THE DEVELOPMENT OF A SENSOR BASED NITROGEN RATE CALCULATOR FOR COTTON PRODUCTION

Daryl Brian Arnall
Randy Taylor
Bill Raun
Oklahoma State University
Stillwater, OK

Introduction

Precision farming has been defined as the use of technologies to map yield variability within a farm field and diagnose its causes, prescribe variable rates of inputs across the field according to soil and crop needs, and apply those inputs at variable rates according to the prescription (Roberts et al., 2002). Johnson et al., 2002, termed precision agriculture is a information and technology based agricultural management system that analyzes, identifies, and manages site spatial and temporal variability within fields for optimum profitability, sustainability, and protection of the environment. The goal of such technologies is to reduce input levels and produce a more homogenous product. To produce a homogenous produce a perfectly homogenous product all factors influencing yield and quality of the final product must be controlled.

Cotton (*Gossypium hirsutum* L.) yield is influenced by many factors. Climatic factors such as moisture availability, length of growing season, and temperature extremes affect yield. Other sources of variability include soil type, soil moisture, pH, fertility levels, organic matter, weed pressure, insect pressure, growth regulators, crop termination, and wildlife damage (Meredith, 1996; Wilkerson, 1996). Significant variation has been reported to occur at distances as short as 10 m, suggesting that a modification of current soil- and plant-sampling schemes might prove necessary and more appropriate for precision agriculture applications (Johnson et al., 2002).

Precision farming is not a new term in the world of cotton production. As the definition eludes too precision farming has many different meanings and over time has taken multiple directions. In the 90's it was reported that developments in cotton yield-sensing technology (Wilkerson, 1996) and soil-fertility mapping (Valco, 1998) indicated that precision agriculture systems show potential for widespread use in cotton production. Precision agriculture in all forms has the ability to offer cotton producers management tools and strategies that could help to control production inputs so that return is maximized. Although absolute quantities of crop inputs may not be decreased, the reallocation of these inputs could result in better utilization and decreased waste (Olson, 1998). Alluding to the year to year variability in crop needs, some years a reduction of inputs is called for while in other years an increase is needed to reach maximum yields (Girma et al., 2007; Machado et al., 2002; Mamo et al., 2003; Mullen et al., 2003). It is projected that in the long term total inputs will not decrease but the efficiency at which they are used will increase.

Building an SBRNC for Cotton

A Sensor Based Nitrogen Rate Calculators (SBNRC) has been created for the majority of the grain crops in Oklahoma. These calculators allow producers to determine a mid-season nitrogen rate for each of there individual fields. By using a reference strip, a non limiting N strip applied in the field at planting, and a handheld spectral reflectance sensor (Figure 1) users are able to prescribe N rates for their fields that are able to account for residual soil N and environmental effects. This paper outlines the steps that are being taken to develop a SBNRC for cotton. For N rate determination by a SBNRC four components are needed:

1. Yield Prediction Model (YP)
2. Response Index (RI)
3. Nitrogen Removal (%N)
4. Nitrogen Use Efficiency (NUE)

These components are put into an algorithm, N Rate = (YP0 * RI – YP0) * %N / NUE, which is referred to as the nitrogen fertilization optimization algorithm (NFOA). This is calculation is outlined in (Lukina et al., 2001). All SBNRC's are available online free for the use of anyone who desires. The goal of the project is to have such a calculator available on line for cotton, similar to that of the other crops (Figure 2).

Figure 1. The Green Seeker™ handheld sensor being used to record the NDVI measurements in cotton.

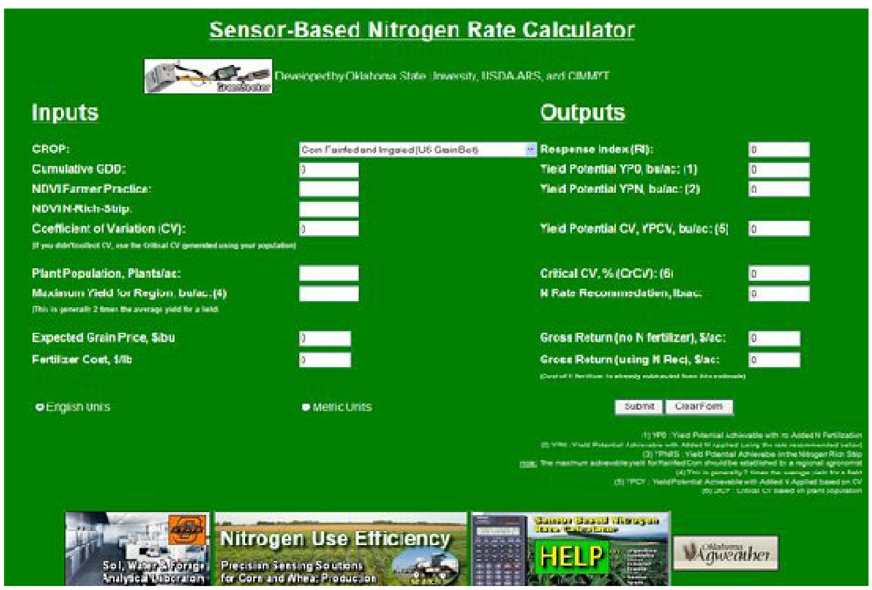

Figure 2. The Sensor-Based Nitrogen rate Calculator utilized for corn produced in the US corn belt, available online at www.nue.okstate.edu.

Yield Potential

The yield potential (YP) of many small grain crops, including winter wheat, spring wheat, corn, and rice, has been shown to be predictable mid-season (Lukina et al., 2001; Raun et al., 2001; Raun et al., 2002). The yield potential is determined through the indices of In Season Estimate of Yield or INSEY, which is calculated by taking the NDVI measured divided by the number of Growing Degree Days (GDD's) greater than zero. For summer crops such as cotton GDD is equal to days from planting to sensing. This calculation gives a value that is related to biomass produced per day. The correlation biomass produced per day final grain yield has been shown to be quite good (Raun et al., 2001). Knowing mid-season what a crop can potential produce in final harvest yields can has many implications upon the normal practices commonly preformed mid-season. Determining yield potential of a crop mid-season is the backbone of the NFOA and SBNRC.

Response Index

The Response Index (RI), was described by (Johnson and Raun, 2003) as the response in yield to additional fertilizer nitrogen, calculated by dividing the yield of the high nitrogen plot or reference strip by the yield of the zero nitrogen plot or farmers practice, this value is referred to as $RI_{HARVEST}$. The importance of $RI_{HARVEST}$ is that it can be determined mid-season (Hodgen et al., 2005; Mullen et al., 2003) by RI_{NDVI}, which is the NDVI of the reference strip divided by the NDVI of the farmer practice. This means that the response, in terms of yield, to additional fertilizer nitrogen can be determined at the time which topdress fertilizer application is made. The yield potential of the zero N plot, or farmers practice at the field scale, is then multiplied by the RI value determined by sensing the high N reference strip and the farmers practice. At this point the yield potential without added fertilizer (YP0) and yield potential with added fertilizer (YPN) has been determined. The approach taken is that the difference of the two is the yield that has to be fertilizers for.

%N and NUE

At this point the yield increase that can be gained by fertilization has been determined. The next step is to calculate the N that will be needed or removed by this additional yield. Research from different parts of the cotton belt suggests that high-yielding cotton crops contain about 0.1-0.14 kg N kg^{-1} lint (Bassett et al., 1970; Mullins and Burmester, 1990; Unruh and Silvertooth, 1996). Oklahoma State Universities yield goal recommendation for cotton is 27 kg $bale^{-1}$ which is equivalent to .125 kg N kg^{-1} lint (Zhang and Raun, 2006). Janat 2005,(Janat, 2005) observed that across a range of N treatments the cotton plant contained .1-.18 kg N kg^{-1} lint. For this paper the N rate per unit of lint, 0.125, that OSU recommends will be used.

With the last step the amount of N required to make up the difference in yield was determined. It is well recorded that the amount of N applied is not equal to the amount of N that is taken up. Across the cotton belt researchers have cited NUE's ranging from 25% to 60% (Bassett et al., 1970; Fritschi et al., 2004; Hou et al., 2007; Janat, 2005; Unruh and Silvertooth, 1996). These reports come from a wide range of soil types, environmental zones, timing regiments, and differing cultural practices. For this paper the value of 60% NUE will be used. This value is on the upper end of the range but this is because it is widely accepted that N applied mid-season will likely have a higher NUE.

N Rate Determination

All of the components have been discussed. So now it is time to put the pieces together. Raun et al., 2002, has reported that with the combined use of the RI concept and mid season prediction of yield INSEY, an accurate topdress nitrogen rate can be made. This is essentially done by predicting the yield of an area that is known not deficient of nitrogen, reference strip and the yield of an area in the field were N status is unknown farmer practice. Total grain nitrogen removed from each area is calculated and the difference between the N-Rich and farmer practice zone multiplied by a theoretical efficiency factor is the prescribed side-dress N recommendation. The calculation of nitrogen rate is known as the Nitrogen Fertilization Optimization Algorithm (NFOA) and it is as follows:

N Rate = (YP0 * RI – YP0) * %N per unit of yield / NUE

Nitrogen Management

Adapting sensor based nitrogen management into modern cotton production has many more challenges than does its adoption into small grain production. In grain production commonly the production of more biomass lends to higher yields, and excessive N fertilization only leads to the loss of nitrogen with no negative impacts on yield. Of course in the production of cotton this is not the case. When a cotton crop had excessive amounts of soil N and the proper environmental conditions the crop will go rank. Excessive vegetative growth yields reduced boll production. If nitrogen can be supply to the crop only where it is needed the likely hood of excessive growth or nitrogen loss to the environment would be reduced. The degree of variability observed in cotton yields suggests precision agriculture techniques could provide effective management strategies for maximizing fiber yield and quality. Possible techniques would include variable-rate fertilizer application and selective harvest (Elms et al., 2001). The use of an optical sensor may be the most accurate method of differentiating nitrogen stress levels. Nitrate concentrations were highly variable, and yield was negatively correlated to N in 1997 (Elms et al., 2001). Currently sensor readings are being collected and yield levels recorded so that the development of a yield prediction model in cotton can begin. Also beginning researched is the use of the N-Rich strip, because of the tendency of excessive nitrogen levels to be detrimental to yield the concept that works well in grain crops will likely need to be adapted to fit cotton production. The fertilization model will need to fertilize to a point and then stop fertilization when either NDVI or height measurements reach a point that indicate excessive growth.

Methods

One experimental site was established in the spring of 2006 one near Stillwater, OK., at the Lake Carl Blackwell Agronomy Research Farm (LCB). Three years of data from 2006-2008, will be collected from this site. During the years of 2006-2008 data will also be collected from the long term cotton fertility study 439 near Altus, OK., at the South West Research Station (SWR).

The two sites LCB and SWR, are under irrigated production systems. The LCB site is irrigated through a TnL lateral roll sprinkler system and the SWR is irrigated through furrow irrigation

The experimental design of the LCB trial consisted of 15 N treatments in a randomized complete block design with three replications. Plots consist of four rows with a total measurement of 3.05 x 6.10 m. Treatments consisted of all N applied preplant, all N applied sidedress, and a split application of N. Treatments that only received preplant N (trts 1-5, 14-15) were utilized for the prediction model.

The experimental design of the long term trial 439 at the SWR was a randomized complete block with four replications. Eleven treatments containing different rates of N-P-K were evaluated. All N treatments that received 20-75 P-K (trts 2-7) were analyzed for the yield prediction model. All treatments were broadcast on the surface and incorporated prior to planting, and irrigation was applied as needed from the Lugert Altus Irrigation District with amounts varying from year to year. Since the irrigation water was furrow applied, the amount applied per irrigation was approximately 50 to 60 mm

At LCB in the spring of 2006, preplant N treatments were applied using urea (46-0-0) as the N source. For 2007 and 2008 preplant N applications used liquid UAN (28-0-0) as the source of N. All sidedress N treatments were applied using liquid UAN dribbled along the base of each row. The long-term plots at SWR received all N at planting using urea (46-0-0).

The LCB site was planted in 76.2 cm row spacing and the SWR was planted in 101.6 cm row spacing. The herbicide Prowl H_20 (BASF Corporation) was applied preemergence at a rate of 2335 ml ha^{-1}. Glyphosate was applied as needed during the growing season at a rate of 3502 ml ha^{-1}per application. Also, recommended rates of growth regulators, fungicides, and insecticides were applied each year.

Plots at LCB and SWR were monitored once a week after crop reached a height of 45 cm. All measurements were collected from the center two rows of each plot. Plots were sensed with a GreenSeeker™ Hand Held optical reflectance sensor (N-Tech Industries, Ukiah, CA), measuring NDVI with the sensor approximately 70 cm directly above the crop canopy. Canopy height was collected at LCB using meter sticks to record the distance from the ground to the top of the canopy at 10 randomly selected locations within a plot at the same when sensor readings were collected.

At both locations Defoliant and a Harvest aid was applied each year to facilitate harvesting. At maturity the two middle rows were harvested. In 2006 LCB was harvested by hand picking the two middle rows of each plot. After harvest the lint was pulled from bolls and weighed. The plots at SWR were mechanically harvested with a commercial cotton striper. Grab samples were collected from the harvested material in each plot and ginned on small ginning equipment in order to approximate lint turn out and ginning percentage.

RI_{NDVI} was calculated by dividing the mean NDVI of an N treatment by the mean NDVI value of the check treatment. $RI_{HARVEST}$ was calculated by dividing the highest N treated yield average by the check average. All statistical data analyses were performed using the General Linear Model (GLM), Regression (REG) and Mixed (MIXED) procedures in SAS (SAS Inst., 2001).

Results

The NDVI data from each plot collected from candle, 55 days after planting, to mature boll, 79 days after planting, was used in the calculation of INSEY. These values are plotted against the plot yield data in Figure 3. The relationship fits an exponential curve with a R^2 = 0.38. Only those plots with preplant N where used. Plots receiving side-dress N can not be used because of the change that would be induced by the additional fertilizer after sensing.

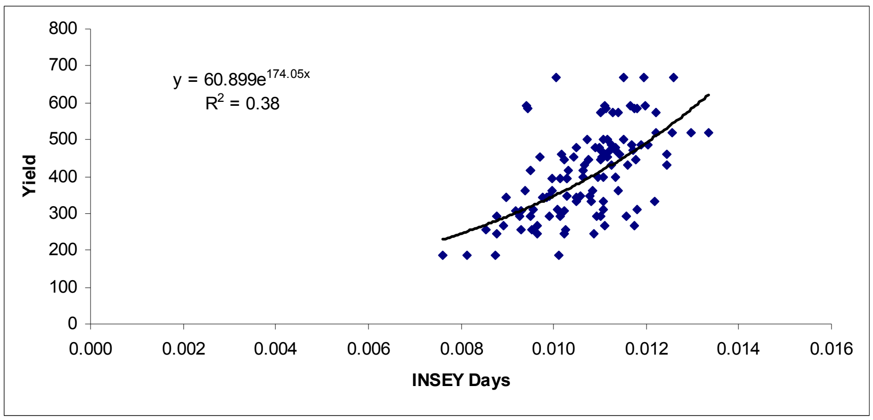

Figure 3. The yield prediction model for lint yield (kg ha^{-1}) using INSEY (NDVI/days from planting to sensing) as the predictor. Data collected from candle (55 days) to mature boll (79 days).

The NDVI and yield value from each plot that received pre-plant nitrogen was divided by the same value from the check plot of the corresponding rep. These calculations created the RI_{NDVI} and $RI_{HARVEST}$. For accurate N rate recommendation it is critical to understand the relationship of $RI_{HARVEST}$ and RI_{NDVI}, this relationship in other such as wheat is not 1:1 (Hodgen et al., 2005). Figure 4 shows the relationship between $RI_{HARVEST}$ and RI_{NDVI}, which fits an exponential curve with a R^2 = .42.

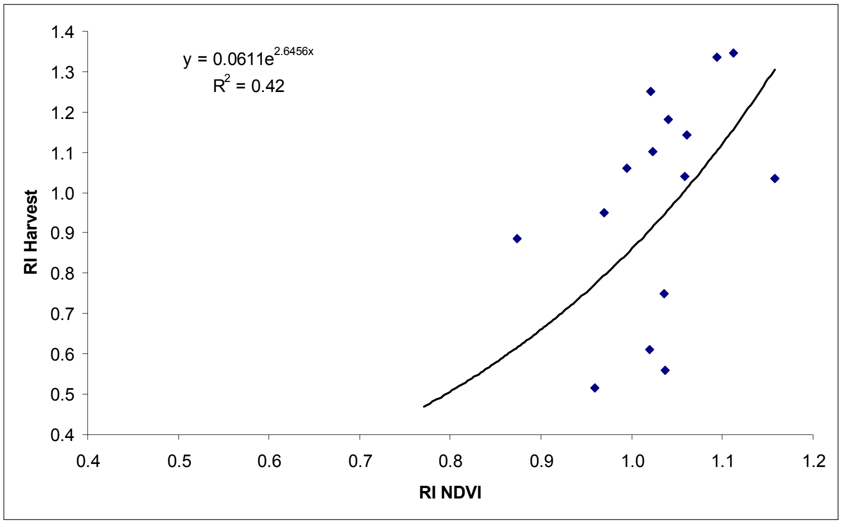

Figure 4. The relationship between RI Harvest (Yield of plot receiving N fertilizer / yield of plot receiving no N fertilizer) and RI NDVI (NDVI of plot receiving N fertilizer / NDVI of plot receiving no N fertilizer).

From just the data above we can create the NFOA for cotton. Below are the calculations or values of each of the four components, as the current data suggest.

1. YP = 60.899e (174.05 * INSEY)
2. RI = .0611e (2.6456 * RIndvi)
3. %N = 12.5
4. Efficiency = 60%

With these components an initial algorithm is developed as follows.

N Rate = (YP0 * RI – YP0) * %N per unit of yield / NUE =
60.899e (174.05 * INSEY) * .0611e (2.6456 * RIndvi) - 60.899e (174.05 * INSEY) * 0.125 / 0.60

This NFOA is now ready to be placed into the SBNRC online. If a producer has placed an N reference strip in his/her field and has access to a hand held sensor that records NDVI a mid-season N application can be determined.

Discussion

This paper outlines the process of the creation of the SBNRC and presents some of the initial data collected. This data is aiding the researchers in the directions that have to be followed to create a superior product. As with all of OSU's SBNRC algorithms and the cotton calculation will change, likely every year. The work being done treats the calculator as a living being that adapts and adopts as new information and situations are placed in front of it. At this time there is no disputing that this approach has flaws. It is important to remember that a technology has to start somewhere, the approach taken at OSU is one that attempting and failing is much better than not trying at all. There is little doubt that the potential of the remote sensing technology use in cotton production is great. With the interdisciplinary work that extends across many boarders the future looks bright. A final question to pose when discussing new technologies should not be whether or not the approach is perfect but instead whether or not it is better than what is currently happening.

Bibliography

Bassett, D.M., W.D. Anderson, and C.H.E. Werkhoven. 1970. Dry matter production and nutrient uptake in irrigated cotton (Gossypium hirsutum). . Agron J. 62:299-303.

Elms, M., C. Green, and P. Johnson. 2001. Variability of cotton yield and quality. Commun. Soil Sci. Plant Anal. 32:351-368.

Fritschi, F.B., B.A. Roberts, D.W. Rains, R.L. Travis, and R.B. Hutmacher. 2004. Fate of Nitrogen-15 Applied to Irrigated Acala and Pima Cotton. Agron. J. 96:646-655.

Girma, K., K.W. Freeman, R. Teal, D.B. Arnall, B. Tubana, S. Holtz, and W.R. Raun. 2007. Analysis of yield variability in winter wheat due to temporal variability, and nitrogen and phosphorus fertilization. Archives of Agronomy and Soil Science 53:435 - 442.

Hodgen, P.J., W.R. Raun, G.V. Johnson, R.K. Teal, K.W. Freeman, K.B. Brixey, K.L. Martin, J.B. Solie, and M.L. Stone. 2005. Relationship between response indices measured in-season and at harvest in winter wheat. J. Plant Nutr. 28,:221-235.

Hou, Z., P. Li, B. Li, J. Gong, and Y. Wang. 2007. Effects of fertigation scheme on N uptake and N use efficiency in cotton. Plant and Soil 290:115-126.

Janat, M. 2005. Assessment of Nitrogen Content, Uptake, Partitioning, and Recovery by Cotton Crop Grown under Surface Irrigation and Drip Fertigation by using Isotopic Technique. Communications in Soil Science and Plant Analysis 35:2515 - 2535.

Johnson, G.V., and W.R. Raun. 2003. Nitrogen response index as a guide to fertilizer management. J. Plant Nutr. 26,:249-262.

Johnson, R.M., R.G. Downer, J.M. Bradow, P.J. Bauer, and E.J. Sadler. 2002. Variability in Cotton Fiber Yield, Fiber Quality, and Soil Properties in a Southeastern Coastal Plain. Agron J 94:1305-1316.

Lukina, E.V., K.W. Freeman, K.J. Wynn, W.E. Thomason, R.W. Mullen, M.L. Stone, J.B. Solie, A.R. Klatt, G.V. Johnson, R.L. Elliott, and W.R. Raun. 2001. Nitrogen fertilization optimization algorithm based on in-season estimates of yield and plant nitrogen uptake. J. Plant Nutr. 24:885-898.

Machado, S., E.D. Bynum, Jr., T.L. Archer, R.J. Lascano, L.T. Wilson, J. Bordovsky, E. Segarra, K. Bronson, D.M. Nesmith, and W. Xu. 2002. Spatial and Temporal Variability of Corn Growth and Grain Yield: Implications for Site-Specific Farming. Crop Sci 42:1564-1576.

Mamo, M., G.L. Malzer, D.J. Mulla, D.R. Huggins, and J. Strock. 2003. Spatial and Temporal Variation in Economically Optimum Nitrogen Rate for Corn. Agron J 95:958-964.

P. Dugger and D. A. Richert (ed.) 1996. Proceedings of the Beltwide Cotton Conferences, Nashville, TN. Jan. 9–12, 1996. National Cotton Council of America: Memphis, TN.

Mullen, R.W., K.W. Freeman, W.R. Raun, G.V. Johnson, M.L. Stone, and J.B. Solie. 2003. Identifying an In-Season Response Index and the Potential to Increase Wheat Yield with Nitrogen. Agron. J. 95:347-351.

Mullins, G.L., and C.H. Burmester. 1990. Dry matter, nitrogen, phosphorus, and potassium accumulation by four cotton varieties Agron J. 82:729-736.

Olson, K. 1998. Precision agriculture: Current economic and environmental issues. 6th Joint Conf. on Food, Agric., and the Environ. .

Raun, W.R., J.B. Solie, G.V. Johnson, M.L. Stone, E.V. Lukina, W.E. Thomason, and J.S. Schepers. 2001. In-Season Prediction of Potential Grain Yield in Winter Wheat Using Canopy Reflectance. Agron. J. 93:131-138.

Raun, W.R., J.B. Solie, G.V. Johnson, M.L. Stone, R.W. Mullen, K.W. Freeman, W.E. Thomason, and E.V. Lukina. 2002. Improving Nitrogen Use Efficiency in Cereal Grain Production with Optical Sensing and Variable Rate Application. Agron. J. 94:815-820.

Roberts, R.K., B.C. English,, R.L.C. J. A. Larson, S.L. B. Goodman, M. Marra,, and J.R. S. Martin, and D. Shurley. 2002. Precision Farming by Cotton Producers in Six Southern States: Results from the 2001 Southern Precision Farming Survey.

Unruh, B.L., and J.C. Silvertooth. 1996. Comparisons between an Upland and a Pima cotton cultivar: II. Nutrient uptake and partitioning. Agron J. 88:589-595.

Valco, T.D., R.L. Nichols, and W.F. Lalor. 1998. Adopting precision farming technology for cotton nutrition. . Procedures of the Beltwide Cotton Conference:627–629.

Wilkerson, J.B., and W.E. Hart. 1996. Yield Sensing Technology in Cotton Harvest Applications. Proceedings of the Beltwide Cotton Conferences:184 –186.

Zhang, H., and W.R. Raun. 2006. Soil Fertility Handbook 2006. 6 ed. Oklahoma Agric. Exp. Stn., Stillwater, OK.