ECONOMIC MODEL TO DETERMINE OPTIMUM NITROGEN RATES FOR SMALL GRAINS

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ABSTRACT

Nitrogen (N) fertilizer is generally the highest input cost for Montana grain growers; therefore, it has become imperative that a tool be developed to assist crop advisers and farmers in determining economically optimum N rates (EONR). Data from all available MSU-conducted N fertility trials were gathered for spring wheat, winter wheat, and barley. Only the data sets for dryland fields following fallow were deemed large enough to have confidence in any resulting models, and all other data were excluded. Regression models that included soil N, fertilizer N, organic matter (O.M.), and yield potential were developed for grain yield and protein for all three data sets, and plump for the barley data set. Yield predictability (as measured by r^2) was determined to be high enough to have confidence in these models. Economic models were then developed that calculated net marginal return (or net revenue) based on grain revenue minus N fertilizer cost. The models are available online allowing users to view changes in predicted yield, protein, plump, and/or net marginal return curves as the user changes input parameters. It is expected that these models will help optimize profits of small grain farmers especially during times of quickly changing commodity prices and high fertilizer costs.

INTRODUCTION

Fertilizer nitrogen (N) guidelines are generally based on supplying a constant amount of available N (soil plus fertilizer N) per bushel of yield. However, the economically optimum nitrogen rate (EONR) amount of available N will vary depending on grain prices, fertilizer costs, organic matter content, and yield potential. Therefore, there is a need to develop economic models that determine the EONR and are useable by growers and their advisers.

OBJECTIVES

The first objective of this study was to develop grain yield and quality models for small grains based on available N responses from plot studies. The second objective was to produce one or more online tools, based on these models, to allow Montana producers, crop advisers, and Extension agents to evaluate economically profitable N levels.

MATERIALS AND METHODS

Plot data for nitrogen (N) yield response for spring wheat, winter wheat, and barley were compiled from Agricultural Research Center annual reports and personnel. These data included both on- and off-station small plot studies. There were a total of 128 spring wheat (1993-2006), 350 winter wheat (1970-2006), and 491 barley data points (1981-2006), with a majority of the data collected in the Golden Triangle. Insufficient hay and sugarbeet data were located to produce suitable models. The vast majority of the studies were conducted on dryland sites; irrigated fields were excluded from further analysis due to small sample size.

For each data set, a minority of the data was for recrop situations. These data were excluded because it was deemed insufficient, and was drastically different in N response, leaving only dryland fallow sites. Although studies were conducted on both no-till and tilled fields, preliminary models found very little difference in N yield response between the two systems, and therefore the data were combined in developing the yield and protein models described here. In addition, the barley data was from a study evaluating seeding rate, N, and S. Because S is rarely added to barley fields, as S can increase grain protein, only the 0 S treatment data were included. The final data sets for spring wheat and winter wheat consisted of 96 and 211 data points for spring wheat and winter wheat, respectively. Plump, protein, and O.M. (used for the yield model) were not consistently measured in the barley studies, therefore the data sets for barley grain yield, protein, and plump consisted of 123, 113, and 157 data points, respectively.

Early models, with only available N as an independent variable, had poor fits (r^2) for spring wheat grain yield (quadratic r^2=0.23) and protein (linear r^2 = 0.30). Yield in Montana is heavily dependent on climate, soil, and management factors, yet climate can not be predicted at fertilization time and most soil factors (such as soil depth, calcium carbonate content, and texture) were not measured in the soil fertility trials. Therefore, models were developed that included maximum yield potential, for total available N, and organic matter. All models shown here use standard English units (e.g. bu/ac, lb N/ac).

Yield Models

The best fit small grain yield models in Montana to date based on soil N + fertilizer N have been quadratic models (Jackson, 1998, 2000, 2001). Although these models produce generally good r^2-values, they predict negative yields at very high N levels and were done for two to three yield ranges, creating a discontinuity near the ends of the ranges (meaning a different yield is predicted at a yield potential of 40 bu/ac, depending on whether one used a 20-40 bu/ac equation or a 40-60 bu/ac equation). In addition, more N response trials have been conducted since these models were developed. Finally, it was conjectured that including organic matter (O.M.) content into these models would improve their fit. Therefore, a "quadratic-plateau" model (Kastens et al., 2006) was used instead and yield potential and O.M. content were incorporated into the model. The yield model has the form:

$\text{Yield} = a*\text{TUN} - b*\text{TUN}^2$ when TUN<YMN [1]
Yield = Yield potential (YP) when TUN≥YMN

Where, TUN = total useable N (soil N to 3 feet + fertilizer N + c*O.M.), YMN = yield maximizing N and c = constant that should equate to lb N/ac released over the growing season for each 1% O.M.

The YMN was found by taking the derivative of Eq. 1 and solving for TUN:

$\text{YMN} = a/(2*b)$ [2]

To develop a relationship between applied N and maximum yield, which was set equal to YP, YMN in Eq. 2 was substituted for TUN in Eq. 1 to find:

$$b = a^2/(4YP) \quad [3]$$

Finally, the equations for b and TUN were substituted into Eq. 1 to determine YP-based yield:

$$Yield = a*TUN - (a^2/(4*YP))*TUN^2 \text{ when } TUN<YMN \quad [4]$$
$$Yield = YP \text{ when } TUN \geq YMN$$

A model optimizer (S-Plus, Tibco Power Inc. Palo Alto, CA) was used to determine the constants ‘a’ and ‘c’ (from TUN definition under Eq. 1 above) for each of the three yield models.

Protein Models

Grain protein was modeled by assuming that protein would be directly related to TUN and inversely related to actual yield. A variety of models with this form were attempted, and the best fit models for spring wheat and winter wheat were determined to be:

$$Protein = a + b*log(TUN^2))/(Predicted\ Yield)^d \quad [5]$$

The best fitting ‘c’ constant from Eq. 4 was used in the calculation of TUN. When this constant was instead allowed to vary, the fit was no better, and the value was very similar to the best fitting constants found in the yield models for both spring wheat and winter wheat. This model did not work well for barley protein. A better fitting equation for barley protein was a simple linear equation:

$$Protein = a + b*TUN \quad [6]$$

Plump Model

At low available N and high yield potentials, plump is generally high, but can’t be above 100%. As N increases and/or yield potential decreases due to lack of moisture, plump can fall rapidly. At very high N, and low yields, plumps will be small but can not fall below 0%. This combination suggests that an “S-shaped” (sigmoidal) equation with respect to TN (Soil N + fertilizer N) may best fit the plump data. The following equation provided an adequate correlation:

$$Plump = 100 - b/YP^3-((100-b/YP^3)/(1+c*e^{-d*TN})) \quad 40<YP<105 \text{ bu/ac} \quad [7]$$

Using TUN instead of TN provided a poorer fit, suggesting that N from O.M. does not affect plump the same as nitrate-N, possibly due to timing (N from O.M. would be released throughout the growing season). The maximum yields for the soil fertility trials used in this model ranged from 40 to 105 bu/ac; therefore, this model should not be used outside of this range.

Economic models

The economic models that followed from the yield, protein, and plump models were based on marginal net return, the increase in revenue from added yield minus the added cost of N fertilizer. It was assumed (based on calls to Montana grain elevators), that grain protein premiums are 2/3 of protein discounts for the spring and winter wheat models. If protein or plump requirements are not met for malt barley, the feed barley price is used instead to calculate net return. While the models for yield, protein, and plump estimate production, the economic model estimates profitably, incorporating the revenue and costs aspects of estimated yields, protein levels, plump (for barley) and fertilizer costs for applied N.

RESULTS

Regression constants and r^2-values for each of the models are shown in Table 1. The r^2-values for the optimized models were fairly high except for the barley protein model (0.37). The r^2-values for yields are inflated compared to models that only contain N as an independent variable because the maximum yield for a given site-year is not known prior to the growing season, yet was used in the plateau models developed. A yield potential model essentially allows the users to incorporate their specific knowledge of their production possibility based on historical data and considering all relevant factors, such as cultivar, moisture, soil type, slope, elevation, etc. The constant 'a' in the yield models should equate to the number of bushels that 1 lb N can grow when TUN is near 0 lb/ac. The inverse of these numbers is the lb N/bu to grow the first bu of grain, or about 1.8 lb N/bu for both spring and winter wheat, and 0.7 lb N/bu for barley. The amount of N needed to maximize yield is higher than these values because the N-yield response functions are not linear, but become less steep so that more N is needed to grow the last bushel of grain compared to the first. The 'c' constant in each of the yield models should theoretically equate to the amount of available N released for each 1% O.M. However, the fairly large differences in c values suggest that O.M. is affecting yield responses among crops differentially and is not simply equated to the amount of N 'mineralized' from O.M.

The models can be used to show expected differences in yield, protein, and economic responses to available N (soil + fertilizer N) depending on yield potential and O.M. content. For example, a soil with high O.M. content requires substantially less available N to maximize spring wheat grain yield than a soil with low O.M. content (Figure 1). The models also show, as

Table 1. Yield, protein, and plump model parameters, numbers (n) of values used in each model, and the goodness of fit (r^2) for spring wheat, winter wheat, and spring barley.

Model and Crop	a	b	c	d	n	r^2
Yield						
Spring Wheat	0.55		27.4		96	0.92
Winter Wheat	0.58		14.8		211	0.92
Spring Barley	1.34		8.5		123	0.89
Protein						
Spring Wheat	-13.3	4.84	27.4	0.166	96	0.61
Winter Wheat	-7.8	3.39	14.8	0.128	211	0.58
Spring Barley	8.37	0.029	8.5		145	0.37
Plump						
Spring Barley		5001880	409.3	.028	157	0.68

expected, that it requires much less N to attain 14% grain protein at low yield potentials than at high yield potentials (Figure 2). The protein model shows that it takes approximately 165 lb N/ac to attain 14% protein at a 50 bu/ac YP, which equates to 3.3 lb N/bu. This value is identical to the guideline listed in the MSU Fertilizer Guidelines for spring wheat (Jacobsen et al., 2005) that was based on achieving 14% protein to avoid protein discounts (Jackson, 1998; 2000; 2001). Note that the N needed to maximize yield at 2% O.M. is approximately 125 lb N/ac or 2.5 lb N/bu showing that less N is needed to maximize yield than reach 14% protein.

The EONR will vary greatly depending on grain price, protein discount, and fertilizer price. For example, assuming a 16¢/0.25% protein discount, the EONR for a 50 bu/ac YP ranges from approximately 120 lb N/ac to 175 lb N/ac (2.6 to 3.5 lb N/bu) depending on assumed grain price and urea cost (Figure 3). Fertilizing for a low grain price to fertilizer cost ratio (P:C) when the actual P:C ratio is high could result in reducing profit by approximately $15/ac which can be substantial over a typical Montana farm size. Protein discounts can have an even larger effect on the EONR. For example, for protein discounts ranging from 8 to 24¢/0.25% protein, the EONR for a 50 bu/ac yield potential was found to range from approximately 120 lb N to 215 lb N/ac (Figure 4). The models are currently available at: http://www.montana.edu/softwaredownloads/cropdownloads.html.

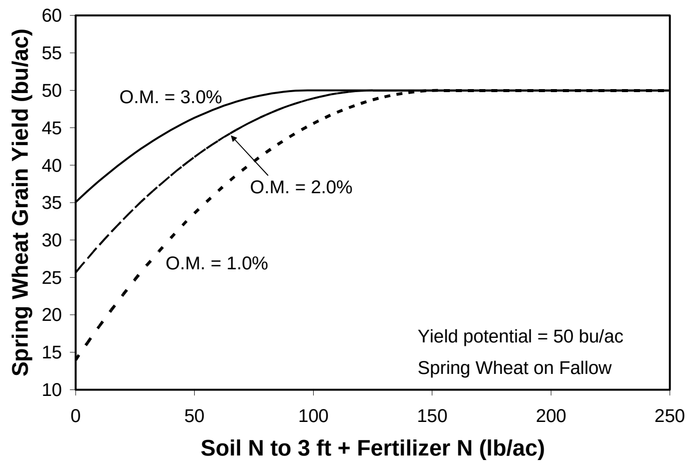

Figure 1. Response of spring wheat grain yield following fallow to available N at three O.M. contents.

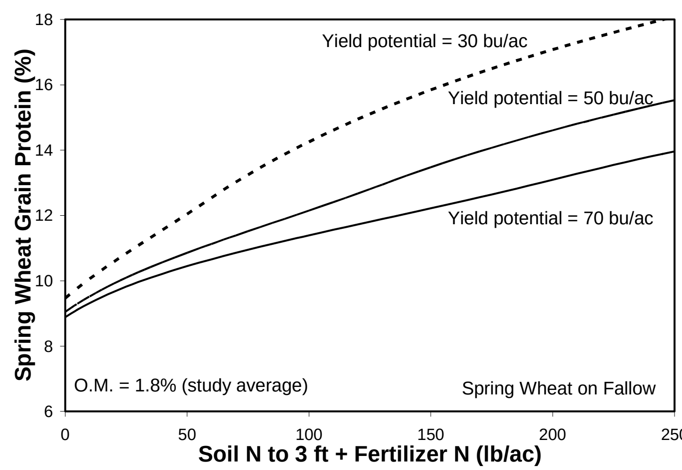

Figure 2. Response of spring wheat grain protein to available N at three yield potentials.

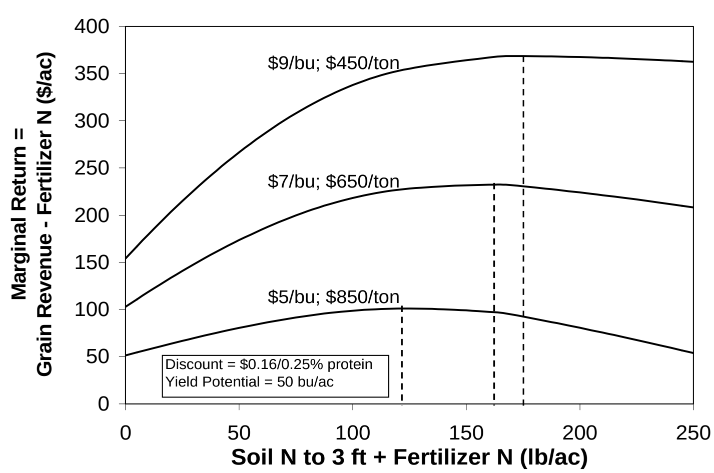

Figure 3. Marginal return as affected by N rate at three price:cost ratios for spring wheat following fallow.

SUMMARY

The economic models produced will be used by producers, crop advisers, and Extension personnel to determine the effect of available N and O.M. on yield, protein, and net marginal return. Specifically, the models can be used to demonstrate the amount of available N per acre that is necessary to optimize yield and net marginal return for different conditions. The culmination of this effort will assist Montana producers and their crop advisers in determining N rates to maximize net profit.

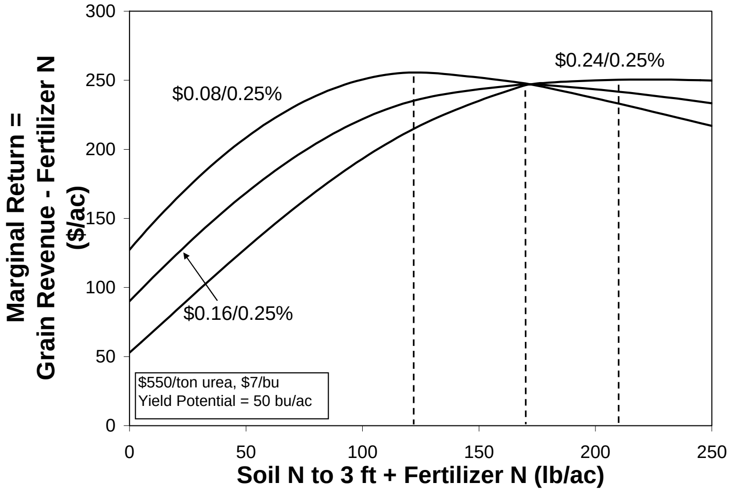

Figure 4. Marginal return as affected by N rate at three protein discounts for spring wheat following fallow.

ACKNOWLEDGMENTS

We would like to thank Ms. Evette Allison (MSU-Bozeman) for her assistance in compiling the yield response data, and the Montana Fertilizer Advisory Committee for funding this project.

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Disclaimer

The models developed in this study were based on soil fertility plot studies conducted on relatively few site-years in Montana; therefore, the actual yield, protein, and plump models are only the best fit for these site-years and will not reflect responses of all fields in Montana for all climatic conditions. Therefore, N responses may be different than on-farm responses, depending on management practices, soil, and climate.

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OF THE

WESTERN NUTRIENT

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Volume 8

MARCH 4-5, 2009
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