Sensor–Based Variable Rate Application for Cotton

Randy Taylor
Extension Engineer
Machinery Systems
Biosystems and Agricultural Engineering
Oklahoma State University

John Fulton
Extension Specialist
Agriculture Machinery Automation
Biosystems Engineering
Auburn University

This publication will guide you through useful information to help make the best of using sensor based application systems in cotton. The following topics will be discussed:

- Map vs. sensor–based application
- Equipment for variable rate application
- Developing prescriptions for plant growth regulators
- Harvest aids and nitrogen

Using sensor systems for variable rate application (VRA) is becoming more popular for cotton production. Several commercially available sensor–based, variable rate systems exist for efficiently managing inputs to maximize yields or returns. Farmers are interested in sensor–based systems in part because they can be easier to use than most map–based systems plus can apply inputs such as nitrogen to better meet real–time crop needs. The sensor–based approach attempts to more efficiently apply inputs by meeting crop requirements at the time of application.

When considering cotton inputs three items for sensor–based variable rate application come to mind: plant growth regulators, defoliant/boll openers, and nitrogen. While each of these inputs has opportunities, they are not without challenges. The major challenges are developing prescriptions and adjusting equipment to properly apply the rates established with the prescriptions.

Map vs. Sensor–based Application

Variable rate application using precision agriculture technologies has generally followed one of two paths. One based entirely on map–based information and the other based on real–time sensors. The map–based approach allows use of historical information, while sensors allow us to assess in–season conditions. Map–based information is typically gathered with yield monitors, soil testing, soil maps, and/or with data from sensors.

The primary differences between map and sensor–based strategies are data analysis and interpretation. With map–based variable rate application, the practitioner must collect and analyze data for input to an expected crop response algorithm and then transfer the prescription map to a variable rate applicator. The prescription may appear as zones as shown in Figure 1 or in a grid format with smoother transitions. A GPS receiver locates the applicator's position on the map and the rate is then adjusted based on the prescription map as the applicator moves across the field.

The sensor–based approach to precision agriculture uses sensors to measure crop and/or soil properties in real–time as the applicator moves across the field. Data from the sensor is collected, processed, and interpreted by an on–board computer which then sends a signal to a rate controller. One of the advantages of this approach is automating the data analysis and interpretation step versus the map–based strategy. A predetermined algorithm is used to convert the sensor information directly to an application rate. This algorithm is typically constant at a field scale and often at the regional scale. However, one challenge associated with this approach is that the prescribed rate is constantly changing (Figure 2) as the applicator moves across the field requiring the rate controller to respond quickly.

Equipment

You must have the proper equipment to variably apply inputs especially in a sensor–based system. This equipment will consist of sensors and control interface, a display and control module, and an application rate controller (Figure 3). Sensors can be used to measure soil or crop properties, but this publication is limited to crop sensors that are used to make in–season variable rate application to cotton.

The application rate controller consists of a control module/user interface, flow meter, flow control valve, and speed sensor. In some cases the display and control module may be the same for the sensor system and rate controller. Furthermore, if a global positioning system (GPS) is used for mapping it can also provide the speed signal.

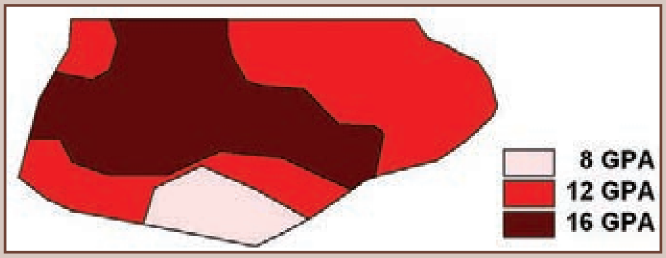

Figure 1. Prescription map for a variable rate application using three distinct zones.

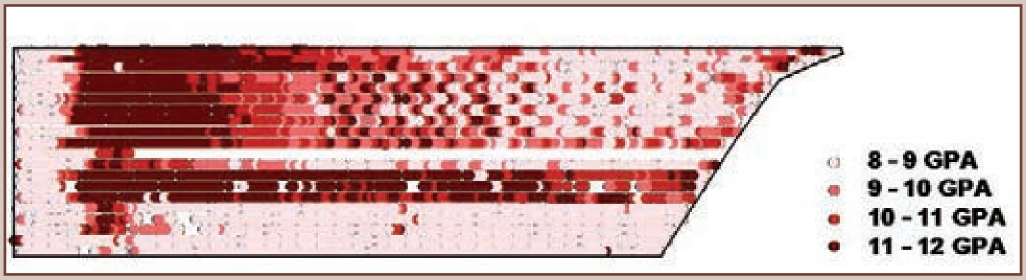

Figure 2. Prescription map for sensor–based variable rate application.

For sensor–based VRA in cotton, the product will likely be a liquid. Liquids are typically metered through orifices on spray tips. Using fixed orifice nozzle tips will greatly limit the range of rates that can be applied, but other options are available.

Sensors and Vegetative Indices

Commercially available sensors operate above the crop and measure reflectance of different colors (wavelengths). The most common colors used for crop vegetation indices are red, near–infrared (NIR), green, and amber. Healthy, vigorous plants absorb red light and reflect near infrared light. The reflectance of these colors is used to calculate indices such as the Normalized Difference Vegetative Index (NDVI) or a simple ratio (RED/NIR). NDVI is determined from red and near infrared reflectance and is probably the most popular vegetative index. Other colors such as green or amber can be used in place of red when calculating NDVI. Though many vegetative indices can be used for VRA, only NDVI will be discussed for the remainder of this publication.

Research has shown that reflective indices such as NDVI measured at the correct growth stage can be highly correlated with cotton yield. While NDVI values can range from 0 to 1, values below 0.3 or above 0.9 are of little value in crop production. When NDVI is below 0.3, there is generally not much green in the field of view (i.e. more stubble, crop residue, or soil). Conversely, when values are greater than 0.9, everything in the field of view is green.

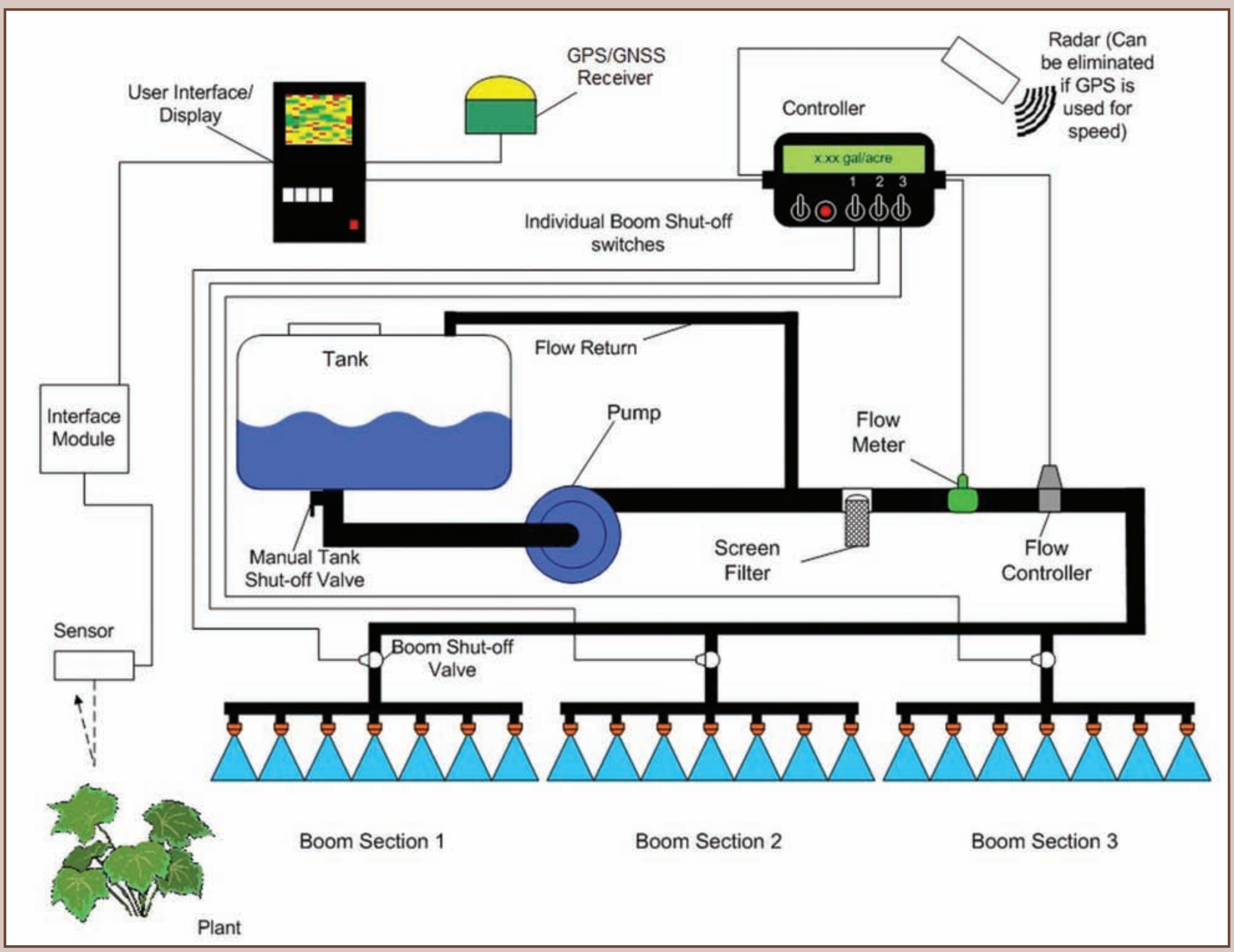

Figure 3. Schematic of a sensor–based, variable rate application system for liquid products.

The popular sensors used today are active light sensors. These sensors supply their own light source and are unaffected by clouds, shadows, sunlight, or other interfering light sources. Since they are unaffected by ambient light, they can be used in varying light conditions including nighttime and cloudy days. Some research has shown that sensor reading may vary throughout the day. However, this research did not determine whether the differences were related to a changing target or sensor issue. Users should be aware that we are using a machine to make agronomic applications and be prepared to make adjustments as necessary.

Most sensor–based systems will have at least four sensors. Research has shown that field variability exists at a very small scale, so naturally, more sensors are better. However, it becomes a tradeoff between more information gained by having more sensors and the system cost. Applicators wider than 40–50 feet should have at least six sensors. This will provide a better average across the entire boom. This average value is sent to the user interface where it is converted to an application rate that the controller understands. The user interface typically sends a new rate to the controller every second.

Sensors should be mounted so they are directly over the crop and evenly spread across the boom (Figure 4). They are generally mounted directly on the boom facing forward, but sometimes will face the rear of the machine so they are not damaged when the boom is folded. If sensors are mounted behind the boom they are actually sensing area that has already been sprayed. However, even a well tuned rate controller will not respond fast enough to change the rate every second. Therefore sensor location (forward or rear facing on the boom) will not affect the system's ability to respond to the larger scale general trend across the field. Some farmers put sensors on an additional boom on the front of the applicator to give the system a little more time to respond.

Figure 4. Example sensor–based system using GreenSeeker sensors mounted along the sprayer boom.

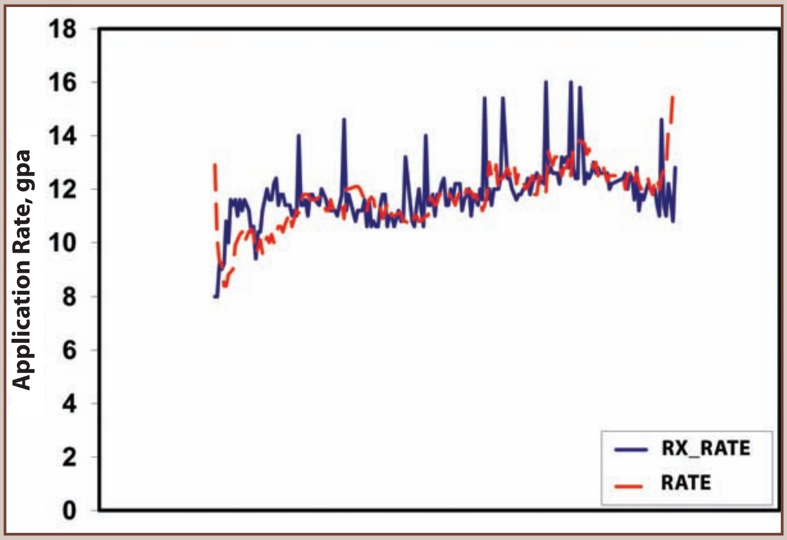

Figure 5. Prescribed (RX_RATE) and applied (RATE) rates for a properly tuned rate controller. It is unrealistic to expect the controller to accurately respond to the instantaneous peaks, but the applied rate does follow the general trend.

Sensors have a height range (distance from the target) where they perform better and should be operated within this range. In general, operating the sensors 2.5–3.5 feet above the crop is a good range. Make sure that sensors are mounted on the boom properly to allow the correct sensor height while maintaining the appropriate spray height for nozzle performance.

Another item of interest related to sensor systems is driven by the increased adoption of boom control systems that can automatically turn off boom sections if they are over areas that have already been sprayed. Some producers are wondering why sensors cannot be used to control individual boom sections to reduce the application scale. In fact, some early research on sensor–based VRA was conducted a small scale (2 feet by 2 feet). However the system used developed through this research was different than the flow based sprayer control systems that are common today. Individual flow control to boom section may be possible in the future, but it is not feasible with today's spray control systems.

Rate Controllers and Tuning

A key to successful variable rate application is a properly tuned and calibrated rate controller. Proper calibration will insure that the flow meter signal is correct thereby transmitting accurate flow data to the rate controller. Tuning the rate controller will ensure that rate changes happen as quickly as possible while the control valve maintains stability during rate changes. Figure 5 shows data taken from a variable rate application where the prescribed rate is updated every second. In general, the rate controller follows the prescribed data. However, there are some peak rates that are missed. In fact, it would be nearly impossible for typical rate controllers to accurately follow most sensor–based prescription inputs. So the rate controller should be tuned to respond as quickly as possible while still maintaining some stability (not continually hunting for the new rate). This will allow the application rate to follow the general trend due to landscape variability across the field and the operator's driving habits.

The ability to tune a rate controller varies among manufacturers and models, ranging from multiple settings to none. Most rate control systems use valve speed to adjust response time while some may use other settings or terminology. The operator's manual should be used as a reference for tuning controllers. Keep in mind that the default settings for most controllers are for maintaining stability within the system. Thus they are probably not the best settings for optimum response time and some type of tuning or adjust is likely needed to improve controller performance for VRA.

For systems using a valve speed setting, two items of interest that may be adjustable are valve speed and brake point. The valve speed setting may also be called gain and will determine how fast the valve will actually move when given a command. The brake point will determine when it will begin to slow down. There is a tradeoff between these two items. Fast valve speeds are desirable. However, if the adjustment speed is too fast, it will require a high brake point to avoid over shooting the desired rate. It is usually desired that a control valve responds quickly adjusting to the next rate without little or no over shoot. For example, consider a person driving between two stop lights. A person that accelerates rapidly and waits until the last minute to brake might 'over shoot' the next intersection. Therefore, equipment operators or those managing this type of equipment need to check the operator's manual and determine how to tune the rate controller for optimum performance with a sensor–based system; then monitor that performance in the field and make necessary adjustments when needed.

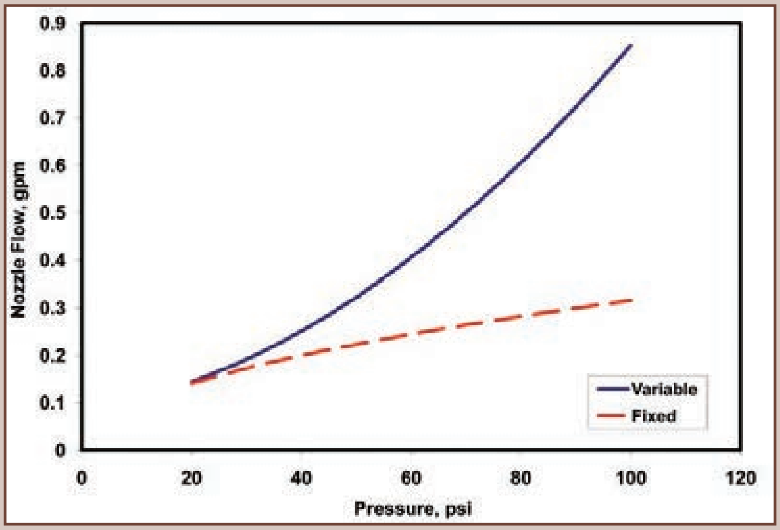

Figure 6. Expected nozzle flow for fixed and variable orifice nozzles as a function of pressure. Note that from 20 to 100 psi, flow through the fixed orifice nozzle barely doubles, while flow through the variable orifice nozzle increases by almost a factor of 6.

Nozzles and Rate Changes

As most VR applications to cotton are in the form of a liquid, it is important to be aware of the challenges associated with variable rate liquid applications. The primary challenge is the limited range of flow rates available when using fixed orifice nozzles. These nozzles require a four–fold pressure increase to double the flow rate (Figure 6). A four–fold pressure change could result in a poor pattern at low pressure and excessive drift potential at high pressure. It is unlikely that an acceptable pattern could be maintained with a two–fold rate change unless the operator slows down when applying at high rates. Operating at lower ground speeds to obtain higher application rates will reduce field capacity of the applicator and should be practiced sparingly.

Variable orifice nozzles have a greater turn down ratio and are an alternative to fixed orifice nozzles for variable rate application (Figure 7). Variable orifice nozzle flow is not constrained to pressure like a fixed orifice nozzle. These nozzles have an orifice area that increases with pressure. Thus as a rate controller sends more flow to the boom for a higher application rate, pressure will increase thereby the nozzle orifice size will increase allowing more nozzle flow. A four–fold flow rate change is possible with variable orifice nozzles. The flow rate to pressure ratio is basically 1:1 for these nozzles which can be advantageous for variable rate application to meet the desired range of application rates.

Another option for VRA is a pulse width modulation (PWM) system to control flow at the nozzle. This system was developed to maintain a constant droplet size when the nozzle flow changes. The system uses a solenoid valve to pulse flow at the nozzle body ten times per second. The length of the pulse is controlled to vary flow rate. A long pulse provides high flow while a shorter pulse results in lower flow. In return, the PWM system allows for a wide range (typically 8:1) of rates.

Prescriptions

Getting a rate controller setup for variable rate application is only half the battle. The variable rate prescription or algorithm is the other half and can be the most challenging aspect in the process.

The algorithm is simply the equation that will convert sensor readings into an application rate that the controller understands. While some algorithms may come directly from land grant universities, it is possible that you will develop your own. The development of the prescription for your operation or even region may require input from a consultant or input/service provider.

Developing a sensor–based prescription happens in two steps. First, we have to determine the relationship between the plant property of interest and what the sensor measures. We must do the first step because commercially available sensors may not measure the plant property that is typically used to determine an application rate (for example plant height or percent open bolls). The data shown in Figure 8 is an example of developing the relationship between the sensor reading (NDVI) and percent open bolls through research data. While the relationship is not perfect the trend is obvious and could likely be applied over a wide range of conditions with some acceptable error. The second step is to determine the application rate as a function of the sensor reading. For this we would convert the application rate for a given percent open bolls to an application rate for the corresponding NDVI.

From a farmer or consultant perspective, the two steps that are outlined for developing prescriptions could be combined if the prescription is developed at

Figure 7. A TurboDrop variable orifice nozzle by Greenleaf. The green portion contains the variable orifice for metering and the grey portion is the flat fan tip to create a pattern.

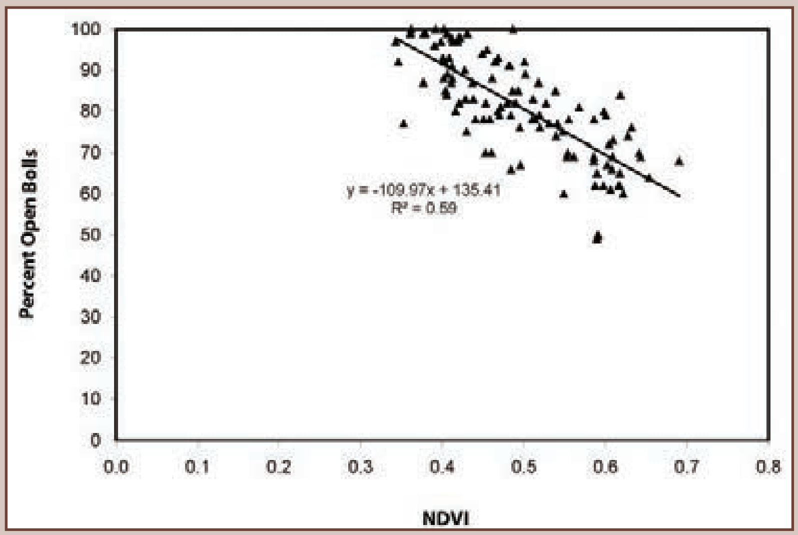

Figure 8. Percent open bolls as a function of NDVI taken from a long term fertility study in Altus, Okla. Data are combined from two sampling dates.

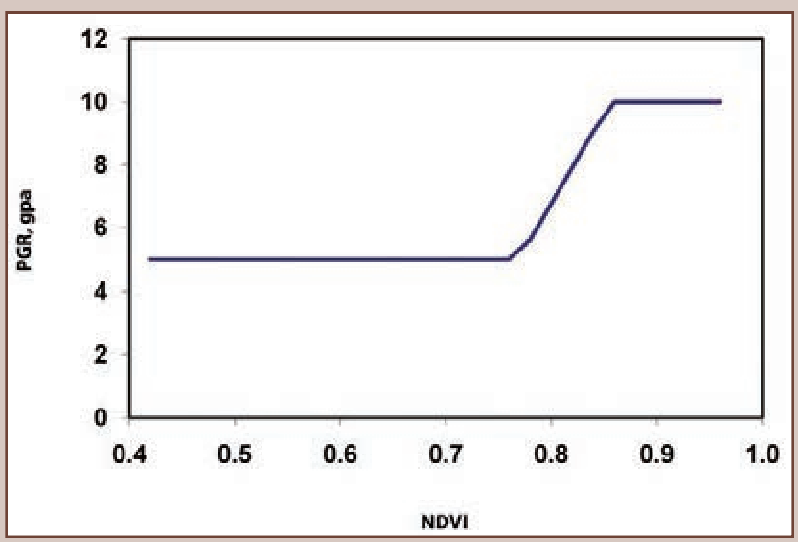

Figure 9. An example variable rate prescription for a PGR as a function of NDVI.

the field level. You could measure NDVI at a location within a field and evaluate the crop to determine the application rate for the product at that location. Repeating this at various locations would yield a direct relationship between NDVI and the application rate.

Another factor when determining prescriptions is whether upper and/or lower limits are desired. In other words do you want to set the maximum and/or minimum application rates so the system is restricted between these? For example, you may not feel comfortable applying less than 50 pounds per acre of nitrogen, so you set the lower limit at this rate. Then regardless of the prescription and sensor reading, the controller will not go below this rate. The same approach can be taken for the upper limit. These limits are established to ensure every part of the field receives some product, but that no part of the field receives excessive application of product.

There are three primary cotton inputs that can be variably applied with a sensor–based system: plant growth regulators, harvest aids, and nitrogen.

Plant Growth Regulators

The prescription for plant growth regulators (PGRs) is likely based on the relationship between NDVI and plant height or the height to node ratio. The NDVI typically increases with plant height. Therefore if the prescription is based on plant height, NDVI become a natural substitute. A PGR prescription based on NDVI is presented in Figure 9. Note the upper (10 gallons per acre [gpa]) and lower (5 gpa) limits on application rate in PGR prescription. Regardless of how low the NDVI may be, the prescribed rate will not go below 5 gpa. Likewise the prescribed rate will never exceed 10 gpa.

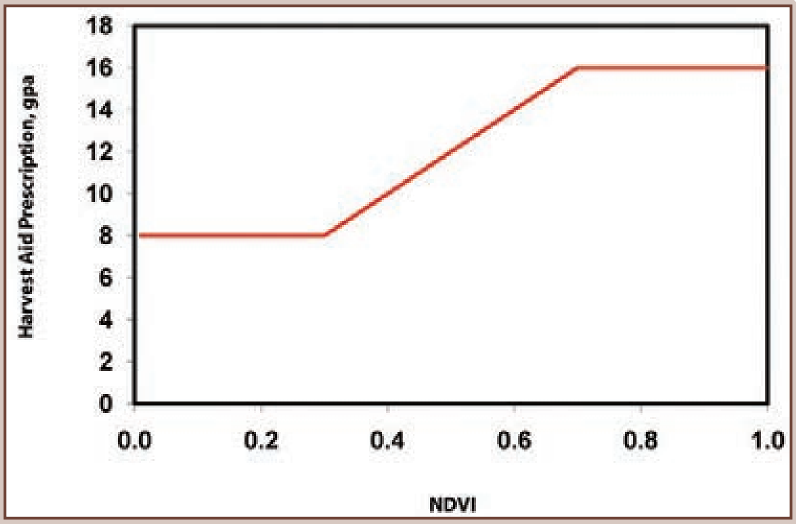

Figure 10. A harvest aid prescription based on NDVI. The lower limit is set at 8 GPA whereas the upper limit is set at 16 GPA.

One challenge associated with variable PGR application is that plant height and NDVI are related early in the season. However, as the canopy begins to close the sensor measured NDVI may reach a plateau and stay the same while plant height continues to increase. When this happens, it may be challenging to variably apply PGRs with a sensor system. Basically the entire field would receive the maximum prescribed rate applied uniformly.

Harvest Aids

The prescription for harvest aids such as defoliants and boll openers is likely based on the relationship between NDVI and percent open bolls or nodes above cracked boll. The NDVI typically decreases as the percent open bolls increases (Figure 8). Though the sensor is not actually measuring open bolls, NDVI is measuring something in the plant, like the natural desiccation, that is associated with open bolls. Therefore if the prescription is based on open bolls, NDVI become a natural substitute (Figure 10). This prescription shows a linear increase in harvest aid application rate as NDVI increases. As with the PGR prescription in Figure 9 upper and lower limits were used to insure all areas receive some harvest aid, but no area gets more than the maximum rate established. In the case of harvest aids, NDVI can be an indicator of two things: more biomass or greenness in the plants and thus more leaves. In either case, a higher NDVI would indicate a greater need for harvest aids.

Nitrogen

Developing a prescription for sensor–based variable rate nitrogen application is more complex than PGRs or harvest aids. However, several universities have developed different approaches to sensor–based variable rate nitrogen on cotton. These are usually for side–dress application from first square to early flower. Some of these use a nitrogen rich reference strip that was developed for cereal grain production. The reference strip is an area where sufficient nitrogen is applied to insure that it is not limiting plant growth. This strip is then used to determine the environmental contribution of nitrogen or the maximum yield if nitrogen is not limiting growth prior to field application.

Two variable rate prescriptions for nitrogen are shown in Figure 11. This data are presented only to illustrate the conceptual differences between different approaches. The OK method is based on yield potential and a nitrogen rich strip. The MO method is based solely on the nitrogen reference strip. The MO method applies a high N rate on the lower NDVI areas of the field and no N on the higher NDVI areas.

The OK method is more complex, but this doesn't affect the end–user because it is programmed in the on–board computer. The user needs to know the NDVI of the reference strip, the NDVI of the adjacent area, growing degree days, and the maximum yield potential. The limits of each prescription (maximum and minimum N rate and NDVI thresholds) are set based on regional experience or user preference. For example, cotton with an NDVI less than 0.3 will likely not respond to extra nitrogen.

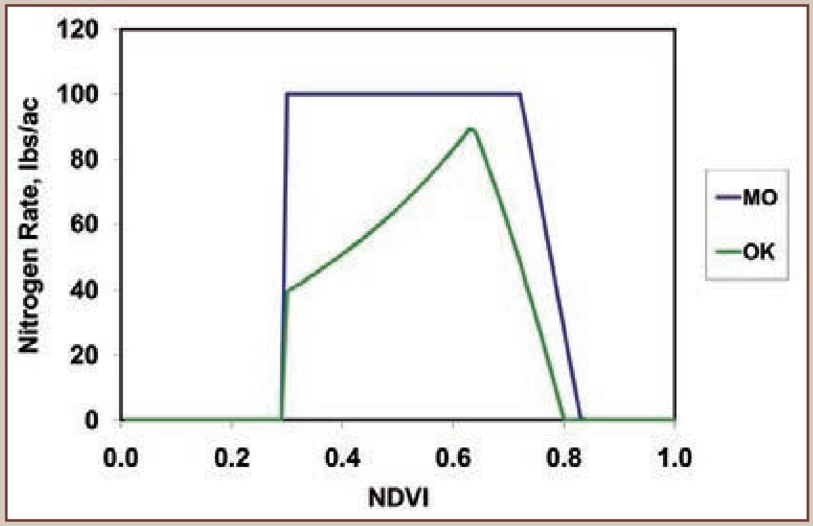

Figure 11. Nitrogen rate derived from two nitrogen prescriptions based on: Missouri (MO) and Oklahoma (OK) methods. Note that in both cases, the prescription requires more information than NDVI alone.

Summary

Sensor–based variable rate application is being implemented in many cotton growing regions. There are great opportunities for this technology in cotton production for varying the application of plant growth regulators, harvest aids, and nitrogen. However, the users must understand the limitations of their equipment and the sensors being used in order to maximize the benefits.

Users should understand the agronomy behind prescriptions and be comfortable with the recommendations. Familiarity with these prescriptions can allow users to fine tune them for their environment or to develop their own prescription algorithms. They should also understand their equipment and know how to tune their controller for optimum response. As with all new technologies, users should seek advice from experts and those who are already implementing sensor–based variable rate application.

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