Incorporating soil electric conductivity and optical sensing technology to develop a site-specific nitrogen application for corn in South Carolina

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Abstract
Development of variable nitrogen application in corn (*Zea mays* L.), based on soil electrical conductivity (EC) and optical-sensing technology, can help to improve nitrogen efficiency in corn, reduce the cost of applied fertilizer, and develop economically sustainable and environmentally sound corn production system for the southeastern Coastal Plain region. The long-term goal of this project is to develop procedures (algorithms) for site specific (variable-rate) application of nitrogen in corn production with the aim of increasing the farm sustainability and developing environmentally sound corn production system. The short-term objective is to determine the optimum nitrogen rates for corn in relation to optical sensing and soil spatial variability. The algorithm for variable N application in corn was originally developed at Oklahoma State University (OSU). However, due to high variability in soil type and texture, the OSU algorithm needs to be modified for Coastal Plain soils to account for these variations. During corn growth, a GreenSeeker™ optical sensor was used to measure the Normalized Difference Vegetation Index (NDVI). This information was correlated to soil EC measurements to help determine optimum side-dress N rates for corn production. The results from this preliminary study showed that there is a potential to use mid-season specific plant NDVI data for variable-rate application of N fertilizer for corn production in South Carolina. Also, the soil EC data need to be included in the N prediction equation for the Southeastern Coastal Plain region due to high soil variability and differences in crop productivity.

Introduction
Nitrogen is the most limiting nutrient for crop production (Fageria and Baligar, 2005) and has the greatest effect on grain yield (da Silva et al., 2005). Fageria and Baligar (2005) noted that crop response to applied N is an important criterion for evaluating crop N requirement for maximum economic yield. The management of N plays a key role in improving crop quality (Campbell et al., 1995) and optimal N management will be influenced by crop type and crop rotation (Grant et al., 2002). Previous research has shown that nitrogen (N) availability depends on seasonal changes in soil water content, temperature, soil structure, and organic matter distribution (Radke et al., 1985; Johnson and Lowery, 1985; Wagger, 1989; Ranells and Wagger, 1992). Fageria and Baligar (2005) stated that improving nitrogen use efficiency is desirable to improve crop yields, reduce cost of production, and maintain environmental quality.

Determination of the extent to which the crop will respond to additional N can help the growers to apply only what is needed. There have been numerous studies that showed high correlations between certain vegetation indices developed from spectral observations and plant stand parameters such as plant height, percent ground cover by vegetation, and plant population (Raun et al, 2005 and Stone et al., 1996). NDVI (Normalized Difference Vegetation Index) is used widely for mapping plant growth. NDVI is defined as (NIR - Red) / (NIR + Red). The Red and NIR values represent the reflectance in the Red and NIR bands, respectively. NDVI values range between –1 and +1 and higher positive values indicate increasing proportions of green vegetation. Researchers at Oklahoma State University have developed an algorithm for corn nitrogen fertilization based on optical sensors. The N fertilizer rates depends on making an in-season estimate of the potential or predicted yield, determining the yield response to additional nitrogen fertilizer, and finally calculating N required obtaining that additional yield (Raun et al, 2005). The results showed $36 to $39/acre profit in corn production while reducing N application rate by 45 to 70% compared to farmers practice. However, in the southeastern United States, due to high variability in soil texture, N is not uniformly utilized in the field, and application of N at one rate over the entire field is not cost effective and may decrease environmental quality.

Greater understanding of spatial-variability due to soil texture can help to obtain optimum yields for different soil zones. Standard procedures for N application on corn, based on soil spatial variability, are not available for the Coastal Plain soils. Therefore, there is a need to develop a site-specific N application based on soil spatial variability in order to decrease the cost and improve the profitability of farms in South Carolina, where corn is mostly grown under dryland conditions. A commercially available soil electrical conductivity (EC) measurement system (Veris Technologies 3100) can help to identify variations in soil texture across the field and create soil zone maps using global position system (GPS) and geographic information systems (GIS). This project will evaluate the effects of different soil zones (type and texture) on N use efficiency on corn production.

Methods and Materials

Tests were initiated in 2006 on Dothan loamy sand (fine loamy, kaolinitic, thermic Plinthic Kandiudult) at Clemson University's Edisto Research and Education Center (REC) near Blackville, SC. Prior to planting wheat as a cover crop in early December, the Veris soil electrical conductivity (EC) measurement system was used to identify variations in soil texture across the test field (Fig. 1).

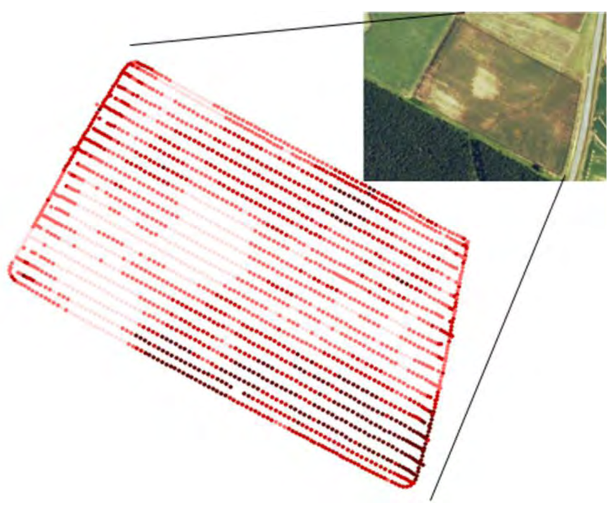

Fig. 1. Aerial image of the test field and soil electric conductivity (EC) map.

About two acres of the experimental area was divided into four different management zones using SSToollbox GIS software (SST Development Group, Inc, Stillwater, OK) based on the EC readings. Wheat cover crop was killed on 26 February 2007 and Pioneer 31G65 corn was planted at 28,000 seeds per acre using a one path strip-till planting system (Unverferth Mtg. Co., Inc., Falida, OH, and John Deere MaxEmerge Vaccum planters) on 14 March 2007. Nitrogen (25-S - liquid formulation of 25% nitrogen and 3.5% sulfur) was applied at planting at 0, 40, 80, 120 and 160 lb N/acre. Weed control was based on the South Carolina Extension recommendations. On 29 and 30 August, corn was harvested by hand and shelled using an Almaco small grain plot combine. Corn grain yield was adjusted to 15.5% moisture.

Plant Normalized Difference Vegetation Index (NDVI) was measured in each plot on 8 June using a GreenSeeker™ Optical Sensor Unit (NTech Industries, Inc., Ukiah, CA). Previous research showed that NDVI is an excellent measure of plant growth and N requirements (Raun et al., 2005). In order to generate the algorithm, planting and emergence dates were recorded and used to compute the number of days from planting to sensing in each zone. For this method, we eliminated those days where Growing Degree Days (GDD) were equal or less than zero. The GDD values were calculated as: GDD = $[(T_{min} + T_{max})/2] - 50°F$; where T_{min} and T_{max} are the minimum and maximum temperatures, respectively. In Season Estimated Yield (INSEY), which is the Yield Goal with no added N, was calculated by dividing the plant NDVI by the number of days from planting to sensing (where GDD > 0). The Response Index (RI) was calculated by dividing the average NDVI readings from the high N plots by the average NDVI readings in the plots without N application. The predicted yield with added nitrogen (YP_N) was calculated as $YP_N = YP_0 * RI$, where the YP_0 is the predicted yield without added nitrogen. The predicted amount of N that is removed in the grain at harvest was computed for both YP_0 and YP_N by multiplying the grain yields by %N in the grain. The fertilizer N rate to be applied was computed by subtracting the predicted amount of grain nitrogen uptake in the YP_0 ($GNUP\_YP_0$) and YP_N ($GNUP\_YP_N$) and then divided the results by expected N use efficiency of 60%. The N use efficiency for corn may range from about 50 to 80%.

In 2008, we established corn plots at the Edisto and Pee Dee Agricultural Experiment Stations in Blackville and Florence, and six other corn producers from Orangeburg, Clarendon, and Sumter counties are cooperating in this project. All of these farms are located in the Coastal Plain region of South Carolina. These eight locations will help to develop algorithm for site-specific application of N fertilizer and improved nitrogen management system for corn.

The tests at Edisto REC (2007) were conducted utilizing a Randomized Complete Block design with four replications. Linear and non-linear regression models were used to determine the relationships present between corn yield, soil EC data, and NDVI using Procedures in SAS (SAS Inst., 1999). In addition, the relationship between actual corn yield and the In Season Estimated Yield (INSEY) was determined to develop an algorithm for N application. The INSEY was calculated by dividing NDVI by number of days from planting to sensing.

Results and Discussion

The established relationship between the harvested corn grain yields and In Season Estimated Yield (INSEY) shows a high correlation between yields and INSEY in this initial study (Fig. 2).

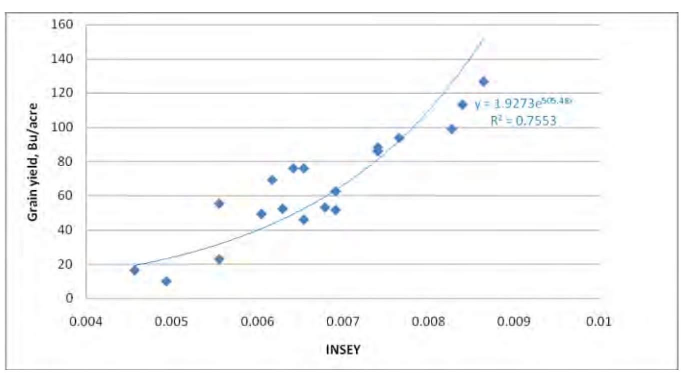

Fig. 2. Relationship between grain yields and In Season Estimated Yield (INSEY).

The INSEY index estimates the plant biomass produced per day when growth was possible. High correlations of early season NDVI readings with the plant biomass were also shown in the research conducted by Stone et al.

(1996). Additionally, Raun et al. (2002) showed that the plant NDVI readings and calculated INSEY can be used to predict corn yields. Our initial model will be used as a framework for developing the algorithm for corn producers in South Carolina.

The Response Index (RI) was calculated by deviding the average NDVI readings in plots with high N applications (0.6325) by the average NDVI readings in plots without N application (0.455). The RI value for the 2007 test was 1.39, indicating that we could likely achieve a 39% increase in yield if fertilizer N was applied. Additionally, we calculated the changes in potential yield of corn with additional N fertilizer (YP_N) by multiplying the yield without added N (YP_0) by Response Index (RI). (Fig. 3). The yield increase with additional N is limited to the maximum potential yield (YP_{MAX}).

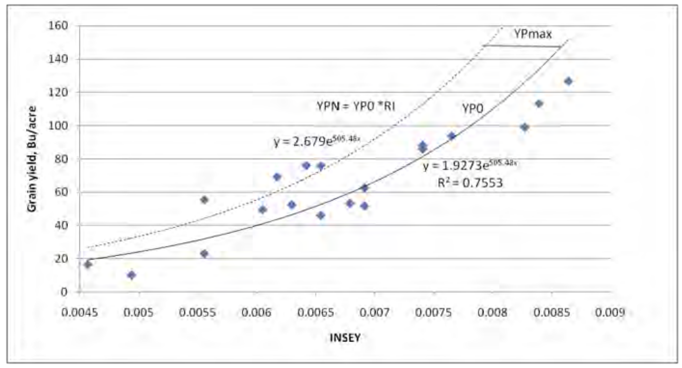

Fig. 3. The predicted yield potentials with N (YP_N) and without N application (YP_0). Yield increase with additional N is limited to the maximum potential yield (YP_{MAX})

The N recommendation was calculated by dividing the difference in grain N uptake of YP_N and YP_0 by the nitrogen use efficiency for corn (60%). Fig. 4 shows the predicted yields and calculated N rates. For example, for the 80 lbs/acre nitrogen applied at planting the average NDVI value measured 81 days after planting was 0.57. Using these numbers the calculated value of INSEY will be 0.007. The RI value for this location was 1.39 which can be used to predict yield potential with added N (YP_N) by multiplying the YP_0 by 1.39. The predicted yield potential (YP_N) should not exceed the maximum corn yield (YP_{MAX}) for a given region and management practices. In our case the YP_{MAX} was set at 150 Bu/acre for the "Savannah Valley Region" of South Carolina for dryland corn. Multiplying the YP_0 and YP_N values by 1.25% (percent of N in corn grain), we calculated N removals with corn grain. Based on the difference in grain removal and nitrogen use efficiency (60%), the fertilizer recommendation would be about 31 lbs N/acre for dryland corn under test field and rainfall conditions for 2007 growing season (dry year). Therefore, it is unlikely that corn would respond to significantly higher N fertilization rates in this location.

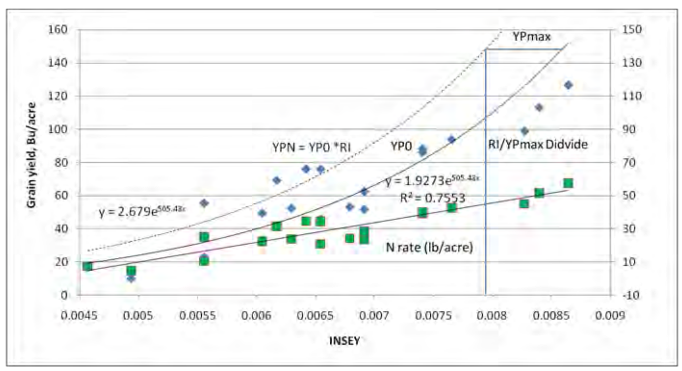

Fig. 4. The predicted yields and calculated N rates for corn experiments in 2007.

Considerable soil variation occurs within and across production fields in the Southeastern US which will have a major impact on fertilizer management strategies. Plant demand and response to N changes from year to year and mobile nutrients (such as N) are used, lost, and stored differently as soil texture varies. Therefore, the accuracy of the algorithm for predicting corn yield from INSEY values and recommended nitrogen prediction equation could be increased significantly by incorporating the soil electrical conductivity measurements into the yield-prediction algorithm (Fig. 5). The R^2 values significantly increased when different algorithm were developed for individual zones as determined by soil EC values.

The preliminary results show that different models (algorithms) could be developed for different soil zones. Work conducted by Khalilian et al. (2004) also showed strong correlations between soil EC maps and crop yield maps. In addition, EC values were strongly correlated with soil texture, water holding capacity, and plant vigor (Khalilian et al., 2007a and 2007b). Furthermore, the results showed that the soil EC data needs to be included in the N prediction equation for the Southeastern Coastal Plain region (Khalilian et al., 2008). Generally, soil EC data can be correlated to specific plant characteristics indicative of corn nitrogen requirements.

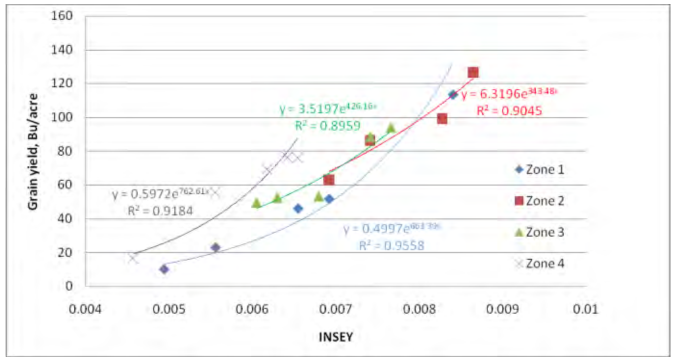

Fig. 5. Relationship between grain yields and In Season Estimated Yield (INSEY) for soil zones 1 (lowest electic conductivity) to 4 (highest electic conductivity).

Conclusion

The results from this preliminary study showed that there is a potential to use mid-season specific plant NDVI data for variable-rate application of N fertilizer for corn production in South Carolina. The Normalized Difference Vegetation Index (NDVI) measured during corn growth, using a GreenSeeker™ optical sensing technology, can be successfully correlated with corn grain yields to determine optimum side-dress N rates. However, the soil EC data need to be included in the N prediction equation for the Southeastern Coastal Plain region due to high soil variability and differences in crop productivity.

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Disclaimer

Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the USDA.

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