ACTIVE OPTICAL SENSOR ALGORITHMS FOR CORN YIELD PREDICTION AND IN-SEASON N APPLICATION IN NORTH DAKOTA

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ABSTRACT

A recent series of seventy seven field N rate experiments with corn (*Zea mays*, L.) in North Dakota was conducted. Multiple regression analysis of the characteristics of the data set indicated that segregating the data into those with high clay soils and those with medium textures increased the relationship between N rate and corn yield. However, the nearly linear positive slope relationship in high clay soils and coarser texture soils with lower yield productivity indicated that rate alone is not a good solution for N management in these soils. Split application of N would be necessary to increase N efficiency in N-loss challenged soils. In sixty of these data sets, the GreenSeeker™ and Holland Scientific Crop Circle™ sensors were used at V6 and V12 growth stages using the red-NDVI and red edge-NDVI optional light and detection filters. Manual canopy measurement was also conducted in these experiments at both growth stages. In 2013, an automatic acoustic height sensor was also tested the date of sensing at most sites. Yield and INSEY (in-season-estimate of yield/ instrument reading divided by growing degree days from planting to sensing) at V6 was generally better related using red-NDVI compared to V12. Red edge NDVI based INSEY was more strongly related to yield compared to red-NDVI based INSEY at V12. Crop height tended to increase the relationship with yield at V6 with red and red edge-NDVI based INSEY, but only the red-NDVI INSEY benefited from crop height at V12. Separate active-optical sensor algorithms are planned for use in residual soils west of the Missouri river. In eastern North Dakota, separate algorithms have been developed for fields in no-till more than six years, for conventional till fields on high clay soils with greater than 9.9 Mg ha^{-1} and less than 9.9 Mg ha^{-1}, and for conventional tilled medium textured soils with greater than 9,9 Mg ha^{-1} and less than 9.9 Mg ha^{-1}.

Keywords: Precision agriculture, NDVI, sensors, corn, nitrogen

INTRODUCTION

Corn (*Zea mays*, L.) is highly dependent on adequate N through the growing season until maturity for highest yield. From the date of planting, N uptake is only about 10 percent of the total required for yield obtained at V6 stage (Bender et al., 2013). Maximum N uptake by corn takes place between V9 and V18 (Scharf and Lory, 2006), suggesting that in soils with high risk of early season losses, split N application or a side-dress N application would be a best management practice for corn within those soils. The rate of N application at side-dress has been dictated by the total N required based on a preplant N formula, less any N applied before or at planting.

The use of active-optical sensors has recently been developed to direct variable-rate N in wheat, corn and other crops (Li et al., 2008; Sawyer and Barker, 2010; Walsh et al., 2012). The basic methodology is to build a data set where sensor reading is related to yield. Using an N-rich strip (Raun et al., 2002) has been suggested as a method to compare sensor reading and associated yield from a previously determined algorithm in the N-rich strip from sensor reading and a perhaps lower yield from other areas of the field. In a mass-balance approach, the N required to reach the higher yield within the N-rich strip is determined. However, there is evidence that over a region there is independence of yield and N rate. This means that over soils and regions a single algorithm alone will not account for yield differences defined by the soils and environments (Raun et al., 2010; Arnall et al., 2013). The use of an N response index is recommended when yield and N rate are expected to be unrelated.

In a recent study over 77 sites in North Dakota, yield and N response data were categorized into several groups based on a multiple regression analysis. Over all sites, the relationship between yield and optimal N rate was low. However, when the data were categorized, the relationship between yield and optimal N rate was much improved. The categories were as follows:

- Region (western North Dakota vs eastern North Dakota)
  - Eastern region tillage (Long-term no-till vs conventional/minimum till)
    - Conventional till surface texture (high clay-silty clay loam and higher clay according to soil survey vs medium textures- silt loams, fine sandy loams, loams, sandy loams)
      - High clay and medium textures by productivity- higher historic yield potential greater or less than 9.9 Mg ha^{-1} .

Through separating soils into categories, there is a good relationship between yield and N rate, therefore, the algorithms produced are a mass-balanced approach that might be implemented through the establishment of an N-rich strip within soil category within hybrid.

METHODS

From 2010 through 2013, a total of 77 sites in North Dakota were established as corn N rate experiments and taken to yield. Each site was established on a farmer cooperator field. Each experiment was arranged in a randomized complete bloc design with 6 N treatments; 0, 44, 88, 132, 176, and 221 kg N ha^{-1} as hand-applied ammonium nitrate granules with four replications. Plot size was 3 m wide and 6.1 m long. Any P, K, Zn or S required within the site that the farmer was unable to apply was applied by the researchers as defined by soil test analysis (Franzen, 2010). The sites were defined by large flags so that the farmer or his fertilizer applicator would not apply any N to the plot area. The farmer planted the field with a corn hybrid of their own choosing after N treatments were applied. Herbicide was applied by the grower. In 2011 through 2013, active-optical sensor readings using a GreenSeeker™ (Trimble, Inc. Sunnyvale, CA) and a Holland Scientific Crop Circle™ sensor (Holland Scientific, Lincoln, NE) were obtained at V6 and V12. One interior row was hand-harvested at maturity, shelled, moisture was analyzed and yield calculated. In analyzing the response to N, a number of soil, region, tillage and productivity factors were evaluated through multiple regression to determine whether segregating sites into categories would increase the relationship between N rate and yield among the sites. Statistical analysis of yield and multiple regression was conducted in SAS 9.1 or SAS 9.2 for Windows® (SAS Inst. Inc., Cary, NC). Analysis of regression models for algorithm development was conducted in Excel 2007.

RESULTS AND DISCUSSION

The relationship between yield and region, and eastern tillage system, surface soil texture and productivity within conventional tillage system was highly significant, which supports the development of algorithms within categories and the use of the algorithms in a mass-balance approach using N-rich strips (Table 1). Category for productivity was derived by trial and error. The other categories were based on reasonable assumptions for possible difference in response from field activities.

Terms used in algorithm development:

NDVI, defined as normalized differential vegetative index. A value computed using near infrared (NIR) and in this paper either red (R) or red edge (RE) wavelength reflectance from vegetation in the formulas-

$$RNDVI = (NIR - R) / (NIR + R)$$

$$RENDVI = (NIR - RE) / (NIR + RE)$$

Readings for the GreenSeeker between 2011 and 2012 were RNDVI. Only algorithms using GreenSeeker RNDVI are reported here. Readings for the Crop Circle from 2011 and 2013 included both RNDVI and RENDVI.

Table 1. The r^2 from multiple regression analysis of 77 N rate studies for factors influencing response of corn to N, 2010-2013, North Dakota.

Factor	F	Pr>F
Region- West of the Missouri River vs Eastern North Dakota	43.5	<0.0001
Within eastern region-	21.8	<0.0001
Tillage- Long-term notill vs conventional/minimum till		
Within conventional/minimum till -textures	15.6	<0.0001
High clay (silty clay loam or more clay) vs medium textures, including fine sandy loam, silt loam, loam, sandy loam		
Within high clay- productivity	103.0	<0.0001
Historic productivity greater than 9.9 Mg ha^{-1} vs productivity less than 9.9 Mg ha^{-1}		
Within medium textures -productivity	172.0	<0.0001
Historic productivity greater than 9.9 Mg ha^{-1} vs productivity less than 9.9 Mg ha^{-1}		

Algorithms are also based not on RNDVI or RENDVI, but the value of INSEY, which is a sensor normalization term developed through Oklahoma State researchers led by W.R. Raun to allow measurements to be included in a similar algorithm within a range of plus or minus about 10 days of sensor measurements. Without the use of INSEY, measurement variability would increase greatly due to small differences in crop stage between sites and years (Raun et al., 2002). INSEY is defined as:

INSEY = Sensor reading / growing degree days from planting.

With any set of regression data, there are options for goodness of fit model choices. With our data, an exponential model of the relationship between INSEY and yield was most consistent compared to a linear or quadratic model. The algorithms for use in corn west of the Missouri River in North Dakota are shown in Table 2. The GreenSeeker RNDVI based INSEY and the Crop Circle RNDVI and RENDVI based INSEY measurements at V6 were similarly related to yield, with r^2 values about 0.38. The GreenSeeker RNDVI based INSEY at V12 had that best relationship to yield.

In eastern North Dakota, the first category break was between long-term no-till sites and conventional till or minimum till sites. The long-term no-till sites were unusual among data sets, because although each the RNDVI and RENDVI was highly related to yield at each site, combining the sites produced a low relationship with yield. This lack of relationship indicates that eastern long-term no-till sites would benefit from a response-index approach. Response index for corn at V6 using the GS RINSEY was 1.42; for CC RINSEY, 1.29; for CC REINSEY, 1.27. The response index for corn at V12 using the GS RINSEY was 1.02; for CC RINSEY was 1.53; for CC REINSEY was 1.59.

In eastern North Dakota in high clay soils with historic yields greater than 9.9 Mg ha^{-1} models were significant for both instruments at red and red edge INSEY measurements at both the V6 and V12 growth stages (Table 3). The greatest r^2 for the models were achieved using the CC RE INSEY at both V6 and V12. Multiplying INSEY by crop height increased the relationship of INSEY to yield with most instrument readings and light sources (Sharma and Franzen, 2013), however, until a practical method for automatic height measurement is found, height is not included in the models.

Table 2. Models for use in corn west of the Missouri River in North Dakota. y is yield in Mg ha^{-1}, x is INSEY value.

Sensor/band and growth stage	Model	r^2
GS R V6	$y = 3.088e^{1788.3x}$	0.39
CC R V6	$y = 3.4507e^{2212.2x}$	0.38
CC RE V6	$y = 3.6227e^{3101x}$	0.37
GS R V12	$y = 3.6423e^{1285.5x}$	0.34
CC R V12	$y = 4.8746e^{743.2x}$	0.20
CC RE V12	$y = 5.3873e^{885.46x}$	0.15

Table 3. Models for use in corn east of the Missouri River in North Dakota in high clay soils with historic yield greater than 9.9 Mg ha^{-1}. y is yield in Mg ha^{-1}, x is INSEY value.

Sensor/band and growth stage	Model	r^2
GS R V6	$y = 7.0365e^{534.29x}$	0.27
CC R V6	$y = 7.6469e^{561.69x}$	0.29
CC RE V6	$y = 7.5504e^{979.69x}$	0.43
GS R V12	$y = 5.1896e^{836.67x}$	0.39
CC R V12	$y = 4.7825e^{988.18x}$	0.36
CC RE V12	$y = 4.8377e^{1740.6x}$	0.49

Table 4. Models for use in corn east of the Missouri River in North Dakota in medium texture soils with historic yield greater than 9.9 Mg ha^{-1}. y is yield in Mg ha^{-1}, x is INSEY value.

Sensor/band and growth stage	Model	r^2
GS R V6	$y = 8.0468e^{364.5x}$	0.27
CC R V6	$y = 7.032e^{956.05x}$	0.29
CC RE V6	$y = 8.70e^{321.7x}$	0.43
GS R V12	$y = 6.6282e^{562.32x}$	0.39
CC R V12	$y = 7.108e^{551.6x}$	0.36
CC RE V12	$y = 6.1673e^{1252.7x}$	0.49

Models for high clay and medium texture soils east of the Missouri River with historic yields less than 9.9 Mg ha^{-1} were generally non-significant. These soils are highly susceptible to N losses. Active-optical sensor readings at V6 were not related to final yield. The greatest reason for lower yield in these soils was early season N loss. For this reason, growers might benefit from choosing the high clay or medium texture models for higher yield. Split application of N would enable the grower on lower yielding soils to achieve yields similar to higher yielding sites by applying N after the period for greatest N loss due to early spring rainfall and saturated soil conditions.

The algorithm from these models in Tables 2 to 4 would include a minimum NDVI reading at V6, probably about 0.25 for R NDVI, and about 0.15 for RE NDVI. There were few readings below these values in our research. When the odd lower reading was observed, it was usually a result of a low plant stand. By selecting a minimum value, errors caused by low plant stand or unusual soil conditions such as high soil salt levels, unrelated to plant N status, might be minimized. Also, a minimum rate of N application between 33 and 56 kg N ha^{-1} if predicted yield was similar to an N-rich standard within the field would compensate for possible N loss within the standard or higher yield potential for soils above that in the area of the N-rich standard.

The algorithm would be based on the model for the soil category for the field or field portion. The predicted yield from an area outside the N-rich standard would be subtracted from the N-rich predicted yield. The difference in yield in kg ha-1 would be multiplied by the N expected in the grain, i.e. 1.25%. The resulting value would be divided by an N application efficiency factor, i.e. 60%. The result would be the rate of N applied to that portion of the field.

CONCLUSIONS

Relationship models in the form of an exponential formula between active-optical ground-based sensor reading and yield were developed for soils west of the Missouri River and soils east of the Missouri River under conventional tillage systems with high clay and medium texture with historic yield potential greater than 9.9 Mg ha^{-1}. Because of the highly significant relationship between instrument readings and yield within category, our algorithms for directing an in-season N application would be beneficial as initial algorithms for growers. The algorithms would use a mass-balance approach based on yield differences between yield predicted from the N-rich standard area and other areas within the field. Multiplying the yield differences by N content anticipated in the grain, and divided by an N application efficiency factor would generate an N rate for that portion of the field. A minimum application rate should be included in the algorithm in case N loss was experienced within the N-rich standard, and instrument readings below a certain number would help avoid over-application of N on areas with low plant stand, or areas suffering from the effects of high salinity for example. No-till soils that have been continuous no-till for greater than six years require an N response index approach, since each field site was unique in N response.

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