Effects of Risk, Disease, and Nitrogen Source on Optimal Nitrogen Fertilization Rates in Winter Wheat Production

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Abstract

Interactions among nitrogen (N) fertilization rate, N source, and disease severity can affect mean yield and yield variance in conservation tillage wheat production. A Just-Pope model was used to evaluate the effects of N rate, N source, and disease on the spring N-fertilization decision. Ammonium nitrate (AN) was the utility-maximizing N source regardless of risk preferences. The net-return-maximizing AN rate was 92 lb N/acre, providing $0.52/acre higher net returns than the best alternative N source (urea). If a farmer could anticipate a higher than average Take-All infection, the difference in optimal net-returns between AN and urea would increase to $35.11/acre.

Introduction

Efficient spring nitrogen (N) fertilization practices increase the economic benefit of N in wheat production (Fiez, Pan, and Miller). Although N fertilization increases wheat yield, it can also affect production risk as measured by yield variability (Just and Pope, 1979). In addition, interactions among N source (e.g., ammonium nitrate versus urea), N rate, and disease severity can affect yield (Colbach, Lucas, and Meynard; Wiese; MacNish; Brennan, 1992a; Brennan, 1992b) and may also affect production risk, leading some farmers to apply non-optimal amounts of N fertilizer (Peters et al.). Farmers may be able to achieve greater utility by adjusting the N fertilization rate and N source to account for the influence of N rate, N source, and disease on risk in wheat production.

Nitrogen fertilization was found to be risk increasing (Larson et al., 2001; Roumasset et al.; Just and Pope, 1979) and risk reducing (Larson et al., 1998; Antle and Crissman; Lambert). The potential impact of N fertilizer on risk is influenced by the crop production system (e.g., conservation versus conventional tillage) and other management factors in addition to N fertilization (Larson et al., 2001). Although, these studies evaluated the effects of risk on N fertilization, they did not evaluate the risk effects of alternative N sources in the presence of disease.

Glume-Blotch is a late-season grain-head infection (Ditsch and Grove) found in all wheat growing areas of the world (Bowden). It is most prevalent in high rainfall, humid areas (Stromberg) such as the southern United States (Howard et al.). Fungicide applications are often incomplete in controlling Glume-Blotch (Bowden). Although N fertilization is essential for increasing Soft Red Winter Wheat (wheat) yield, high spring N-fertilization rates can interact with Glume-Blotch to reduce yield potential (Boquet and Johnson). The lush vegetative growth that accompanies high N fertilization reduces air movement through the canopy, producing an environment more suited for Glume-Blotch development (Ditsch and Grove; Wiese). Without fungicide application in the presence of Glume-Blotch, higher N rates significantly reduced wheat yield (Kelley; Howard, Chambers, and Logan; Cox et al.; Roth and Marshell; Ditsch and Grove). Roth and Marshell showed that Glume-Blotch severity was lowest at a zero N rate and increased for rates above 70 lb N/acre; however, Orth and Grybauskas found that higher levels of N significantly decreased susceptibility to Glume-Blotch infection. Although these studies found that N rate affects Glume-Blotch severity and yield, they did not evaluate the effects of N rate and Glume-Blotch severity on risk and the N-fertilization decision. In addition, no other studies were found evaluating the effects of Glume-Blotch severity and risk on optimal N fertilization.

The lack of resistant varieties and chemical control make the fungal root disease, Take-All Root Rot (Take-All), the most important wheat root disease in the United States and in the world (Duffy and Weller; Monsanto). The severity of Take-All in wheat production was influenced by the N source, with more severe root damage in plots fertilized with nitrate (NO_3^-) compared with ammonium (NH_4^+) forms of N (Colbach, Lucas, and Meynard; Wiese; MacNish; Brennan, 1992a; Brennan, 1992b). Ammonium fertilizers may reduce Take-All severity because of decreased rhizosphere pH that promotes more vigorous root growth, allowing roots to escape severe disease damage (Brennan, 1989). Brennan (1992a) found that 100 lb N/acre significantly reduced Take-All severity when ammonium forms of N were applied to wheat. However, where Take-All was at high levels, ammonium forms of N were ineffective in reducing Take-All severity (MacNish). Howard et al. found that ammoniacal N sources (ammonium nitrate and ammonium sulfate) resulted in higher wheat yields than urea-containing N sources (urea and urea-ammonium nitrate) when Take-All was present. Yield losses for the urea-containing N sources were probably due to volatilization N losses and disease. These studies showed that N source and N rate can affect Take-All severity and yield; however, they did not evaluate the effects of N rate, N source, and Take-All severity on risk and the optimal wheat N-fertilization decision.

A comprehensive evaluation of the interactions among N rate, N source, Glume-Blotch and Take-All severity, and their effects on expected wheat yield and risk was not found (Walters). The objectives of this research were 1) to evaluate the effects of N source, N rate, and disease severity on risk, optimal N rate, expected yield, and net returns in conservation tillage wheat production, and 2) to evaluate the risk-return tradeoffs among alternative N sources for farmers with different risk preferences.

Yield Data

Wheat yields for 1998 through 2000 were obtained from an N-fertilization experiment on conservation tillage wheat at the West Tennessee Experiment Station, Jackson, Tennessee

(Howard et al.). Planting dates were 22 October 1997, 9 October 1998, and 15 October 1999. The experimental design was a randomized complete block with split plots. Treatments were replicated five times. Main plots were treated with 0, 30, 60, 90, 120, and 150 lb N/acre around 1 March at Feekes' Growth Stage (GS) 6 (Large) when the first node of the stem was visible. Sub-plots included three N sources: ammonium nitrate (AN), urea, and urea-ammonium nitrate (UAN). AN and urea were broadcast as dry fertilizers, while UAN was broadcast as a liquid. Individual plots were 40 feet long and 12 feet wide. Glume-Blotch affected the 1998 crop and Take-All affected the 2000 crop. Both diseases occurred naturally. In 1998, Propiconazole was applied at 0.030624 gal/acre at GS 9 with a second application at GS 10 before heading. In 1999 and 2000, a single application of Quadris was applied at 0.0616704 gal/acre at GS 9. Propiconazole and Quadris are both foliar fungicides used to control Glume-Blotch severity (Bailey). No chemicals were applied to control Take-All because no effective chemical control exists to limit Take-All severity (Colbach, Lucas, and Meynard). Disease ratings were recorded each year at GS 10.1 when the sheath of the last leaf was completely grown out. Disease ratings were recorded on a scale of 0 to 10, with 10 being the most severe disease rating. Plots were harvested mid-June.

Methods

Farmers can use measures of expected net return and net-return variance to make agricultural production decisions such as the one addressed in this research (Barry). The Just-Pope (1978, 1979) model was chosen to evaluate the risk-return tradeoffs of the N-fertilization decision in wheat production. This method isolates the impacts of changes in input use on expected yield and yield variance. Among others, this method has been used to evaluate the risk effects of: 1) N as a non-point pollution problem with alternative policies and farmer response to those policies (Lambert); 2) genetic improvement on wheat yields during the green revolution (Traxler et al.); 3) winter cover crop, tillage, and N-fertilization systems in cotton production (Larson et al., 2001); 4) genetic resources and diversity variables in wheat production (Smale et al.); 5) variable rate N application in corn production (Larson, English, and Roberts); 6) integrated pest management in cotton production (Hurd), and 7) input use in farm-raised salmon production (Asche and Tveteras). Results from the Just-Pope model can be used to determine the level of input that maximizes certainty-equivalent net return (Lambert; Larson et al., 2001; Larson, English, and Roberts).

The Just-Pope model takes the form:

(1) $$Y_t = f(X_t,\beta)+h^{1/2}(Z_t,\alpha)\varepsilon_t,$$

where Y is wheat yield; X and Z are matrices of explanatory variables; t is a subscript for year; β and α are parameter vectors; ε is a random error term with a mean of zero; f is the mean yield production function that relates X_t to mean yield; and $h^{1/2}$ is the yield standard deviation function that associates Z_t with yield standard deviation and with yield variance through h.

Data from the aforementioned experiment were used to evaluate the N-fertilization decision in wheat production as affected by three N sources, two diseases, six N-fertilization rates, and risk under the maintained assumption that the farmer attempts to control Glume-Blotch with the fungicides in the amounts applied in the experiment, or ones of similar effectiveness. This maintained assumption was needed because the same amount of fungicide was applied each year to all plots, and a fungicide application variable would produce perfect collinearity in the econometric analysis of the Just-Pope model.

The mean yield production function for each N source was estimated as:

(2) $$Y_t = \beta_0 + \beta_1 N_t + \beta_2 N_t^2 + \beta_3 G_t + \beta_4 N\times G_t + \beta_5 TA_t + \beta_6 N\times TA_t + e_t,$$

where Y was wheat yield (bu/acre); N was the N rate (lb/acre); G was the natural logarithm of the Glume-Blotch rating from 0.01 to 10, with 0.01 being no disease present and 10 being the most severe disease rating; N×G was the interaction between N and G; TA was the natural logarithm of the Take-All rating from 0.01 to 10, with 0.01 being no disease present and 10 being the most severe disease rating; N×TA was the interaction between N and TA; β_i (i = 0,1,…, 6) were parameters to be estimated; and e was a random error with a mean of zero.

The quadratic functional form for N was chosen because low amounts of N fertilization generally increase wheat yields, while excessive N fertilization can reduce wheat yields by increasing the potential for lodging and delayed maturity (McKenzie; Vitosh; Beuerlein and Lipps). Yield response to N fertilization was hypothesized to exhibit diminishing marginal productivity ($\beta_1 > 0$, $\beta_2 < 0$).

The Glume-Blotch and Take-All severity ratings in the experiment were visual ratings related to the condition of the wheat plant. Implicit in the logarithmic functional forms for these disease ratings is the assumption that increases in ratings at the lower end of the scale (e.g., from 1 to 2) reduce yields by larger amounts than increases in ratings at the upper end of the scale (e.g., from 9 to 10). The logarithmic functional form required that the zero disease rating be replaced by a number close to zero, in this case 0.01, because the natural logarithm of zero is undefined. Glume-Blotch severity (β_3 and β_4) and Take-All severity (β_5 and β_6) were hypothesized to negatively influence mean yield.

Efficiency gains in parameter estimates are possible with Weighted Least Squares (WLS) when multiplicative heteroscedasticity is found. Multiplicative heteroscedasticity in the mean yield functions was tested using the Breusch-Pagan statistic (Breusch and Pagan) and the model F-statistic from the yield variance function. When evidence of heteroscedasticity was found for a particular N source, predicted values from the estimated yield variance function were used as weights in producing WLS estimates for the mean yield function for that N source.

Exponential yield variance functions were estimated as (Hurd; Traxler et al.):

(3) $\ln\hat{e}_t^2 = \alpha_0 + \alpha_1 N_t + \alpha_2 N_t^2 + \alpha_3 G_t + \alpha_4 N\times G_t + \alpha_5 TA_t + \alpha_6 N\times TA_t + u_t$,

where $\ln\hat{e}_t^2$ was the natural logarithm of the squared residuals from the estimation of Equation (2); α_i (i = 0,1,…, 6) were parameters to be estimated; and other variables were defined in Equation (2). Although u_t does not have a zero mean, this specification allowed asymptotically valid hypothesis testing of marginal risk effects (Harvey; Hurd; Traxler et al.).

Previous literature did not lend itself to developing firm hypotheses about the signs of the N parameters (α_1, α_2, α_4, and α_6). Several previous studies found that N fertilization increased risk (e.g., Roumassett et al.), while others found that it reduced risk (e.g., Antle and Crissman; Lambert). Therefore, the expected effect of N rate on wheat yield variance was uncertain.

Larson et al. (2001) hypothesized that increased weed and insect pressure would increase yield variance in cotton production. As with weed and insect pressure, Glume-Blotch and Take-All may increase wheat yield variance because of their random effects on yields, but they may also decrease yield variance if they tend to equalize yields by disproportionately reducing yields in highly productive areas of a field and in good weather years when lush vegetative growth is more conducive to disease development. Thus, the effects of Glume-Blotch and Take-All severity on yield variance were uncertain.

The partial derivatives of the exponential of Equation (3) with respect to N rate, Glume-Blotch rating, and Take-All rating were evaluated at the means of the variables for each N source to estimate marginal effects on risk. Joint F-statistics were used to test the null hypothesis that the coefficients for N, N^2, N×G, and N×TA were jointly equal to zero for each N source.

Rejection of the null hypothesis for a particular N source would suggest that N rate significantly affected yield variance when N was applied using that N source. Similar F-tests were performed for the Glume-Blotch severity coefficients (G and N×G) and the Take-All severity coefficients (TA and N×TA).

The estimated mean yield response and yield variance functions for each N source were used to predict certainty-equivalent-optimizing N fertilization rates, yields, and net returns above N costs. Expected net returns above N costs and net-return variances were calculated using an average wheat price of $3.43/bu for 1991-2000 (Tennessee Department of Agriculture). Wheat prices were inflated to 2002 dollars by the Gross Domestic Product Implicit Price Deflator (U.S. Department of Commerce: Bureau of Economic Analysis) before averaging. Average retail prices paid by Tennessee farmers in 2002 for pure N were: AN, $0.26/lb; urea, $0.21/lb; and UAN, $0.23/lb (Duke, Personal Communication, Tennessee Farmers Cooperative). These prices included the cost of application equipment, but not the cost of the tractor to pull the equipment. Tractor costs were assumed equal across N sources because the dry and liquid N sources evaluated have about the same tractor-size and speed requirements for broadcast application. Other wheat production costs were also assumed constant among N sources.

Certainty equivalent net return per acre (CE) was approximated as (Robison and Barry):

(4) $CE = E(NR) - \lambda/2 \, Var(NR)$,

where E(NR) was expected net return; λ was the Pratt-Arrow absolute risk aversion coefficient; and Var(NR) was the variance of net returns. Freund showed that the linear mean-variance objective function is consistent with normally distributed profits and the negative exponential utility function (or exponential utility function), which exhibits constant absolute risk aversion. E(NR) was calculated as:

(5) $E(NR) = (\hat{Y} * \overline{WP}) - (\hat{N} * \overline{NP})$,

where $\hat{Y}$ was mean wheat yield predicted from the mean yield function estimated in Equation (2) (bu/acre); $\overline{WP}$ was average wheat price from 1991-2000 in 2002 dollars ($/bu); $\hat{N}$ was the N rate associated with $\hat{Y}$ (lb/acre); and $\overline{NP}$ was the 2002 price of N ($/lb). Var(NR) was calculated as (Bohrnstedt and Goldberger):

(6) $Var(NR) = (\hat{Y}^2)\sigma^2_{WP} + \overline{WP}^2(\sigma^2_Y) + \sigma^2_{WP}(\sigma^2_Y)$,

where σ^2_{WP} was the wheat price variance from 1991-2000 in 2002 dollars ($/bu); σ^2_Y was the variance of wheat yield obtained by taking the exponential of the yield variance function estimated in Equation (3) (bu/acre), and other variables were defined in Equation (5).

The CE-maximizing N fertilization rate for each N source was found by solving:

(7) $Max\ CE = E(NR) - \lambda/2\ Var(NR)$, s.t. $0 \leq N \leq 150$ lb N/acre.

Maximum CE was constrained within the range of N-fertilization rates in the experimental data. Equation (7) 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 and Larson et al. (2001).

Results and Discussion

Mean Yields

The estimated mean wheat yield functions are presented in Table 1. The mean yield functions for urea and UAN were estimated with WLS after Breusch-Pagan statistics and F-statistics from the yield variance functions (Table 2) suggested the possibility of multiplicative heteroscedasticity. The adjusted R^2 coefficients in Table 1 suggest that considerable amounts of variation in wheat yields were explained by the nitrogen and disease variables. The coefficients for N and N^2 had the hypothesized signs and were statistically significant for each N source.

Glume-Blotch (G) and Take-All (TA) severity significantly reduced wheat yields for each N source, as did the N-Take-All interactions (NxTA) for urea and UAN. The N-Take-All interaction for AN and the N-Glume-Blotch interactions (NxG) for all N sources were not significantly different from zero. Multicollinearity diagnostics found that the mean yield functions did not have condition indexes greater than 20, which was the lower threshold suggested by Belsley, Kuh, and Welsch, indicating that the standard errors of the coefficients were not seriously degraded.

Yield Variances

The estimated yield variance functions are presented in Table 2, as are the marginal effects of the explanatory variables on yield variances evaluated at the means of the variables. The F-statistics and marginal risk effects indicate that N rate and Take-All severity increased yield variance for urea, that Glume-Blotch severity did not affect yield variance for any N source, and that none of the variables affected yield variances for AN and UAN. Results suggest that risk averse wheat farmers may adjust the ranking of preferred N sources with higher levels of anticipated Take-All severity, but that Glume-Blotch severity may not be useful in differentiating among N sources for farmers with different levels of risk aversion.

Risk-Return Tradeoffs

Optimal N rates, wheat yields, net returns, and certainty equivalent net returns per acre for each N source under the assumptions of risk neutrality ($\lambda = 0$) and two level of risk aversion ($\lambda = 0.01$ and $\lambda = 0.02$) are presented in Table 3. When the disease variables (G and TA) were at their three-year means (upper half of Table 3), the optimal N rate for a risk neutral farmer was lowest for AN at 92 lb N/acre compared with 147 and 126 lb N/acre for urea and UAN, respectively. AN had an optimal yield of 68 bu/acre that was 2 bu/acre less than the 70 bu/acre optimal yield for urea. Although AN produced a lower optimal yield, the lower N rate gave it the highest optimal net return of $209.14. AN was the optimal N sources for a net-return-maximizing farmer, producing $0.52/acre higher net return than the next best N source (urea) using 55.4 lb/acre less N. A lower optimal yield of 65 bu/acre gave UAN the lowest maximum net return of $193.61/acre; $15.53/acre less than the optimal net return for AN. Thus, a net-return-maximizing wheat farmer would rank the N sources as AN preferred to urea and urea preferred to UAN.

The larger effect of N rate on yield variance for urea than for AN and UAN is manifest in the widening gap between CEs for AN and urea and the narrowing of the gap between CEs for urea and UAN. The CE gap between AN and urea increases from $0.52/acre to $9.94/acre, while the CE gap between urea and UAN narrows from $15.01/acre to $2.16/acre as λ increases from 0 to 0.02. As expected from the lack of statistically different marginal N-rate effects on yield variances among N sources, increasing risk aversion did not affect the preference rankings of N sources when evaluated at the means of the variables. Thus, AN is the preferred N source regardless of risk preferences.

Because the marginal effect of Take-All severity on yield variance was statistically significant for urea only, and different than the marginal yield-variance effects for AN and UAN, a question remains about whether the ranking of N sources would change if a farmer anticipated Take-All severity at the higher level found in the experiment in 2000. The lower half of Table 3 shows that when Take-All severity is at its 2000 average level, AN is still the net-return and utility-maximizing N source. The risk neutral farmer who fertilizes with AN has a $35.58/acre advantage over the one who fertilizes with urea ($127.47/acre - $91.89/acre) and a $41.90/acre advantage over the farmer who fertilizes with UAN. The preference ranking of N sources remains as before with AN preferred to urea and urea preferred to UAN for the risk neutral farmer. The ranking of N sources changes for risk averse farmers in that UAN is preferred to urea when $\lambda = 0.01$ and $\lambda = 0.02$. Regardless of the ranking of urea and UAN, AN is still the net-return and utility-maximizing N source. Thus, the decision to apply AN is robust over a wide range of risk preferences and disease severity levels.

Summary and Conclusions

This study evaluated the mean yield and risk effects of alternative N sources and N rates for wheat production in the presence of the diseases Glume-Blotch and Take-All. A Just-Pope model was developed to analyze the risk effects of alternative N sources and to evaluate risk-return tradeoffs among N sources.

Results suggest: 1) the marginal effects of N rate and Take-All severity on wheat yield variance were statistically significant for urea but not for AN and UAN; 2) Glume-Blotch severity did not have a significant marginal effect on yield variance for any N source; 3) AN required considerably less N fertilizer to achieve optimal yield than did urea and UAN giving AN the highest optimal net return among the three N sources even though yield was slightly lower than when urea was the N source; 4) risk-return tradeoffs suggest that the N rate had no effect on the utility-maximizing N source at different absolute risk aversion levels; and 5) anticipation of higher than average Take-All severity would make AN an even more attractive N source compared to urea or UAN.

The small effects in the experiment of the N fertilization rate on yield variances suggest that risk is not a significant factor in the wheat N-fertilization decision. This finding is important to wheat farmers in West Tennessee and surrounding states with similar expected disease levels and growing conditions because AN is the optimal N source under a wide variety of risk preferences and disease-severity levels; thus, wheat farmers can apply AN instead of urea or UAN with confidence. The estimated yield response functions in this article indicate that wheat farmers in West Tennessee, or in other areas with similar conditions, would maximize net returns by fertilizing with AN at around 92 lb N/acre, whereas the optimal AN rate would decrease by only a small amount to 88 lb N/acre if the 2000 average Take-All severity level occurred. In addition, risk averse farmers ($\lambda = 0.02$) would maximize utility by fertilizing with only slightly less AN at around 86 to 87 lb N/acre.

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Table 1. Estimated Mean Wheat Yield Response Functions for Alternative N Sources

	Nitrogen Source		
Variable[a]	AN[b]	Urea[c]	UAN[c]
Intercept	11.54***	11.20***	11.89***
	(2.74)[d]	(3.78)	(3.25)
N	0.55***	0.29***	0.29***
	(0.05)	(0.08)	(0.06)
N^2	-0.0026***	-0.0010***	-0.0011***
	(0.0003)	(0.0004)	(0.0003)
G	-4.33***	-4.64***	-4.94***
	(0.48)	(0.61)	(0.54)
N×G	0.004	-0.001	0.005
	(0.005)	(0.007)	(0.006)
TA	-6.02***	-5.94***	-5.49***
	(0.64)	(0.66)	(0.55)
N×TA	-0.005	-0.023***	-0.025***
	(0.006)	(0.008)	(0.006)
Adjusted R^2	0.89	0.85	0.90
n[e]	90	89	90
Breusch-Pagan	5.85	23.09***	17.25***

[a] Wheat yield (bu/acre) is the dependent variable; N is pure nitrogen applied (lb/acre); G is the natural logarithm of the Glume-Blotch rating from 0.01 to 10, with 0.01 being no disease present and 10 being the most severe disease rating; N×G is the interaction between N and G; TA is the natural logarithm of the Take-All rating from 0.01 to 10, with 0.01 being no disease present and 10 being the most severe disease rating; and N×TA is the interaction between N and TA.

[b] Ordinary Least Squares results.

[c] Weighted Least Squares results.

[d] Numbers in parenthesis are standard errors.

[e] Urea has one less observation because of missing data.

*** Significantly different from zero at the 1% level.

Table 2. Estimated Wheat Yield Variance Functions and Marginal Risk Effects for Alternative Nitrogen Sources

Variable[a]	Nitrogen Source		
	AN	Urea	UAN
Intercept	3.06***	1.18	1.01
	(1.16)[b]	(0.83)	(0.96)
N	-0.008	0.04**	-0.02
	(0.023)	(0.02)	(0.02)
N^2	0.00001	-0.0001	-0.00001
	(0.00013)	(0.0001)	(0.00011)
G	0.21	-0.07	-0.16
	(0.21)	(0.15)	(0.17)
N×G	-0.002	-0.002	0.0007
	(0.002)	(0.002)	(0.0019)
TA	0.32	-0.19	-0.22
	(0.22)	(0.15)	(0.18)
N×TA	-0.002	0.005***	0.003
	(0.002)	(0.002)	(0.002)
Model F-statistic	0.64	2.85***	0.75
Adjusted R^2	-0.03	0.11	-0.02
n	90	89	90
Marginal Risk Effects			
N[c]	0.027	0.629**	-0.024
	(0.44)	(2.96)	(0.67)
Glume Blotch[d]	0.194	-4.532	-0.050
	(0.54)	(0.84)	(0.74)
Take-All[e]	1.110	5.901***	0.003
	(1.32)	(7.56)	(1.12)

[a] The dependent variables are the natural logarithms of the squared residuals from the respective mean wheat yield functions in Table 1. Variables are defined in Table 1.

[b] Standard errors for the yield variance functions and F-statistics for the marginal risk effects.

[c] Partial derivative of the exponential of the estimated wheat yield variance function with respect to N evaluated at the means of the variables. The F-statistic test the null hypothesis that the coefficients for N, N^2, N×G, and N×TA are jointly equal to zero.

[d] Partial derivative of the exponential of the estimated wheat yield variance function with respect to the Glume-Blotch rating evaluated at the means of the variables. The F-statistic tests the null hypothesis that the coefficients for G and N×G are jointly equal to zero.

[e] Partial derivative of the exponential of the estimated wheat yield variance function with respect to the Take-All rating evaluated at the means of the variables. The F-statistic tests the null hypothesis that the coefficients for TA and N×TA are jointly equal to zero.

***, ** Significantly different from zero at the 1% and 5% levels, respectively.

Table 3. Risk-return Tradeoffs for Alternative Nitrogen Sources

Nitrogen Source	Coefficient of Absolute Risk Aversion		
	λ=0.00	λ=0.01	λ=0.02
Variables at Three-year Means[a]			
Ammonium Nitrate (AN)			
Nitrogen Fertilizer (lb/acre)	91.9	89.8	87.1
Wheat Yield (bu/acre)	67.9	67.8	67.5
Net Return ($/acre)	209.14	209.10	208.93
Certainty Equivalent ($/acre)	209.14	194.67	180.29
Urea			
Nitrogen Fertilizer (lb/acre)	147.3	140.6	128.2
Wheat Yield (bu/acre)	69.8	69.4	68.3
Net Return ($/acre)	208.62	208.46	207.37
Certainty Equivalent ($/acre)	208.62	189.26	170.35
Urea-Ammonium Nitrate (UAN)			
Nitrogen Fertilizer (lb/acre)	125.6	121.7	116.8
Wheat Yield (bu/acre)	64.9	64.6	64.2
Net Return ($/acre)	193.61	193.56	193.32
Certainty Equivalent ($/acre)	193.61	180.83	168.19
Take-All Rating at 2000 Mean[b]			
Ammonium Nitrate (AN)			
Nitrogen Fertilizer (lb/acre)	88.4	87.3	86.0
Wheat Yield (bu/acre)	43.9	43.8	43.7
Net Return ($/acre)	127.47	127.46	127.42
Certainty Equivalent ($/acre)	127.47	120.88	114.31
Urea			
Nitrogen Fertilizer (lb/acre)	102.9	74.6	61.9
Wheat Yield (bu/acre)	33.1	30.6	28.9
Net Return ($/acre)	91.89	89.14	86.12
Certainty Equivalent ($/acre)	91.89	81.47	74.99
Urea-Ammonium Nitrate (UAN)			
Nitrogen Fertilizer (lb/acre)	81.3	79.7	77.9
Wheat Yield (bu/acre)	30.4	30.3	30.2
Net Return ($/acre)	85.57	85.56	85.53
Certainty Equivalent ($/acre)	85.57	82.72	79.89

[a] Glume-Blotch and Take-All ratings at three-year means.

[b] Glume-Blotch rating at three-year mean and Take-All rating at 2000 means.