Effects of Risk on Optimal Nitrogen Fertilization Dates in Winter Wheat Production as Affected by Disease and Nitrogen Source

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Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Mobile, Alabama, February 1-5, 2003

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Introduction

Timing of nitrogen (N) fertilization in wheat production is an important management decision (Boman et al.). N fertilization increases wheat yields and can affect production risk (Just and Pope, 1979) measured by yield variability (risk). Yield and risk also can be affected by interactions among N timing, N source and disease severity (Alcoz, Hons, and Haby; Eilrich and Hageman). If N fertilization is not timed for accelerated N uptake by the plant, optimal yields are not obtained. By adjusting the date of N fertilization to optimize N uptake, farmers can achieve greater economic returns.

Previous research found that applying N at Feekes' Growth Stages 4 to 6 (Figure 1) significantly increased yields (Alcoz, Hons, and Haby). However, Boman et al. found that N can be delayed until later in the season without significantly affecting yield. Because disease stress can reduce N uptake (Dilz et al.), N timing and fungicide applications should be based on the characteristics of each wheat crop and environment (Roth and Marshell). These studies evaluated the effects of N timing and disease severity on yield; however, they did not evaluate the risk effects of N timing in the presence of disease.

Glume-Blotch is a late-season head infection (Ditsch and Grove). Although N fertilization is an important determinant of wheat yield (Beuerlein, Oplinger, and Reicosky), it can interact with Glume-Blotch to limit yield (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 levels significantly reduced wheat yield (Kelley; Howard, Chambers, and Logan; Cox et al.; Roth and Marshell; Ditsch and Grove). Although these studies found that N timing affects Glume-Blotch severity and yield, they did not evaluate the risk effects of N timing and Glume-Blotch severity on the N-timing decision.

Take-All infections in autumn or early spring are most likely to affect wheat yield (Wiese), while later infections are less likely to affect yield. The severity of this root disease 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 a decrease in rhizosphere pH that promotes more vigorous root growth, allowing roots to escape severe disease damage (Brennan, 1989). However, where Take-All is at high levels, ammonium forms of N are ineffective in reducing Take-All severity (MacNish). These studies showed that N source and N rate affect Take-All severity and yield, but they did not evaluate the risk effects of N timing, N source and Take-All severity.

A comprehensive evaluation of the interactions among N timing, N source, Glume-Blotch and Take-All severity, and their effects on expected yield and risk has not been found (Walters). Our objective was to evaluate the effects of N source, N timing, and disease severity on expected yield and risk in winter wheat production and to evaluate the risk-and-return trade-offs between N sources for farmers with different risk preferences.

Analytical Framework

Farmers can use measures of expected yield and risk to make decisions about wheat production (Barry). A Just-Pope econometric analysis is one method for evaluating risk. It isolates the impacts of changes in input use on expected yield and risk. This method has been used to evaluate the risk effects of genetic improvement of wheat yields during the green revolution (Traxler et al.); winter cover crop, tillage, and N fertilization systems in cotton production (Larson et al.); the relationship between genetic resources and diversity variables in wheat production (Smale et al.); and N as a non-point pollution problem with alternative policies and farmer response to those policies (Lambert).

The Just-Pope econometric model takes the form:

(1) $Y_t = f(X_t,\beta)+h(Z_t,\alpha)\varepsilon_t$,

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; and ε is a random error term with a zero mean. The production function, $f(X_t,\beta)$, relates X_t to mean wheat yield. The variance function, $h(Z_t,\alpha)$, associates Z_t with risk.

Data and Empirical Methods

Yield Data

Wheat yields for 1998 through 2000 were obtained from a wheat fertilization experiment at the West Tennessee Experiment Station, Jackson, Tennessee (Howard et al.). Planting dates were 22 Oct. 1997, 9 Oct. 1998, and 15 Oct. 1999. The experimental design was a split plot with treatments replicated five times. Main plot treatments were fertilized on 15 February, 1 March, 15 March, 1 April, and 15 April. These dates corresponded to Feekes' Growth Stages (GS) 5, 6, 8, 9, and 10 (Large). The N sources and fertilization rate were Ammonium Nitrate (AN) and Urea-Ammonium Nitrate (UAN), both applied at 90 lb N/acre. 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 gallons per acre at GS 9 with a second application at GS 10 before heading to control Glume-Blotch severity. In 1999 and 2000, a single application of Quadris was applied at 0.0616704 gallons per acre at GS 9 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 zero to ten, with ten being the most severe disease rating and zero being no disease present. Plots were harvested mid-June.

Empirical Model

A Just-Pope model was used to evaluate the risk effects of two N sources and two diseases at five N fertilization dates. The mean yield production function, $f(X_t,\beta)$, for each N source was first estimated with Ordinary Least Squares (OLS) as a quadratic function of the fertilization-date management variable;

(2) $Y_t = \beta_0+\beta_1 T_t+\beta_2 T_t^2+e_t,$

where Y was wheat yield (bu/acre), T was the day of the year when N was applied; t was a subscript indicating year; β_0, β_1 and β_2 were parameters to be estimated; and e was a random error term with a zero mean. The mean yield function was hypothesized to be concave ($\beta_1 > 0$, $\beta_2 < 0$).

The variance of yield function, $h(Z_t,\alpha)\varepsilon_t$, was estimated using the residuals obtained from the mean yield production function. Because Glume-Blotch and Take-All severity affect wheat yield differently (Boquet and Johnson; Colbach, Lucas, and Meynard), variance of yield was specified as a function of T, Glume-Blotch rating, Take-All rating, two dummy variables for disease presence, an interaction between T and Glume-Blotch rating, and an interaction between T and Take-All rating. The Just-Pope approach allowed direct statistical testing of hypotheses about how T, Glume-Blotch severity, and Take-All severity interact to influence risk in wheat production for the two N sources. The variance of yield function for each N source was specified as:

(3) $\ln\hat{e}_t^2 = \alpha_0+\alpha_1 T_t+ \alpha_2 G_t+\alpha_3 DG_t+\alpha_4 TG_t+\alpha_5 A_t+\alpha_6 DA_t+\alpha_7 TA_t+u_t$,

where $\ln\hat{e}_t^2$ was the natural log of the squared residuals from equation 2; T was the day of the year when N was applied; G was Glume-Blotch rating, with 10 being the most severe disease rating and zero indicating no disease; DG was equal to one when Glume-Blotch was present and zero otherwise; TG was an interaction term between N timing and Glume-Blotch rating; A was the Take-All rating, with 10 being the most severe disease rating and zero indicating no disease; DA was equal to one when Take-All was present and zero otherwise; TA was an interaction term between N timing and Take-All rating; α_i ($i = 0,1,\ldots, 7$) were parameters to be estimated; and u was a random error term with a zero mean.

Efficiency gains in parameter estimates are possible with weighted least squares (WLS) when multiplicative heteroscedasticity is found. Multiplicative heteroscedasticity in the mean yield functions (2) was tested using the model F-statistic from the individual N source variance functions (Judge et al.). If the F-statistic was significant, the null hypothesis of homoscedasticity was rejected and multiplicative heteroscedasticity was assumed. Predicted values from equation 3 were used as weights for producing WLS estimates for the mean yield function (equation 2) for each N source.

Net returns 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. Tennessee average retail prices paid by farmers in 2002 for pure N were: AN, \$0.26/lb and UAN, \$0.23/lb (J. Duke, Personal Communication, Tennessee Farmers Cooperative). Other production costs were held constant between the two N sources.

The estimated mean yield response and variance functions for each N source were used to predict certainty-equivalent-optimizing N fertilization dates, yields, and net returns above N costs. Certainty equivalent of per-acre profit was approximated as (Robison and Barry):

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

where E(NR) was expected net return; λ was the value of the Pratt-Arrow absolute risk aversion coefficient; and Var(NR) was the variance of net return. E(NR) was calculated using:

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

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

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

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 from the yield variance function (bu/acre), and other variables were defined in equation 5.

The certainty-equivalent-maximizing N fertilization date for each N source was found by solving:

(7) $\text{Max } CE = E(NR) - \lambda/2\ Var(NR)$,

s.t. $46 \leq T \leq 105$.

Maximum CE was constrained by the range of N fertilization dates 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. The value to a farmer of the information about wheat yield and risk developed in this research was estimated for each level of risk aversion as the difference between the maximum CEs for the two N sources.

Results and Discussion

Mean Yields

The mean yield response functions were estimated with WLS (Table 1) after the F-statistics for the variance of yield functions indicated multiplicative heteroscedasticity. The WLS coefficients for T and T^2 had the hypothesized signs. Results indicate that little difference existed in optimal fertilization dates between the N sources. Maximum yields were obtained for AN and UAN on March 8 and 9, respectively.

Variance of Yields

The low R^2 coefficients for the WLS regressions indicate that the management variable T explained little of the variation in wheat yield (Table 1). Error sums of squares from the OLS regressions for the mean yield functions indicate that AN and UAN did not produce significantly different variation in wheat yields ($F = 0.10$, df 72/72), suggesting that variation in wheat yield was the same for both N sources at average disease levels.

The variance of yield functions, which quantify the effects of disease on yield variance by N source, are presented in Table 2 and joint F-statistics for the fertilization date and disease coefficients are presented in Table 3. The fertilization date (T, TG, TA) and Glume-Blotch (G, DG, TG) coefficients were not significantly different from zero for either N source (Table 2). However, the Take-All rating coefficient (A) and the Take-All presence coefficient (DA) were significantly different from zero for AN; Take-All rating positively affected risk and DA negatively affected risk. The joint F-statistics (Table 3) indicate that Take-All significantly reduced risk (Table 4) when AN was applied. Take-All reduced risk possibly because the ammonium form of AN may have reduced Take-All severity when yields were high compared with lower yield situations when yields were less responsive to N fertilization, tending to equalize yields. No other coefficients were significantly different from zero. Pair-wise F-statistics indicated that fertilization date, Glume-Blotch and Take-All did not affect risk differently between N sources (Table 5).

Risk-Return Trade-offs

Because the fertilization date had little effect on yield variance, no change was found in the optimal fertilization date for increased levels of risk aversion. Optimal fertilization dates were March 8 for AN and March 9 for UAN. Given that optimal fertilization dates did not change and N was applied at a constant rate of 90 lb N/acre, optimal yields and net returns above N costs also did not change with increased risk aversion. Optimal wheat yields were 67 and 62 bu/acre and optimal net returns were \$206.32 and \$190.54/acre for AN and UAN, respectively. A combination of a higher net return for AN and the lack of an effect of fertilization-date on risk resulted in maximum CE for AN being higher than maximum CE for UAN for all levels of risk aversion evaluated. Certainty equivalents for AN were \$206.32, \$192.07, and \$177.82/acre for λ = 0 (risk neutral), 0.01, and 0.02, respectively, and for UAN they were \$190.54, \$178.33, and \$166.12/acre. The value of the above information to wheat farmers who adjust their N fertilization source from UAN to AN is \$15.78, \$13.74, and \$11.70/acre (\$177.82 - \$166.12/acre) for farmers with risk aversion levels of λ = 0, 0.01, and 0.02, respectively. Although AN costs slightly more, \$0.26/lb compared with \$0.23/lb for UAN, the five bushel per acre increase in yield more than covers the added cost. Results indicate that winter wheat farmers will maximize utility if they apply AN on March 8, regardless of their risk aversion level.

Summary

This study evaluated risk efficiency of two N sources and five fertilizations dates in winter wheat production in the presence of two diseases (Glume-Blotch and Take-All). A Just-Pope econometric model was developed to analyze the risk effects of the N sources and to evaluate risk and return tradeoffs between these N sources.

The results indicated that fertilization date had no affect on risk and that AN was the optimal N source. The risk-return trade-offs suggested that fertilization date had no effect on utility maximizing N source for increased levels of risk aversion. At mean values of the disease variables, AN fertilization on March 8 was the utility maximizing N source and date regardless of risk preferences. The information provided by this research would be worth at least \$11.70/acre to winter wheat farmers who adjust their N fertilization source from UAN to AN.

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Table 1. Estimated Weighted Least Squares Nitrogen-Fertilization-Date Wheat Yield Response Functions for Alternative Nitrogen Sources.

	Nitrogen Source	
Variable[a]	**AN**	**UAN**
Intercept	5.11 (39.62)[b]	-12.65 (36.36)
T	1.85* (1.18)	2.17* (1.02)
T^2	-0.014* (0.007)	-0.016* (0.007)
Error Sums of Squares[c]	26,982	25,424
R^2	0.10	0.12
N	75	75

[a] Wheat yield (bu/acre) is the dependent variable and T is the N-fertilization day of the year.
[b] Numbers in parenthesis are standard errors.
[c] From Ordinary Least Squares estimates.
* Significantly different from zero at the 10-percent level.

Table 2. Estimated Nitrogen-Fertilization-Date Wheat Variance Functions for Alternative Nitrogen Sources.

	Nitrogen Source	
Variable[a]	**AN**	**UAN**
Intercept	4.83***	5.75***
	(1.20)[b]	(0.98)
T	0.02	0.003
	(0.02)	(0.013)
G	-0.02	-0.08
	(0.45)	(0.37)
DG	-3.30	-2.64
	(3.07)	(1.79)
TG	-0.00006	-0.0005
	(0.003)	(0.003)
A	0.80*	0.02
	(0.46)	(0.38)
DA	-3.38***	-1.03
	(0.005)	(0.81)
TA	-0.003	-0.0005
	(0.005)	(0.004)
F-statistic	10.10***	13.54***
R^2	0.51	0.59
N	75	75

[a] Wheat yield (bu/acre) is the dependent variable; T is N-fertilization day of the year; G is Glume-Blotch rating, with 10 being the most severe disease rating and zero when no disease was present; DG equals one when Glume-Blotch was present and zero otherwise; TG is an interaction term between N timing and Glume-Blotch rating; A is the Take-All rating, with 10 being the most severe disease rating and zero when no disease was present; DA equals one when Take-All was present and zero otherwise; and TA is an interaction term between N timing and Take-All rating.

[b] Numbers in parenthesis are standard errors.

***, * Significantly different from zero at the 1- and 10-percent levels, respectively.

Table 3. Joint F-tests for the Nitrogen-Fertilization-Date, Glume-Blotch, and Take-All Coefficients within the Variance Equation for Each Nitrogen Source.

Comparison	F-statistic
Fertilization Date[a]	
AN	0.51
UAN	0.02
Glume-Blotch[b]	
AN	0.04
UAN	2.62
Take-All[c]	
AN	3.24*
UAN	1.21

[a] The F-statistic tests the null hypothesis that the coefficients for T, TG, and TA (definitions in Table 2) are jointly equal to zero for a given N source.

[b] The F-statistic tests the null hypothesis that the coefficients for G, DG, and TG (definitions in Table 2) are jointly equal to zero for a given N source.

[c] The F-statistic tests the null hypothesis that the coefficients for A, DA, and TA (definitions in Table 2) are jointly equal to zero for a given N source.

* Significantly different from zero at the 10-percent level.

Table 4. Estimated Effects of Take-All on Risk for AN.

Variable	No Take-All[a]	Mean Take-All[b]
T	75	75
G	2.41	2.41
DG	0.33	0.33
TG	180.75	180.75
A	0	4.58
DA	0	1
TA	0	343.5
Wheat Yield Std. Dev.	11.09	7.95

[a] Variables other than A, DA, and TA (definitions in Table 2) are held constant at their three-year means.

[b] Take-All variables, A, DA, and TA (definitions in Table 2), are at their 2000 means, while other variables are held constant at their three-year means.

Table 5. Pair-Wise F-tests between Nitrogen Sources for Nitrogen-Fertilization-Date, Glume-Blotch and Take-All Coefficients.

Comparison	**F-statistic**
Fertilization Date[a]	
AN-UAN	0.15
Glume-Blotch[b]	
AN-UAN	0.26
Take-All[c]	
AN-UAN	0.37
Equation[d]	
AN-UAN	0.06

[a] The F-statistic tests the null hypothesis that the coefficients for T, TG, and TA (definitions in Table 2) are equal between N sources.

[b] The F-statistic tests the null hypothesis that the coefficients for G, DG, and TG (definitions in Table 2) are equal between N sources.

[c] The F-statistic tests the null hypothesis that the coefficients for A, DA, and TA (definitions in Table 2) are equal between N sources.

[d] The F-statistic tests the null hypothesis that the yield variance equations are equal between N sources.