In-Season Fertilizer Nitrogen Rates Using Predicted Yield Potential and the Response Index

By W.R. Raun, G.V. Johnson, J.B. Solie, M.L. Stone, K.L. Martin, and K.W. Freeman

Refining in-season fertilizer nitrogen (N) rates through the use of optical sensor technology has been a major research priority at Oklahoma State University (OSU). Basing mid-season N fertilizer rates on predicted yield potential and a response index have increased N use efficiency (NUE) by over 15% in winter wheat when compared to conventional methods.

From the early 1950s to the early 1970s, increased food production was a priority in agricultural areas around the world. During this time period, the largest increase in the use of agricultural inputs was N fertilizer, because it had the largest impact on yield. Since the early '60s, the increase in fertilizer N consumption has continued, becoming somewhat stable over the past 10 years. Although fertilizer N consumption and cereal grain production have both increased over the last 5 decades, contamination of surface water and groundwater supplies continues to be a concern in some areas. According to analysis by scientists at OSU, the efficiency at which fertilizer N is used has remained at 33% worldwide.

Current strategies for winter wheat recommend that farmers apply about 2 lb N/A for every bushel of expected wheat grain yield, subtracting the amount of NO_3-N in the surface soil (0 to 6 in.). When grain yield goals are applied using this strategy, the risk of predicting the environment (good or bad year) is placed on the producer, especially when farmers take the risk of applying all N preplant.

Why Should N Rates Be Based on Predicted Yield?

In the last century, yield goals have provided methods for determining

Optical sensor technology is helping Oklahoma researchers refine in-season fertilizer N rates for winter wheat, based on projected N removal. The applicator shown here is a field scale machine, 60 ft. wide.

pre-plant fertilizer N rates in cereal production. This makes sense, because at a given level of yield for a specific crop, nutrient removal can be estimated based on concentrations in the grain. Once expected removal amounts are known, mid-season application rates are determined by dividing removal by the projected use efficiency. Similarly, known quantities of phosphorus (P), potassium (K), sulfur (S), and other nutrients within particular cereal grain crops have been published. Based on these concentrations, mid-season nutrient rates could be determined at specific foliar nutrient application efficiencies.

The algorithm for refining mid-season fertilizer N rates has been divided into components that follow. Our approach is based on the ability to predict yield potential since this will ultimately determine the total amount of a given nutrient that will be removed in each crop.

1. Estimate of Yield Potential

Work at OSU has shown that early-season Normalized Difference Vegetation Index (NDVI) optical sensor readings of winter wheat were highly correlated with total plant biomass. The effect of timing (i.e., the number of days of active plant growth prior to sensing) can be minimized by dividing NDVI readings by the number of days from planting to sensing for those days where growing degree days... (GDD=[(T_{min}+T_{max})/2]-40°F) ...are more than 0. In essence, the index, or In-Season Estimated Yield (INSEY), was an estimate of biomass produced per day when growth was possible. We have shown that optical sensor readings can be collected once, anytime within Feekes growth stages 4 and 6, and that INSEY was an excellent predictor of yield (grain or forage). This work was recently updated to include 30 locations over a 6-year period from 1998 to 2003 (**Figure 1**).

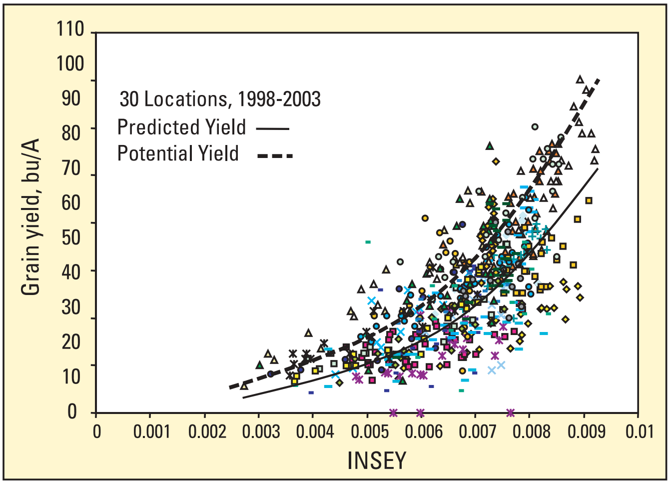

Figure 1. Relationship between observed wheat grain yield and the In-Season Estimated Yield (INSEY) determined by dividing NDVI by the number of days from planting to sensing (days where growth was possible, or GDD>0) at 30 locations from 1998 to 2003.

What is striking from this research is that planting dates ranged from September 24 to December 1, and sensing dates ranged from February 10 to April 23, yet yield prediction (solid line) remained reasonably good. The results indicate that for winter wheat, biomass produced per day is an excellent predictor of grain yield. Furthermore, over this 6-year period, five different varieties (Tonkawa, 2163, Custer, 2137, and Jagger) were included. It is noteworthy to find such a good relationship with final grain yield simply because so many uncontrolled variables from planting to sensing have the potential to adversely affect this relationship.

Because of the importance of yield potential for determining N application rates, we must expand on the concept. To correctly predict the potential yield, the model should be fitted to yields unaffected by adverse conditions from sensing to maturity. This curve more realistically represents the yield potential achievable in rainfed winter wheat, considering that post sensing stresses (moisture, disease, etc.) from February to July can lower "observed yields." We currently add 1 standard deviation to the predicted yield equation in order to better reflect actual yield potential **(Figure 1)**.

Added work has shown that it is possible to establish reliable yield potential prediction from only 2 years of field data, provided that enough sites were evaluated within this time period.

2. Estimating the Responsiveness to Applied N

Identifying the specific yield potential does not necessarily translate directly to a recommendation for N. Determining the extent to which the crop will respond to

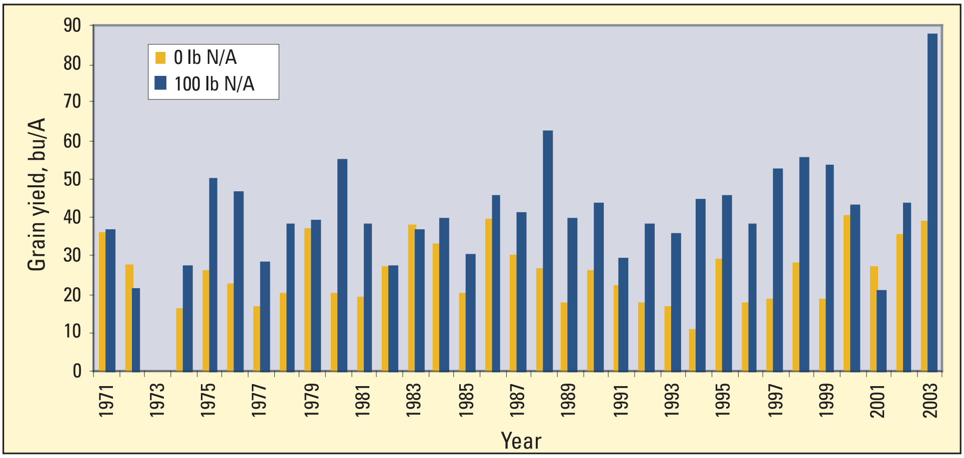

Figure 2. Average winter wheat grain yield from 1971 to 2003 from treatments receiving 100 lb N/A annually and no fertilizer N (0 lb N/A), long-term experiment #502, Lahoma, Oklahoma. Both P and K were applied each year to both treatments at rates of 41 lb P_2O_5/A and 60 lb K_2O/A, respectively.

additional N is equally important. The response index (RI_{NDVI}) is computed by taking average NDVI from a strip within farmer fields where N has been applied at non-limiting, but not excessive amounts (N Rich Strip) and dividing by the NDVI in the farmer check plot (common farmer practice). This fertilizer index was developed following comprehensive work at demonstrating that the response to applied N in the same field is extremely variable from one year to the next, and independent of whether or not previous year yields were high or low. We studied grain yield response to applied N in a long-term replicated experiment where the same rates were applied to the same plots each year for over 30 years (**Figure 2**).

Because the response to N fertilizer depends on the supply of non-fertilizer N (mineralized from soil organic matter, deposited in the rainfall, etc.) in any given year, N management strategies that include a reliable mid-season predictor of RI_{NDVI} should dramatically improve NUE in cereal production. This same work noted that the RI values changed considerably when collected from the same plots that had been managed the same way for 30 years. This is attributed to the striking differences in rainfall and temperature from one year to the next and associated crop need, which influenced how much non-fertilizer N was used by the crop. Furthermore, the in-season RI_{NDVI} was found to be an excellent predictor of the actual responsiveness to applied fertilizer N when measured at harvest.

3. Integrating Yield Potential and the Response Index

For the Nitrogen Fertilization Optimization Algorithm (NFOA) currently being used, yield potential with no added N fertilization (YP_0) is predicted using NDVI readings divided by the number of days from planting to sensing. The yield obtainable with added N fertilization (YP_N) is determined by multiplying YP_0 by RI_{NDVI}. The fertilizer rate to be applied is determined by computing N uptake in the grain at YP_N minus N uptake in the grain at YP_0 divided by an expected use efficiency factor (between 0.5 and 0.7).

Grain N uptake for YP_0 and YP_N is determined by multiplying the respective predicted grain yield times a known percent N value in each grain or forage crop for each specific region. For winter wheat in the central Great Plains, the percent N in the grain averages 2.39% for winter wheat, 1.18% for corn grain, and 2.45% for spring wheat. This same concept could apply for different nutrients and different crops. Although factors other than N can influence yield potential, the value of this approach is that N fertilizer will ultimately be applied based on the specific yield potential of each 4.3 ft^2 area and the potential responsiveness to N for each particular field.

The need to sense biological properties on a small scale was established at OSU. Current work is focusing on the evaluation of statistical properties within each 4.3 ft^2 area, understanding that the nutrient variability within this area will likely be minimal. Fortunately, the sensors developed and used in all of the OSU sensor research are capable of collecting enough data within each 4.3 ft^2 to calculate meaningful statistical estimates. Now, more importantly, these statistical estimates combined with average NDVI have been shown to be useful for mid-season yield prediction and subsequent fertilizer N rate recommendations. Using the algorithm reported earlier, we showed that winter wheat NUE was improved by more than 15% when N fertilization was based on optically sensed INSEY and the RI_{NDVI} compared to traditional practices at uniform N rates. We are not aware of any biological basis to suggest that this approach would not be suitable in other cereal crops.

The sufficiency approach that is being evaluated in the Corn Belt today and that applies fertilizer to all plots when found to be below a theoretical maximum (<95%) does not take into account yield level, or yield potential, and more importantly the quantitative responsiveness to applied N inherent in the response index.

There is ample evidence that wheat potential yield can be reliably predicted from in-season sensor measurements. Basing fertilizer N needs on projected removal (dry matter yield times known concentrations in the grain) should be encouraged since removal amounts are known to vary temporally and spatially. BC

The authors are with the Department of Plant and Soil Sciences, Department of Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, OK 74078. Contribution from the Oklahoma Agricultural Experiment Station. E-mail: wrr@mail.pss.okstate.edu.

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crops—when managed with practices other than "conventional". However, in both of the "non-conventional" management systems evaluated, the applied nutrients included large amounts of P. Unfortunately the level of P fertilization in the "conventional" system was unknown. It is possible that the results obtained—attributed to differences among systems in pests and pesticide use—were in fact caused by differences in nutrient levels. More attention to nutrient levels is necessary when making system comparisons. BC

Dr. Bruulsema is Director, PPI/PPIC Northeast Region, 18 Maplewood Drive, Guelph, Ontario N1G 1L8 Canada; e-mail: tbruulsema@ppi-ppic.org. Drs. Paliyath, Schofield, and Oke are with the Department of Plant Agriculture, University of Guelph, Guelph, Ontario N1G 2W1, Canada; e-mail: gpaliyat@uoguelph.ca.

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