RECOVERABLE YIELD: A NEW COMPONENT FOR IMPROVING ALGORITHMS USED FOR SENSOR BASED NITROGEN MANAGEMENT IN WHEAT

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Abstract

Increased interest in N management over the past decade has stimulated interest in using optical sensors to predict N needs in a number of crops. Many universities have created N recommendation algorithms for winter wheat, with slightly differing approaches. While many university algorithms operate under the assumption that 100% of the yield potential difference between the N rich strip and the farmer practice can be recovered, we believe that this will not always be possible. The objective of this study was to determine how much yield could be recovered at a given response index, level of N deficiency, and determine if there was a predictable the relationship between response index (RI) and recoverable yield (RY). Field studies were conducted in 2006-2012 at 12 locations in Kansas using a factorial treatment structure in a randomized complete block design with four replications. Treatments included five N rates (0, 30, 60, 90, 120 lb N ac^{-1}) and four application dates (Fall-Winter, Feekes 4, 7, and 9). N was applied in single applications or in split applications. Current findings suggest that a predictable relationship between RY and RI does exist, and that this relationship changes as the plant matures. Results show that it is possible to group the growth stages from Feekes 4 through 5 and Feekes 6 through 9. Using these groupings, it is only necessary to use RI for the predictor of RY at Feekes 4 through 5. However, during the Feekes 6 through 9 growth stages, fall-winter split application N Rate and RI both significantly impact RY. Therefore it is recommended to use both as predictors of RY. Based on this research, including the RY component in algorithms has the potential for increasing the efficiency of sensor-based N management.

Introduction

Over the past decade, interest in enhancing the efficiency of N management programs for wheat has increased. Some of the reasons for this are: increased fertilizer and application costs; increased wheat prices and the desire to increase yield; and environmental concerns over excess N application. A number of different approaches have been taken to find new ways to improve N management. One of these approaches has been the use of optical sensors. Some of the pioneering efforts into making optical sensors usable for N management in wheat were by Oklahoma State University, with the optical sensor now known as the Greenseeker (Trimble Navigation, Agricultural Division). The OSU research resulted in the creation of algorithms for using optical sensors to make N recommendations for wheat (Raun et. al, 2005). Their algorithms use the basic approach of comparing the Normalized Difference Vegetative Index (NDVI) of an “N rich strip” (Raun et. al., 2010) to the NDVI of a target area to be fertilized to make an N recommendation. Similar algorithms have been released by other universities, one of which is Kansas State University (Tucker and Mengel, 2009). Each university’s algorithm uses a slightly different approach, but all make the same assumption, which is that 100% of the yield potential difference between the N rich strip and the farmer practice can be recovered by the addition of the appropriate N addition. However, 100% yield recovery may not always be possible, especially in cases where N deficiency is severe. In these cases the algorithm will be recommending N for yield which cannot be obtained. Therefore, while these N recommendations may provide a significant improvement over traditional soil test/yield goal based systems they may still have instances of over application, thus reducing the efficiency of the system.

Kansas State University has been working on new components for improving sensor-based N recommendation algorithms. One of the components has been termed as “recoverable yield.” The basic definition of recoverable yield is how much yield can be recovered at a given growth stage and response index by making an N application. To determine the relationship between recoverable yield and response index, an N treatment regimen was established to create multiple levels of N stress at different growth stages to create a series of response indexes. At the given growth stage of interest, the RI was determined use optical sensors and different rates of N applied. In this way we could determine the response index of each N treatment compared to a high N status reference strip, measure the response to applied N and determine how much yield we were able to recover in comparison to the N rich strip.

We hypothesize that there is an inverse relationship between response index and recoverable yield: As response index increases and N deficiency becomes more severe, the amount of yield that can be recovered by an N application decreases. We also believe that there likely is a threshold for RI, or N deficiency, for any particular growth stage in which 100% yield recovery can be obtained by an N application. However, after this threshold has been crossed, permanent yield loss occurs.

The objective of the study was to establish the relationship between RI and RY and evaluate the effects of incorporating this new component into N recommendation algorithms.

Materials and Methods

Twenty-one experiments were conducted starting in 2006 and continuing through 2012 at 12 locations throughout Kansas in cooperation with producers and KSU experiment stations. Each location was rain-fed and used crop rotations, tillage, cultural practices, and wheat varieties that were representative of the area. Each field study utilized small research plots normally10 feet in width by 50 feet in length. Treatments consisted of multiple N rates ranging from 0 to 150 lbs N $acre^{-1}$ that were applied in single or split applications at different times during the growing season (Fall-Winter, Feekes 4, 7, and 9) with Urea as the N source. Treatments were in a factorial arrangement and placed in a randomized complete block design with four replications. N rich reference strips were established at each location and consisted of total applied N rates greater 120 lbs. N $acre^{-1}$ applied in the fall.

Soil samples to a depth of 24 inches were taken by block, prior to planting and fertilization. 0-6 inch samples were analyzed for soil organic matter, Mehlich-3 phosphorus, potassium, pH, and zinc. The 0-24 inch samples were analyzed for nitrate-N, chloride, and sulfate. Fertilizer needs other than N were applied in the fall at or near seeding.

Optical sensors used were the Greenseeker (Trimble Navigation, Ag Division, Westminster, CO), the CropCircle ACS-210 (Holland Scientific, Lincoln NE), and CropCircle ACS-470 (Holland Scientific, Lincoln NE). Upon receiving the CropCircle ACS-470, use of the ACS-210 was discontinued. The Greenseeker sensor utilizes two channels set for 656 nm and 774 nm. The CropCircle ACS-470 has 3 channels that allow changeable filters, and were set to 670 nm, 550 nm, and 760 LWP. Canopy reflectance was used to calculate the Red NDVI and was averaged for each plot. NDVI was used to calculate the Response Index (RI=N Rich Strip NDVI/treatment NDVI) of each plot. Canopy reflectance of the wheat was measured multiple times throughout the growing season with Feekes 4, 7, and 9 being key points of measurement.

Flag Leaf tissue samples were taken at Feekes 10.5 and were analyzed for N content. Grain yield was measured by harvesting an area of 5 feet by 47 feet within each plot at all locations. Yields were adjusted to 12.5 percent moisture, and grain was analyzed for N content and protein.

Recovered yield was calculated (RY = treatment yield/N reference yield) for each plot and the relationship with RI, N rate, and N application timing was established using GEN. REG. in Minitab 16 using an alpha of 0.05.

Results and Discussion

Initial analysis of the data has shown that the relationship between RY and RI changed depending on the growth stage. This significant difference developed between Feekes growth stages 5 and 6, but there was not a significant difference before or after that junction. Because of this issue, the data was put into two groups based on growth stage, Feekes 4 and 5 and Feekes 6 through 9.

Analysis of the data obtained at Feekes 4 through 5 showed that RI was the only significant factor which influenced RY, while at Feekes 6 through 9 both RI and early N application rate were significant factors, but they did not have an interaction effect. Non-significant factors were removed from the model and the results can be seen in Tables 1 and 2. Both models were highly significant and suggest that a yield recovery prediction can be made throughout the growing season, thus helping tailor N recommendations to be more directed at yields that are actually obtainable. The data in Figures 1 and 2 the data suggest that a RI < 1.2 should be maintained if a yield recovery greater than 95% is desired. Allowing the crop to become N deficient to the point that RI> 1.2 develop will result in permanent yield reduction.

An additional cause for concern can be seen in Figures 1 and 2. There were many data points that had a RI <1.0. The primary reason for this was the degradation of the N rich strip. There are many potential reasons why the growth of an N Rich strip would degrade, such as N loss, plant disease, and water stress. While all of these were seen in these experiments, the primary problem observed was in the experiments presented in Figures 1 and 2 was plant disease. Excess early season vegetative growth resulted in an ideal microclimate for diseases such as stripe rust. Despite being treated with a fungicide, disease overwhelmed some of the N rich strips, resulting in serious yield reductions. However, the split application treatments did not develop serious disease conditions due to having less biomass, thus yields were maintained. The degradation of the N rich strip is an issue that has not been addressed, but can have a significant impact on the efficacy of algorithms designed to utilize these strips. The recoverable yield component can recognize the degradation of the N rich strip, but does not have the ability to predict what the yield potential could have been if degradation did not occur.

The recoverable yield concept is being incorporated into a new KSU algorithm. A comparison of the current KSU algorithm with a proposed new algorithm is shown in Figure 3. The current KSU algorithm continues to increase N rate until approximately RI >2.2 where the N recommendation is capped at 100 lbs. N $acre^{-1}$. With the new algorithm which includes the RY concept version RK 2.2, when the RI reaches 1.6, the N recommendation reaches its max at 71 lbs. N $acre^{-1}$, and then declines as the potential to recover additional yield declines rapidly. Figure 1 shows that at RIs above 2.0 response to N applications are severely low. The reasons for these severe yield reductions have primarily due to poor stands and differences in the number of tillers. At this point in the growing season, tiller production is ending, and as such, any differences in tiller numbers are a permanent yield loss. Therefore, increasing N recommendations with high RIs will only result in lower nitrogen use efficiency.

The RY component is showing promise for improving N recommendation algorithms by only applying N for yield that can be attained. However, incorporating this concept into recommendation algorithms will require that other components such as yield predictions and N uptake and response components will also need to be more specific. Further research is being conducted to fully develop the RY component and integrate it into N recommendation algorithms for wheat and other crops.

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Table 1. ANOVA for Feekes 4-5 Recoverable Yield

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	2	1.58534	1.58534	0.79267	374.674	< 0.00000
Response Index	1	1.46154	0.04526	0.045262	21.394	0.0000085
Response Index*Response Index	1	0.1238	0.1238	0.123795	58.515	< 0.00000
Error	138	0.29196	0.29196	0.002116		
Total	140	1.8773				

RY = 0.695541 + 0.79554RI - 0.515213 RI*RI
R^2 = 84.45%

Table 2. ANOVA for Feekes 6-9 Recoverable Yield

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	2	0.74217	0.742168	0.371084	86.49	< 0.00000
Response Index	1	0.6575	0.379582	0.379582	88.4708	< 0.00000
FallWinter N	1	0.08467	0.084669	0.084669	19.7341	< 0.00002
Error	112	0.48053	0.480534	0.004290		
Total	114	1.2227				

RY = 1.18817 - 0.299495RI + 0.00114635FallWinterN
R^2 = 60.70%

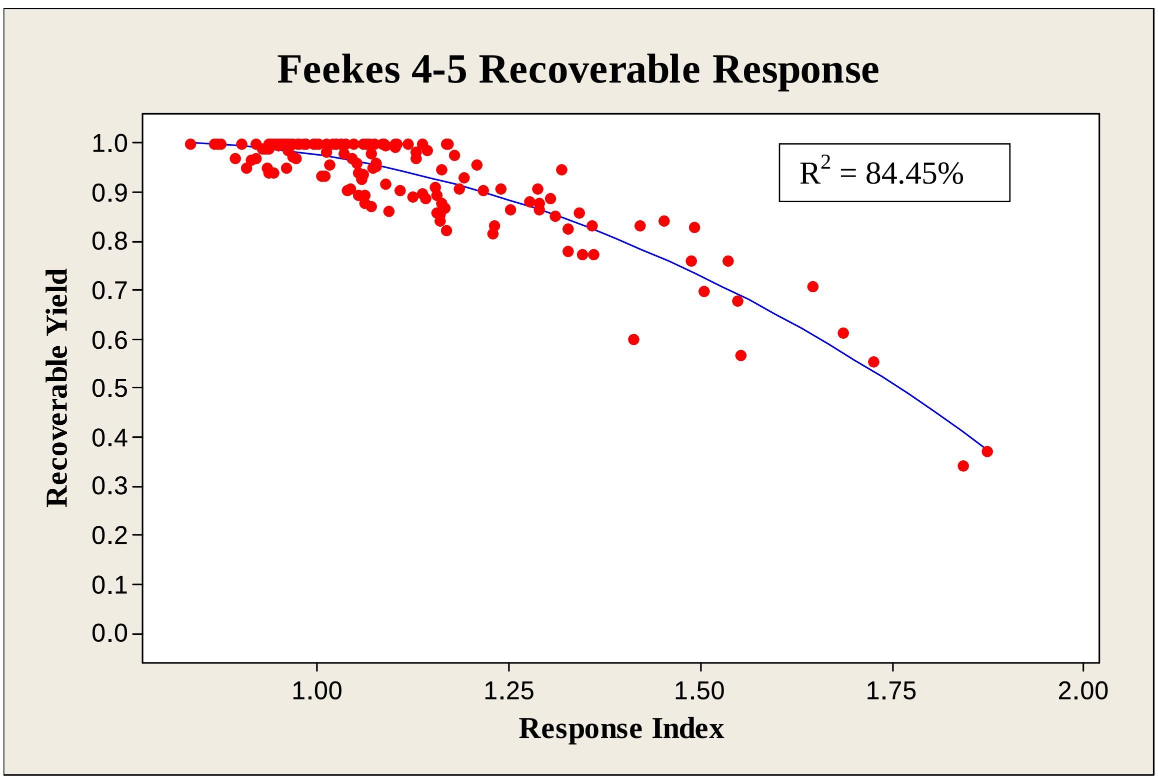

Figure 1. Relationship between RY and RI at Feekes 4-5

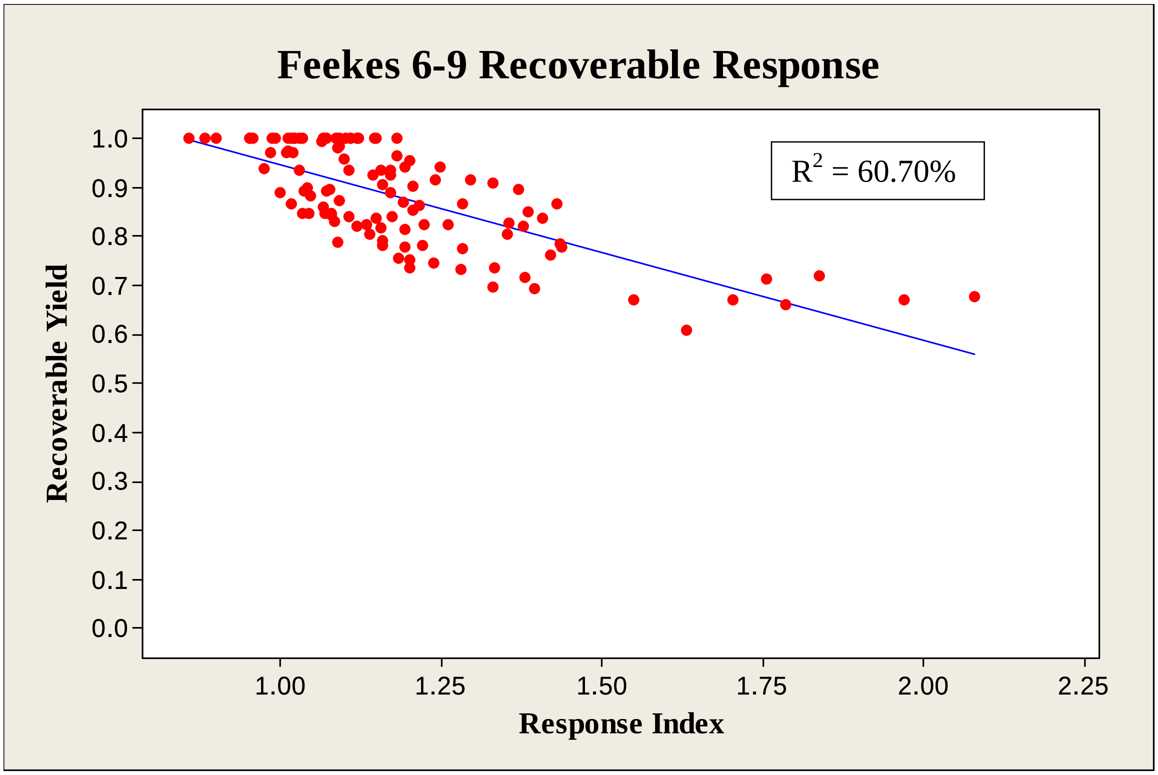

Figure 2. Relationship between RY, RI, and Fall-Winter N rate for Feekes 6-9

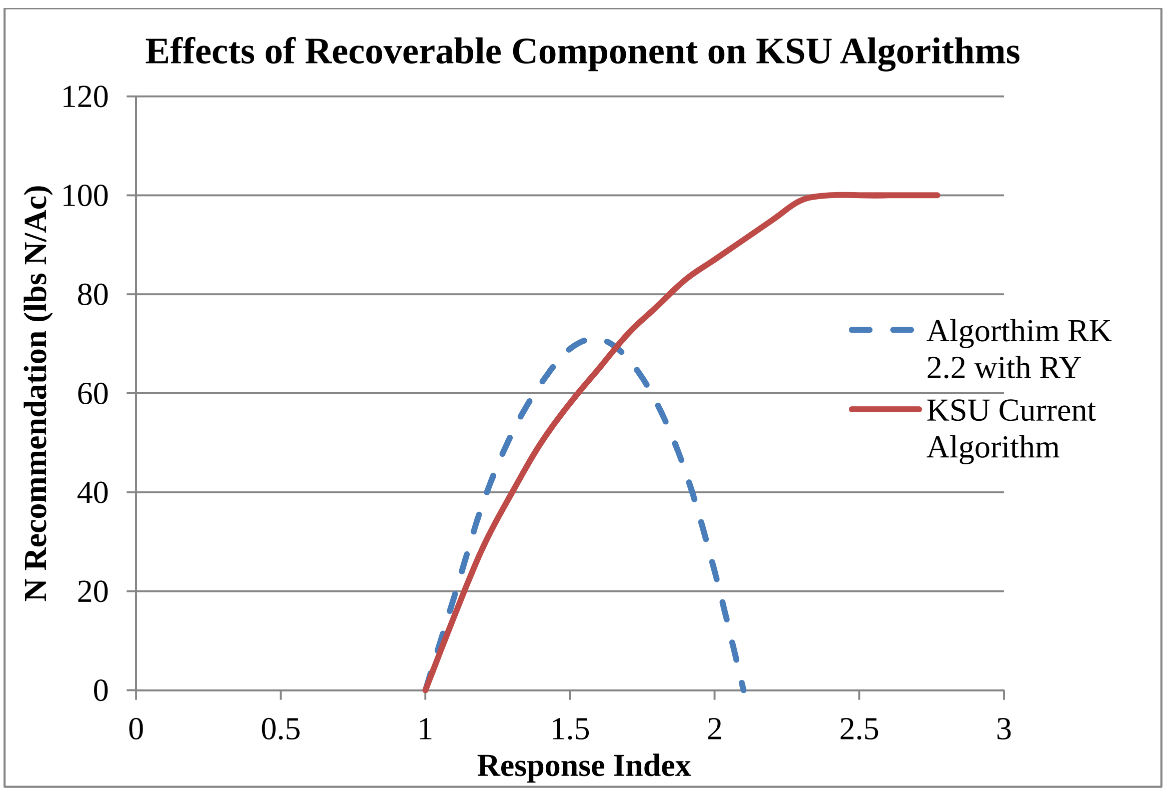

Figure 3. Comparison of KSU N Recommendation algorithms at Feekes 4

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NORTH CENTRAL
EXTENSION-INDUSTRY
SOIL FERTILITY CONFERENCE

Volume 28

November 14-15, 2012
Holiday Inn Airport
Des Moines, IA

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Published by:
International Plant Nutrition Institute
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Brookings, SD 57006
(605) 692-6280
Web page: www.IPNI.net