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SPATIALLY VARIABLE PLANT GROWTH REGULATOR (SVPGR) APPLICATIONS BASED ON REMOTELY SENSED IMAGERY

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Abstract

Spatially variable application techniques can be used to apply Plant Growth Regulator (PGR) to cotton crops. Remote sensing can be used to generate prescriptions that guide the location of the PGR application on the crops. Maps of vegetation indices generated from the remotely sensed data indicate differing regions of vegetative health. Crop scouts using these maps can specify the vegetation index classes which correspond to the areas that need PGR application. Then spray rigs equipped with precision application equipment can target just these areas for application. This paper discusses an experiment that compares the results of Spatially Variable Plant Growth Regulator (SVPGR) applications to the results from traditional (blanket) application of PGR. Economic Analysis is presented that shows the potential savings for implementing the SVPGR technique.

Introduction

Plant Growth Regulator (PGR) is used in cotton plant management. When applied to the crop, it redirects plant growth from the vegetative leaves to boll production and as a result can increase yield. In the 2000 growing season an experiment was performed by Spectral Visions to study the effect of PGR application across different Normalized Difference Vegetation Index (NDVI) regions of a field. NDVI measurements were extracted from remotely sensed data acquired over the field. This experiment segmented the research field into two types of treatment strips. One type received blanket applications of PGR according to traditional methods. The other treatment strips received no PGR. The treatment strips were crossed with the three different NDVI groupings to research if plants with different NDVI measurements respond differently to PGR.

The results of this research, indicated that there may be benefit in using spatially variable application techniques to apply PGR on cotton fields. The application would vary the PGR spatially according to specific NDVI regions. The 2001 experiment replicated the design of the 2000 study and also performed Spatially Variable Plant Growth Regulator (SVPGR) applications to new treatment strips added to the 2000 design layout. The intent of this study was to determine if SVPGR application methods could be used as a technique to reduce PGR application costs and at the same time maintain or increase yields over the traditional (blanket) method of applying PGR.

Background

Assuming an application of 8 ounces per acre, Plant-Growth Regulator (PGR)—in this case Pix® (Mepiquat Chloride) costs $4.50/acre. It is applied to inhibit cell elongation, to restrict vegetative growth and to promote earlier and heavier boll production on lower node branches and thus increase lint yield (Weir and Kerby, 1988). It is usually applied in a blanket fashion based on factors such as height, height-to-node-ratio, average length of top five internodes, internode length, and moisture status (Kerby et al., 1990). Plant height is widely recognized as a strong indicator for PGR application, by Weir and Kerby (1988), Kerby et al. (1990) and by Munier et al. (1993), who showed that plant height was "related to plant vigor and early fruit retention and this is a good indicator of the need for Pix®." Kerby et al. (1990) cited plant height prior to first bloom as the premier of six indicators for triggering PGR application. These factors are commonly checked in the field by consultants, sometimes aided by GPS (Thurman and Heiniger, 1998). Kerby (1985) observed yield benefits in the use of PGR, and Cothren and Oosterhuis (1993) found that the maintenance of a uniform cotton crop benefits insect management, crop termination, and harvest. However, blanket applications of PGR at a constant rate sometimes expend the chemical needlessly in areas where they are not needed and may decrease yield in these areas by repressing the growth of weaker or slower maturing cotton. Likewise, insufficient application may decrease yield in robust, excessively leafy areas.

Spectral Visions observed these patterns in 1998-1999 when we quantified yield corresponding to five levels of NDVI during 23 image dates in two different fields during two different years. The NDVI shows areas of varying vegetation health (Lillesand and Kiefer, 1994). The patterns showed empirical evidence that the highest 20 percent of NDVI areas became increasingly indicative of lower-yielding areas as the season progressed, indicating that these areas may be ideal candidates for site-specific PGR application. These observations resulted in a more formal PGR experiment at Perthshire Farms in 2000.

The 2000 experiment partitioned a cotton field into two different types of treatment strips that represent different application rates of PGR. One treatment type received blanket application of PGR and were labeled as Blanket-Spray-On treatments. The other treatment type was not sprayed with any PGR and labeled as Spray-Off treatments. NDVI measurements were computed for the entire field during the season. In addition to the partitioning by PGR application type, the field was also partitioned by equal area NDVI values taken from the 07/05/2000 data set, which was just prior to the first PGR application in 2000. Equal area partitioning establishes a partitioning scheme on the NDVI data. It establishes thresholds in the NDVI data range such that the partitioning segments the data into n groups each with the same number of data elements. This NDVI classification was segmented into 5 equal area NDVI regions. From the equal area segmentation 3 NDVI groups were created. They consisted of the highest 20%, the middle 60% and the lowest 20% NDVI measurement. Even though the growing season was dry and the yields were low, there were some statistical differences in the yields within the treatment/NDVI regions. This motivated a Spatially Variable Plant Growth Regulator (SVPGR) experiment to be designed for the 2001 growing season.

Spectral Visions reviewed many papers that discussed variable rate applications of PGR, including Weir and Kerby (1988), Munier et al. (1993) and Thurman and Heiniger (1998). Most had generally positive results with the potential of minimizing the use of the chemical and maintaining or increasing yield. Other research explored adjustments in the timing and quantity of PGR applications. However, we have not found any specific references to the use of imagery for site-specific PGR application in cotton. Thurman and Heiniger (1998) briefly mentioned the use of aerial photographs "to assist in identifying areas of the field which differed in growth and development" in the context of a PGR study, but the photos were not directly germane to the study. Thurman and Heiniger did, however, determine (through grid-based field samples) that the variability in key cotton indicators was "wide enough to justify VRT practices and application of Pix® . Spatial analysis would improve the decision process of PGR application timing." Thurman and Heiniger (1999) identified growth areas and soil types in fields using aerial photography, GPS scouting, digital soil surveys and field histories. They also demonstrated that height control in rapid growth situations is critical to high boll retention and yield in variable cotton fields. Coupled with our own investigations, this previous research points to the use of imagery to identify vigorous areas, which are likely to exhibit excessive plant height, and thus may serve as a sound basis for a spatially variable PGR application. NDVI change maps may complement NDVI maps in locating the "rapid growth areas".

This experiment tested two separate concepts simultaneously in a factorial design: (1) the impact of plant-growth regulator (PGR) application on yield when applied to high, medium, and low NDVI regions, and (2) the impact of Spatially Variable PGR (SVPGR) application on yield. As in past years, a NDVI segmentation was generated by breaking the NDVI image into the lowest 20%, middle 60% and highest 20% equal area groupings. This year's data was calibrated so that the NDVI values from one date could be directly compared to other dates. This compensated for in-season differences in atmospheric effects and radiometric differences. This provided the capability of creating NDVI change maps in addition to NDVI maps. The NDVI and NDVI change maps were broken into equal area classes and were downloaded to IPAQ handheld computers so that the field scouts could navigate to the different NDVI and NDVI change zones within the field. Using measurements collected at different locations in the fields, the scouts made prescription recommendations on which NDVI index type and threshold to use. The threshold specifies the location in the data range where the geographic area corresponding to the NDVI values on one side of the threshold have PGR applied and the geographic area corresponding to the NDVI values on the other side of the threshold do not have PGR applied. In this way the research attempted to use SVPGR to further refine which vegetation index and what index threshold is best suited to delineate PGR-On and PGR-Off areas for the spatially variable prescriptions. We hypothesize that by applying plant growth regulator only to the areas that need PGR chemical, significant savings in cost for PGR application may be achieved by reducing the amount of chemical applied in the field.

Project Goal

This year's project goals are to :

1) Replicate the 2000 experiment by testing the relationship between areas that are blanket sprayed (Blanket-Spray-On) and areas that are not sprayed (Spray-Off). We expect the yield to be higher for the Blanket-Spray-On areas. The reason to repeat this segment of the 2000 experiment is to determine if the patterns observed last year are consistent from year to year.
2) Replicate the 2000 experiment by testing the relationship between the yield of the six factors of Blanket-Spray-On/Spray-Off and high, medium, and low NDVI areas. The reason to repeat this segment of the 2000 experiment is to determine if the patterns observed last year are consistent from year to year.
3) Test the relationship between yield of areas of SVPGR applications and traditional Blanket-Spray-On PGR applications.

Study Area

The study area is a 126 acre cotton field identified as T167-18 at Perthshire Farms near Gunnison, Mississippi. This field was used in the PGR experiment last year. Figure 1 shows the false color composite image generated from data collected on June 16, 2001.

Hypothesis

Analysis will be conducted to determine the significant differences between the yield of the Spray-Off and Blanket-Spray-On areas. The first hypothesis to test is:

1) Ho: Yield for the Spray-Off and Blanket-Spray-On treatments are equal.
   $\text{Yield}_{\text{Spray-Off areas}} = \text{Yield}_{\text{Blanket-Spray-On areas}}$
   H_A: At least one combination is statistically different.

Analysis will be conducted to determine significant differences in the yield between paired comparisons of high-20%, mid-60%, and low-20% NDVI areas; and Spray-Off and Blanket-Spray-On areas. The second hypothesis to test is :

2) Ho: Yield for the NDVI x spray-off/on regions are equal.
   $\text{Yield}_{\text{Spray-Off/high-20 areas}} = \text{Yield}_{\text{Spray-Off/mid-60 areas}} = \text{Yield}_{\text{Spray-Off/low-20 areas}} =$
   $\text{Yield}_{\text{Blanket-Spray-On/high-20 areas}} = \text{Yield}_{\text{Blanket-Spray-On/mid-60 areas}} = \text{Yield}_{\text{Blanket-Spray-On/low-20 areas}}$
   H_A: At least one combination is statistically different.

Analysis will be conducted to determine differences between spatially variable PGR areas and Blanket-Spray-On areas. The third hypothesis to test is :

3) Ho: Yield for the SVPGR and Blanket-Spray-On PGR treatments are equal.
   $\text{Yield}_{\text{SVPGR areas}} = \text{Yield}_{\text{Blanket-Spray-On areas}}$
   H_A: One combination is statistically different.

If we fail to reject Ho, then analysis indicates that SVPGR can reduce the chemical material cost of PGR applications while maintaining yield. If Ho is rejected, and $\text{Yield}_{\text{SVPGR areas}} > \text{Yield}_{\text{Blanket-Spray-On areas}}$ then the analysis shows that SVPGR may help increase yields and also reduce overall PGR material cost.

Experimental Design

This experiment used a randomized complete block design that allowed for testing of the underlying concept from last year's data—that yield may increase if PGR is specifically applied to targeted NDVI areas—as well as to test SVPGR for yield differences. The 2001 treatments are:

Treatment A: PGR Spray-Off application
Treatment B: PGR Blanket-Spray-On application
Treatment C: SVPGR application

Each block contained three field strips; one strip for each treatment type. Treatment A area was unsprayed. Treatment B was blanket sprayed. Treatment C used spatially variable spraying techniques. The PGR application prescription used on Treatment C was driven by vegetation indices created from remotely sensed data. Equal area NDVI and NDVI change maps were generated to direct the field scouts to the different vegetative areas of the field. The scout determined if NDVI regions within the strip were ready for the spatially variable application. The scout determined a NDVI or NDVI change value as a threshold to separate the SVPGR spray/no-spray areas of the treatment. Prescriptions were generated directing the spray rig to apply PGR only on the selected spray areas. Not only was there a choice of using equal area NDVI and NDVI change maps, but the field scout was also given the opportunity to fine tune the actual threshold value used to delineate the SVPGR spray/no-spray areas.

The study area was a 126-acre field at Perthshire Farms (owned and operated by Ken Hood) made available to the researchers and that had PGR applied by a ground based spray rig (as opposed to aircraft). We utilized 24 rows, each 40" wide (.0254 meters), spanning the length of the field to form a whole plot. There were 8 replications (blocks) of the combinations of the above factors. The total study area comprised :

- 3 treatments x 8 replications (blocks) = 24 whole plot strips
- 24 plot strips x 24 rows each = 576 rows in the total study area.

The 3 treatments within each block were randomly assigned, creating 24 plots within the field. Figure 2 shows the results of the assignments.

During the course of the season, several different scout maps were generated. During last year's experiments, three NDVI groups were established for yield comparisons. The three groups were the highest 20%, middle 60% and lowest 20% of the NDVI values. These NDVI values were generated from inseason imagery. The resulting areas "split" the field into three NDVI sub-regions, and allowed Spectral Visions to test what happens to yield at different NDVI/treatment combinations. This year's experiment studied the repeatability of these findings. In addition, the SVPGR yields were compared with the Blanket-Spray-On and Spray-Off yields to determine the benefit of using spatially variable techniques for PGR application.

Imagery and Field Data Specifications

The experiment was supported by remotely sensed data acquired over the research field. In addition, plant information such as population density and plant height was measured and collected by scouts in the field.

Image Data

This experiment relied upon airborne three-band (840nm, 695nm, 540nm, +-5 nm) multispectral imagery acquired at 2-meter spatial resolution by the ITD-Spectral Visions RDACS camera. The RDACS 2-meter data was resampled to 4-meter data to simulate the spatial resolution of the Space Imaging's Ikonos data sets. By using the spatial resolution of the Ikonos data set, any techniques resulting from the experiment should be replicable with Ikonos and DigitalGlobe Quickbird satellite data.

Field Data

Plant characteristics were measured by field scouts to determine optimal PGR application timing. These measurements included plant height and plant density. In the SVPGR treatment strips the field scouts were provided with NDVI and NDVI change maps in order to help navigate to areas of differing vegetation vigor and to help them determine threshold recommendations for prescription generation. The plant characteristics were recorded into data files using the iPaq handheld computer. PGR application times were determined by the field scouts. In addition, the field scout recommended a threshold on the NDVI or NDVI change map to use in order to establish Spray-Off/Spray-On areas.

Methodology

Remotely sensed data was collected over the research field every 7-10 days. After preprocessing the data, NDVI maps were generated by the ITD Spectral Vision's iCrop software package. This software was built upon the ESRI ArcView product and computed NDVI maps, generated "go-to" shapefiles to hold field measurements, created spray prescriptions, and several other important functions. A smaller version of iCrop was loaded on the Compaq iPaq hand-held computer and ran on the ESRI ArcPad software. It was used to help the field scout navigate in the field and collect field measurements.

Image Pre-Processing Procedures

The image pre-processing procedures used in the experiment are listed below.

1. RDACS imagery was captured at 12,000 feet AGL over the SVPGR field in conjuction with data collected for the Spatially Variable Insecticide experiment that was being conducted on adjacent fields. The data was delivered on 8mm tape and the image frames were extracted onto disk.
2. The image frames were band-to-band registered.
3. Imagery was georeferenced using nearest-neighbor resampling and output in the Universal Transverse Mercator (UTM) coordinate system. The data was georeferenced to a 1-meter panchromatic Ikonos image. All data manipulation was performed in UTM. However, the final prescriptions were generated in lat/long coordinates in order to accommodate the AIM Navigation applicator software.
4. Radiometric calibration was performed on the imagery. This process utilized pseudo-invariant features (static features) as radiometric targets. Spectroradiometer reflectance data of the radiometric targets taken in the field were used to transform raw 8-bit Digital Numbers (DN) to percent reflectance in the imagery. This was performed by introducing the raw data extracted over the calibration target and also

the radiometer data into a calibration procedure that was written into the Imagine application software package.
5. The image data was resampled to a spatial resolution of 4 meters to simulate the Ikonos spatial resolution. This resampling was also performed within the Imagine application software.
6. All non-field areas, including field edges and roads among the fields, were masked out of the image scene, leaving only pixels within the study area.

Image Processing Procedures

The image processing procedures used in the experiment are listed below.

1. Most of the image processing tasks were performed by the iCrop software developed by Spectral Visions. The processing for the SVPGR field was conducted in tandem with the processing for the SVI fields. There were several vegetation classifications generated and several indexes used. The vegetation classifications were NDVI and NDVI change maps. The indexes included equal area slicing of the NDVI based on statistics of the SVPGR field. In addition, a season adjusted index was generated that allowed the NDVI on different dates to be directly compared. The equal area NDVI classification/index was used to generate the prescriptions.
2. The original vegetation indices were transformed to ESRI grid files to allow image math to be performed.
3. Scout images resulting from the indices or technique applied to the imagery were produced in digital format as well as printed hard copy for delivery to the field scouts. The digital data was converted to shapefile format and emailed to the research farm. In addition to the NDVI products, a shapefile of location points was sent to the research farm

Field Data Collection

Plant height and density measurements were taken every 7-10 days in the experiment strips through June and July. The locations of the measurements were fixed at the beginning of the season. There were 6 measurement locations in the SVPGR treatment strips. There were 3 measurement locations in the Blanket-Spray-On treatment strips. The Spray-Off treatment strips also had 3 measurement locations. These measurements were used to help determine the time of PGR application. The treatment zones with the location of the measurement points are shown in Figure 3.

The NDVI maps were sent in digital and hardcopy form to the scout at the research farm. The scout loaded the digital version of the NDVI map and its supporting information onto the iPaq hand-held computer. A "go-to" shapefile containing the location of the field measurement points was included with the NDVI image. The iPaq was configured with a GPS. The scout used the iPaq to navigate to the field measurement points. Field measurements were recorded and entered into the "go-to" shapefile for each "go-to" point. This information was emailed to Spectral Visions. If it was determined that an SVPGR application was needed, the scout filled out a prescription request form, which were also available with the digital NDVI map. The field scout provided the vegetation index threshold to use in generating the prescription. The prescription request form was emailed to Spectral Visions. The prescriptions were generated at Spectral Visions and then emailed back to the farm. This was installed on the Patriot Spray Rig for the application.

Statistical Analysis

The SVPGR research field was harvested with Case International 6 row pickers on September 27, 2001. Ag-Leader yield monitors were used on the cotton pickers to measure the yield. In addition, a weigh wagon was used to assess the accuracy of the yield monitors. Each picker has 6 collection shoots and the yield monitors were placed on the second and fifth collection shoot of the picker. The yields were extrapolated to calculate the yields of the other collection shoots. This technique reduces the number of yield monitors and as a result also the cost. The Ag-Leader representative stated that analysis had been performed to show that any loss of accuracy resulting from this extrapolation was negligible. After the yield monitors were calibrated, the error in the yield monitor measurements from random loads was determined to be less than 5% when compared with the weigh wagon measurements. On some individual loads the error was less than 1%.

The yield data was collected and processed. From time to time the pickers had to stop to dislodge redvine weeds from the picker heads. At other times the picker may have slowed to a stop for other reasons. This resulted in spurious reports in the yield monitor data. Any time the picker stops, a lag time is needed to reestablish the flow of cotton through the collection tubes. This takes a few seconds to occur. Data recorded during this time was edited out from the final yield data. In addition, when the cotton picker is sitting idle on the field while being attended for weed removal or attention to the mechanics, useless data is being recorded by the yield monitor. This data was edited out of the final yield data. In order to more accurately represent the yield results, the data was averaged over 15-meter areas. This gives better overall representation to the yield data. These processes and others were performed to provide high quality yield data.

Once the yield data was processed, the average for each treatment strip was calculated. ArcView was used to aggregate the yield down the center 12 rows of each treatment strip. The average yield for each treatment strip was recorded in a text form for use as input into the statistical analysis. In addition, the yield map was intersected with the 3 NDVI groups generated from the 5 class equal area NDVI map from July 6, 2001. Yields were collected for the High 20%, Middle 60% and Low 20% areas of the Blanket-Spray-On and Spray-Off areas. The 3 NDVI x 2 treatment types resulted in 6 groupings. These yields were also stored in a text form for use as input into the statistical analysis.

An Analysis of Variance (ANOVA) was conducted on the yield measurements for the different groups to test each of these hypotheses. ANOVA is usually employed in comparisons involving several population means. Even though the hypotheses are written as two-tailed tests, this method has also been proven effective in similar studies for statistical analysis of one-tailed experimental designs consisting of two variables (Kleinbaum et al., 1998). Several different statistical analysis ANOVA tests including Duncan, t-Tests, LSD and Student-Newman-Keuls were used.

The three different hypotheses were evaluated using programs written in the Statistical Analysis System (SAS) (Cody and Smith, 1997). Data was imported from the excel spreadsheets to be used in the SAS programs. The output from SAS is presented in the Results section. The SAS program focused on using the General Linear Model (GLM) to provide information about the statistical differences between each group.

Results

The management for the SVPGR treatments was different than the Blanket-On treatments. The Blanket-On treatments were managed according to traditional management practices. This resulted in a blanket application in mid-July. There was also a SVPGR application at the same mid-July date. However, there was an additional light SVPGR application on June 21, 2001 over the highest 40% NDVI zones to administer early control of the most vegetated areas of the field.

The first PGR application was performed on June 21, 2001. It was based on the NDVI generated from imagery collected on June 16, 2001. Within the SVPGR treatment, the top 2 NDVI groupings of a 5 class equal area NDVI of the entire field were selected as the areas for the application. The as-applied data shows this area to be 41% of the SVPGR treatment strips. Since it was early in the season only 4 ounces/acre was applied. Normally throughout the season a total of 8-16 ounces/acre is applied. There was no blanket application for the Blanket-On Strips at this time. Figure 4 shows the NDVI image of June 16, 2001 with the as-applied data from the June 21, 2001 application overlaid on top.

The second PGR application was performed on July 20, 2001. It was based on the NDVI generated from imagery collected on July 6, 2001. Within the SVPGR treatment, the top 4 NDVI groupings of a 5 class equal area NDVI of the entire field were selected as the areas for the application. The as-applied data shows this area to be 81% of the SVPGR treatment strips. There were 8 ounces/acre of Pix® applied to the SVPGR treatments. In addition, the Blanket-On Strips also received an application of 8 ounces/acre of Pix®. Figure 5 shows the NDVI image of July 16, 2001 with the as-applied data from the July 20, 2001 application overlaid on top.

The SVPGR treatments yielded highest with an average of 2664 lbs/acre. The Blanket-Spray-On treatments yielded on average 2640 lbs/acre. The Spay-Off treatments had the poorest yield at 2429 lbs/acre. A graph of the mean yield per treatment is shown in Figure 6.

The mean yield for the segmentation of the NDVI/treatment regions is shown in Figure 7 and had the following mean yield breakout :

Low-20%-NDVI/Spray-Off	1665 lbs/acre
Low-20%-NDVI/Blanket-Spray-On	1840 lbs/acre
Mid-60%-NDVI/Spray-Off	2468 lbs/acre
Mid-60%-NDVI/Blanket-Spray-On	2722 lbs/acre
High-20%-NDVI/Spray-Off	2869 lbs/acre
High-20%-NDVI/Blanket-Spray-On	3057 lbs/acre

There were three hypotheses in the experiment. The first tests for differences in the yield of the Spray-Off and Blanket-Spray-On treatments. The second tests for differences in the yield of the 6 regions consisting of the 3 NDVI zones crossed with the Blanket-Spray-On and Spray-Off areas. The third tests for differences in the yield of the SVPGR and Blanket-Spray-On treatments. The hypotheses were tested at the alpha=0.1 level.

Several different tests were performed to test the first and third hypothesis. Contrast comparison tests as well as the Duncan, t-Test, LSD and Student-Newman-Keuls GLM tests were performed. The model of this test was significant (P = 0.0078). All the tests showed the same statistical grouping of the treatment strip yields. Table 1 shows the results of the Duncan test at the 0.1 alpha level. These results show there was no statistical difference between yields of the Blanket-Spray-On and SVPGR treatment strips. It also shows that the yield from the Spray-Off treatment strips was statistically significantly lower than the yield from the Blanket-Spray-On and SVPGR treatment strips.

Therefore the first hypothesis is rejected and yield from the Spray-Off treatments is considered to be statistically significantly poorer than the Blanket-Spray-On treatments. This differs slightly from last year's results that indicated the Spray-Off areas were lower yielding, but not statistically significantly lower yielding, than the Blanket-Spray-On areas. When considering the PGR impact on yield, this year's results supports the case for the use of SVPGR applications.

In addition, we fail to reject the third hypothesis and average yield from the SVPGR treatments are considered to be statistically similar to those from the Blanket-Spray-On treatments. This promotes the use of SVPGR applications in the sense that it doesn't reduce yield while at the same time it does reduce the amount of PGR chemical applied on the field.

The second hypothesis was also tested using several tests. The Duncan, t-Test, LSD and Student-Newman-Keuls GLM tests were performed. All the tests showed the same statistical grouping of the NDVI/treatment strip yields. The model of this test was significant (P = 0.0001). The results of the Duncan test at the alpha=0.1 level are represented in the output of the Duncan test in Table 2.

Therefore the hypothesis that the yields by NDVI class and Treatment Strip are equal is rejected. There are four significantly differently yielding groups. The first group contains the High-20%-NDVI /Blanket-Spray-On and the High-20%-NDVI/Spray-Off regions. The second group contains the High-20%-NDVI/Spray-Off and Middle-60%-NDVI/Blanket-Spray-On region. The third contains the Middle-60%-NDVI /Spray-Off region. The fourth group contains the Low-20%-NDVI /Blanket-Spray-On and Low-20%-NDVI /Spray-Off regions.

This year the data shows that yields could be significantly improved if the PGR application is limited to the middle 60% of the NDVI values. It should be noted that the 20/60/20 percent NDVI groupings was set from observed data over two years ago. The refinement of this process would be to determine optimal NDVI ranges to target for SVPGR applications. In order to implement SVPGR, a subrange of the percent NDVI range must be found where when PGR is applied to geographic areas corresponding to the NDVI values in this subrange, the yield increases and when PGR is applied to geographic areas corresponding to the NDVI values outside this NDVI subrange, the yield does not increase. Future research is needed to determine this NDVI subrange. In fact, this NDVI subrange may change from year to year (due to weather conditions such as moisture stress). Some decision criteria needs to be developed to determine what the optimal NDVI subrange is for each growing season.

Economic Analysis

The economic analysis was performed under the direction of the MSU Agriculture Economics Department from the statistical analysis of the data. The economic analysis compares the cost of traditional (blanket) applications to the cost of SVPGR applications. This cost includes equipment, chemical, human resource and imagery costs. It computed the total cost of application for both SVPGR and blanket PGR. The cost for blanket PGR includes the cost of the spraying equipment and human resources to operate the equipment. For SVPGR, the additional costs include agriculture consultants, remote sensing data collection, and processing. The comparison provides a percentage cost savings of SVPGR over blanket PGR.

The costs associated with implementing the conventional (Blanket) method include Pix® chemical and application. The PGR application costs cover the cost of the spray rig with the 90' (27.432 meters) boom, the fuel consumption, diesel fuel cost, salvage, repair, maintenance costs, performance rates, and driver costs. All calculations assume a fully utilized machine. The summary costs are presented in Table 4.

The SVPGR method has some additional costs for spray rig equipment enhancements, remote sensing data acquisition and value added data processing, prescription generation, and management by a service consultant or private farm precision farming specialist. The additional spray rig costs include the cost of the ruggedized notebook computer, spray controller and miscellaneous GPS equipment. This analysis assumes there are 3 data acquisitions performed in order to provide 3 NDVI scout maps during the June/July time period. This analysis only calls for one SVPGR application to be performed per field during the season.

The remote sensing data acquisition costs are taken from advertised costs from Agri-vision. Agri-vision is a company based in Columbus, Indiana that provides imagery to the precision agriculture industry. The Agri-vision imagery cost is $1/acre. The data provided by Agri-vision is already band-to-band registered and georeferenced. The only pre-processing that would need to be performed would be field masking and possibly calibration. There are other companies such as Geotek Management Services at Stennis Space Center that also provide remotely sensed imagery. The $1/acre will be used as the Raw Data Collection cost in this analysis. It will be assumed that a service such as Agri-vision will provide the data in a band-to-band registered and georeferenced format. The value added processing costs include estimations for downloading data, masking fields, generation of NDVI image map, materials, and data grid generation. The prescription generation costs include costs for prescription creation, loading the prescription into the spray rig, and downloading and archiving as applied data. These costs were calculated as "loaded costs" and assume overhead and fringe. These costs have been generated in dollars/acre units and are presented in Tables 5, 6 and 9.

Assuming an application of 8 ounces/acre, the cost of Pix® is $4.50 per acre. The Pix® cost is the same for the SVPGR and conventional methods. The PGR application cost is $1.31 per acre for the conventional method and $1.55 per acre for SVPGR method. The remote sensing data collection and processing costs for the SVPGR method are $1.12 per acre. The service consultant costs for the SVPGR method are $0.16 per acre. This results in a total of $5.81 per acre cost for the conventional application and $7.33 per acre cost for the SVPGR application. These costs are presented in Table 3.

The field scout used the scout maps based on the remotely sensed data to determine if an SVPGR application should be performed. In addition, the field scout or the producer makes a determination of what rate of PGR should be applied. This analysis assumes that one application will be administered and the rate will be 8 ounces/acre. Traditionally the field scout visits large number of locations in the field. The scout maps allow the field scout to visit fewer more focused areas of the field. Since the field scout has not been acclimated to using the scout maps, for this analysis it will be assumed that there is no savings in the field scouting time.

A very critical piece of information is to what extent the SVPGR technique will reduce the amount of PGR applied to the field. During this study the amount of reduction of the SVPGR over the blanket application was 41% on June 21, 2001 and 81% on July 20, 2001. Further research needs to be performed to make recommendations of what percent of the field should be treated. The percentage of chemical reduction is critical to the economic analysis in that the chemical reduction value used has a big impact on the final percent savings amount.

The High-20%-NDVI and Low-20%-NDVI groups did not have a statistically significant yield difference across the Blanket-Spray-On and Spray-Off regions. These two NDVI groups represent 40% of the field. This economic analysis will take a conservative approach and assume that there does not need to be a PGR application on this 40% of the field. It is anticipated that as the recommendations for which ranges of the NDVI are better understood that this percentage will be reduced and the overall savings will become greater.

The costs associated with the conventional and SVPGR applications are shown in Tables 8, 9 and Figures 8 and 9. The columns show the information for the conventional and SVPGR methods and also the cost savings. The rows show the cost per acre; number of acres, total cost and percentage cost as compared to the conventional method. They show that if the PGR application is reduced by 40%, the SVPGR has a cost savings of 24.30% over the conventional method. Assuming an application chemical reduction of 40% for the 126 acres in the SVPGR research field, the cost to perform the PGR application using the conventional method would be $732.06; the cost of the SVPGR technique would be $554.15; and the cost savings would be $177.91. When extrapolated to 10,000 acres, the cost of the conventional method would be $58,100; the cost of the SVPGR method would be $43,980; and the 24.30% cost savings would be $14,120.

The economic analysis demonstrates that the SVPGR method is cost effective. Assuming the amount of PGR saved by utilizing SVPGR techniques is 40%, after integrating the application costs, data collection costs and prescription management costs, the cost of the SVPGR method as compared to the conventional method is reduced by 24.30%. Therefore, this economic analysis demonstrates that using SVPGR techniques for application of PGR to treat rank cotton growth and increase yields compared to today's conventional methods reduces the cost of PGR applications to the American cotton producer.

Conclusions

There were three different hypothesis tests performed. The first tested the hypothesis that the yield of the Spray-Off and Blanket-Spray-On treatments were equal. The second tested the hypothesis that the yield of the 6 different NDVI/Treatment regions were equal. The third tested the hypothesis that the SVPGR and Blanket-Spray-On treatments were equal. These tests were done at a 0.1 alpha level.

The hypothesis for the first test was rejected. Therefore the yield from the Blanket-Spray-On treatments is significantly greater than the Spray-Off treatments. This indicates that, for this year's growing conditions, application of PGR increases yield. In general the yields at Perthshire this year were greater than they were last year were potentially due to more favorable growing conditions, such as the higher rainfall rate that occurred during the growing season.

The hypothesis for the third test was not rejected. The yield from the SVPGR treatments, although higher than the yield from the Blanket-Spray-On, is not statistically significantly different. This provides a foundation for the use of the SVPGR as a technique to reduce the quantity of PGR applied on cotton fields. The reduction of PGR would both reduce chemical cost to the farmer and also reduce the impact of the chemical on the environment.

The hypothesis for the second test was rejected. Mid-60%-NDVI/Blanket-Spray-On regions yielded significantly higher than the Mid-60%-NDVI/Spray-Off regions. The yields from the High-20%-NDVI/Blanket-Spray-On regions and the High-20%-NDVI/Spray-Off regions were not statistically significantly different. The yields from the Low-20%-NDVI/Blanket-Spray-On regions and the Low-20%-NDVI/Spray-Off regions were not statistically significantly different. Therefore this data targets the middle 60% NDVI range as the optimal range for the SVPGR application.

In addition, this year's results show that although the High-20%-NDVI/Blanket-Spray-On regions did yield higher than the High-20%-NDVI/Spray-Off region, it was not significant. This would seem to indicate that it is not always necessary to apply PGR to the highest NDVI areas. Applying PGR to these higher NDVI regions certainly did not hurt yield. In fact, it is possible that the PGR in these regions did contribute to the higher yields. The statistical test, however, cannot separate the contribution of the PGR application to higher yields in these higher NDVI regions from the experimental error. These conflicting results pose a dilemma on recommendations on the NDVI ranges for PGR application.

Future Work Recommendations

The dilemma of making recommendations on the NDVI ranges was discussed in the previous section. Further research needs to be done to determine optimal targeting of the range of NDVI values that will benefit from the PGR application.

This work began two years ago. Observations on yield were made after breaking the field into these Low 20% NDVI, Middle 60% NDVI and High 20% NDVI. These observations were incorporated last year into a PGR experiment, which did not perform any spatially variable applications. It concerned itself only with testing yield results from different NDVI regions. In order to make the study manageable, the 3 NDVI groupings were used in the yield comparison. 2000 was a rather dry year and the yields were not all that high. The study did show some yield differences across the NDVI/treatment regions.

Last year's results motivated this year's experiment. This year the experiment was replicated and in addition, tests were performed to see whether yield was maintained, lost, or gained by using the spatially variable application technique to spray the PGR on treatment strips in the field. The yield was maintained within the SVPGR treatments when compared with the Blanket-Spray-On treatments. This growing season had more rainfall than last year and the yields in general were greater. This year's analysis showed a significant difference in the yields in the middle 60% NDVI region. The economic analysis of SVPGR shows that a reduction of 40% in the chemical application results in 24.30% reduction in the cost of applying PGR.

The results from last year would seem to indicate different optimal NDVI ranges than this year's data. Optimal NDVI ranges to target for SVPGR application need to be better understood. Next year's experiment should focus on developing methods to recommend NDVI ranges for SVPGR application. Yield differences may result from different rainfall rates across different seasons and therefore, installation of a weather station near the research field may help find optimal NDVI ranges for SVPGR applications. Once these recommendation methods are better established, SVPGR should become more efficient and economical.

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The NASA ESAD Program, Mr. Kenneth Hood, Hood family and the Perthshire Farms staff, Johnny Freeman, Doug Cauthen, Russell Cauthen, Dr. Jeff Willers, Dr. David Laughlin, Dr. Greg Carter, Stuart Helming of Ag-Leader, Geotek Management Services, Mid-South Ag Co., CASE-IH, AIM.

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Table 1. Results for Differences in Yield Means of Treatment Strips.

Contrast	**Difference Between Yield Means (lbs/acre)**	**Significantly Different at the alpha = 0.1 level**
Spray-Off vs. Blanket-Spray-On	211.61	yes
Spray-Off vs. SVPGR	235.16	yes
Blanket-Spray-On vs. SVPGR	23.55	no

Table 2. Duncan Test for Differences in Yield Means of Spray Off-On Treatments/NDVI zones.

The GLM Procedure
Duncan's Multiple Range Test for YIELD at alpha = 0.1 level

Group	**Mean Yield (lbs/acre)**	**Treatments**
1	3057.2	(High-20%-NDVI, Blanket-Spray-On)
1,2	2869.8	(High-20%-NDVI, Spray-Off)
2	2722.6	(Mid-60%-NDVI, Blanket-Spray-On)
3	2468.3	(Mid-60%-NDVI, Spray-Off)
4	1840.1	(Low-20%-NDVI, Blanket-Spray-On)
4	1665.9	(Low-20%-NDVI, Spray-Off)

Table 3. Perthshire 2000 SVPGR Experiment Conventional vs SVPGR summary costs.

Item	**Conventional**	**SVPGR**
	$/acre	$/acre
Plant Growth Regulator material (Pix)	$4.50	$4.50
Plant Growth Regulator application	$1.31	$1.55
Imagery	$0	$1.12
Service consultant	$0	$0.16
Total	$5.81	$7.33

Table 4. PGR Cost for Conventional System.

	Unit	Price	Quantity	Cost	$/acre
Pix®	1 oz	$0.45	10 oz	$4.50	$4.50
Application	1 trip	$1.31	1	$1.31	$1.31

Note: Application cost reflects:
1. 90' Boom, 800-1000 gal. Capacity Sprayer
2. New cost, $173,363
3. Fuel consumption, 11.71 gal/hr. (diesel)
4. $1.10/gal diesel price
5. Includes salvage,repair & maintenance
6. Useful life 8 years, 350 hrs/year
7. Performance rate .009 hrs./acre (avg 10mph)
8. Driver Labor Cost, SSI and Fringe of $8.66/hour
9. Assumes fully utilized machine

Table 5. PGR Cost for SVPGR System.

	Unit	Price	Quantity	Cost	$/acre
Pix®	1 oz	$0.45	10	$5.40	$4.50
Application	1 trip	$1.55	1	$1.55	$1.55

Note: Application cost reflects:
1. 90' Boom, 800-1000 gal. Capacity Sprayer
2. New cost, $185,863
3. Fuel consumption, 11.71 gal/hr. (diesel)
4. $1.10/gal diesel price
5. Includes salvage,repair & maintenance
6. Useful life 8 years, 350 hrs/year
7. Performance rate .01 hrs./acre (avg 9 mph)
8. Driver Labor Cost, SSI and Fringe of $8.66/hour
9. Assumes fully utilized machine

Table 6. Imagery Cost for SVPGR Method.

	Unit: Hours	Price	Acres	Cost	$/acre
1. Raw Data Collection	*	*	*	*	$1.00
2. Value Added Processing	2	$60	1,000	$120	$0.12
Total					$1.12

Note: * Agri-Vision 1 acre of imagery cost Value Added Processing includes download data, mask fields, generate NDVI, Create scout maps for service provider consultant.

Table 7. Service Consultant Cost for SVPGR Method.

	Unit : Hours	Price	Acres	Cost	$/acre
1. Prescription Generation and Application	3	$55	1000	$165	$0.16

Note Prescription Generation and Application includes Consultant or Private Farm employee to take Value Added Data Product and create prescription, load prescription into sprayer, download and archive as applied data. Price taken from previous years work with Precision Farming Application Service Provider.

Table 8. Cost Analysis for SVPGR Fields assuming 60% Application.

	Conventional	SVPGR	Savings
Cost/Acre	$5.81	$7.33	-1.52
Acres	126.00	75.60	50.40
Total Cost	$732.06	$554.15	$177.91
% Cost	100.00	75.70	24.30

Table 9. Cost Analysis for Extrapolated Acreage.

	Conventional	SVPGR	Savings
Cost/Acre	$5.81	$7.33	-1.52
Acres	10,000.00	6,000.00	4,000.00
Total Cost	$58,100.00	$43,980.00	$14,120.00
% Cost	100.00	75.70	24.30

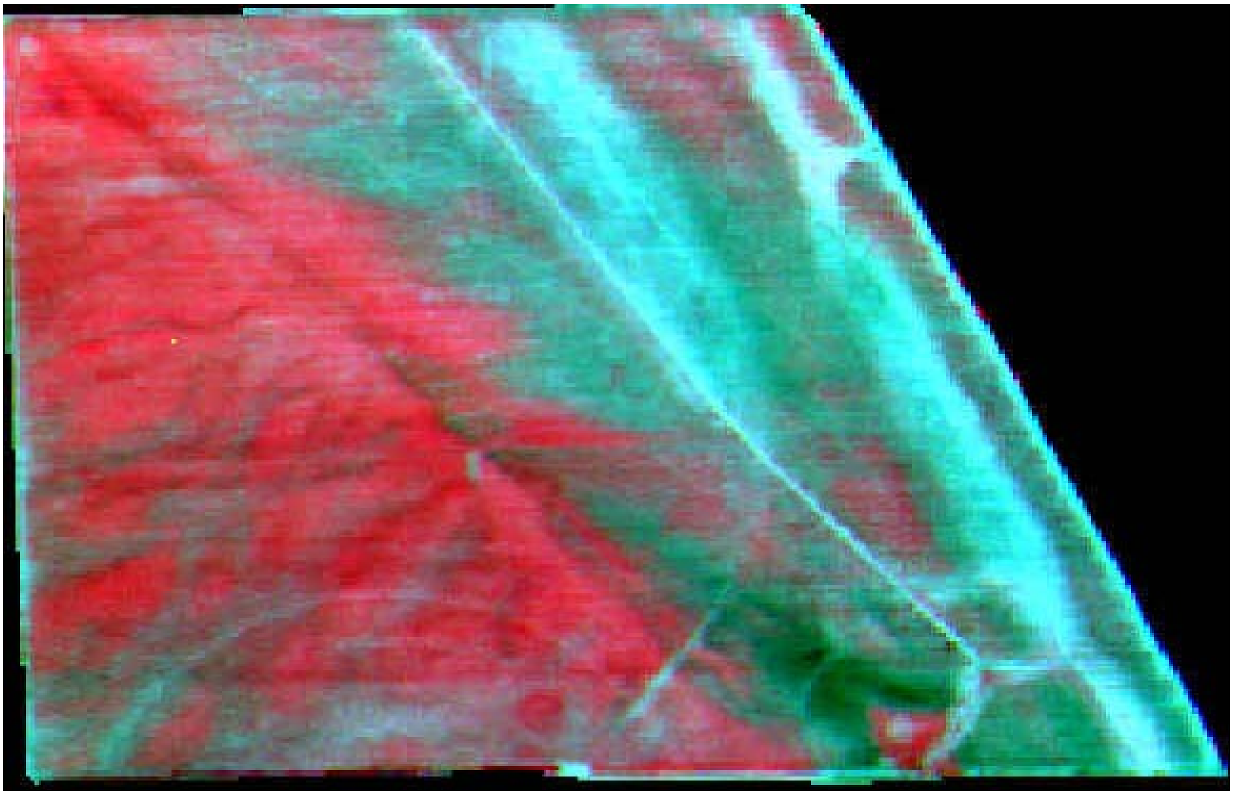

Figure 1. False Color Composite of Field T167-18 of Perthshire Farms from June 16, 2001 Data.

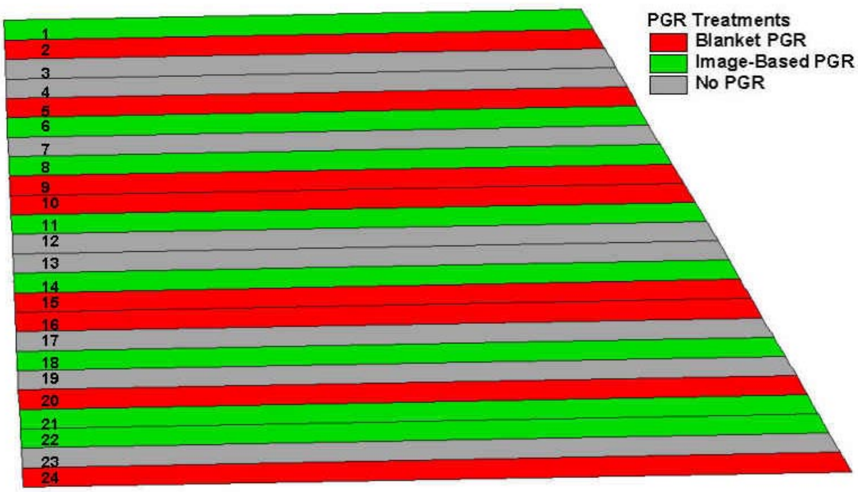

Figure 2. Treatment Zones for Field T167-18.

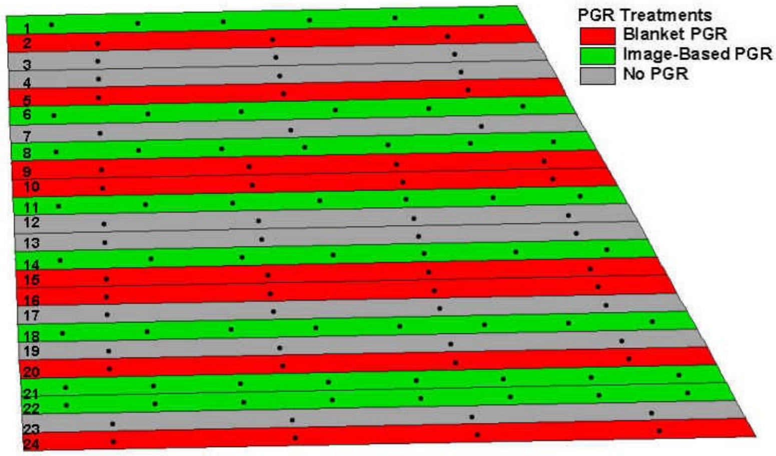

Figure 3. Treatment Strips with Field Measurement Points.

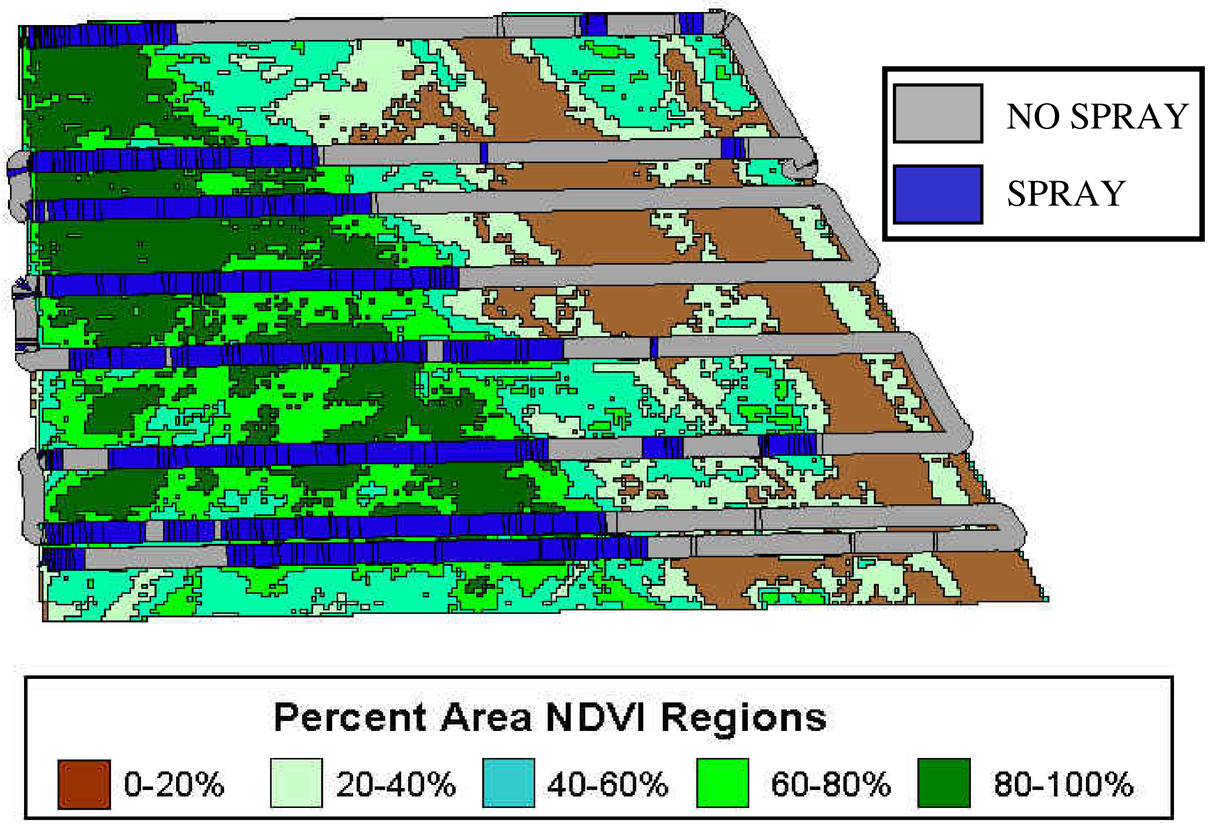

Figure 4. NDVI from June 16, 2001 data with June 21, 2001 As-Applied Data.

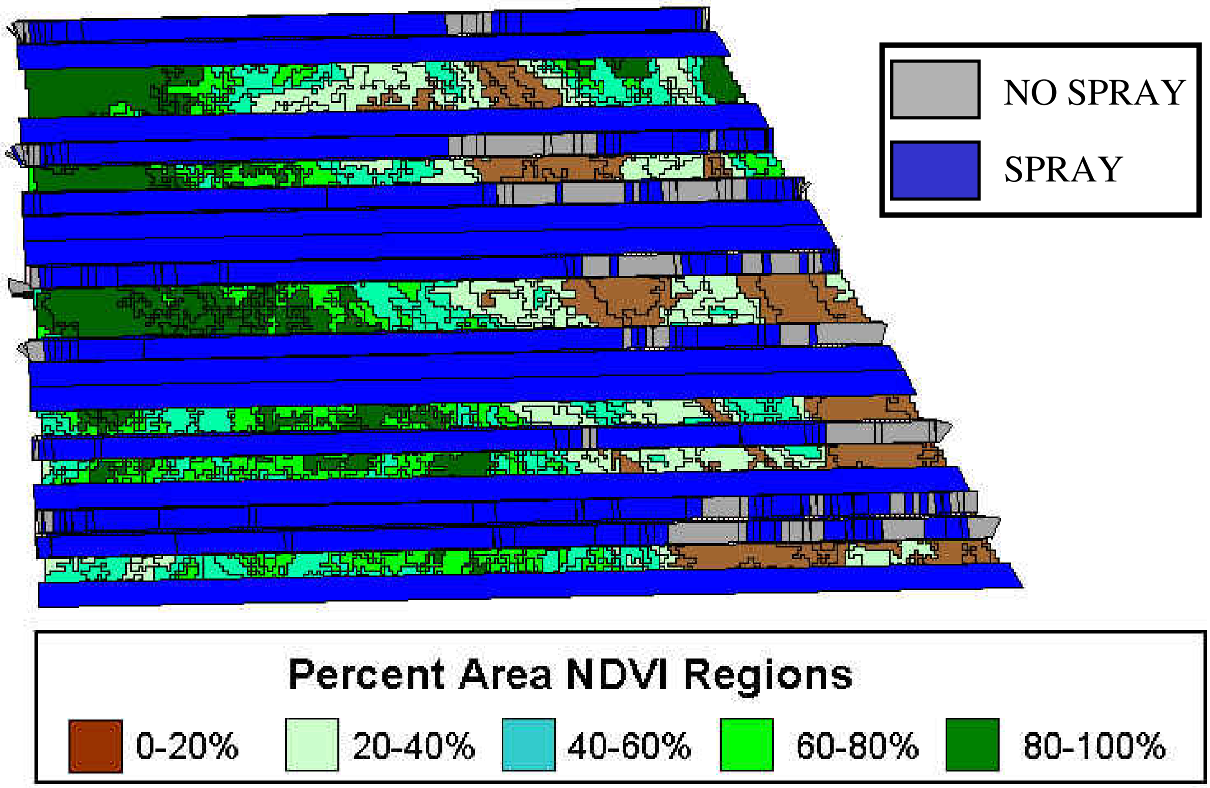

Figure 5. NDVI from July 6, 2001 data with July 20, 2001 As-Applied Data.

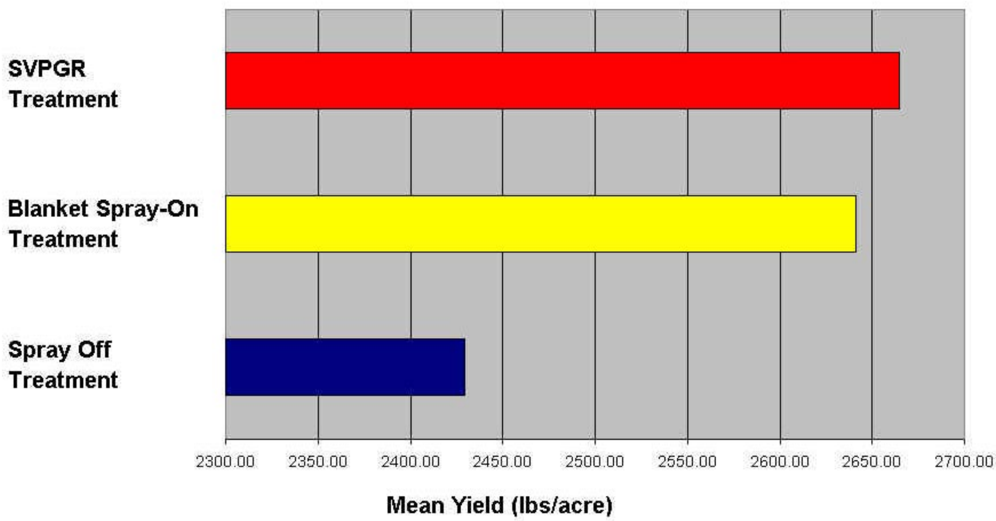

Figure 6. Mean Yield per Treatment.

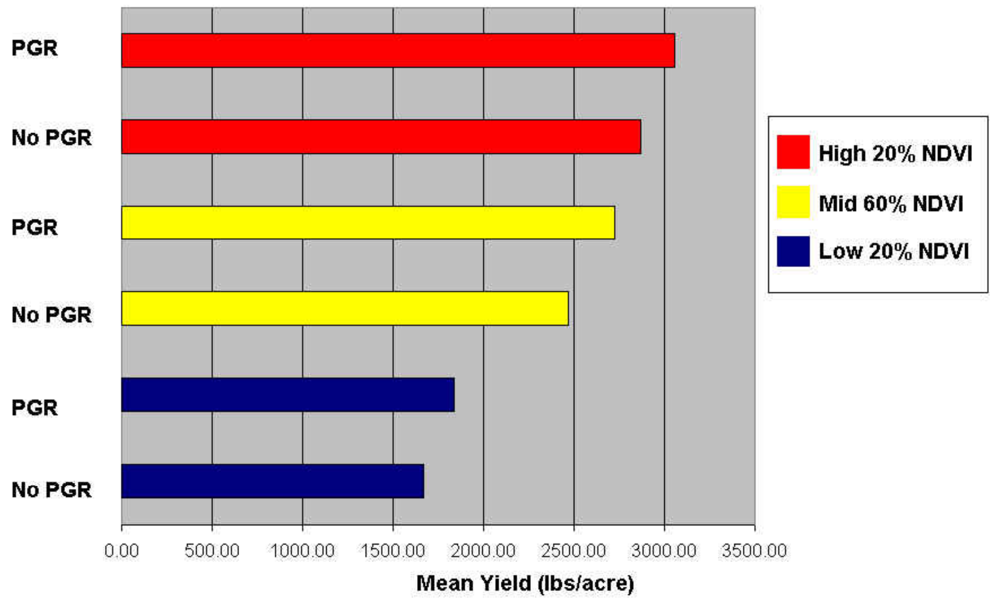

Figure 7. Mean Yield by NDVI/Treatment Type.

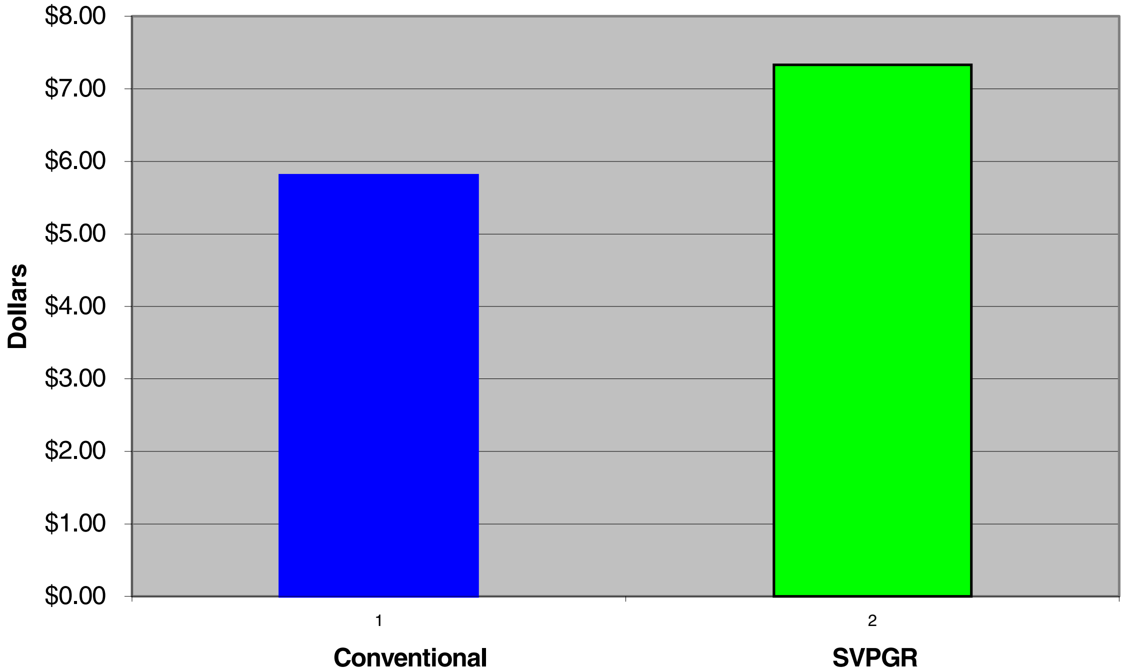

Figure 8. Conventional and SVPGR Cost/Acre.

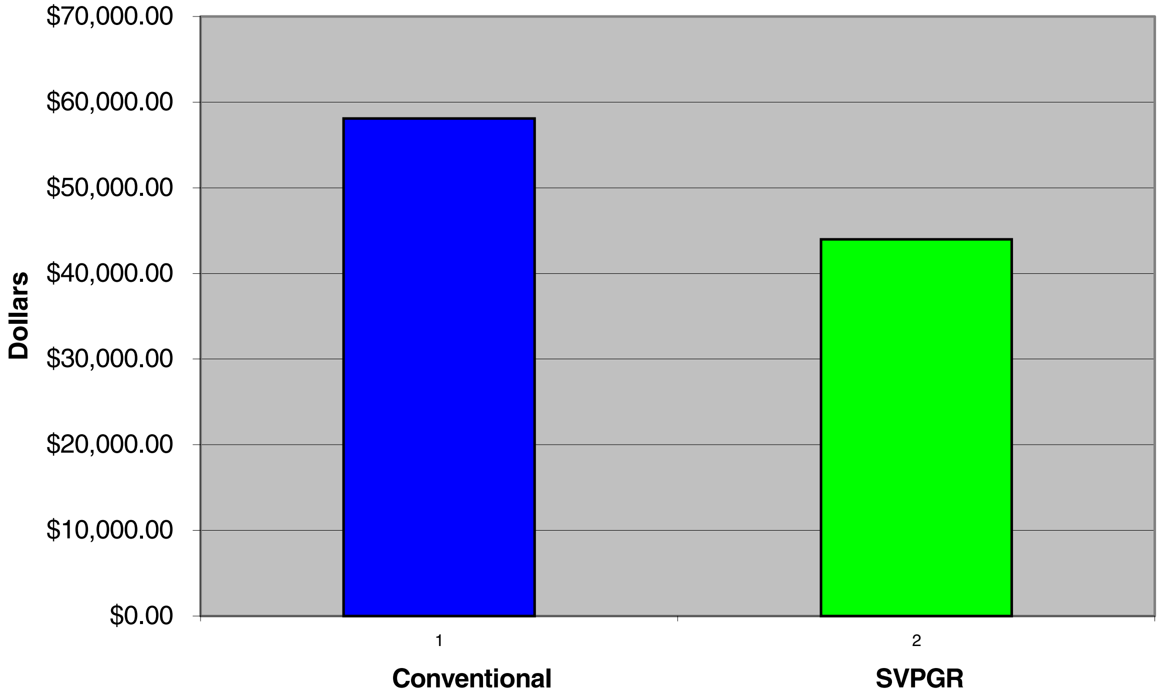

Figure 9. Costs Savings Extrapolated to 10,000 Acre Field.