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Nitrogen-Fixing Winter Cover Crops and Production Risk: A Case Study for No-Tillage Corn

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ABSTRACT

Winter legumes can substitute for applied nitrogen fertilization of corn. Stochastic dominance was used to order net revenues from legume and applied nitrogen alternatives. Stochastic dominance orderings indicate that systems combining vetch with low applied nitrogen fertilization (50 and 100 pounds/acre, respectively) were risk inefficient. By contrast, vetch and 150 pounds/acre applied nitrogen maximized expected net revenue and was risk efficient for a wide range of risk-averse and risk-seeking behavior. Farmers with these risk attitudes may not reduce applied nitrogen if they switch to a vetch cover. Extremely risk-averse or risk-seeking farmers would not prefer winter legumes.

Key Words: legume winter crops, nitrogen, risk premiums, stochastic dominance.

Corn is an important production alternative for farmers in West Tennessee (Tennessee Department of Agriculture). Relative to other crops, the corn plant requires a large amount of nitrogen to maximize expected net revenue. Farmers are concerned about the uncertain cost of providing nitrogen to the crop through petroleum-based nitrogen fertilizers. Factors beyond the control of a producer, such as a tightening in the world supply and demand for petroleum products, embargos, or other political events, may significantly increase commercial nitrogen prices and reduce corn profitability. In addition, the soils on which corn is row-cropped in West Tennessee are highly erodible and subject to surface and groundwater pollution (Bradley and Tyler). The public has become more concerned about the potential for off-farm pollution caused by agricultural production (Keeney and Follett). The possibility of taxes or restrictions on commercial nitrogen that are designed to decrease its use may also significantly impact profitability (Choi and Feinerman; Chowdhury and Lacewell; Huang, Shank, and Hewitt).

Given these concerns, researchers at the University of Tennessee have recommended that farmers consider winter cover crops and no-tillage practices for row-crop production (Duck and Tyler). Cover crops and no-tillage practices can benefit soils by reducing soil ero-

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sion, improving soil physical characteristics, and conserving soil nutrients (Duck and Tyler; Meisinger et al.). Moreover, winter legumes can provide 36 to 110 pounds/acre of nitrogen to the next crop (Decker et al.). Notwithstanding these benefits, no-tillage and legume covers may increase production risk by increasing variability in corn yields (Ebelhar, Frye, and Blevins; Decker et al.; Holderbaum et al.; Reeves, Wood, and Touchton) and net revenues. In addition, the effects of legume cover crops on nitrate leaching are uncertain (Meisinger et al.).

The impact of using winter legumes as an alternative to commercial nitrogen has not been evaluated with respect to the expected value and variability of net revenues for no-tillage corn production in Tennessee. The objectives of this study are: (*a*) to evaluate how alternative legume cover crops and applied nitrogen rates affect the expected value and variability of net revenues from no-tillage corn production, and (*b*) to perform a limited risk analysis of the potential impacts of legume cover and applied nitrogen fertilization systems on nitrate leaching.

Methods and Data

Stochastic Dominance

Stochastic dominance is used to accomplish the objectives of this study. This method has been used to order many kinds of farm management decisions (Giesler, Paxton, and Millhollon). The procedure is based on the theory of expected utility and involves a pairwise comparison of expected utilities derived by decision makers from a set of risky alternatives. Assume a group of decision makers (one or more) has utility for income (x) defined by the monotonically increasing function $u(x)$. These decision makers must decide between two risky alternatives, A_1 and A_2, with cumulative outcome probability distribution functions (CDFs) given by $G(x)$ and $F(x)$, respectively. If the expected utility of $F(x)$ is greater than the expected utility of $G(x)$, then A_2 stochastically dominates A_1 and is preferred by these individuals. Through this pairwise comparison procedure, stochastic dominance provides an ordering of alternatives by dividing them into two mutually exclusive sets: the risk-efficient set and the risk-inefficient set. Strategies in the efficient set unambiguously provide higher expected utilities for all decision makers than alternatives in the inefficient set.

Meyer developed a computer algorithm to identify risk-efficient strategies for alternative stochastic dominance criteria. The generalized stochastic dominance procedure establishes the necessary and sufficient conditions for $F(x)$ to be preferred to $G(x)$ by individuals with coefficients of absolute risk aversion $[r(x)]$ in the interval $r_1(x)$, $r_2(x)$. Mathematically, the absolute risk-aversion coefficient is defined as $r(x) = -u''(x)/u'(x)$, where $u'(x)$ and $u''(x)$ are the first and second derivatives of $u(x)$. A value of $r(x)$ can be viewed as the percentage change in marginal utility per dollar of additional income (Raskin and Cochran).

The Meyer algorithm is limited to modeling decision makers with constant absolute risk-aversion functions, i.e., $r(x)$ does not change with the level of income. For the utility function, $u(x)$, the following expression is minimized:

$$(1) \qquad \int_{-\infty}^{+\infty} [G(x) - F(x)]u'(x)\,dx$$

subject to

$$r_1(x) \leq \frac{-u''(x)}{u'(x)} \leq r_2(x).$$

If the minimum of the difference in expected utility between $F(x)$ and $G(x)$ in (1) is positive, then A_2 is unanimously preferred by all individuals to A_1. If the difference is zero, then the decision makers are indifferent between A_1 and A_2. When the expected utility difference is negative, then $F(x)$ is not unanimously preferred to $G(x)$. For the case of a negative difference, $G(x)$ and $F(x)$ are switched in (1) and the expression is minimized to determine if A_1 is unanimously preferred to A_2.

The bounds of $r(x)$ between positive infinity and negative infinity include the risk attitudes of all decision makers. Different levels of risk attitude are modeled by varying $r(x)$. Positive values of $r(x)$ imply risk-averse behavior, with decision-maker utility increasing with income but at a decreasing rate, i.e., $u'(x) > 0$, and $u''(x) < 0$. In general terms, a risk averter may be willing to accept lower mean income in exchange for a less risky (variable) distribution of income. The degree of risk-averse behavior increases with larger positive values of $r(x)$. When $r(x) = 0$, utility increases at a constant rate as income increases and the individual is risk neutral, i.e., $u'(x) > 0$, and $u''(x) = 0$. Risk-neutral decision makers only consider expected income when ranking risky management choices. Negative values of $r(x)$ imply risk-seeking behavior, i.e., $u'(x) > 0$, and $u''(x) > 0$; utility increases at an increasing rate as income increases. A risk seeker may be willing to accept lower mean income in exchange for a riskier distribution of income. The degree of risk-seeking behavior increases as values of $r(x)$ become more negative.

The three most common stochastic dominance criteria modeled with the Meyer algorithm are first-degree stochastic dominance (FSD), second-degree stochastic dominance (SSD), and generalized stochastic dominance (GSD). FSD imposes the single restriction, $u'(x) > 0$, on decision-maker preferences regardless of risk attitude [$r_1(x) = -\infty$; $r_2(x) = +\infty$]. For all levels of cumulative probability, an alternative in the FSD set produces income equal to or higher than income from an alternative in the inefficient set. The SSD criterion places the additional restriction on decision-maker preferences of risk-averse behavior [$r_1(x) = 0$; $r_2(x) = +\infty$]. GSD is more flexible than FSD or SSD because specific levels of risk attitude, including risk-seeking behavior, can be modeled by varying $r_1(x)$ and $r_2(x)$.

Yield Data

This research uses 1986 through 1995 yield data from a winter cover crop experiment for no-tillage corn at the Milan Experiment Station, Milan, Tennessee. The two legume cover crops in the experiment that were evaluated in this analysis were vetch (hairy vetch) and clover (crimson clover). Plots with no winter cover crop also were analyzed. The experimental design was a randomized complete block design with split plots and four replications per year. Applied nitrogen fertilizer rates were varied in the main plots, and the winter cover crops were varied in the split plots. To evaluate the long-term effects of covers on soils, plots received the same cover crop and applied nitrogen rate in each year.

The cover crops were established in the fall after corn harvest. Before corn planting each spring, the no-cover and legume cover plots were sprayed with a "burndown" herbicide to control weeds or kill the cover crop. The application rate of the herbicide did not vary among cover crop treatments. Ammonium nitrate was the applied nitrogen source and was surface broadcast after planting. The rates of commercial nitrogen applied to the plots were 0, 50, 100, 150, and 200 pounds/acre. After corn plant emergence, plant populations were thinned to uniform adequate stands in all plots.

Selected plots also were used to study nitrate leaching. Tyler et al. measured nitrate leaching for no-cover and 100 pounds/acre applied nitrogen, and vetch cover and 100 pounds/acre applied nitrogen between May 1990 and February 1992. They monitored seasonal movement of nitrate-nitrogen concentrations of leachate into the soil below the root zone following rainfall events. Even though the leaching study was limited, the data provide some information on the impact of vetch covers on the probability of nitrate leaching exceeding the maximum contamination level of 10 mg/L.

Farmers are most concerned with the impact of weather on net revenues. For this reason, yields from the four replications were averaged within year before estimating net revenues. Experimental error measured from the replications in small-plot, controlled research was not considered relevant for this study.

Net Revenues

Enterprise budgets were constructed for each treatment to reflect the cultural practices specific to the Milan experiment and the study area. To isolate the effects of stochastic yields on net revenues, a constant corn price of \$2.72/bushel and a constant commercial nitrogen fertilizer cost of \$0.31/pound of pure nitrogen were used to calculate net revenues. These prices are the means of 1986–95 annual Tennessee prices inflated to 1995 dollars using the Implicit Gross Domestic Product Price Deflator Index (Tennessee Department of Agriculture; Congress of the U.S., Council of Economic Advisors). In addition to the materials, labor, and equipment expenditures for applied nitrogen, the costs that varied among treatments were those required to establish the winter cover crop. The estimated materials, equipment, labor, and interest costs were \$24/acre for vetch and \$27/acre for clover.

Yield data were entered into the Agricultural Policy Analysis Center Budgeting System (Slinsky, Ray, and De La Torre Ugarte) to generate the distribution of net revenues (over variable costs, fixed equipment costs, and overhead) for each treatment, with each distribution including 10 observations. Fifteen distributions were generated, one for each applied nitrogen fertilization rate for the no-cover, hairy vetch, and crimson clover treatments. These distributions then were analyzed using stochastic dominance criteria.

Risk-Efficient Systems

Risk-aversion coefficients can be elicited from individuals (Robison et al.) or numerically determined from net revenue data (McCarl 1990). Because we did not have information about the risk preferences of West Tennessee farmers, the following numerical procedures were used to determine $r(x)$ values and order legume cover and applied nitrogen systems. The generalized stochastic dominance computer program developed by Goh et al. was used to identify the first-degree stochastic dominance systems from the 15 net revenue distributions. Alternatives in the FSD set were systematically ordered from "best" to "worst" for different $r(x)$ levels using the Riskroot computer program (McCarl 1988). This program is a modification of Meyer's GSD algorithm and numerically searches for the breakeven $r(x)$ value where dominance switches between CDF pairs under constant absolute risk aversion. This breakeven risk-aversion coefficient (BRAC) is the point where the expected utility difference between two alternatives is zero. For decision makers with risk-aversion coefficients above the BRAC, one distribution will dominate, while below the BRAC, the other will dominate. This procedure was used to enumerate all possible $r(x)$ levels that influence the ordering of systems in the FSD set. At the extremes of risk attitudes, the systems in the FSD set include the strategies which maximize the minimum net revenue (a maximin strategy) and maximize the maximum net revenue (a maximax strategy). Maximin and maximax decision criteria are consistent with extreme risk aversion and extreme risk preference (Grube).

Risk Premiums

Risk premiums were calculated to provide an economic measure of the tradeoffs among the benefits of legume cover crops, production risk, and nitrate leaching risk. The Goh et al. program was used to calculate these risk premiums, or the amounts that farmers would be willing to pay to maintain the dominant distribution over the comparison distribution. They were calculated using the following mathematical formulas:

$$(2) \qquad \min \pi \ni EU(F - \pi) - EU(G) < 0 \quad \forall\, u \in U,$$

and

$$(3) \qquad \min \pi \ni EU(F - \pi) - EU(G) \leq 0 \quad \text{for at least one } u \in U,$$

where π is the risk premium, F is the dominant CDF, G is the comparison CDF, EU = expected utility, U = admissible set of utility functions, and u = individuals' utility function (Cochran and Raskin). Equation (2) gives the lower-bound π that all individuals in the interval $r_1(x)$, $r_2(x)$ are willing to pay for the

Table 1. Yield Statistics for Legume Winter Cover Crop and Applied Nitrogen Systems for No-Tillage Corn, Milan, Tennessee, 1986–95

	Corn Yield (bu./acre)				
System[a]	Mean	Standard Deviation	Maximum	Minimum	Skewness
N0	29	17	72	6	1.56
N50	62	18	92	37	0.12
N100	104	22	133	69	−0.27
N150	115	27	148	70	0.64
N200	116	42	174	38	−0.65
V0	74	19	101	50	0.04
V50	102	19	124	71	−0.54
V100	117	31	154	60	−0.72
V150	125	30	168	82	−0.42
V200	127	33	170	78	−0.33
C0	57	16	90	39	0.91
C50	88	23	115	43	−0.77
C100	100	32	142	44	−0.38
C150	116	37	173	52	−0.10
C200	120	36	167	55	−0.67

[a] This column identifies the legume cover and applied nitrogen system, where the capital letters denote the cover crop treatment (N = no cover, V = vetch cover, and C = clover cover), and the numbers denote the applied nitrogen rate (pounds/acre).

dominant strategy. Equation (3) gives the upper-bound π that at least one person is willing to pay.

For the purpose of estimating risk premiums, a systematic iterative procedure was employed to search for the widest $r_1(x)$, $r_2(x)$ interval just above the BRAC that ordered all distributions in the FSD set without question.[1] The GSD program was then used to calculate risk premiums for the identified $r_1(x)$, $r_2(x)$ intervals. The lower-bound risk premiums just above the BRACs are reported in the results.

To accomplish the first objective, the system that maximized expected net revenue was compared with selected systems which include those that depended on legumes for all or part of their nitrogen requirement. The estimated risk premiums were used to evaluate farmer willingness to pay for legume nitrogen as an alternative to commercial nitrogen at different levels of absolute risk aversion. To accomplish the second objective, risk premiums for the system that maximized expected net revenue were compared with systems for which we had nitrate leaching data (no cover and 100 pounds/acre applied nitrogen, and vetch cover and 100 pounds/acre applied nitrogen) (Tyler et al.).

Results and Discussion

Yields for the 15 winter cover crop treatments are summarized in table 1 and net revenues are summarized in table 2. Corn yields showed a large positive response to clover and vetch covers with no applied nitrogen when compared with the no-cover system. The vetch cover produced the highest mean yields for all five applied nitrogen levels. In order of descending mean yields, the top five systems are V200, V150, C200, V100, and N200 (table 1). The top five systems in order of descending

[1] The relative rankings of alternatives in the FSD set do not change between BRACs; however, one or more intervals of varying width where all of the alternatives are ranked without question may be found between BRACs (McCarl 1990). These sub-intervals occur because one or more alternatives cannot be unambiguously ranked when a wider interval is used.

Table 2. Net Revenue Statistics for Legume Winter Cover Crop and Applied Nitrogen Systems for No-Tillage Corn, Milan, Tennessee, 1986–95

		Net Revenue ($/acre)				
System[a]	Risk Efficiency Criteria Met[b]	Mean	Standard Deviation	Maximum	Minimum	Skewness
N0		−51	47	68	−111	1.59
N50		25	49	105	−44	0.11
N100	FSD, SSD, maximin	121	61	201	27	0.28
N150	FSD, SSD	135	74	226	13	0.64
N200	FSD, maximax	122	114	280	−89	0.65
V0		49	50	121	−16	0.04
V50	FSD	108	53	170	24	−0.54
V100	FSD	133	84	235	−21	−0.70
V150	FSD, SSD, max EV	138	82	256	23	−0.41
V200	FSD	128	89	245	−3	−0.33
C0		−1	43	93	−48	0.92
C50		68	63	143	−54	−0.77
C100		86	87	200	−67	−0.38
C150	FSD	113	100	268	−60	−0.07
C200		108	98	234	−68	−0.67

[a] Refer to table 1 footnote.
[b] FSD = first-degree stochastic dominance set, SSD = second-degree stochastic dominance set, maximin = maximized minimum net revenue, max EV = maximized expected net revenue, and maximax = maximized maximum net revenue.

mean net revenues are V150, N150, V100, V200, and N200 (table 2).

Risk-Efficient Systems

Analysis of net revenues found eight of the 15 distributions in the FSD set (table 2). The three FSD risk-efficient no-cover systems are N100, N150, and N200. The N100 and N150 systems are also SSD risk efficient, i.e., preferred by risk-averse individuals. N100 produced the largest minimum net revenue ($27/acre) and is preferred by extremely risk-averse individuals (maximin strategy). N150 maximized expected net revenue ($135/acre) for the no-cover systems. By contrast, N200 maximized maximum net revenue ($280/acre, maximax strategy) and is preferred by extreme risk-seeking individuals.

The four vetch cover crop systems in the FSD efficient set are V50, V100, V150, and V200. V150 produced the maximum expected net revenue among all treatments in the experiment ($138/acre) (table 2). The V150 system is also the only legume cover to be SSD risk efficient. V100 was the only legume system with an applied nitrogen rate less than 150 pounds/acre that produced an expected net revenue ($133/acre) similar to N150 and V150. The single crimson clover cover crop strategy in the FSD set is C150.

The above results for N150 and V150 have implications for farmers not currently using legume covers who maximize expected net revenue. If these risk-neutral farmers switch to a vetch cover system, they may be able to slightly increase expected net revenue by adopting V150. Therefore, risk-neutral farmers may have little incentive to reduce applied nitrogen when they adopt a vetch cover.

Ordering of Systems

The Riskroot computer program identified 27 breakeven risk-aversion coefficients for the strategies in the FSD set. Because of limited space, the BRACs reported in table 3 are for the maximum and minimum $r(x)$ values influencing the ordering of strategies, the $r(x)$ values where the number one ranking changes,

Table 3. Selected Breakeven Risk-Aversion Coefficients (BRACs) and Ordering of Legume Cover and Applied Nitrogen Systems in the FSD Risk-Efficient Set

		Ordering of Systems Above the BRAC[b]							
No.	BRAC[a]	1	2	3	4	5	6	7	8
1	0.024714	N100	V50	**V150**[c]	**N150**	V200	V100	C150	N200
5	0.012975	**N100**	**N150**	V150	V50	V100	V200	C150	N200
9	0.008170	**N150**	**V150**	N100	V100	V200	V50	C150	N200
15	0.000142	V150	N150	V100	V200	**N100**	**N200**	C150	V50
16	−0.002924	V150	N150	V100	**V200**	**N200**	N100	C150	V50
22	−0.008322	**V150**	**N200**	V100	V200	N150	C150	N100	V50
27	−0.017035	N200	**V150**	**C150**	V200	V100	N150	N100	V50

[a] Rounded to six decimal places.
[b] Refer to table 1 footnote.
[c] Boldface denotes the strategies (two in each row) where dominance switches at the BRAC.

and the $r(x)$ values where preferences change from risk averse to risk seeking. The ordering of systems from "best" to "worst" for $r(x)$ values between the BRACs is greatly influenced by the level of absolute risk aversion. Three of the no-cover strategies and one vetch cover strategy are ranked first depending on the level of absolute risk aversion: N100, N150, N200, and V150. The V150 system is ranked first most often for a wide range of risk-averse and risk-seeking behavior (between BRACs 9 and 22). Farmers preferring V150 may be able to take advantage of improved soil quality, reduced erosion, and other long-term soil improvements associated with winter covers without lowering expected net revenue. N150 is preferred by farmers who are more risk averse than those who rank V150 first (above BRAC 9), while extremely risk-averse farmers (above BRAC 5) would rank N100 first. By contrast, extremely risk-seeking decision makers (below BRAC 22) prefer the N200 system.

The orderings in table 3 have implications for farmers who are not currently using legume covers and wish to reduce applied nitrogen from the expected net revenue-maximizing V150 system. Risk averters above BRAC 9 who prefer N150 have little incentive to switch to a vetch system to provide nitrogen or to improve soil quality. However, farmers who are extremely risk averse would prefer to reduce applied nitrogen by 50 pounds/acre from the expected value-maximizing rate. Individuals who are less risk averse may prefer switching to a vetch cover system. These individuals may choose not to reduce applied nitrogen when they adopt a vetch cover. By contrast, extremely risk-seeking farmers would not adopt a vetch system to provide nitrogen or improve soil quality, but would have incentive to increase applied nitrogen by 50 pounds/acre above the expected value-maximizing rate.

Risk Premiums

Risk premiums for N150 compared with V150 are shown in figure 1A. These systems were compared to evaluate switching from the no-cover/net revenue-maximizing strategy to the vetch cover/net revenue-maximizing strategy. The premiums are presented as positive numbers when V150 is preferred to N150 between BRACs, and as negative numbers when N150 is preferred to V150. The risk premiums vary by less than $3/acre for different levels of farmer risk-aversion behavior (BRACs 1–15). At lower levels of cumulative probability, the two CDFs are very similar, resulting in the very small risk premiums shown in figure 1B. However, the premiums for risk seekers rise from $3.47/acre (BRAC 16) to $10.21/acre (BRAC 27). For risk seekers, V150 has a somewhat more favorable distribution of net revenue at higher cumulative probability levels (figure 1B). A factor that may explain this distribution of risk premiums is the ability of

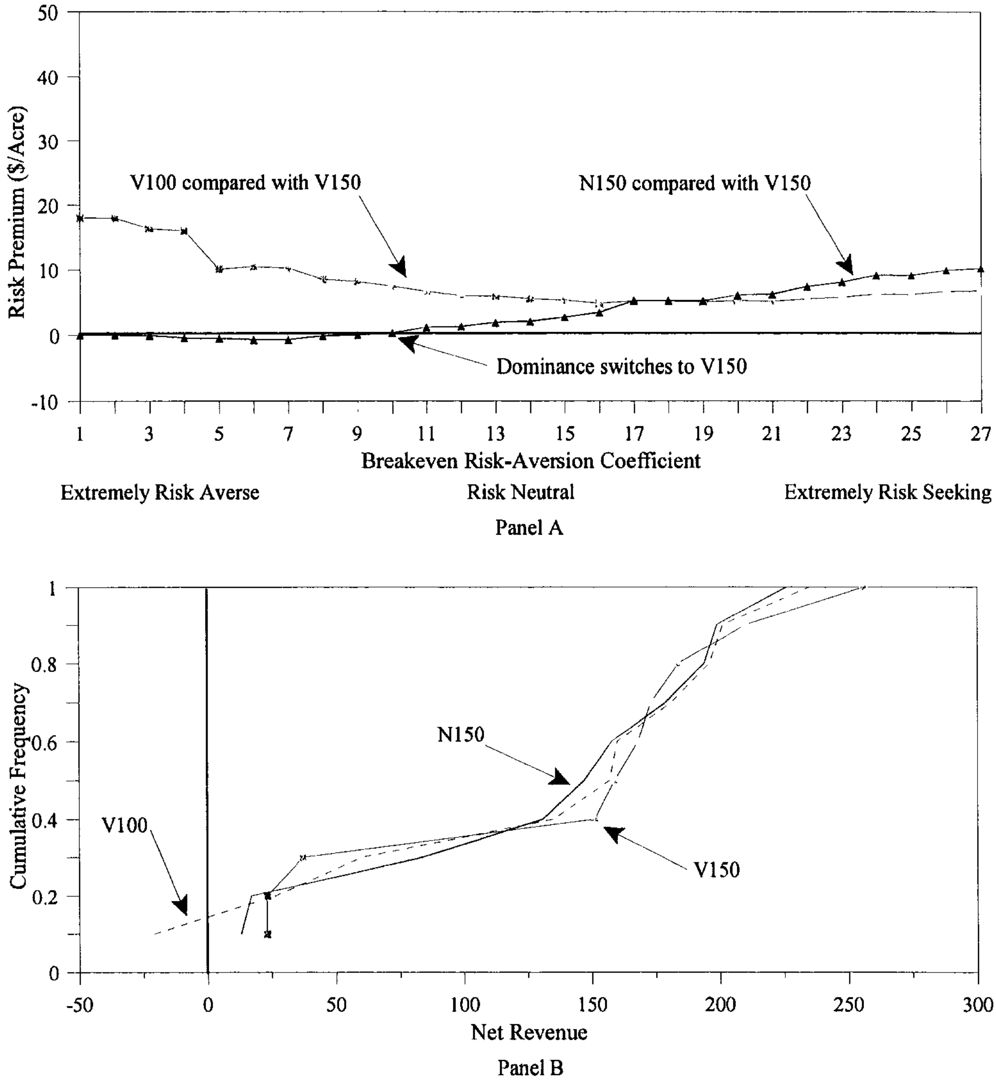

Figure 1. Lower-bound risk premiums and cumulative frequency distributions of net revenue for no cover, 150 lbs./acre applied nitrogen (N150) and vetch cover, 100 lbs./acre applied nitrogen (V100) compared with vetch cover, 150 lbs./acre applied nitrogen (V150)

legumes to be net producers or net consumers of nitrogen depending on available soil nitrogen and weather (Meisinger et al.). In years with good growing conditions, the V150 system may have provided additional nitrogen to the corn plant that resulted in higher yields and net revenues. In other years, vetch may have fixed little nitrogen or may have been a net consumer of nitrogen.

The second comparison illustrated in figure 1A is between V100 and V150. This comparison addresses the hypothesis that vetch may be more efficient at fixing nitrogen by reducing the applied nitrogen rate by 50 pounds/acre. V100 produced higher risk premiums for risk-averse farmers than for risk-seeking farmers. The premiums for risk-aversion behavior vary from $5.30/acre (BRAC 15) to $18.04/acre (BRAC 1). Net revenues for V100 were more variable at lower cumulative probability levels (figure 1B). By contrast, the risk premiums required to make risk-seeking individuals indifferent vary from $4.85/acre (BRAC 16) to $6.76/acre (BRAC 27). At higher levels of cumulative probability, V100 produced net revenues more similar to N150 and V150. Several factors may explain why V100 was risk inefficient even though it produced similar expected net revenue to V150 and N150. The availability of legume nitrogen is dependent on cover crop biomass production and the decay rate of the cover after it is killed, both of which are affected by weather. Harsh winters may decrease the winter cover stand and result in less nitrogen being available. Reducing applied nitrogen may also cause a more variable winter cover crop stand and growth after the stand is established, and will carry over into more variable corn yields. In addition, the crop decay and nitrogen release in a dry year may not be synchronized with the highest nitrogen requirement of the corn crop, thus increasing yield variability. The cover crop may compete for soil water in a dry year and reduce the amount available to the corn crop. In other years with favorable growing conditions, V100 may produce net revenues similar to N150 and V150.

The final two comparisons are between V50 and V150, and N100 and V150 (figure 2). These systems were compared to evaluate farmer willingness to pay for a reduced nitrogen system (legume and applied) using either a vetch cover or no cover. In contrast to V100, using the V50 system to reduce applied nitrogen by 100 pounds/acre from the expected net revenue-maximizing level produced a distribution of net revenue preferred by extremely risk-averse individuals (figure 2A). Extremely risk-averse farmers would be willing to pay a small risk premium varying from \$0/acre to \$2.34/acre for V50 (figure 2B). These risk premiums compare with \$7.78/acre to \$9.58/acre for N100 maximin strategy. At lower cumulative probability levels, net revenues are similar between V50 and N100; however, N100 produces larger net revenues at higher levels of cumulative probability. V50 may not be providing the same amount of nitrogen to the corn crop as N100 in some years because of weather. Risk premiums required to maintain indifference with V150 for farmers less risk averse than BRAC 5 are much larger for V50 when compared with N100. The premiums for V50 rise to a maximum of \$48.44/acre compared with \$30.06/acre for N100 (BRAC 27).

Nitrate Leaching Risk

For V100, the maximum nitrate contamination level of 10 mg/L was exceeded 17% of the time compared with 4% of the time for N100 (table 4). These results indicate that V100 may be risk inefficient in terms of both net revenue and nitrate leaching. N100 was more effective than V100 because of reduced nitrate-nitrogen levels between corn harvest in the fall and corn planting in the spring, which is the period of high leaching risk (Tyler et al.). At 100 pounds/acre applied nitrogen, the vetch cover may be fixing its own nitrogen during periods of high leaching risk.

If a farmer is interested in legume covers and reducing nitrate leaching, applying less than 100 pounds/acre nitrogen may be required for the vetch cover to achieve the same frequency of not exceeding the 10 mg/L maximum as for N100. Unfortunately, the impact of the V50 system on nitrate leaching risk was not quantified in the cover crop experiment. Notwithstanding the absence of leaching data for V50, the analysis of net revenues found that N100 was ranked above V50 for all risk-aversion coefficient levels (table 3). Farmers require much larger risk premiums for V50 compared with N100 to be indifferent with V150 (figure 2B). For farmers more risk averse than BRAC 6, N100 dominates V150, and reducing nitrate leaching may be compatible with risk attitude. Conversely, farmers who are less risk averse prefer V150 to N100, and limiting nitrate leaching may not be compatible with risk preferences. The impact of the V150 system on nitrate leaching risk also was not quantified in the cover crop experiment. As with V100, the V150 system may increase the frequency of nitrate concentrations above the maximum of 10 mg/L depending on whether vetch is a net provider or net consumer of nitrogen at 150 pounds/acre of applied nitrogen. Because V150 is risk efficient for a wide range of risk attitudes, the nitrate leaching risk for this legume cover

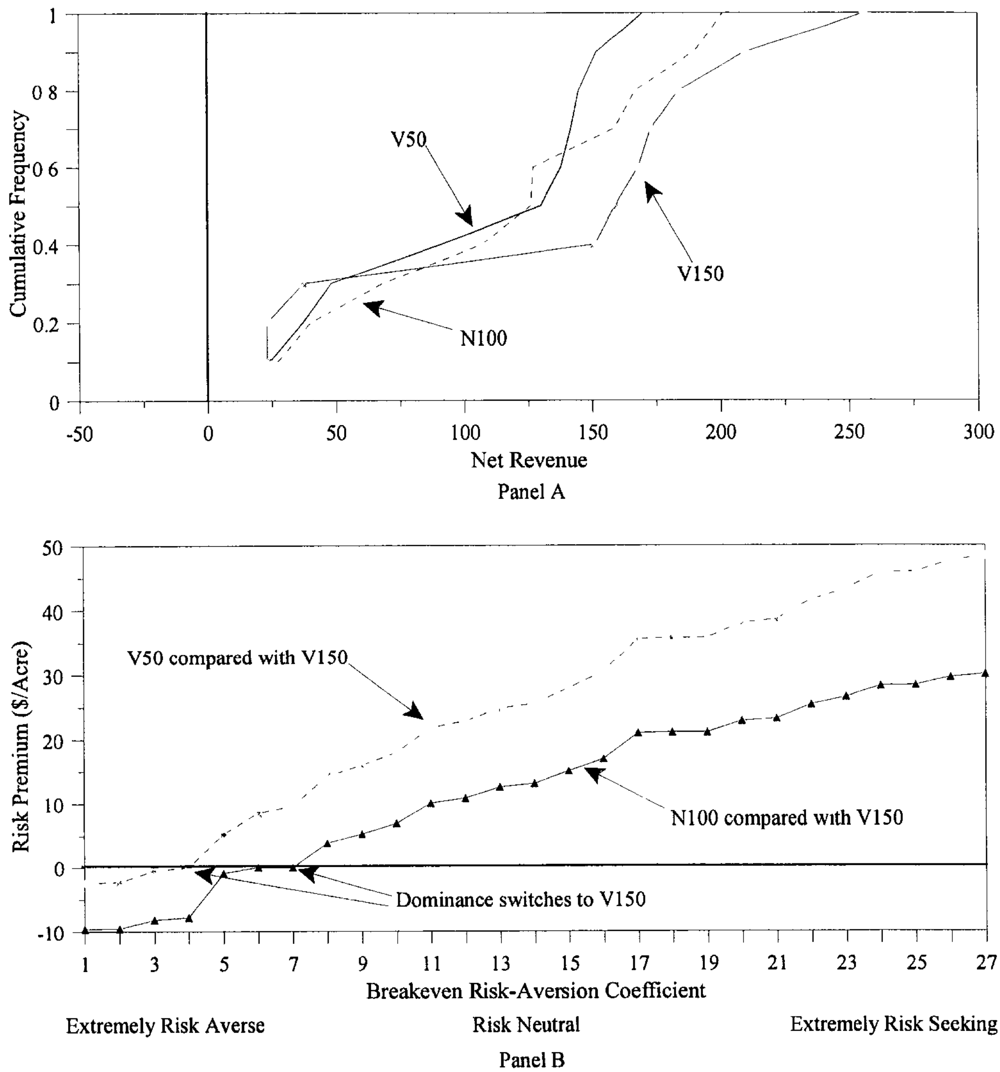

Figure 2. Cumulative frequency distributions of net revenue and lower-bound risk premiums for no cover, 100 lbs./acre applied nitrogen (N100) and vetch cover, 50 lbs./acre applied nitrogen (V50) compared with vetch cover, 150 lbs./acre nitrogen (V150)

strategy should be quantified before making a recommendation to farmers.

Summary

This study evaluated the risk efficiency of legume winter cover crops as a substitute for applied nitrogen for no-tillage corn production. The strategy that maximized expected net revenue was the vetch cover and 150 pounds/acre applied nitrogen. The expected net revenue was $138/acre compared with $135/acre for no cover and 150 pounds/acre applied nitrogen, and $133/acre for vetch cover and 100 pounds/acre applied nitrogen. Stochastic dominance ordering of net revenues indicates that vetch and 150 pounds/acre applied nitrogen is risk efficient for a wide range of risk-aversion and risk-seeking behavior. Farmers with these risk attitudes may choose not to reduce applied nitrogen when they adopt a vetch cover. Farmers who are moderately to extremely risk averse prefer either no cover and 150 pounds/acre applied nitrogen, or no cover and 100 pounds/acre applied nitrogen. These risk averters have little incentive to switch to a vetch

Table 4. Percentage of Samples with Nitrate-Nitrogen Concentrations Above 1, 5, and 10 mg/L for No-Tillage Corn, Milan, Tennessee

Nitrate-Nitrogen Concentration	Percent Winter Cover Crop[a]	
	N100	V100
1 mg/L	65	70
5 mg/L	12	33
10 mg/L	4	17

Source: Tyler et al., p. 2.
[a] N100 = no cover and 100 pounds/acre applied nitrogen; V100 = vetch cover and 100 pounds/acre applied nitrogen.

system to provide nitrogen or to improve soil quality. However, farmers who are extremely risk averse may prefer to reduce applied nitrogen by 50 pounds/acre from the expected value-maximizing rate. In contrast, no cover and 200 pounds/acre applied nitrogen is risk efficient for extremely risk-seeking individuals. These individuals may prefer to increase applied nitrogen but would not use a vetch cover to provide nitrogen or to improve soil quality.

The systems combining vetch covers with lower applied nitrogen fertilization (50 and 100 pounds/acre, respectively) produced risk-inefficient distributions of net revenue at all risk attitude levels. Farmers may not be willing to adopt legume winter crops as a method to reduce applied nitrogen because these crops produce risk-inefficient distributions of net revenues. The potential for increased nitrate leaching with vetch and 100 pounds/acre applied nitrogen may also increase environmental risk. Of the two systems studied, no cover and 100 pounds/acre applied nitrogen was better than vetch and 100 pounds/acre applied nitrogen at reducing nitrate leaching risk, and is preferred by extremely risk-averse decision makers. On the other hand, farmers who are less risk averse prefer vetch and 150 pounds/acre applied nitrogen, which may potentially increase nitrate leaching risk. However, the impact of this system on nitrate leaching risk was not measured in the cover crop experiment and should be quantified before making a recommendation to farmers about risk-efficient legume systems.

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