. Other than the Giesler, Paxton, and Millhollon results, knowledge of how cover crops, tillage, and nitrogen fertilizer influence risk for cotton is limited. The objectives of this study are (*a*) to assess the effects of alternative winter cover crop, tillage, and nitrogen fertilization systems on yield risk in cotton and (*b*) to evaluate the risk and return tradeoffs among these systems.

Analytical Framework

A Just-Pope (1978 and 1979) econometric model was developed to evaluate the marginal risk effects of tillage and nitrogen fertilizer on cotton grown after three separate winter cover crops and a baseline no-winter-cover situation. The Just-Pope model has the following functional form:

$$(1) \qquad Y_t = f(\mathbf{X}_t, \beta) + h(\mathbf{Z}_t, \alpha)\epsilon_t,$$

where Y_t is cotton lint yield for cotton grown after one of the four winter cover crop alternatives, $\mathbf{X}_t$ and $\mathbf{Z}_t$ are matrices of explanatory variables, t is a year subscript, $\boldsymbol{\beta}$ and $\boldsymbol{\alpha}$ are parameter vectors, and ϵ_t is a random variable with mean zero. The production function, $f(\mathbf{X}_t, \boldsymbol{\beta})$, relates management variables to mean yields. The variance function, $h(\mathbf{Z}_t, \boldsymbol{\alpha})$, associates explanatory variables to the variance of yields.

Estimation of the variance of yields function provides a method for evaluating the marginal risk effects of tillage and nitrogen fertilizer in the presence of alternative winter cover crops. However, the agronomic literature indicates that cotton yield variability with winter cover crops and no tillage may also be influenced by weather and pest events (Meisinger et al.; Triplet, Dabney, and Siefker). Therefore, variance of lint yields was specified as a function of management, weather, and pests in this analysis. Explanatory variables in the Just-Pope model do not have to be identical between the mean and variance functions, so $\mathbf{X}_t$ need not equal $\mathbf{Z}_t$ (Smale et al.). The Just-Pope approach enables direct statistical testing of hypotheses about how management and growing environment factors interact to influence risk for cotton grown after alternative winter covers.

With the Just-Pope model, variance of the production function error term is assumed to be a function of the level of one or more inputs. This assumption, which can be tested, implies a model with multiplicative heteroscedasticity. The multiplicative heteroscedastic model for each winter cover was estimated using the three-step procedure outlined in Judge et al. (1985).

Data and Methods

Yield Data

Cotton yield data for 1981 through 1997 were obtained from a winter cover crop experiment at the West Tennessee Experiment Station, Jackson, TN. Tillage and nitrogen fertilizer were also varied in the study. The experimental design was a randomized complete block with split-plots and four replications per year. Nitrogen fertilizer was varied in the main plots with winter cover and tillage being varied in the split plots. The same plots received the same nitrogen fertilizer rate, cover crop, and tillage treatment each year.

Cotton was planted on conventional-tillage and no-tillage plots after winter wheat, hairy vetch, crimson clover, and no-winter-cover crop alternatives. A burn-down herbicide was used to kill the cover crop before planting cotton in the no tillage plots. Conventional tillage plots were disked to destroy the cover crop before planting. Winter covers were reestablished each season after cotton harvest. Broadcast ammonium nitrate was the nitrogen source applied after planting. Rates of nitrogen fertilizer applied to the plots were 0, 30, 60, and 90 lb/acre.

The purpose of the risk analysis was to evaluate temporal variation in yields and net revenues caused by weather and pests for alternative winter cover and tillage systems. Therefore, lint yields from the four replications for each treatment in each year were averaged to approximate the field level yields generally observed by farmers. From a risk perspective, farmers are usually most concerned with the impact of temporal variation on overall yields and profits for the field, and not whether those yields and profits were produced uniformly across the field or research plots (Lowenberg-DeBoer). In addition, the study started with rye and vetch-rye covers that were switched to winter wheat and crimson clover in the fourth year of the experiment. Therefore, the first three years of data from the experiment (1981–1983) were excluded, leaving a total of 448 observations (112 for each cover).

Two important events in the experiment complicated the analysis of the yield data. Researchers experienced increasing difficulty with controlling weeds over time. Pigweed was especially prevalent in the no tillage and legume winter cover plots. Researchers were better able to control pigweed with the availability of prythiobac sodium (Staple) herbicide in 1995. Researchers also conducted a lime recommendation study. After letting pH deteriorate by delaying the regular application of lime for several years, they split the plots and applied different lime rates—the full extension service recommended rate and half the recommended rate—in 1995. Declining soil pH may have negatively impacted yields over time, especially at the higher nitrogen fertilizer rates. Plots receiving half the recommended lime rate were excluded from this analysis.

Weather and pest data for the variance of yield model came from several sources. Precipitation and temperature data were from a weather station at the West Tennessee Experiment Station (U.S. Department of Commerce). Because direct estimates of insect and weed damage were not available from the plots, two proxy variables were created to explain potential yield variance due to these pests. Cotton insect damage, *CID*, and pigweed damage, *PWD*, were both created using statewide average percentage yield damage estimates (Head; Williams; Byrd, Jr.).

Empirical Model

In the first step of the Just-Pope approach, mean yields for each winter cover crop alternative were estimated with the following function:

$$(2)\quad Y_t = \beta_0 + \beta_1 N_t + \beta_2 N_t^2 + \beta_3 TM_t + \beta_4 T_t + \beta_5 N_t \times TM_t + \beta_6 N_t \times T_t + \beta_7 TM_t \times T_t + \beta_8 pH_t + e_t,$$

where N = applied ammonium nitrate (nitrogen lb/acre); TM = tillage binary variable (no tillage = 1, conventional tillage = 0); T = time trend index (1 = 1984, 2 = 1985, . . . , 14 = 1997); $N \times TM$, $N \times T$, and $TM \times T$

are interactions between the respective variables; pH = soil pH experiment binary variable where pH = 1 for 1995 through 1997, 0 otherwise; t = a subscript indicating year of the experiment; β_i (i = 0, 1, . . . , 8) = parameters to be estimated; and e is a random error term.

The explanatory variables were included in equation (2) for various reasons. N was modeled to allow for diminishing marginal productivity of nitrogen fertilizer ($\beta_1 > 0$, $\beta_2 < 0$). Triplet, Dabney, and Siefker indicate that no tillage yields may initially be lower than conventional tillage yields but those yields may eventually exceed conventional tillage yields in succeeding years. Nevertheless, the expected sign of the coefficient for TM was uncertain because of the TM interactions and the potential negative impact of the weed control problems and the pH study described earlier. T was included to capture the expected long-term benefits of no tillage and a winter cover crop on soil quality and lint yields. Notwithstanding the potential benefits, the sign of the coefficient for T was uncertain because of the T interactions terms and because of the potential negative effects on yields caused by weed problems and the pH study described previously. The coefficient for $N \times TM$ was expected to be positive because nitrogen fertilizer was broadcast on the soil surface and not incorporated into the soil under no-tillage. The sign for $N \times T$ was hypothesized to be positive because of the expected increase in the marginal physical product of nitrogen fertilizer as soil quality increases over time with no tillage and winter covers. The coefficient for $TM \times T$ was expected to be positive because soil productivity was expected to increase over time under no tillage. Finally, the coefficient for the pH binary variable was expected to be positive after the application of lime in spring 1995. However, the pH variable may also reflect the effects of using prythiobac sodium herbicide beginning in 1995.

The second step in the Just-Pope approach was to estimate the variance of yield function using residuals obtained from the mean yield model. Variance of lint yield for each winter cover was specified as a function of management, weather, and pests such that

$$(3)\quad \ln \hat{e}_t^2 = \alpha_0 + \alpha_1 N_t + \alpha_2 TM_t + \alpha_3 T_t + \alpha_4 N_t \times TM_t + \alpha_5 N_t \times T_t + \alpha_6 TM_t \times T_t + \alpha_7 PPT_t + \alpha_8 DD60_t + \alpha_9 CID_t + \alpha_{10} PWD_t + \mu_t,$$

where $\hat{e}_t^2$ = natural log of the squared residuals; N, TM, T, $N \times TM$, $N \times T$, and $TM \times T$ were defined previously; PPT = cumulative inches of rainfall between July 15 and August 31; $DD60$ = cumulative daily temperature units above 60°F between May 1 and October 31; CID = estimated annual yield losses to all cotton insects (percent); PWD = estimated annual yield losses to pig weed (percent); α_i (i = 0, 1, . . . , 10) = parameters to be estimated; and μ = random error term.

While substantial literature exists on the risk effects of nitrogen fertilizer on crop production (Roumasset et al., Antle and Crissman, Lambert, Traxler et al.), little information is available about the specific form of the input-output relationship between N and yield variance. Given the lack of knowledge about the nitrogen-variance relationship, nitrogen fertilizer was modeled as a linear function in the variance equation. Many of the previous nitrogen fertilizer studies have indicated that applied nitrogen is moderately risk increasing (Roumasset et al.). However, some studies have found that nitrogen fertilizer reduces risk (e.g., Antle and Crissman, Lambert). The potential impact of nitrogen fertilizer on yield variability is influenced by the crop production system (e.g., dryland production versus irrigated production) and other management factors. Therefore, the hypothesized sign for N was uncertain. As indicated before, no tillage (TM) may positively or negatively affect yield variance depending on weather and pest events that occur during cotton plant growth and development. The cumulative effects of these events on yield variability are difficult to discern; therefore, the sign for the TM coefficient was uncertain. Because no tillage and winter covers are expected to improve soil quality over time, thereby decreasing yield variability, the coefficient for T was hypothesized to have a negative sign.

The July 15 through August 31 period is a critical period for cotton. Low rainfall at this stage is stressful to the plant and causes growing bolls to be shed and reduces yields. Surface residues and improved soil-water holding capacity with winter covers may help preserve soil moisture during drought. The coefficient for *PPT* was expected to be positive in the presence of winter covers. Available growing season as measured by *DD60* may impact the variability of yields under alternative cover crops. However, the direction of the impact of *DD60* on yield variability is unknown. The coefficients for yield damage from insects and pigweed are hypothesized to have a positive sign. However, winter covers may provide habitat for insects and may cause larger yield losses because of higher insect populations in cotton. Consequently, the coefficient for *CID* was hypothesized to have a larger value in the presence of a winter cover. Legume winter covers provide additional nitrogen to growing plants which may exacerbate weed problems. Accordingly, the coefficient for *PWD* was expected to have a large value for cotton grown after legumes than for cotton after wheat or no cover.

The third step of the Just-Pope approach was to use the predicted values from the variance model (equation 3) as weights for producing generalized least squares (GLS) estimators for the mean yield equation for each winter cover. With the GLS procedure, efficiency gains in parameter estimates are possible when the assumption of multiplicative heteroscedasticity holds.

Analysis

To achieve the first objective, equations (2) and (3) were estimated for the four winter cover systems. Using the residuals from the estimated ordinary least squares (OLS) mean yield equations, the null hypothesis of homoscedasticity was tested against the alternate hypothesis of general heteroscedasticity using the Breusch-Pagen test and multiplicative heteroscedasticity using the model F-tests from the individual winter cover crop variance equations (Judge et al., 1982). The error sums of squares from the estimated OLS mean yield equations were used to test the null hypothesis that variance estimates were identical for pairwise comparisons of winter cover systems. Estimated coefficients from the variance of yield model were used to evaluate how nitrogen fertilizer, tillage, time, weather, and pests influenced yield risk in the presence of a winter cover crop.

To accomplish the second objective, the GLS mean yield function and the variance function for each winter cover were used to predict certainty equivalent maximizing applied nitrogen rates, yields, costs, and net revenues above variable, fixed equipment, and overhead costs. Certainty equivalent (*CE*) of per-acre profit was approximated by (Robison and Barry):

$$(4) \qquad CE = E(NR) - \lambda/2 \ \mathrm{Var}(NR),$$

where $E(NR)$ is expected net revenue, λ is the value of the Pratt-Arrow absolute risk aversion function, and $V(NR)$ is the variance of net revenue. Variance of net revenue for each winter cover was calculated assuming that lint prices and yields are random and independent (Bohrnstedt and Goldberger). Certainty equivalent maximizing nitrogen fertilizer levels for each winter cover and tillage alternative were found by solving:

$$(5) \qquad \max_{N} CE = E(NR) - \lambda/2 \ \mathrm{Var}(NR),$$

subject to $0 \leq N \leq 90$. Equation (5) was solved for risk neutrality ($\lambda = 0$) and two levels of risk aversion, $\lambda = 0.01$ and $\lambda = 0.02$, consistent with the range of risk aversion evaluated by Lambert.

Net revenues were calculated using a constant lint price of \$0.73/lb (1984–1997 average) and a constant ammonium nitrate price of \$0.34/lb (1984–1997 average) of pure nitrogen (Tennessee Department of Agriculture). These prices were inflated to 1999 dollars by the Implicit Gross Domestic Product Price Deflator before averaging (Congress of the U.S., Council of Economic Advisors). The cost for

Table 1. Estimated Cotton Lint Yield Response Functions for Alternative Winter Cover Crops[a]

	Winter Cover Crop			
Variable[b]	No Cover	Winter Wheat	Hairy Vetch	Crimson Clover
Intercept	1010.36***[c]	1040.69***	1150.31***	1137.57***
	(13.99)	(18.15)	(14.94)	(18.21)
N	4.25**	4.11**	0.33	−0.21
	(2.24)	(2.71)	(0.16)	(0.13)
N^2	−0.04**	−0.03**	−0.02	-5.91×10^{-3}
	(2.10)	(2.40)	(0.82)	(0.39)
TM	−127.45	−218.86***	−87.09	−170.83**
	(1.63)	(3.50)	(1.04)	(2.47)
T	−57.40***	−55.94***	−58.39***	−61.23***
	(6.72)	(8.20)	(6.47)	(8.17)
$N \times TM$	0.95	1.49**	−1.05	0.41
	(1.03)	(2.00)	(1.07)	(0.50)
$N \times T$	0.02	0.01	0.08	0.06
	(0.20)	(0.15)	(0.68)	(0.58)
$TM \times T$	−0.37	12.50**	5.50	17.66***
	(0.05)	(1.99)	(0.66)	(2.56)
pH	463.48***	368.70***	452.53***	384.77***
	(8.69)	(8.63)	(8.02)	(8.03)
Adjusted R^2	0.53	0.59	0.44	0.48
n	112	112	112	112

[a] Weighted least square results.
[b] Cotton lint yield (lb/acre) is the dependent variable, N = applied ammonium nitrate (nitrogen lb/acre), TM = tillage method binary variable (no tillage = 1, conventional tillage = 0) T = time trend index (1 = 1984 to 14 = 1997), and pH = soil pH experiment binary variable where pH = 1 for 1995 through 1997, 0 otherwise.
[c] Numbers in parenthesis are t-statistics.
***,**,* Significantly different from zero at the 1-, 5-, or 10-percent level, respectively.

ginning and handling was $0.13/lb of lint. Cotton seed revenues were calculated by multiplying lint yield by 1.6 and then multiplying that product by the 1984–1997 average real cottonseed price of $0.05/lb (Tennessee Department of Agriculture). Estimated materials, equipment, labor, and interest costs for each winter cover were $25/acre for wheat, $34/acre for vetch, and $25/acre for clover. Other costs of production that did not vary in this analysis were from enterprise budgets for conventional-tillage and no-tillage cotton (Gerloff).

Results and Discussion

Mean Yields

Weighted least square mean yield response functions for each winter cover crop are presented in Table 1. The nitrogen fertilizer response coefficients, N and N^2, in the cotton after winter wheat and cotton after no-winter-cover equations were significantly different from zero (p = 0.05) and had the hypothesized signs. Nitrogen fertilizer coefficients in the cotton after hairy vetch and cotton after crimson clover equations were not significantly different from zero. Cotton yields after vetch or clover were not responsive because the marginal physical product of nitrogen fertilizer was essentially driven to zero or negative in the presence of legume nitrogen.

Evaluation of the mean yield equations with respect to TM and its interactions (with other variables set at their means) indicates that no-tillage yields were lower than conventional-tillage yields for all four winter covers. The estimated TM coefficients were significantly different from zero for cotton after winter wheat (p = 0.01) and cotton after crimson clover (p = 0.05). Difficulty controlling pig-

Table 2. Winter Cover Crop Model Heteroscedasticity Test Results and OLS Error Sums of Squares Results

	Winter Cover Crop			
Variable	No Cover	Winter Wheat	Hairy Vetch	Crimson Clover
Breusch-Pagan Statistic	15.56**	10.79	24.28***	17.22**
Yield Variance Equation F-statistic	0.97	1.66*	2.67***	2.30**
Error Sums of Squares	2,873,289	1,881,768	3,401,130	2,235,916

***, **, * Significantly different from zero at the 1-, 5-, or 10-percent level respectively.

weed in the no tillage plots likely explains the lower yields. On the other hand, the interaction of nitrogen and no-tillage ($N \times TM$) for cotton after wheat was statistically significant ($p = 0.05$) and had the expected positive sign. The significant and positive relationship for $N \times TM$ indicates that more nitrogen fertilizer is required for winter wheat followed by no-tillage cotton when compared with conventional-tillage cotton. The no tillage-time trend interaction term ($TM \times T$) for the cotton after wheat and cotton after clover had statistically significant ($p = 0.05$) and positive coefficients. The significant and positive tillage-time interaction term indicated that no tillage yields for wheat and clover increased over time when compared with conventional tillage yields.

Coefficients for the time-trend variables in all four winter cover equations were statistically significant ($p = 0.01$) and had negative signs. However, because of the interaction of time with other variables in the model, the net impact of time on yields was not clear. An evaluation of changes in yields with respect to the T and its interactions indicated that yields declined over time for all four cover crops. As discussed previously, problems controlling pigweed and deteriorating soil pH induced by delaying lime applications likely caused the downward trend in yields. Pigweed infestations coupled with low rainfall during the critical growth period (July 15 through August 31) contributed to lower lint yields between 1989 and 1993, especially in the no-tillage plots with a winter cover. Soil acidity measured in the experimental plots increased over time. Problems with soil acidity were more prevalent at the high nitrogen fertilizer rates and in the no-tillage plots. These negative influences on yields more than offset any positive long-term benefits of winter covers and no tillage on soil quality.

Variance of Yields

Breusch-Pagen tests reported in Table 2 indicate evidence of general heteroscedasticity for the no-cover ($p = 0.05$), hairy vetch ($p = 0.01$), and crimson clover ($p = 0.05$) equations but not for the winter wheat equation. The yield variance model F-tests reported in Table 2 indicate evidence of multiplicative heteroscedasticity for the winter wheat ($p = 0.10$), hairy vetch ($p = 0.05$), and crimson clover ($p = 0.05$) equations but not for the no-cover equation. While the two tests give conflicting results, taken together they suggest evidence of heteroscedasticity in all four cover crop equations.

Error sums of squares from the first-step, OLS regressions are reported in Table 2 and indicate the relative yield variance ranking for each winter cover, all other factors being equal. Cotton after winter wheat produced the least variable lint yields followed in ascending order by cotton after clover, cotton after no cover, and cotton after vetch. F-tests constructed using the error sums of squares for each cover crop to evaluate whether one cover crop produced yield variance that was significantly different from another cover crop are presented in Table 3. Variability of lint yield for winter wheat was significantly different from the variability for no cover ($p = 0.05$) and hairy vetch ($p = 0.01$) but not significantly different from the variability for crimson clover. Lint

Table 3. Results of Pair-Wise Comparisons of Winter Cover Crop Yield Risk Hypothesis Tests

Winter Cover Crop Comparisons	F-statistic[a]
No Cover vs Hairy Vetch	1.18
No Cover vs Winter Wheat	1.53**
No Cover vs Crimson Clover	1.27
Hairy Vetch Cover vs Winter Wheat	1.81***
Hairy Vetch Cover vs Crimson Clover	1.50**
Winter Wheat Cover vs Crimson Clover	1.20

[a] F-test degrees of freedom was 103 in the numerator and 103 in a denominator.
***, **, * Significantly different from zero at the 1-, 5-, or 10-percent level, respectively.

yield variability for crimson clover was also significantly different from the variability for hairy vetch ($p = 0.05$) but was not significantly different from the variation observed for no cover and winter wheat.

Pair-wise comparisons of winter cover system results indicate that cotton after vetch produced the most yield variability while cotton after winter wheat produced the least risky yields, all other factors being equal. However, yield risk for cotton after a winter cover may also be influenced by the level of nitrogen fertilizer, tillage, time, weather, and pests. The risk-reducing and risk-increasing impacts of these specific factors on yields in the presence of a winter cover were evaluated using the variance of yield equation results presented in Table 4.

None of the management or growing environment variables was statistically significant in explaining yield variability for cotton after no winter cover. For cotton after a winter wheat cover, the coefficients for nitrogen fertilizer (N), the nitrogen-time interaction ($N \times T$), and July–August precipitation (PPT) were statistically significant ($p = 0.05$) in explaining yield risk. An evaluation of yield variability with respect to N and its interactions indicated that a higher level of nitrogen fertilizer increased yield risk for both conventional and no-tillage cotton grown after winter wheat. The estimated coefficient for N had a positive sign and the estimated coefficient for $N \times T$ had a negative sign. The two significant nitrogen fertilizer coefficients (N and $N \times T$) indicate that a higher level of N increased lint yield variability in the presence of a winter wheat cover but yield risk at a given level of N declined with the passage of time. July–August precipitation also increased variability of yields, a finding consistent with a priori expectations. Results indicated that lint yields were less variable during drought periods for cotton after winter wheat. Consequently, the winter wheat cover reduces yield risk for cotton during drought conditions.

Coefficients for nitrogen fertilizer, time, and pigweed damage were statistically significant in explaining yield variation for cotton following vetch. Nitrogen fertilizer had a positive sign ($p = 0.10$), indicating that higher nitrogen levels increased yield risk (see also Figure 1). The time-trend coefficient in the cotton after vetch variance equation had a negative sign ($p = 0.01$). However, because of the interaction of time with other variables in the model, the net impact of time on yields was not clear. An evaluation of the cotton after vetch variance equation with respect to T and its interactions indicated that yield variance declined over time under both conventional tillage and no tillage. Improved soil quality with the vetch winter cover may explain the reduced yield risk with the passage of time. The coefficient for pigweed damage had a positive sign ($p = 0.05$) in the vetch variance equation. Additional nitrogen to growing plants provided by vetch exacerbated weed problems and yield losses, thereby increasing risk. With the introduction of more effective herbicides (Staple) and glyphosate-tolerant (Roundup Ready) cotton, this source of yield risk may be less of a problem in the future for cotton grown after a legume cover.

Four explanatory variables in the crimson clover variance equation were significantly different from zero (Table 3). The time-trend coefficient had a negative sign ($p = 0.05$). Evaluation of the variance equation with respect to T and its interactions indicated that yield risk decreased with time for cotton grown after a clover winter cover. As with the vetch winter cover, enhanced soil quality with the clover cover may explain the reduced cot-

Table 4. Estimated Variance of Cotton Lint Yield Functions for Alternative Winter Cover Crops

	Winter Cover Crop			
Variable[a]	No Cover	Winter Wheat	Hairy Vetch	Crimson Clover
Intercept	14.12***	7.80*	13.72**	6.46
	(2.59)[b]	(1.66)	(2.44)	(1.35)
N	0.02	0.03**	0.028*	9.46×10^{-3}
	(1.18)	(1.98)	(1.74)	(0.69)
TM	−0.54	−0.45	−0.68	1.57
	(0.48)	(0.46)	(0.59)	(1.59)
T	−0.18	0.12	−0.58***	−0.40**
	(0.92)	(0.68)	(2.85)	(2.30)
N × *TM*	3.39×10^{-3}	5.19×10^{-4}	-5.27×10^{-3}	−0.03**
	(0.25)	(0.05)	(0.38)	(2.33)
N × *T*	-1.90×10^{-3}	-2.98×10^{-3}**	-1.46×10^{-3}	3.45×10^{-4}
	(1.14)	(2.08)	(0.85)	(0.24)
TM × *T*	0.06	0.05	0.15	−0.10
	(0.56)	(0.54)	(1.29)	(1.03)
PPT	4.83×10^{-3}	0.14**	−0.02	7.50×10^{-3}
	(0.06)	(1.97)	(0.28)	(0.11)
DD60	-1.93×10^{-3}	-2.99×10^{-4}	-2.07×10^{-3}	5.25×10^{-5}
	(1.05)	(0.19)	(1.09)	(0.03)
CID	−0.05	−0.04	0.04	0.06**
	(1.38)	(1.41)	(1.09)	(1.95)
PWD	0.12	−0.11	0.39**	0.45***
	(0.68)	(0.73)	(2.21)	(3.01)

[a] The natural log of the squared residuals (e_t^2) is the dependent variable, *N* = applied ammonium nitrate (nitrogen lb/acre), *TM* = tillage method binary variable (no tillage = 1, conventional tillage = 0), *T* = time trend index (1 = 1984 to 14 = 1997), *PPT* = cumulative inches of rainfall between July 15 and August 31, *DD60* = cumulative daily temperature units above 60°F between May 1 and October 31, *CID* = estimated annual yield losses to all cotton insect damage (percent), and *PWD* = estimated annual yield losses to pig weed damage (percent).

[b] Numbers in parentheses are t-statistics.

***, **, * Significantly different from zero at the 1-, 5-, or 10-percent level, respectively.

ton yield variability over time. The nitrogen-tillage interaction term had a negative sign ($p = 0.05$) indicating that yield risk decreased under no tillage when compared with conventional tillage, holding nitrogen fertilizer constant (see also Figure 1). The coefficients for cotton insect ($p = 0.05$) and pigweed ($p = 0.01$) damage had the hypothesized positive signs. Results indicated that cotton grown after a winter legume had increased yield risk because it was more susceptible to pest damage. Nitrogen fixing covers may create a more favorable environment for these pests to flourish, causing higher yield risk in cotton.

Variance equation results indicate that higher nitrogen fertilization rates increase yield risk for cotton grown after vetch. However, Figure 1 illustrates that yield risk for cotton after vetch with no nitrogen fertilization compared favorably with cotton grown after wheat with nitrogen fertilizer, which had the lowest overall yield variability among the winter covers evaluated (Table 3). Under conventional tillage, yield variability (standard deviation) for cotton after vetch with no applied nitrogen was less than the yield risk for wheat grown with more than 40 lb/acre of applied nitrogen. With no tillage, cotton yields after vetch with no applied nitrogen were less variable than cotton yields after wheat grown with more than 80 lb/acre of nitrogen fertilizer. When compared with the yield variability for cotton grown without a winter cover, hairy vetch reduced yield risk when no nitrogen fer-

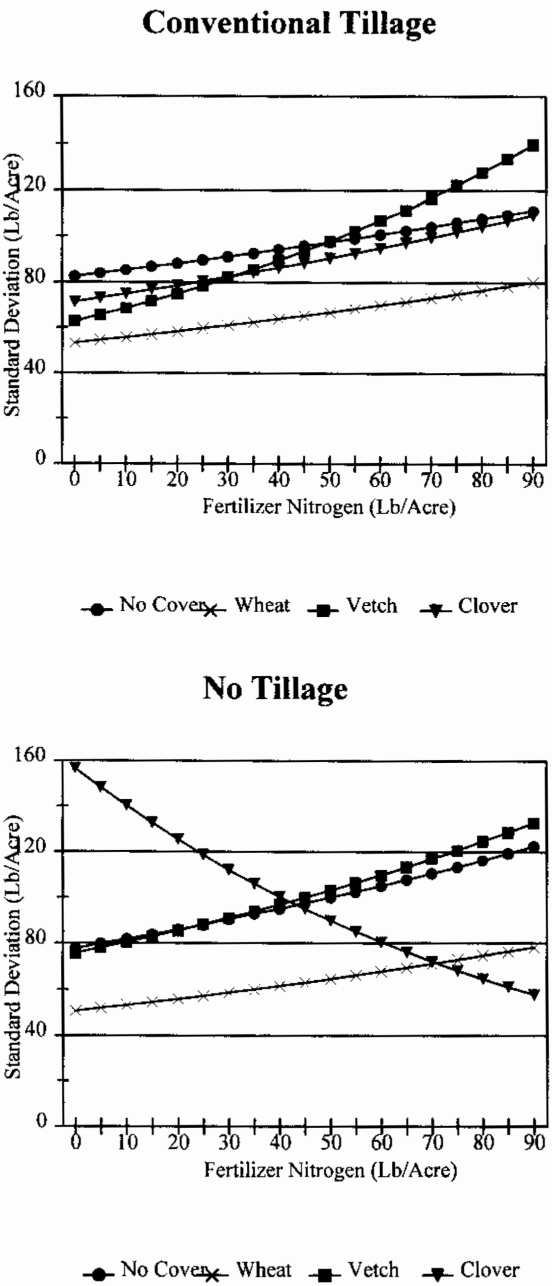

Figure 1. Standard deviation of cotton lint yield with respect to tillage, nitrogen fertilizer, and winter cover

tilizer was applied to supplement the nitrogen fixed by the vetch winter cover. Yield risk for both conventional and no-tillage cotton grown after vetch with no nitrogen fertilization was less than the yield risk for cotton produced without a winter cover at all nitrogen fertilizer levels examined in this analysis.

Risk-Return Tradeoffs

The optimal nitrogen fertilization rates and net revenues for each winter cover and tillage combination under the assumption of risk neutrality ($\lambda = 0$) are reported in Table 5. For all four winter covers, no-tillage net revenues were lower than conventional-tillage net revenues primarily because of smaller yields. For both conventional-tillage and no-tillage systems, cotton without a winter cover provided the largest net revenues followed in descending order by cotton after vetch, cotton after wheat, and cotton after clover. Cotton following vetch produced the largest profit-maximizing yields; however, higher revenues and lower nitrogen fertilizer costs for cotton after vetch were more than offset by the cost of establishing and killing the vetch cover. Cotton after wheat or clover produced lower yields and had higher production costs when compared with cotton without a winter cover. The above results indicate that risk-neutral farmers may have little profit incentive to adopt winter cover crops and no tillage in cotton production.

At the profit maximizing nitrogen fertilizer level, cotton managed with no tillage produced more variable net returns than cotton managed with conventional tillage for all four winter covers. For both conventional-tillage and no-tillage systems, cotton grown without a winter cover produced the most variable net returns followed in descending order by cotton after clover, cotton after vetch, and cotton after wheat.

Farmer willingness to accept lower net revenue variability along with lower expected net revenues in order to adopt winter covers and no tillage may be influenced by risk-aversion behavior. Optimal fertilizer nitrogen rates and net returns for two levels of risk aversion ($\lambda = 0.01$ and $\lambda = 0.02$) also are reported in Table 5. Conventionally tilled cotton grown without a winter cover produced the largest certainty equivalent of net revenue in both risk-aversion categories ($\lambda = 0.01$ and $\lambda = 0.02$). Certainty equivalent rankings indicate that conventionally tilled cotton without a winter cover was risk efficient and dominates

Table 5. Winter Cover Crop, Tillage, and Nitrogen Fertilization System Risk and Return Comparisons

	Coefficient of Absolute Risk Aversion					
	Conventional Tillage			No Tillage		
Winter Cover Crop/Item	λ = 0.00	λ = 0.01	λ = 0.02	λ = 0.00	λ = 0.01	λ = 0.02
No Cover						
Nitrogen Fertilizer (lb/acre)	54	49	42	67	60	51
Net Return Mean ($/acre)	491.75	491.24	488.43	450.97	449.91	441.90
Net Return Std. Dev. ($/acre)	139.41	138.74	137.43	135.95	134.49	132.06
Certainty Equivalent ($/acre)	491.75	395.00	299.56	450.97	359.47	270.50
Winter Wheat						
Nitrogen Fertilizer (lb/acre)	56	52	46	78	74	68
Net Return Mean ($/acre)	429.43	429.11	427.41	416.04	415.65	413.65
Net Return Std. Dev. ($/acre)	127.27	126.81	125.95	126.27	125.70	124.67
Certainty Equivalent ($/acre)	429.43	348.70	268.78	416.04	336.65	258.23
Hairy Vetch						
Nitrogen Fertilizer (lb/acre)	14	2	0	0	0	0
Net Return Mean ($/acre)	470.85	469.39	468.93	444.32	444.32	444.32
Net Return Std. Dev. ($/acre)	133.20	131.07	130.74	128.35	128.35	128.35
Certainty Equivalent ($/acre)	470.85	383.49	298.00	444.32	361.95	279.58
Crimson Clover						
Nitrogen Fertilizer (lb/acre)	0	0	0	9	33	49
Net Return Mean ($/acre)	410.59	410.59	410.59	387.22	384.94	380.92
Net Return Std. Dev. ($/acre)	122.42	122.42	122.42	125.91	121.48	119.20
Certainty Equivalent ($/acre)	410.59	335.65	260.71	387.22	311.16	238.84

all the other winter cover and tillage combinations. Risk-averse producers may not adopt winter cover crops because these systems are risk inefficient.

Conventionally tilled cotton following vetch produced the second largest level of certainty equivalent of net revenue for both λ = 0.01 and λ = 0.02. Cotton after vetch was not risk efficient using the costs assumed in this analysis. When the cost of vetch seed was reduced from $1.22/lb to less than $1.14/lb, conventional tillage cotton after vetch dominated no winter cover when λ = 0.02. The price of vetch seed must drop to less than $0.64/lb when λ = 0.01 before vetch dominates no cover.

The certainty equivalence results reported in Table 5 also have implications for risk-averse farmers who have adopted no tillage for conservation compliance or other reasons. Cotton grown after vetch produced the largest certainty equivalent income among the no tillage, winter cover systems for both λ = 0.01 and λ = 0.02. Results also indicate that risk-averse farmers who use no tillage may have a risk incentive to use no nitrogen fertilizer when they adopt a vetch cover.

Summary

This study evaluated the risk efficiency of alternative winter cover crop, tillage, and nitrogen fertilization systems in cotton. A Just-Pope econometric model was developed to analyze the marginal risk effects of alternative systems and evaluate risk and return tradeoffs among systems. In an evaluation of the yield risk properties of alternative winter covers, cotton after winter wheat produced the least variable yields and cotton after hairy vetch produced the most variable yields, all other factors being equal. Higher levels of nitrogen fertilizer increased yield risk for cotton grown after winter wheat or hairy vetch covers. However, yield risk for cotton after hairy vetch was less than for cotton with no winter cover when no nitrogen fertilizer was used to supplement the vetch nitrogen. Moreover, yield risk for cotton after hairy vetch or crimson clover decreased with the passage of time. Weather and pests events also influenced yield risk in the presence of winter cover crops. Yield risk due to drought was reduced in the presence of a winter wheat cover crop. Hairy vetch and crimson clover covers increased yield risk from pigweed damage. Yield risk from insect damage was higher for cotton after clover.

Even though certain winter covers may reduce yield risk, the evaluation of risk and return tradeoffs suggests that farmers may be slow to adopt winter cover crops and no tillage because these systems may not be risk efficient for risk-neutral and risk-averse decision makers. A major factor influencing the unfavorable risk rankings of winter covers is the cost of establishing the cover crop in the fall. From an environmental policy perspective, subsidizing legume winter cover establishment may be an effective policy option to reduce nitrogen use in no-tillage cotton production. While a substantial reduction in the nitrogen fertilization rate for cotton is possible with legume covers, the impact of reduced fertilizer nitrogen use for the vetch system on nitrate leaching is uncertain and is an empirical question that should be examined. Finally, with the availability of glyphosate-tolerant (Roundup Ready) cotton and prythiobac sodium (Staple) herbicide, weed control for no-tillage cotton following vetch may be much less of a problem for farmers than indicated by the data examined in this study. These weed control technologies may provide a more favorable risk-return tradeoff for cotton following a legume winter cover when compared with the no-cover system.

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