INCLUSION OF WEATHER AND SOIL DATA IN NITROGEN YIELD RESPONSE CURVES AND ECONOMIC MODELS

Clain Jones and Duane Griffith
Montana State University, Bozeman, MT
clainj@montana.edu (406) 994-6076

ABSTRACT

Near record-high fertilizer prices have created the need for models that predict economically optimum nitrogen (N) fertilizer rates for small grains in Montana. Current yield and protein models, necessary for the development of economic models, have been based on available N (soil plus fertilizer N) and grouped into two to three yield ranges to improve model fit. The goal of this study was to add climate parameters and organic matter (O.M.) content into grain yield, protein, and economic models, to improve the robustness, and hopefully the accuracy, of these models. All available plot study data collected in Montana for the past thirty years was compiled for spring wheat (n=128), winter wheat (n=350), and barley (n=511). Climate data (monthly precipitation and temperature) was gathered from the closest weather station from each study site. Stepwise multiple linear regressions were performed on non-transformed and transformed independent variables (e.g. O.M. content, available N, and overwinter precipitation), including selected interaction terms, with a goal of identifying a reasonable model that contained a minimum of significantly important independent variables. A reasonably good fit (R^2=0.77) was found for a spring wheat grain yield model (on fallow) that included four independent variables: available N, May-August precipitation, June average temperature, and O.M. content. A somewhat poorer fit (R^2=0.63) was found for a spring wheat grain protein model that used the first three of these four variables. The winter wheat and barley models are still under development. The spring wheat grain yield and protein models were included in an economic model to demonstrate the effect of O.M. content and climate on optimum N fertilizer rates.

INTRODUCTION

Fertilizer has become a major input cost for small grain growers in Montana. Traditionally, recommended fertilizer rates in Montana have been based on maximizing yield, yet with higher fertilizer costs, economically optimum rates likely do not coincide with maximum yield. Therefore, there is a need for economic models to assist growers and their advisers in selecting fertilizer rates that maximize net profit. Ideally, yield, protein, and economic models would only be based on data available at the time of fertilization; however, inclusion of growing season climate data may still be valuable in allowing users to see how climate affects optimum N levels. In addition, the diverse climate conditions across Montana may make the use of historical climate data as yield and protein predictors more useful than not including climate.

Small grain N response yield models include linear plateau, quadratic plateau, and multiplicitive models (Kastens et al., 2003; Kastens et al., 2006). These models are very suitable for moist environments, yet in semi-arid regions, increasing N beyond maximum yield generally results in decreased yields, rather than a plateau. Therefore, quadratic N response models have been found to reasonably predict grain yield in Montana (Jackson, 1998, 2000, 2001). This study included O.M. content, climate variables, and N in a multiple linear regression analysis to develop yield, protein, and economic models for small grains to optimize fertilizer N rates for a range of soil and climatic conditions.

MATERIALS AND METHODS

Nitrogen yield response curve data for spring wheat, winter wheat, and barley were compiled from MSU Agricultural Research Center reports. These data were for both on and off-station small plot studies. There were a total of 128 spring wheat, 350 winter wheat, and 511 barley data points, with a majority of the data collected in north central Montana ("The Golden Triangle"). Insufficient hay and sugarbeet data were located to produce suitable models. The N yield response studies were conducted from approximately 1985 to 2005, though this time span varied somewhat depending on crop. The vast majority of the studies were conducted on dryland sites; irrigated fields were excluded from further analysis due to small sample size.

Because the models are still being reviewed for barley and developed for winter wheat, the remainder of this report focuses on spring wheat yield and protein response curves. Of the 128 spring wheat data points, 100 were for studies conducted on previously fallow fields with the remainder continuously cropped. It was deemed that 28 points were insufficient to produce a yield model with suitable confidence, and therefore only a yield model for spring wheat following fallow was developed. Although the N yield response studies were conducted on both no-till and tilled fields, preliminary models found very little difference in N yield response between the two systems; therefore, the data were combined in developing the yield and protein models. A major goal of this project was to develop a model with only a few independent factors to increase the likelihood that the model would be used. Ideally, growing season climate data would not be needed, since growing season climate conditions can not be predicted at spring fertilization time. However, when only total available N (Total N) was used as an independent factor, the model fit was poor for grain yield (quadratic R^2=0.23) and protein (linear R^2 = 0.30). Therefore, climate data (monthly precipitation and temperature) were compiled from the weather station closest to each study site. In addition, Palmer Drought Severity Index (PDSI) data were obtained for each of six cropping districts in Montana and assigned to individual study locations for each study year. Finally, O.M. contents were added to the compiled data.

Grain yield was regressed stepwise in Stat Tools against each of the parameters listed in Table 1, as well as all of the parameters combined, with a goal of developing a model with no more than four independent variables. Only those parameters that contributed significantly to the model were investigated further. In addition, models that did not agree with what is known about yield in semi-arid areas were not considered (e.g. if precipitation was negatively correlated with yield). In all models, four data points were consistently determined to be outliers. All of these were for one location and one year (four N rates); therefore, these data were not used for the remainder of the analysis. Grain protein was modeled using the same procedure with a focus on those parameters that explained most of the variation in the yield model.

It was assumed (based on calls to Montana grain elevator personnel), that grain protein premiums are ½ of protein discounts, and for purposes of this report, that a typical discount (averaged over the past 5 years) is 8¢ per 0.25% protein below 14%. In the user-friendly calculator that is being developed, the actual discount will be entered.

RESULTS AND DISCUSSION

The highest regression correlation (R^2=0.77) for a 4-factor spring wheat grain yield model included the following independent factors: Total N (soil + fertilizer N), May-Aug Precip, O.M.^{2}, and Jun Avg Temp (Figure 1). This was a large improvement over the model that only used total N. Overwinter precipitation (Sep – Mar) was not significantly related to yield, suggesting that the long fallow period is sufficient for recharging soil moisture. It was somewhat surprising that May-Aug Precip produced a better fit than May-July Precip (R^2=0.73) since spring wheat grain-fill is largely complete by the start of August. Research in western Canada has found that correlations between grain yield and moisture use were lower when the model used May to August rather than May to July moisture use (Campbell et al., 1988). It is possible that in our study that August precipitation was positively correlated with late July precipitation when grain-fill is still occurring, and that this improved the correlation. Only monthly precipitation averages were used, so this hypothesis was not tested. June average temperatures were positively correlated with yields likely because cool spring soil

Table 1. Independent parameters for spring wheat grain yield model.

Individual	Interactions
Applied N	(Total N x Precip)
Soil N	(Total N x Apr – Jul P)
Soil N^2	(Total N x sqrt(Apr – Jul P))
Ln(Soil N^2)	(Total N x sqrt(May – Aug P))
Total N (soil + fertilizer N)	(Total N x Sep – Mar P)
Total N^2	(Total N x WaterYear Precip)
Ln(Total N^2)	(Total N x OM)
OM	(Applied N x Apr - Jul P)
OM^2	(Applied N x Sep - Mar P)
Annual Precip	(Sep – Mar P x Jun Avg MaxT)
Water Year Precip	(Sep – Mar P x Jul Avg MinT)
Apr – Jul Precip	(Sep - Mar P x PDSI July)
May – Jul Precip	(PDSI June x PDSI July)
May – Aug Precip	(Jun Avg T x Jul Avg T)
Previous Sep – Mar Precip	Jun Avg Max T x Jul Avg MaxT
Jun Avg T	(Jun Avg MinT x Jul Avg MinT)
Jul Avg T	(Total N x PDSI May)
Jun Avg MaxT	
Jul Avg MaxT	
Jun Avg MinT	
Jul Avg MinT	
PDSI May	
PDSI June	
PDSI July	
PDSI Aug	

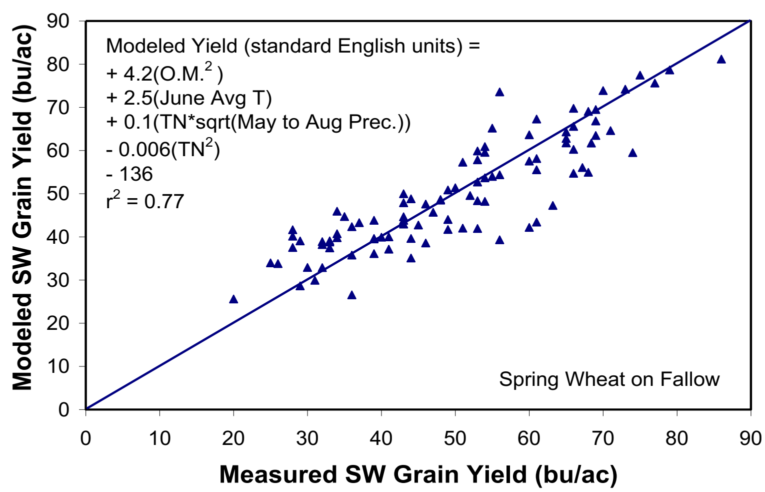

Figure 1. Modeled vs. measured spring wheat grain yield following fallow. TN = soil N + fertilizer N.

temperatures can depress wheat growth in this cool region. Grain protein was adequately modeled (R^2=0.63) with the above factors, although O.M. did not improve the model and was excluded from the analysis (Figure 2). As expected, climate factors that were positively related to yield were negatively related to grain protein due to N dilution.

Although May to August precipitation and June temperature cannot be predicted when spring wheat is typically fertilized (late March to late April), the grain yield and protein models can still be used to determine the effects of moisture, temperature, and N on grain yield and protein. For example, Figure 3 and 4 illustrate the effect of growing season moisture on grain yield and protein, respectively. The models indicate that approximately 3.5 lb N/bu are needed to maximize yield for an average May to August Precip; similar to the 3.3 lb N/bu recommended by Montana State University (Jacobsen et al., 2005). However, only about 2.9 lb N/bu are needed to maximize yield in a dry growing season. It should be noted that research studies are generally conducted under optimum conditions; meaning, phosphorus and potassium fertility is usually optimized by using a starter fertilizer, and seeding dates are usually as early as possible. In addition, soils of the Golden Triangle are generally thick, optimizing water storage and root development. Therefore, yields shown in Figure 3 may exceed what a producer could expect on a particular field, especially if that

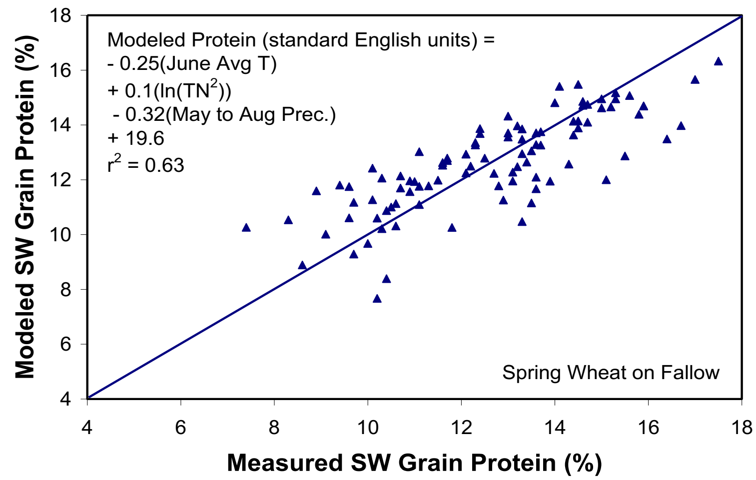

Figure 2. Modeled vs. measured spring wheat grain protein following fallow. TN = soil N + fertilizer N.

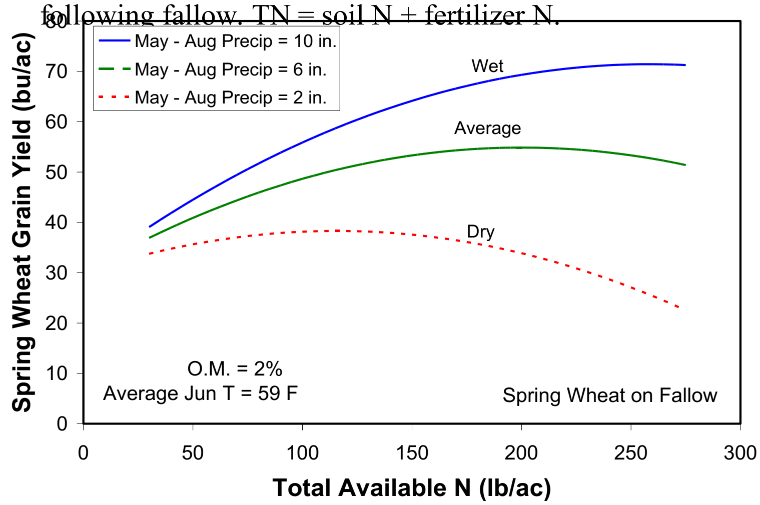

Figure 3. Modeled effect of total available N on spring wheat grain yield for different May-Aug precip. amounts.

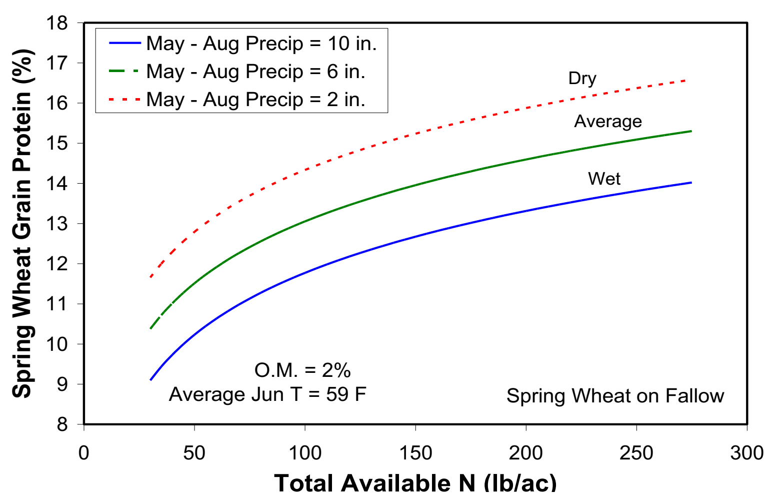

Figure 4. Modeled effect of total available N on spring wheat grain protein for different May-Aug precip. amounts.

field has other factors such as shallow soil depth or low levels of other nutrients.

When yield and protein models were integrated into an economic model to predict marginal return (grain revenue – fertilizer N cost), peak marginal returns (at $7/bu and $450/ton urea) ranged from $230/ac to $380/ac for dry and wet seasons, respectively (Figure 5). Yields varied by more than a factor of two for these two moisture regimes, yet higher protein in dry years helped offset revenue losses from much lower yields. Maximum marginal return is predicted to occur near 2.8 lb N/bu for an average precipitation season. This number will vary depending on commodity price, protein discount/premium, and fertilizer N price, as well as O.M. content and June temperature based on the yield model. This work demonstrates that with high N prices, that N fertilizer rates should generally be slightly reduced compared to N rates needed to maximize yield (Figure 6); however, reducing rates too much can substantially lower profits especially in average to wet years. For the assumptions made, the model indicates that fertilizing for maximum return in an average year can increase marginal return by almost $100/acre compared to not fertilizing.

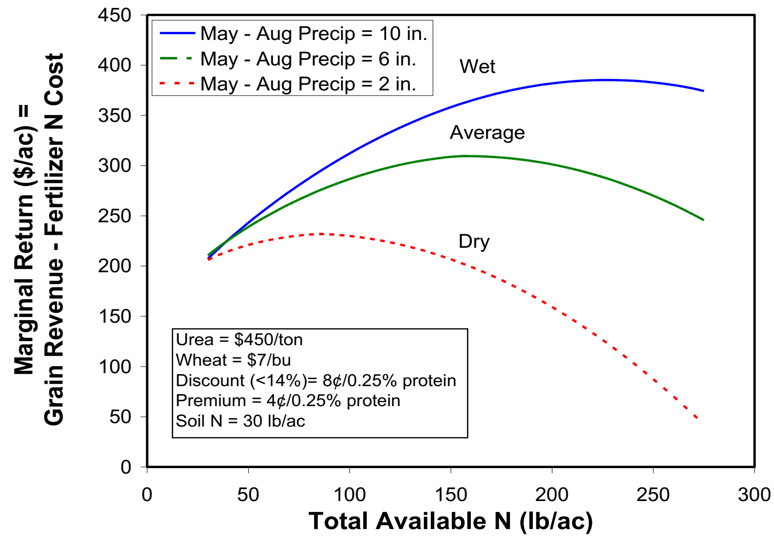

Figure 5. Marginal economic return for spring wheat on fallow as affected by total available N (soil + fertilizer N) for three precipitation amounts, an average O.M. content (2%), and average June temperature (59°F).

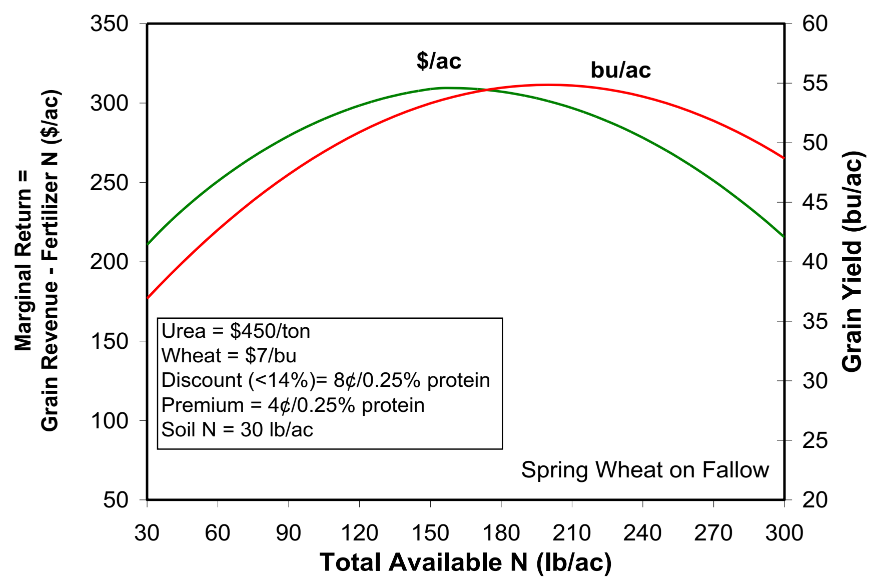

Figure 6. Marginal economic return for spring wheat on fallow compared to grain yield for an average May to August precipitation amount (6 inches), average O.M. content, and average June temperature.

After the barley and winter wheat models have been developed, a user-friendly web interface will be developed. This interface will allow the user to vary precipitation, temperature, commodity price, and fertilizer N cost in determining optimum fertilizer rates for a particular

O.M. content. In addition, we plan to assess what historical climate period (e.g. last 5 yr, 20 yr, or period of record) best predicted actual yield for each site location.

SUMMARY

Inclusion of precipitation, temperature, and O.M. content greatly improved the accuracy of spring wheat grain yield and protein nitrogen-response models. Although growing season climate can not be predicted at typical fertilization times in Montana, the addition of climate variables into the models allows producers and their advisers to evaluate the effect of different climate scenarios and nitrogen rates on grain yield, grain protein, and marginal return. With high and variable commodity prices and fertilizer costs, economic models are likely to become more important as decision making tools for today's growers and crop advisers.

ACKNOWLEDGMENTS

We would like to extend our utmost appreciation to Dr. Grant Jackson (Western Triangle Agricultural Research Center) for supplying the majority of the data used in this study, and to the Montana Fertilizer Advisory Committee for funding this study.

REFERENCES

Campbell, C.A., R.P. Zentner, and P.J. Johnson. 1988. Effect of crop rotation and fertilization on the quantitative relationship between spring wheat yield and moisture use in southwestern Saskatchewan. Can. J. Soil Sci. 68:1-16.

Jacobsen, J., G. Jackson, and C. Jones. 2005. Fertilizer guidelines for Montana crops. Publication EB 161. Montana State University Extension Service. Bozeman, MT.

Jackson, G. 1998. Predicting Spring Wheat Yield and Protein Response to Nitrogen. Fertilizer Fact 17. Montana State University Extension Service. Bozeman, MT.

Jackson, G. 2000. Nitrogen Fertilization of Dryland Malt Barley for Yield and Quality. Fertilizer Fact 24. Montana State University Extension Service. Bozeman, MT.

Jackson, G. 1998. Fertilizing Winter Wheat with Nitrogen for Yield and Protein. Fertilizer Fact 26. Montana State University Extension Service. Bozeman, MT.

Kastens, T.L., Dhuyvetter, K.C., Schlegel, A.J., and T.J. Dumler. 2006. N Response Functions for Today's Production Costs. *In* Great Plains Soil Fertility Conference Proceedings. Vol. 12 p. 95-105. March 7-8, 2006. Denver, CO.

Kastens, T.L., J.P. Schmidt, and K.C. Dhuyvetter. 2003. Yield models implied by traditional fertilizer recommendations and a framework for including nontraditional information. Soil Sci. Soc. Am. J. 67:351-364.