USING OPTICAL SENSORS TO MAKE N RECOMMENDATIONS FOR SORGHUM, WHEAT AND CORN IN KANSAS

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Abstract

Efforts were begun in 2005 focused on developing sensor based N recommendations for grain sorghum (*Sorghum bicolor* L. Moench), winter wheat (*Triticum aestivum* L) and corn (*Zea mays* L.). The objective of these studies was to develop sensor based mid-season N recommendations using active crop sensors currently available on the commercial market. Sensors used to date include the GreenSeeker and CropCircle. Our approach used has been to establish multiple in-field well fertilized reference strips and calculate a Response Index based on NDVI using red and near infrared wavelengths at key growth stages: GS 3 for grain sorghum, Feekes 3 to 5 for wheat, and V-8 to 10 for corn. N recommendation is based on yield potential at sensing, the relationship between RI at sensing and RI at harvest, expected N uptake and NUE. Rate calculators for each crop have been developed and are based on data collected in a series of field conducted across Kansas with each crop. Field confirmation experiments on farmer fields are being conducted to ensure accuracy in the "Real World". Calculators were first available on-line for farmer use in 2009 for sorghum and wheat. They were also available as a menu option with the GreenSeeker variable rate application system. A draft corn calculator using a similar format was developed and tested in 2009, will be available for farmers in 2010.

Introduction

The majority of the field crops in Kansas are grown under dryland conditions, in places which vary, from areas where precipitation and stored soil water regularly are inadequate for optimum yield, to regions where excess moisture regularly delays field operations and N loss is expected. Yields in Kansas vary from year to year, and region to region, generally tracking annual variations in rainfall during the growing season. Residual soil N is regularly available in sizeable quantities in the Western 2/3 of the state, but is not easily or routinely measured by farmers or crop consultants. Surveys conducted during the fall of 2006 for fields being planted to wheat and the spring of 2007 in fields being planted to sorghum and corn showed the average residual soil nitrate-N in the top 24 inches of soil to average over 90 pounds per acre, but ranging from less than 15 to over 300, in both situations. With this high variability in yield and residual soil N, plus variable costs of inputs such as fuel and fertilizer, it seems logical to try to develop better N fertilization practices which can improve yield and N use efficiency, reduce costs and enhance profitability for crops such as sorghum, wheat and corn, grown on approximately 15 to 17 million acres annually.

Being able to delay the final fertilization decisions and investments as late as possible allows farmers to have a better feel for the stored water available in droughty areas, and allows the crop to be used as an indicator of residual and/or mineralized N available, preplant N lost, and yield potential that year. By comparing with a well established reference strip, a strip which is not limited in nitrogen, and in some cases a check strip or area where no fertilizer N has been applied, N fertilizer rates can be adjusted to meet the crop's need based on N availability and crop need at that time.

The overall objective of this study was to develop an active sensor based mid-season N recommendation system that would work state wide over a range of growing conditions, and enhance crop yield, N use efficiency and profitability of corn, wheat and grain sorghum. Since our work on sorghum is essentially complete and the system is fully operational, we will use that model to explain the concept, and then show brief summaries of the wheat and corn systems.

Materials and Methods

Field experiments were established, beginning in 2006, at the following locations with the express purpose of evaluating the use of active sensors to make N recommendations for sorghum: the North Central Kansas Experiment Field near Belleville in 2006, the South Central Kansas Experiment Field near Hutchinson/Partridge in 2006, 2007, and 2008, the Agronomy North Farm in Manhattan in 2006, 2007 and 2008, the Western Kansas Experiment Station near Tribune in 2006, and 2007 and the East Central Kansas Experiment Field in 2008. At all locations a Randomized Complete Block design was used with N rates ranging from 0-120 lbs/ac applied with timings of pre-plant, side-dress, and split applications. The sensors used for this study included the Crop Circle sensor (ACS-210, Holland Scientific) which simultaneously emits light in amber (590nm ±6nm) and NIR (880nm ±10nm) wavebands, and the GreenSeeker (Hand-held unit Model 505, NTech Industries) which emit light in red (660 ± 15nm) and NIR (770nm ± 15 nm) wavebands. Both of these sensors calculate NDVI by the following equation: (NIR-Visible) / (NIR+Visible). To collect these NDVI readings, sensors were positioned approximately 30 inches above the leaf canopy, and walked with the sensor head facing parallel to the row, and directly over the row. The middle two rows of each plot were sensed, and the NDVI values were averaged for the plot, as well as for each treatment. A response index (RI) was calculated by taking the NDVI of the highest pre-plant N rate at GS-3 and dividing this by each of the NDVI of the other treatments which were below the optimum N response. In addition, a calculation of response index grain yield RIgy was made by taking the grain yield of the highest pre-plant N-Rate treatment and dividing this by the grain yield of the other treatments. In season estimate of yield (INSEY) was determined by taking NDVI divided by the days after planting to sensing. The sensor data presented in this paper is for the GreenSeeker sensor only. Similar studies were conducted with wheat and corn.

Results and Discussion

Sorghum. A screen shot of the Sorghum Sensor rate calculator, in its current form, is shown in Figure 1. Inputs provided by the farmer are in the upper box and outputs from the program in the lower. The first two inputs the farmer is asked to provide are the NDVI of the Reference Strip and the NDVI of the bulk field or farmer practice. The calculator is most accurate when low levels of N are available prior to sensing. Since many sorghum growers (and corn growers) are concerned about not being able to make sidedress N applications due to weather complications, they may apply 50% or more of an expected N rate at planting, and then plan on "topping off

Farmer Inputs

NDVI Reference Strip	**0.6**
NDVI Farmer Practice	**0.57**
Max Yield for Area bu/ac	**130**
Days from planting to sensing where avg. temp > 63 F	**35**
Grain Price, $/Bu	**3**
Nitrogen Price, $/lb actual N	**0.6**
Application Cost, $/Ac	**5**
Expected Nitrogen Efficiency, % Recovery	**50**
Outputs	
Expected Response Index of Grain Yield	**1.26**
Grain to Nitrogen Ratio (G:N)	**5.00**
Yield Potential of Reference Strip bu/ac	**100.1**
Yield Potential without N bu/ac	**79.6**
Yield Potential with N rec. bu/ac	**99.2**
N Rec. lbs N/Ac unadjusted for G:N price ratio	**39.0**
Coefficient to adjust for G:N ratio	**0.96**
N rec. lbs N/Ac adjusted for G:N price ratio	**37.4**
Gross Return (no Nitrogen) $/ac	**238.73**
Gross Return (using N Rec) $/ac	**270.30**

Figure 1. Screen shot of the KSU Sorghum Rate calculator.

the system" at sidedress. In these situations, or when significant residual or mineralized N is expected, using a true check strip with no N applied for the farmer practice and subtracting the N applied preplant or at planting from the calculated recommendation based on the check, can provide improved accuracy.

The farmer is next asked to provide a maximum yield for the area to use in the calculations. This value places limits on the yield calculated based on the NDVI of the reference strip. This is especially useful in areas or on soils where rainfall or soil water holding capacity limits yield at later stages of growth.

The fourth input is days from planting with an average daily temperature > 63^{o} F. Sorghum is a tropical perennial plant with little cold tolerance. Most sorghum is planted in mid-May or later, and the temperature issue doesn't come into play. However, some growers are pushing the envelope on planting date and planting in April. In these situations little or no effective growth occurs on many cool days. Without the adjustment the sensor prediction of yield based on NDVI at a specific number of days from planting will be low, and the resulting N need underestimated. This adjustment corrects for those slow growth days and gives good sensor based yield predictions and N rate recommendations. A logical question is why not use GDD's? We tried several approaches, and this worked best. The INSEY graph is shown below as Figures 2 to illustrate this relationship. Note that the equation has an R^2 of 0.76. Using NDVI alone the relationship with yield had an R^2 of 0.49, and adjusting for temperature using GDU's, base 60, the relationship has an R^2 of 0.61.

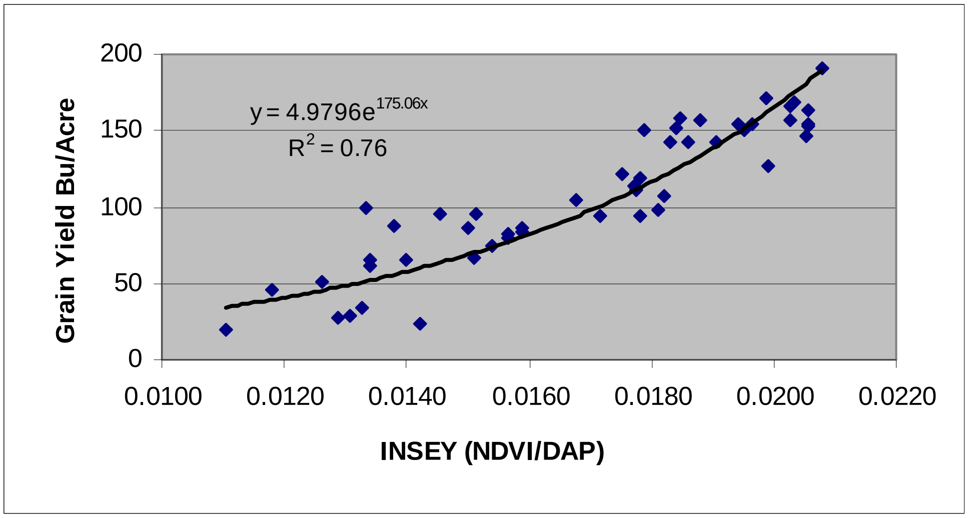

Figure 2. Relationship INSEY (NDVI/Days after planting) and Grain yield used in grain yield predictions based on NDVI of the reference at planting.

The next three lines of input are grain price, nitrogen price and application cost. This will allow for modifications of N recommendations due to economics of N fertilization.

The last input value is Expected NUE. This input is the expected percent recovery of applied nitrogen and has a default value set at 50%. In Kansas NUE can vary widely and is one of the focus points of our Nitrogen Extension Program. Values ranging for 35 to 65% in sorghum are not uncommon.

The program calculates and provides the following output:

Expected Response Index of Grain Yield. That value is obtained form the relationship between RIvegetation at GS-3 and RIgrain at harvest, illustrated in Figure 3.

Yield potential of the reference strip and yield potential of the farmer practice or bulk field, both based on the relationship shown in Figure 2.

N recommendations, adjusted and unadjusted for price. N recommendations are calculated based on an N uptake vs. yield relationship shown in Figure 4, and the selected NUE. In the example shown, yield with fertilization increases from 80 to 100 bushel per Acre, or 20 bushel per acre.

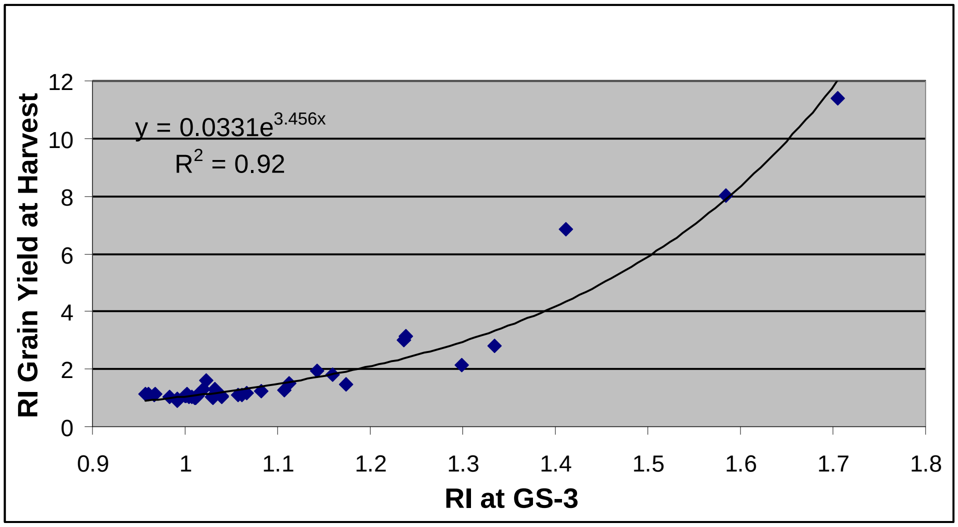

Figure 3. Relationship between RI veg at GS-3 and RI grain at harvest.

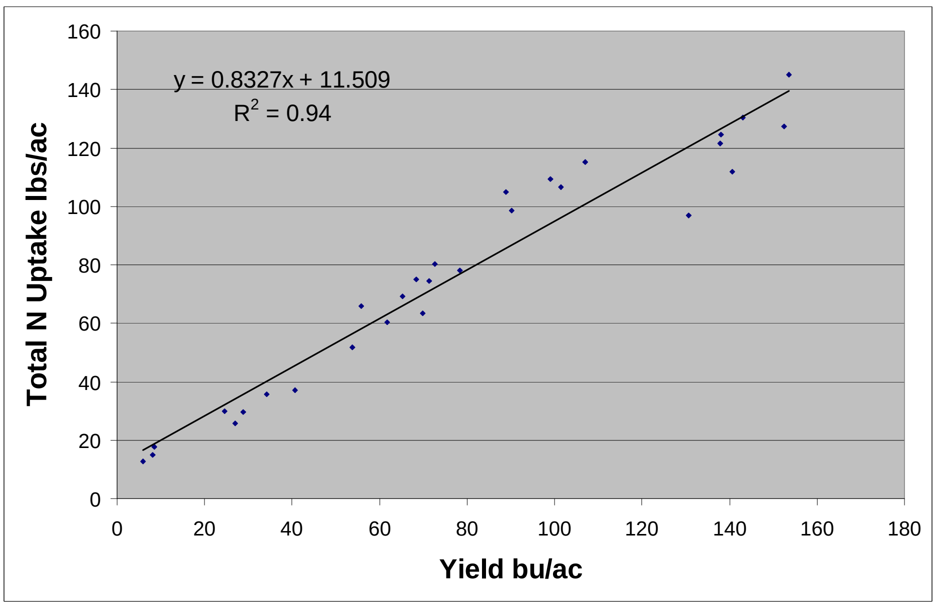

Figure 4. Relationship between N uptake and yield in sorghum

N uptake would increase from 77 lbs per acre to 96 lbs per acre, or an increase of 19 lbs N per acre. With a fertilizer N NUE of 50%, it would require fertilizer application of 38 pounds N per acre to supply the required N.

So, how well does the system work? The summary of 10 field trial conducted from 2006 through 2008 is given in Table 1. As can be seen from the data, the relationships developed with the sensor did a good job of estimating yield and N response, as compared to what actually was found at each location. The sensor estimated N recommendation differed on average 4.3 lbs N per acre from the optimum rate observed. This was substantially less than the 25.6 lbs N difference between actual response and that predicted based on a soil test based N recommendation.

Table 1. Summary of the results of 10 sorghum field trials using the KSU sensor based N rate calculator compared to measured results.

Location	Year	Sensor Yield	Actual Yield	Sensor Rec.	Actual N Resp.	Sensor Dif
Belleville	2006	95	96	0	0	**0**
Manhattan	2006	160	155	33	33	**0**
Partridge	2006	48	32	57	55	**2**
Tribune	2006	130	128	24	15	**9**
Manhattan	2007	111	109	98	105	**-7**
Partridge	2007	77	70	15	20	**-5**
Tribune	2007	71	79	0	0	**0**
Manhattan	2008	151	128	45	45	**0**
Ottawa	2008	58	64	55	60	**-5**
Partridge	2008	140	123	30	15	**15**
Mean difference						**4.3**

Wheat. A wheat rate calculator has also been developed and looks and performs similarly. While our approach to making the recommendations differs from that used by OSU, the initial results were similar. Results in 2009 were not as good, so it is likely there will be further "tweaking" as the data set expands.

Table 2. Summary of the results from 8 wheat fields using the KSU sensor based N rate calculator compared to measured results.

Location	Year	Sensor Yield	Actual Yield	Sensor Rec.	Optimum N	Sensor Diff.
Manhattan	2006	63	61	78	75	3
Manhattan	2007	45	45	1	0	1
Johnson	2008	34	31	67	65	2
Manhattan	2008	36	36	47	40	7
Partridge	2008	66	69	47	44	3
Johnson	2009	30	21	18	30	-12
Manhattan	2009	80	78	35	40	-5
Partridge	2009	47	43	25	60	-35
Mean Difference						-4.5

Corn. Work is underway using the same general approach with corn. Unfortunately, the midseason sensor based yield predictions have not been as good as those obtained with sorghum or wheat. There are several possible reasons for this including: the range of yield levels in the data set, the relatively small portion of final N and dry matter accumulated by V-8, 9 where sensing has been done, or the fact that the sensors are approaching saturation and are losing sensitivity. But, while this poor relationship has been discouraging, other results have been more successful.

The results from a three year study just concluded at our Kansas River Valley Experiment Field have shown that the sensors have been valuable when used to make final adjustments in N applications for irrigated corn. In this study applying 120 lbs of N/ac early in the season and then using the sensors at V-8,9 to make final adjustments has resulted in the same yield with slightly less N than traditional all preplant or split applications with fixed rates of N (Table 3). In this study both the GreenSeeker and CropCircle sensors resulted in similar yields to the 160 lb N/a preplant or split application systems with 10 to 15 pounds less N/a. The same experiment has been repeated at two other locations in Kansas in 2008 and 2009, with similar results.

Table 3. Results comparing sensor based N recommendations for irrigated corn to traditional preplant or split application systems, Rossville, Kansas, 2007-2009.

Nitrogen Treatment applied	Average N applied, 2007-2009 (lbs N/acre)	Mean Grain Yield, 2007-2009 (bu/acre)
Starter Only	20	103
120 preplant	120	213
160 preplant	160	223
200 preplant	200	232
120 split	120	208
160 split	160	223
200 split	200	224
120 preplant + GS	144	227
120 preplant + CC	153	226
120 preplant + Spad	141	213
GS sd + Spad	130	225
CC sd + Spad	146	224
LSD 0.1		14

In addition to the traditional small plot N work, we have been cooperating with a local fertilizer dealer who has a GreenSeeker system mounted on a high clearance sprayer on several on-farm trials. These fields were set up with farmer applied reference strips of normal N rates, with the balance of the fields treated with ½ rates anticipating variable rate applications of the balance of the required N at V-7 to 8. Small plot rate studies in two of those fields showed no response to additional applied N beyond the preplant rate in one, and a response to 60 pounds of additional N in the other. In several other fields, the NDVI values were so high at V-7 that the reference strips could not be distinquished from the ½ rate bulk areas. Variable rate application with the commercial applicator on those fields using a draft KSU algorithm similar to that used in the Rossville experiment summarized above (Table 3) resulted in whole field average applications of 10-15 lbs N/a application rates.

Conclusions

Sensor technology allows growers to make mid-season estimates of nitrogen needs in sorghum and wheat production. While reliable soil tests have not been developed to estimate mineralizable N, sensors provide an opportunity to allow the crop to serve in that capacity. The KSU system relies on the use of a reference strip, and the calculation of a Response Index comparing the NDVI of the bulk field to that of the reference strip. Sensor readings made 35-45 days after planting appear to be optimum for sorghum. Readings at Feekes 4 to 5 appear optimum for wheat in eastern Kansas. Earlier readings do not allow for adequate differentiation between the bulk field and the reference strip, especially if the bulk field areas received significant amounts of N fertilizer, for both crops. Using a check strip rather than the bulk field or “farmer practice” for sensing to establish N needs and subtracting preplant N from the resulting recommendation, gives more accurate recommendations where higher rates of preplant N are used.

Early work appears promising for corn. A draft rate calculator for corn will be available for farmer use in 2010. Additional work is planned to look at both the late sidedressing plus later “rescue” or “top-off” applications on corn at V-11 to15 growth stages. While results are still preliminary with corn, and the system is not without problems, the results are promising.

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