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SPATIALLY VARIABLE INSECTICIDE RESEARCH IN COTTON BASED ON REMOTELY SENSED IMAGERY

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Abstract

This year's Spatially Variable Insecticide (SVI) research was based on the experience gained from the 2000 SVI studies conducted at Hardwick and Perthshire Farms (Spectral Visions, 2000). The concept of SVI is founded on the results of similar past studies, as well as the preliminary results of ongoing studies that are using remote sensing to support cotton insect management. These studies were researched prior to beginning the SVI experiments last year. During the literature review, we found that remote sensing to support cotton insect control has been pursued by a number of researchers, mostly at the level of exploratory or basic research. Due to the migratory nature of the insects which affect cotton production, producers and researchers feel that large scale or field level research is needed to fully explore, and understand the potential for utilizing remote sensing technologies to better manage entomological practices at the farm level. The natural environments and frequent movement of these insects cannot be properly duplicated or simulated in basic or plot level studies. We have not found reference to any applied research that uses remote sensing to spatially vary insecticide applications for plant bugs in Southern cotton. In fact, few researchers have taken the use of remotely sensed data to the applied ends envisioned by Ag20/20. One example of current research in cotton insect management was done by Nahum Gat of Opto-Knowledge Systems, is researching hyperspectral imaging for insect-infestations in western cotton (Gat et al., 1999). Perhaps the most thorough basic research for remote sensing in cotton insect management has been done by Fitzgerald et al., (2000) which examined the effects of spider mites and other insects in cotton through a variety of datasets, including thermal imagery. Spider mite damage was also examined through multispectral imagery by Fitzgerald et al., (1999), with some promising results deriving from bit-error filtering on the near infrared band. Another study by Summy et al., (1989) used color infrared photography to detect undestroyed cotton in support of a boll weevil eradication program.

One example of an applied remote sensing cotton insect project is a boll weevil eradication GIS that uses satellite imagery (Smith et al, 1997). Remote sensing in entomology was reviewed by Riley (1989), who discussed a wide range of attempts at insect mapping through aerial photos, radar, airborne and satellite digital imagery, and other data, including research of direct observation of flights of moths, grasshoppers, locusts, and other phenomena. A greater emphasis was placed on inference techniques, that is, detecting the effects or habitat of certain insects to infer their presence. Remote sensing projects for agricultural insect management at the time (Riley, 1989) included mention of corn leaf aphids, milkweed as an indicator of monarch butterfly presence, and post-harvest standing cotton plants as an indicator of boll weevil overwintering sites.

In addition, there are a number of research papers that approach site-specific management techniques for insect control, but not including remote sensing. Parker et al., (1999), for example, evaluated insect management strategies through the use of yield-monitor data but not imagery data. In summary, a review of the literature and the experience gained from past SVI research conducted at Perthshire and Hardwick Farms revealed an opportunity to continue to do groundbreaking applied experimentation in Spatially Variable Insecticide that may have a satisfactory effect on both Southern cotton producers and the remote sensing industry.

Introduction

The research team has exercised spatially variable insecticide (SVI) at Perthshire Farms, Mississippi based on the concept that tarnished plant bugs (*Lygus lineolaris*) are drawn to fast-growing, vibrant cotton, and that remotely sensed imagery may be used to identify these areas to prescribe insecticide (in this case Bidrin, $4.50/acre) in a site-specific manner. This concept was first envisioned and researched by Willers et al. (1999a), who "demonstrated that plant bug densities differed by crop growth stage" and that, by using remotely sensed imagery, "crop growth patterns throughout the field can be quickly distinguished." These observations were taken to practical application in 1999 (Dupont et al., 2000). Results of this study indicate a potential for about 40% savings in insecticide costs compared to traditional blanket application. Extensive scouting data are available to suggest that spatially variable insecticide sprays (SVI) were as effective in controlling pest populations of interest (namely, the tarnished plant bug) as broadcast sprays (Willers, 2001). The analysis of the 1999 SVI results at Perthshire Farms suggest no loss in yield due to usage of SVI applications compared to fields that were managed exclusively by broadcast applications. In 2000, we wanted to expand this research, in terms of test points and acreage, at Perthshire Farms. We also wanted to replicate the work at Perthshire Farms by testing SVI on another farm in the region, Hardwick Farms (Newellton, Louisiana) on the west bank of the Mississippi River southwest of Vicksburg. This second experiment was highly similar to the design we implemented at Perthshire Farms. By maintaining a consistent experimental design in the twin experiments, we attempted to compare the effectiveness of the SVI concept in two different farm-management environments, which represents an important element to Ag20/20 success.

The 2000 experiments at Hardwick Farms were designed to test the effectiveness of remote-sensing-based spatially variable insecticide to increase profits to the producer in terms of the following criteria; (1) cost savings, (2) effectiveness in managing plant bugs, and (3) ability to maintain acceptable yield levels compared to traditional blanket application of insecticide (Spectral Visions, 2000). Due to the absence of a plant bug infestation at Hardwick Farms in 2000, there were no data to analyze in order to test our hypotheses. However, the experience gained from the 2000 Hardwick Farms SVI study allowed us to modify the experimental design for SVI at Hardwick Farms in 2001 to take into account the problems experienced in 2000 that nullified the experiment. The experience gained at Hardwick Farms last year, which included preparing the applicator equipment to be capable of implementing the SVI prescriptions that were generated for this research, as well as the development and implementation of the automated image processing methodology that allowed for the timely generation and dissemination of NDVI scout maps and SVI prescriptions, were invaluable in implementing the SVI experiment in 2001.

A research team meeting was held at Hardwick Farms in November of 2000 to discuss the results of the 2000 study and plan for research in 2001. A key issue discussed at this meeting was how to adjust the experimental design to reflect the concerns of Dr. Hardwick and the LSU researchers involved with this study. Recommendations by the research team to adjust the experimental design based on the experience of the 2000 SVI study were to create a more flexible plan that takes into account the complete insect population rather than focuses on a single insect (like the tarnished plant bug, as in the 2000 SVI research) (Bagwell, Hardwick, Hood, 2000), and to remove the hypothesis that SVI maintains or increases yield when compared to traditional blanket methods. Both the effectiveness in controlling insect populations and insecticide cost savings to the producer hypotheses were tested to determine if SVI was a more efficient method than the traditional blanket approach. The recommendations discussed at this meeting, which included comments by Dr. Andy Jordan and Dr. Anne Wrona of the National Cotton Council, were the basis of the 2001 experiment plan which we proposed.

Project Goal

The goal of the 2001 field-level research at Hardwick Farms was to continue to build upon the experiences and knowledge gained from the 1999 and 2000 spatially variable insecticide research conducted at Perthshire and Hardwick Farms. The results of the 1999 and 2000 experiences has enabled the research team to develop scientific experiments which continue to explore the use of remote sensing and other geo-spatial technologies to better manage entomological practices at the farm level. These experiments were designed to test the effectiveness of remote-sensing-based spatially variable insecticide to increase profits to the producer in terms of the following criteria; (1) cost savings and (2) effectiveness in managing the insect populations which adversely affect the cotton crop. Both of these criteria determined the successful execution of this experiment.

Study Area

The research study area is a series of semi-contiguous fields totaling 1038 acres at Hardwick Farms in Tensas Parish, Louisiana about 35 miles Southwest of Vicksburg, Mississippi (figure 1). Located on the floodplain of the Mississippi River, the region is noted for its fertile alluvial soils and high cotton yields. Dr. Jay Hardwick, a nationally known cotton producer, graciously allowed the research team to pursue this experiment on his farm, while also providing his expertise in progressive cotton production. Dr. Hardwick works closely with the National Cotton Council and Cotton Incorporated to ensure the research conducted on his farm is inline with Ag20/20 priorities and any benefit from this research can be disseminated throughout the U.S. cotton belt.

Hypothesis

We are testing the following hypotheses based on the definition of a traditional blanket prescription/application being an application of chemical that is placed over the entire (100%) field, and an SVI prescription/application would be any application that covers less than the entire (100%) field. Due to the aforementioned definition of blanket and SVI prescription/applications, it is implied that any SVI application performed in lieu of a blanket application would result in a chemical reduction/cost savings to the producer, and thus allows for a one-tailed test for significant cost savings. The effectiveness hypothesis may also be considered a one-tailed test given that wherever insecticide is applied, insect populations will be reduced. Since SVI, by definition, is any application that covers less than the entire field, SVI effectiveness can not be significantly greater than that of a blanket application.

(1) Effectiveness of SVI treatments (as measured through pre- and post-spray insect counts) is statistically equal to traditional blanket treatments as defined by reducing insect populations below the treatment threshold which Dr. Hardwick's crop scout used to call for a spray;
H_o: $u_{\text{svi effectiveness}} >= u_{\text{blanket effectiveness}}$
H_A: $u_{\text{svi effectiveness}} < u_{\text{blanket effectiveness}}$
We hope to accept the null hypothesis, thus showing that effectiveness of SVI treatments in reducing insect populations to numbers that are not statistically significantly different than that of blanket insecticide applications.

(2) SVI treatments result in a significant increase in producer profitability as opposed to traditional blanket insecticide treatments.
H_o: $u_{\text{svi insect control costs}} = u_{\text{blanket insect control costs}}$
H_A: $u_{\text{svi insect control costs}} \neq u_{\text{blanket insect control costs}}$
We hope to reject the null hypothesis, thus showing that there was a significant increase in crop profitability by using SVI over blanket insecticide applications.

- Both hypotheses were tested for each block (field), as described in **Experimental Design**.
- Sampling points on a 2-acre grid layout were generated for the treatment areas. The research team attempted to visit each one of the sampling sites to collect pre-spray and post-spray insect count data. Financial expenses for the SVI applications will be tabulated to judge economic feasibility versus the traditional blanket method (see **Economic Analysis**).

Experimental Design

A randomized block design replicated five times.

- The experimental units were fields ranging from 64-159 acres each (see figure 1.1.1), selected for (1) adjacency to insect-producing areas (such as corn field, milo fields, and forests), (2) soil variability, and (3) availability.
- The blocks comprise each field, in which were blanket insecticide application areas, as well as areas subjected to SVI treatments; The treatment zones within each block (field) were delineated so that access to adjacent insect-producing areas are evenly shared. The treatment areas were randomly assigned to each field.
- This research incorporated the entire insect population which adversely affected cotton production at Hardwick Farms during the 2001 growing season, given that the insects were controllable with conventional spray applicators. We relied on the expertise of the LSU entomologists involved with this research to determine what insects migrate to the most vigorously growing areas of the crop (i.e. those insects that behave similarly to the tarnished plant bug), as well as those that tend to migrate to the least-vigorously growing areas of the crop. Insecticide application prescriptions were tailored according to the behavior of the specific insect to be sprayed as specified by the field scout in the parameters of a prescription generation request form.

Each SVI prescription map was produced based on the parameters defined in the prescription request table (see **Image Processing Procedures** below). The prescriptions generated were in an ArcView Shapefile format that could be loaded into the AgLeader 170 variable rate controller on the GPS equipped sprayer for application.

Imagery and Field Data Specifications

Field Data

Field data was collected on a two-acre grid basis as described in the above hypothesis section and consisted of insect counts measured through the drop-cloth or sweep net methods recommended and routinely used by the team's entomologists. Plant physiological observations were also recorded at the sampling sites, to include plant height, number of nodes above white flower, and evidence of damage due to insect pressure. The sampling routines are detailed in the **Methodology/Field Data Collection** section below. Scout images were produced (see **Image Processing Procedures** below) and loaded into iPAQ hand-held computers for use by scouts in the field. These iPAQs were linked to GPS antennas in order to allow field scouts to reference their location in the field to a point in the digital scout map and instantly record data such as insect counts and physical plant measurements for that point. Once this data was recorded, it was e-mailed and uploaded automatically into a database. Soil, yield, and other data was provided by Dr. Hardwick's contractors who currently archive this information. Field spectroradiometer reflectance data of calibration static feature sites was collected at the beginning and end of the growing season. The field spectroradiometer data was used to facilitate calibration of the image data to percent reflectance as described in **Image Processing Procedures** below.

Image Data

This experiment relied upon airborne three-band (840nm, 695nm, 540nm, +-5 nm bandwidths) multispectral imagery flown at 2-meter resolution and captured by the ITD-Spectral Visions RDACS camera. The 1320 x 1024 pixel array captured a footprint of 2640m x 2070m on the ground (1350 acres). We also wanted to use Space Imaging's IKONOS 4-meter, four-broadband multispectral satellite imagery, however, this dataset was not available in a timely fashion, and when delivered contained clouds over much of the study area. Thus the RDACS 2-meter data was resampled to 4-meter spatial resolution in order to simulate the spatial resolution of the IKONOS data sets. The RDACS 4-meter data was then used to generate SVI prescriptions as part of the experiment. The plan was to acquire image data every 7 to 10 days. However, the data acquisition schedule was impacted, most notably from mid-July to August, by adverse weather conditions. Image turn around time needed for successful implementation of this research was within two days, from data acquisition to scout map creation and prescription generation. The eventual utilization of satellite imagery for this application is an important long-term goal but was premature for the 2001 season.

Methodology

Field Data Collection

Sampling sites were generated and established using a two-acre grid sampling design in each of the study fields. The data collected at these sampling sites were used as ground-truth to evaluate the effectiveness of SVI at Hardwick Farms, as well as to correlate NDVI classes with insect populations. The coordinates for each sample point were uploaded into GPS units. Using GPS, each sampling point was flagged and labeled with a point identification number. Once the cotton became tall enough to make it difficult to see the sample site flags, PVC pipe was used at each sample point to elevate the flags above the cotton.

The goal of the research team was to visit each one of the sampling sites in a field determined to have sufficient insect pressure to warrant a spray, and to collect pre-spray and post-spray insect count data from that SVI field and its corresponding blanket field. The determination of fields to be sprayed was made by Dr. Hardwick's private scouts as is normally done. Once a potential SVI field is identified, the LSU entomologists and a team of summer intern students guided by the LSU researchers would sample those fields by the drop cloth and sweep net methods at the flagged points. A sample at each site consisted of approximately 35 sweeps with a 15-inch diameter net or shaking several plants onto a cloth spread out under the canopy. The contents of the sweep net or drop cloth were then removed and insects were counted. There was also sampling performed with two iPAQs provided to the LSU sampling team at the beginning of the season. This sampling with the iPAQs was guided by NDVI class rather than the flagged 2-acre grid points. At each sampling point, the LSU team took four samples of insect counts and recorded indicators of insect crop damage in a four-square meter area around each point. The data was recorded as a presence or not of insects at a particular flagged point. The data recorded for the points sampled with the iPAQs was aggregated for a total insect count at that particular point.

ASD FieldSpec FR spectroradiometers were used to collect reflectance measurements at static feature sites located in the vicinity of the study fields. These reflectance measurements were taken at the beginning of the growing season (April 16, 2001) and toward the end of the growing season (August 16, 2001) to determine any significant change in their reflectance properties over the course of the season. A team of researchers involved with this study scouted the area in the vicinity of the study fields for appropriate sites. Sites were chosen based on their apparent permanency, reflective properties, and size. Static feature sites that were identified by the team included asphalt road intersections, concrete bridges, and concrete pads. Five random radiometer measurements were taken within a GPS defined area at each static feature location. The radiometer data was collected by NASA's Ground Reference Information Team (GRIT) according to the standard operating procedures established by Lockheed Martin Stennis Operations.

Harvest yield data was recorded by GPS equipped pickers with AgLeader and AgriPlan yield monitors. Dr. Hardwick and his personnel calibrated the combine's yield monitor against weigh wagons with known weights of picked cotton at the beginning of harvest season. The picker recorded yield data at 3-second intervals as the picker traveled along the rows. Yield data was recorded as an individual file for each field harvested. This yield data was exported to shapefile format by

Ouachita Fertilizer, Inc. and delivered to ITD-Spectral Visions. This yield data was used to test whether SVI applications significantly affected yield.

Image Pre-Processing Procedures

Given the farm-scale focus of this research, there were large amounts of image frames acquired to be processed for each data acquisition throughout the season. Scripts were developed to automate some of the image pre-processing procedures to facilitate the rapid turn-around time needed from image acquisition to scout map and subsequently prescription generation. A script was developed which created thumbnail jpeg format images of each frame in a dataset by extracting a single band from each frame. These thumbnails were then displayed together in a viewer so that the analyst could pick the frames which contained only the study fields of interest. The subsequent image pre-processing procedures were then performed on just those identified frames, which cut down on processing time and memory usage.

Band to band registration was performed on the imagery using one frame from the dataset which an image analyst picked based on the availability of easily identifiable control points present within that image frame. The analyst picked control points between the bands in order to register one band to another spatially. Registration was done using a polynomial quadratic equation in ERDAS Imagine. The same control points were used for all frames within a particular flightline since the band to band misregistration is the same for each frame. Once the control points were selected, an automated script was run to band to band register the specified frames which contained the experimental cotton fields. At times for a particular dataset, the control points used on previous dates of band to band registration were reused. The control points were reusable if the multispectral camera alignment had not been changed since the previous image acquisition, and the altitude of the platform remained constant. When judged to be possible, re-usage of control points helped to save processing and analyst time.

Once the image frames for each of the research fields were band to band registered, an analyst georeferenced the image frames to a USGS Digital Ortho-Photo Quarter Quad of the study site using using nearest-neighbor resampling in ERDAS Imagine. The georeferenced frames were then calibrated to percent reflectance. Calibration of the image frames was performed using the radiometer reflectance measurements collected at the static features described above in **Field Data Collection**. Vector polygons collected with GPS that defined the area of radiometer data acquisition at each static feature site were overlaid on the georeferenced image frames to facilitate precise image raw digital number extraction from those sites in the imagery. The radiometer reflectance data was then used to model the raw 8-bit digital numbers in the imagery to percent reflectance using an empirical line regression method (Moran et al., 1997).

The study fields were then masked out of their respective image frames using an automated script. This script masked out the fields of interest by using the frame number to index the file and the field name to index a corresponding field mask file that was generated at the beginning of the season. Once the frame file was georeferenced, the mask process used the mask file to turn the area surrounding the research field to a background value. The mask script also cropped the dimensions of the resulting masked file to the dimensions of the field as specified in the mask file. The result was a dataset that only contained the field of interest for each research field. The dataset was then resampled to 4-meter spatial resolution in order to simulate the spatial resolution of an IKONOS dataset. The resample script performed this function by averaging four adjacent RDACS 2-meter pixels together to transform the image data to 4-meter pixels. The resulting image data was then exported to a geotif format.

Image Processing Procedures

Once the image data was pre-processed, a script was run which generated a Normalized Difference Vegetation Index (NDVI). The formula used to calculate the NDVI was (NIR band – Red band) / (NIR band + Red band). The NDVI images were stored as floating-point ESRI Grid raster files. The raw NDVI Grid files were classified according to several different classification schemes depending on the needs of the field scouts and crop growth stage. The 10 and 12-class classification schemes represented the crop variability as seen by the scout very well until mid-July when canopy closure occurred. Once the crop reached canopy closure, the NDVI classifications became too homogenous and were not useful to the field scout. The 5-class equal area classification was created as a result of the increasing crop uniformity (figure 2). An ArcPad project and related set of files were created for each classified NDVI dataset to allow insect scouting and prescription requests. These files were zipped, e-mailed to a computer at the farm, and loaded on GPS-equipped hand-held computers (Compaq iPAQ) for scouting. The following files were included for each date of image acquisition:

1. **Season-adjusted NDVI Image**. The classes were standardized to reflect ranges of NDVI values for the season and fields could be compared throughout the season with each other as whole farm statistics were used in calculating the classification. A 12-class map was used until canopy closure occurred around mid-July, after that a 16-class map was used as an increased classification sensitivity was needed to show crop vigor variability that became increasingly uniform.

2. **NDVI Change Image**. This delineated positive and negative vegetation change from date to date of image acquisition. For this product, the raw NDVI of a specified date is subtracted from a current NDVI date. The difference image was divided into 10 fixed classes. Classes 1 – 4 represented negative change (with 4 being slight and 1 severe) while classes 5 – 10 represented positive change (with 5 being slight and 10 being proportionately greater change).
3. **MaxView NDVI Image**. Originally this was a 10-class equal area classification using global statistics. This was not deemed useful by the field scouts and a 5-class equal area image based on the within field statistics for the date of imagery was tested. The 5-class did a good job of enhancing the within field differences as observed by the field scouts, and thus was adopted as the MaxView NDVI image product generated for the remainder of the season.
4. **Hardcopy maps** of the above. These were created as JPEG format images and displayed the multispectral composite image and the selected NDVI for each field.
5. **Prescription Request Table**. This table allowed the user to create variable-rate prescription based on the NDVI images described above. All parameters needed to create a prescription were included in this table. Some of the columns in the table were preset (crop, application type, etc), and the rest of the parameters were set in the field by the scout. The prescription was based on the Season-Adjusted NDVI, the Change map or the MaxView map. Chemical rates were set by the scout or the producer for each of the classes in the chosen index.
6. **Scouting GoTo Points**. These were empty point shapefiles that were available for the scouts to use in a random stratified sampling scheme according to NDVI class. The scouts using the iPAQs for sampling could generate sampling points in these empty shapefiles. Crop physiological information as well as insect names and counts could be recorded for each chosen sampling point.

After the fields were scouted, the scout files were copied from the iPAQ to the hard drive of the computer at the farm. Software developed by ITD-Spectral Visions was used to display the scouting GoTo files and send them to ITD-Spectral Visions via e-mail or ftp. This software was also used to request prescriptions as needed through an edited Prescription Request Table. Prescription settings were made for one or more fields for a particular date, and that request was sent to ITD-Spectral Visions via e-mail or ftp as well. The software continually monitored the e-mail or ftp site. The prescription shapefiles and controller files were automatically generated based on the edited parameters when a prescription request table was received. The output files were automatically zipped and sent back to the farm via e-mail.

The prescriptions were based on the map values at the center of the sprayer as it moved along the rows. To insure that the prescription was applied correctly, a new map was needed based on the physical characteristics of the spray rig and controller. The mapping unit was a rectangle with a width that was equal to the width of the spray boom and a depth which depended upon how quickly the spray boom could respond to changes in the application rate. Based on the controllers used in this SVI research, it was shown that a 20-foot depth was determined to be the shortest practical distance. A polygon shapefile was created for each field and for each spray boom width used. This shapefile was then overlaid onto the field boundaries, rotated to match the row orientation, and then moved in the XY direction to line up with the edge of the field. This spray grid approximates the movement of the sprayer in the field.

A copy was made of each spray grid shapefile. A column representing the application rate was added to each shapefile's table. The spray grid was then overlaid onto the rate map image. Based on the user-specified statistic, a rate was calculated for each spray grid cell. For SVI, which either sprays the full amount or doesn't spray, that statistic was a threshold percentage. A 20% threshold was chosen, thus if 20% or more of the pixels under the spray grid cell were set for spray, then the cell was set to the ”on” rate. If not, then the spray grid cell was set to the zero rate. If the application was to be variable rate, then the statistic could be the mean, minimum, maximum, median, minority, or majority of the pixels under that cell. Figure 3 illustrates the prescription generation process for one particular SVI field.

The SVI prescriptions generated were copied onto a PCMCIA card and then loaded into the AgLeader 170 controller in the sprayer for application. As-applied data files that contained actual rate and spatial distribution of chemical applied information were produced coincident with insecticide application and written to a PCMCIA card for download. These as-applied files were used to verify the accuracy of the insecticide application according to the prescription.

Statistical Analysis

The statistical analysis of the yield data after harvest was performed on the average yield per acre of seed cotton for each field in the study. The GLM procedure in SAS (Cody et al., 1997) was used to test for any significant differences in yield between the SVI and blanket fields. The yield data was compared between treatments with 4 observations of the SVI application and 6 observations of the blanket application (there were 6 blanket observations because Field 15S had no SVI applications this season, but did have a blanket aerial application due to the inability to get into this field with the ground-based sprayer given adverse conditions). The yield data analysis results were factored into the economic analysis performed for this study.

Statistical analysis of the insect sampling data was performed to determine effectiveness of SVI applications in significantly reducing insect presence for each application. Pre-spray insect sampling data was compared to post-spray insect sampling data for each SVI event. Pre-spray sampling data was defined as the closest sampling dataset collected prior to a particular SVI application, and the post-spray sampling dataset was that which was collected closest following a particular SVI application. The insect sampling data was recorded at each 2-acre flagged point as either a presence or absence of insects. Insect presence was determined by finding actual insects or indications of damage to the cotton from insect presence. Given the categorical nature of the sampling data (presence or not), a non-parametric statistical test (Wilcoxon rank-sum test) was used to perform the analysis of variance. A parametric t-test was not used because our datasets did not meet the assumptions of a t-test, namely that the distribution of sampling means must be normally distributed. Nonparametric tests do not assume a normal distribution of the data and are often more appropriate for very small sample sizes (Cody, 1997). We used the Wilcoxon rank-sum nonparametric test to analyze the data for significant differences in SAS. "The Wilcoxon test is almost as powerful as its parametric equivalent, the t-test", and "if there is a question concerning distributions or if the data are really ordinal, you should not hesitate to use the Wilcoxon test instead of the t-test" (Cody, 1997).

It should be noted when considering the results of this analysis that insect sampling did not necessarily coincide closely with the actual SVI event. In one instance the flagged grid points were not sampled for 17 days prior to SVI application, and there was not a post-sampling for 8 days after another SVI application. At other times, however, the insect sampling occurred within 1 day prior and 3 days after an SVI event. In an ideal situation, the sampling would occur consistently within a couple of days of an SVI application. Practically, however, this was not possible due to prolonged rain events which occurred during the latter part of July which kept the LSU sampling teams out of the fields, and also irrigation timing which sometimes fell immediately after an SVI application for a particular field. At times, even crop-dusting of insecticide in adjacent fields at the time immediately prior to or following an SVI for a particular field kept the sampling team from entering that field in a timely manner.

Results

The results from the analysis of variance performed on the field radiometer data collected at the static feature sites used for the calibration of the image data determined that there was significant change in the reflectance of those sites over the course of the season. A repeated measures analysis was performed on the bands of radiometer reflectance data from April 16th and August 16th which corresponded to the RDACS multispectral bands for each of the 5 static feature locations. The resulting p-values were significant at <0.0001. Change maps produced throughout the season that utilized calibrated imagery from one date to compare with another in order to show relative vegetation vigor change were accurate in showing the time of 'crop cutout' (a crop growth stage in which the maximum growth of the crop is experienced, and it starts to decline toward senescence) as verified by the producer. This crop phenomenon that showed up in the change maps created from the calibrated images reinforced confidence in the calibration technique used.

There were relatively low insect pressures at Hardwick Farms this season, however, there was sufficient insect populations to warrant five SVI applications with corresponding blanket insecticide applications in the study area (Leonard, 2001). The SVI applications occurred on three separate dates, and are reported in table 1.

The results of the analysis of variance for the yield data between the SVI and blanket application fields showed no statistical significant difference existed. The p-value for the model was 0.7824. Summary statistics for each treatment are shown in table 2. These results indicate that there is no significant loss of yield to a producer who utilizes SVI as opposed to the traditional blanket method of insecticide application. It is interesting to note that when only each respective SVI and blanket experimental field pair is considered, the SVI treatment field had higher yields (though not determined to be statistically significantly higher in the overall model) than the respective blanket application field in every instance (table 3). One possible reason for this yield difference that has been suggested is that SVI may leave more beneficial insects than the blanket applied fields. These beneficial insects would naturally help the crop by consuming harmful pests continuously over the course of the season.

The yield data from fields 12 and 13 were much lower than that for the other fields in this study. One reason for this reduction in yield is that these fields were not irrigated, the other fields in this study were. Another yield data result of note was that the field pair that did not receive an SVI application this season had identical average yields.

SVI fields 13 and 43 were used to test the effectiveness hypothesis. These fields were chosen because of the timely insect sampling data that was recorded there. The July 17th SVI pre-spray sampling occurred on July 12th and the post-spray sampling on July 20th for field 43, and on July 16th and July 20th respectively for field 13. Insect sampling that occurs within 5 days of an insecticide treatment was judged to be representative of the insect population condition of a particular field before an insecticide application and representative of the insect population as was affected after an insecticide application (Willers, 2001). The results of the nonparametric analysis of variance tests on the pre and post-spray insect count datasets showed no statistically significant difference in the presence of insects for either field. The p-value for the one-sided Wilcoxon test was 0.24 for field 43, and a 0.29 for field 13.

An analysis was also performed on the insect sampling data in order to determine any correlations with the raw NDVI values calculated from the imagery. This analysis was meant to support the assumptions made in this research by the associated entomologists which the study attempted to build upon. The analysis included the flagged grid point insect sampling data. The proportion of insect occurrences on a particular sampling date within an NDVI class was determined in order to fairly incorporate differences in total insects between fields and between days. The raw NDVI values were rounded to the nearest 0.05, and a 10-meter grid was overlaid on the raw NDVI values to compare insect occurrences at a particular scouting location. Proportions of insects found were computed as the count of insects, and was divided by the number of samplings in a particular field for a particular date and NDVI class. This data preparation methodology allowed for normalization between different dates and fields.

An index was then created by dividing the probability of insects occurring in a particular NDVI class location by the proportion of area for that NDVI class for a given field and date (figure 4). For example, if on June 19th there was 50% raw NDVI 0.2 and 50% raw NDVI 0.3 available to the insects then the probability of insects found on NDVI 0.2 is divided by 0.5. This index showed whether insects are preferentially found in higher NDVI ranges, or are simply found in the most common NDVI ranges for a particular field. An NDVI ranking was also created where the NDVI values were ranked from 1 to n where 1 was the lowest NDVI value. This ranking was performed in order to allow for differences in NDVI values found on different dates (figure 5). The analysis of 'index' and ranked NDVI value resulted in a model that was significant ($p=0.0001$) with a coefficient of determination of 0.34.

Economic Analysis

This analysis summarizes the economic comparison of SVI and blanket application of insecticides conducted on the Hardwick farm in 2001. The original experiment design included a total of 10 fields designated as either SVI or blanket treatment. Table 4 shows the yields obtained from the test as seed cotton, lint cotton, and cotton seed. As shown here, the SVI fields yielded about forty pounds more lint per acre than the SVI fields. All the fields receiving SVI applications had higher yields. Field 15S, while designated as an SVI field, received no SVI application and had the same yield as field 15N.

The yield differential experienced in 2001 accounted for approximately $23.46 more revenue from lint per acre for the SVI fields. In addition, the extra seed would contribute an additional $3.30 per acre for the SVI fields. These estimates are based on the previous five year average price for cotton lint in Louisiana of $0.5722 per pound and a seed price of $100 per ton.

Insecticide and application costs were also different between SVI and blanket treated fields. Table 5 shows the total number of applications received by each field and the associated costs. Overall, the SVI fields averaged about $2.11 per acre less in insecticide and application costs than the blanket fields. This saving resulted from applying less total insecticide per acre on the SVI fields. On average, the SVI fields had a 65% coverage rate compared to a 100% coverage rate for the blanket treated fields. This means that, on average, insecticide costs for the SVI fields were 65% of those for the blanket treated fields. These data are based only on fields receiving SVI applications. Field 15S did not receive SVI applications.

Table 6 shows the as-applied information for the SVI fields. A total of five SVI applications were made during the season to the fields as indicted in Table 6. As shown here, SVI fields averaged about 65 percent coverage for those fields receiving SVI applications. Note that field 15S, a designated SVI field, did not receive SVI applications and is not included in this table.

Cost comparisons for the conventional and SVI applications are shown in Table 7. The cost comparison is shown including the insecticide Baythroid, assuming 100 percent coverage per acre. The important numbers in Table 7 are the application costs. As shown here, it was assumed that conventional applications would be done by air at a cost of $2.50 per acre. SVI applications are assumed to be applied by a self-propelled sprayer with a per acre cost of $1.56. If conventional applications were made with a similar sprayer, the per acre cost was estimated to be approximately $1.33 per acre. This lower cost is the result of a lower initial cost because the sprayer does not need modification or extra equipment to apply SVI and the machine can cover more acres per hour than the SVI equipped machine. Material costs assumed for this comparison are: Bidrin $89.00/gal; Baythroid, $330/gal; Malathion ULV, $28.50/gal; and Acephate, $9.20/lb.

In summary, the comparison of SVI and blanket application of insecticides indicated that SVI applications were, on average, \$2.11 less than the blanket applications. In addition, yield differences between the two treatments accounted for a \$26.76 increase in revenue for the SVI fields compared to the blanket treated fields. Since most fields in the SVI treatment only received one SVI application, these are conservative estimates of the potential benefit of SVI applications. The implication is that if all SVI fields had received only SVI applications, insecticide costs could have been reduced by approximately 35% compared to conventional blanket application of insecticide.

Note that conventional application assumes airplane used to apply insecticide. SVI utilizes self-propelled sprayer with 90 foot boom. The assumed price for the sprayer is \$185,000. The price included an allowance for modifications to permit SVI applications. Imagery costs of \$1 per acre are consistent with estimated image-based products as reported in consultation with DigitalGlobe, Inc. personnel (Knobloch, 2001). Fuel consumption is estimated to be 11.71 per hour at a cost of \$1.10 per gallon. Labor costs are included at \$12.00 per hour. Other costs included are repairs and maintenance as well as allowances for fixed costs (depreciation, insurance, interest on investment etc.).

Conclusions

Based on the yield data results, there is no negative impact to a producer's yield from SVI applications. This yield data analysis result is consistent with previous SVI research results at Perthshire Farms in Mississippi. These consistent results are promising in that the 2000 season was exceptionally dry, while the 2001 season experienced normal to wet weather conditions. The consistent yield results of SVI over two very different growing season environments suggest the possible robust nature of SVI applications with regard to yield.

The results of the effectiveness analysis showed that there was no significant reduction in the insect presence following an SVI event for the two fields tested. However, this result may be due to dynamic environmental conditions existing by the time the post-sampling was performed. The crop canopy reached the critical closure stage between the time of pre and post sampling for the SVI application that occurred on the 17th of July. The mostly uniform distribution of crop vigor and availability of the abundant attractive food source for insects during this time of dynamic crop growth may have encouraged a rapid repopulation of insects before the post-spray sampling was performed. Willers et al., (1999b) showed that sampling prior to canopy closure should be approached much differently than following canopy closure in that the insects typically respond differently to the changing field conditions.

The economic analysis performed by Dr. Paxton showed a cost savings of approximately 35% in using SVI as opposed to traditional blanket applications of insecticide throughout a typical growing season. The comparison of SVI and blanket application of insecticides indicated that SVI applications were, on average, \$2.11 less than the blanket applications. This savings includes image cost estimates provided by an image-data service provider. These results demonstrate the potential economic benefit to a producer when SVI is incorporated into a farm management system. Also of note is that economic gain can be realized by the producer with SVI while reducing the impact of excess insecticide runoff to the surrounding environment.

Based on the analyses to determine the relationship between insects and NDVI values, there was a slight tendency for insects to choose higher relative NDVI values early in the season. This tendency shows up in the time period prior to canopy closure (mid-July for this past season). After canopy closure there was not enough difference in raw NDVI values for an analysis to be performed. The fact that NDVI variability within the study fields became so uniform after canopy closure indicates that perhaps another vegetation index that may be more sensitive to the variability that exists may be appropriate after that time.

Future Work Recommendations

There are some recommendations for subsequent work based on the experiences of this year's study. These recommendations are as follows:

1. Given the weaker than expected correlation found with insect presence and NDVI values, any future work should incorporate a study site where the focus on testing the ability of processed imagery to relate indirectly to insect populations in cotton through crop vigor variations. The SVI method may still be tested in separate locations, but the site identified to test insect population correlations with imagery should be subjected to the typical farming practices of the area. This site should also be small enough to allow for intensive and continuous sampling, while at the same time be large enough to allow for the recognition and subsequent observation of normal insect distribution and dispersion patterns across a crop.

2. In determining the ability of the imagery to relate to insect populations within a field, other vegetation indexes than NDVI should be tested at various growth stages of the crop, to definitely include pre and post canopy closure.
3. Future SVI work should incorporate a field, or fields, with much greater historical variability (that being variability in topography, soils, and residual N content).
4. Weather is always unpredictable, as we experienced with this year's study. We understand that Dr. Hardwick has a responsibility of crop maintenance and maximizing profits for his farm. With this understanding, we must also have assurances that the research will not be compromised to maximize the cooperating producer's yields. The solution may be to have a document stating the risks involved with the research which all involved parties would sign, including the producer. That would ensure that all involved parties would know what was expected of them up front before the experiment was implemented. Perhaps also, arrangements would be agreed upon and made to compensate the producer, to some degree, for any yield loss due to the experiment.
5. Future SVI research should consider the reduction of acreage included in the study in order to arrive at a more manageable study area. This reduced size would allow for more efficient sampling and reduce the chance of producer intervention due to unforeseen circumstances arising from such things as adverse weather conditions and necessity for rapid insecticide applications.
6. Another recommendation is that there be flexibility in choosing a study site. There should be several alternate sites identified in advance of the research in the event that no insect pressures appear at the primary study site. Because of the uncontrollable nature of insects, there is no guarantee that a particular chosen site will have sufficient insect pressures to warrant an SVI study for a given season. The chances of experiencing a significant insect infestation for future SVI research is greatly enhanced with the flexibility to establish the study area where early season indicators point to sufficient insect populations being present.

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References

Bagwell, Ralph. Personal Communication, Louisiana State University Agricultural Research Center, Winnsboro, LA (2000).

Carter, Greg. Personal Communication, NASA, Earth Science Enterprise Office, Stennis Space Center, MS (2000).

Chapelle, E., M. Kim, and J. McMurtrey, Ratio Analysis of Reflectance (RARS): "An algorithm for the Remote Estimation of the Concentrations of Chlorophyll A, Chlorophyll B,, and Carotenoids in Soybean Leaves", Remote Sensing of the Environment, 39:239-247 (1992).

Cody, Ronald P. and Jeffrey K. Smith. "Applied Statistics and the SAS Programming Language". Prentice Hall, Inc. New Jersey. Pp. 140-144 (1997).

Dupont, J.K., J.L. Willers, R. Campanella, M.R. Seal and K.B. Hood. "Spatially Variable Insecticide Applications Through Remote Sensing". *Proceedings of the Beltwide Cotton Conference*, vol. 1: pp. 426-429 (2000).

Gat, N., Erives, H., Maas, S.J., and Fitzgerald, G.J. Application of low altitude AVIRIS imagery of agricultural fields in the San Joaquin Valley, CA, to precision farming. Proc. 1999 Airborne Geoscience Workshop, Pasadena, CA. (1999).

Fitzgerald, G.J., Maas, S.J., and DeTar, W.R. Multispectral multitemporal remote sensing for spider mite detection in cotton. Proc., 5th International Conf. on Precision Agric., Bloomington, MN. (2000).

Fitzgerald, G.J., S.J. Maas, and W.R. DeTar. “Early Detection of Spider Mites in Cotton Using Multispectral Remote Sensing”, Proceedings of the Beltwide Cotton Conference, Volume 2:1022-1024 (1999).

Hardwick, Jay. Personal Communication, Hardwick Farms, Newellton, LA (2000).

Hood, Kenneth. Personal Communication, Perthshire Farms, Gunnison, MS (2000).

Knoblauch, Greg. Personal Communication, DigitalGlobe, Inc., Longmont, CO (2001).

Moran, M. S., T. R. Clarke, J. Qi, E. M. Barnes, and P. J. Pinter Jr. “Practical Techniques for Conversion of Airborne Imagery to Reflectances”. *Proceedings of the 16th Biennial Workshop on Videography and Color Photography in Resource Assessment*. 82-95 (1997).

Leonard, Roger. Personal Communication, Louisiana State University Agricultural Research Center, Winnsboro, LA (2001).

Parker, C.D., R.G. Luttrell, and F.A. Harris. “Evaluating Insect Management Strategies Using Yield Mapping”, *Proceedings of the Beltwide Cotton Conference*, Volume 2:1128-1132 (1999).

Paxton, Kenneth. Personal Communication, LSU Department of Ag Economics, Baton Rouge, LA (2001).

Riley, J.R. “Remote Sensing in Entomology”, Annual Review of Entomology, Volume 34:247-71 (1989).

Robbins, J.T., F.A. Harris, and R.E. Furr. “Tarnished Plant Bug and Boll Weevil Control Trails in the Mississippi Delta”, *Proceedings of the Beltwide Cotton Conference*, Volume 2:901-904 (1999).

Smith, J.K. and Wiygul, G. “Activities of the Mississippi boll weevil geographic information system and satellite imagery”, *Proceedings of the Beltwide Cotton Conference*, Volume 2:994-995 (1997).

Spectral Visions. *Spectral Visions’ 2000 Year End Report to NASA’s Geospace Applications and Development Directorate*. NASA Commercial Applications Technical Collaboration Cooperative Agreement #NCC13-00001. 10-21 (2000).

Summy, K.R., J.H. Everitt, W.G. Hart, D.E. Escobar, and M.R. Davis. “Applications of Remote Sensing Technology in Cotton Pest Management”, *Proceedings of the Beltwide Cotton Conference* (1989).

Willers, J.L. Personal Communication, USDA-ARS, Mississippi State University, Starkville, MS (2001).,

Willers, J.L., M.R. Seal, and Randall G. Luttrell. “Remote Sensing, Line-Intercept Sampling for Tarnished Plant Bugs (Heteroptera: Miridae) in Mid-South Cotton”, The Journal of Cotton Science, Volume 3:160-170 (1999a).

Willers, J.L., D.C. Atkins, M.R. Seal, and R.G. Luttrell. “Sampling for Plant Bugs (Heteroptera: Miridea) in Cotton Prior to Canopy Closure: Applications of Line-Intercept Sampling and Remote Sensing”, *The Journal of Cotton Science* (1999b).

Willers, Jeffrey L. “Perspectives on Sampling for *LYGUS* in Cotton: Applications of Quadrant-Based Sampling Schemes”, *Proceedings of the Beltwide Cotton Conference*, Volume 2:928-933 (1998).

Table 1. Fields and dates of SVI applications at Hardwick Farms in 2001.

Date of SVI	Fields	Image Date Used for Prescription
July 17th	13, 43	July 11th
August 6th	97N, 98S	August 2nd
August 8th	43	August 2nd

Table 2. Yield (in average lbs/acre of seed cotton) summary statistics for treatments.

Treatment	N	Mean	Standard Deviation	Minimum	Maximum
SVI	4	2107	529	1335	2475
Blanket	6	2024	394	1246	2378

Table 3. Average seed cotton yield/acre for each treatment field.

Field ID	TRT	Yield in average lbs/acre
F15N	Blanket	2151
F15S	Blanket	2151
F12	Blanket	1246
F13	SVI	1335
F44	Blanket	2090
F43	SVI	2425
F97S	Blanket	2127
F97N	SVI	2192
F98N	Blanket	2378
F98S	SVI	2475

Table 4. Cotton Yield, by Field, Hardwick Farm, 2001.

Field No.	Type	Seedcotton Yield (#/ac)	Lint (#/ac)	Cotton Seed #/ac
15N	Blanket	2151	753	1205
97S	Blanket	2127	744	1191
98N	Blanket	2378	832	1332
12	Blanket	1246	436	698
44	Blanket	2090	732	1171
Average			700	1119
15S	SVI	2151	753	1205
97N	SVI	2192	767	1228
98S	SVI	2475	866	1386
13	SVI	1335	468	749
43	SVI	2425	850	1360
Average			741	1185

Table 5. Insecticide and Application Costs, Blanket and SVI Fields, Hardwick Farm, 2001.

Field No.	Type	Number of Applications*	Application Cost	Insecticide Material Cost ($/ac)	Total Cost ($/ac)
15N	Blanket	6	15	27.88	42.88
97S	Blanket	6	15	25.45	40.45
98N	Blanket	6	15	25.45	40.45
12	Blanket	3	7.5	12.13	19.63
44	Blanket	3	7.5	12.13	19.63
Average					$32.61
15S**	SVI	6(0)	15	27.88	42.88
97N	SVI	6(1)	14.06	23.92	37.98
98S	SVI	6(1)	14.06	23.92	38.76
13	SVI	3(1)	6.56	10.78	17.34
43	SVI	3(2)	5.62	9.93	15.55
Average					$30.50

* The number of SVI applications made to each field are shown in parenthesis.

** No SVI applications were made to this field, only blanket applications were made, but it is included here because it was originally designated as an SVI field.

Table 6. SVI Applications, Hardwick Farm, 2001.

Field	application date	Field Size	Area Treated	Area Untreated	% Treated	% Untreated
			Acres			
13	17-Jul	65.4	48.23	17.2	73.75%	26.25%
43	17-Jul	70.3	47.82	22.5	68.02%	31.98%
43	8-Aug	70.3	55.15	15.2	78.45%	21.55%
97N	6-Aug	72.4	42.56	29.8	58.78%	41.22%
98S	6-Aug	54.9	23.51	31.4	42.82%	57.18%

Table 7. Comparison of Conventional and SVI Application Costs Per Acre.

Item	Conventional	SVI
Insecticide Material (Baythroid)	$ 4.38	$ 4.38
Application	2.50	1.56
Imagery	0.00	1.00
Service Consultant	0.00	0.16
Total	$6.88	$ 7.10

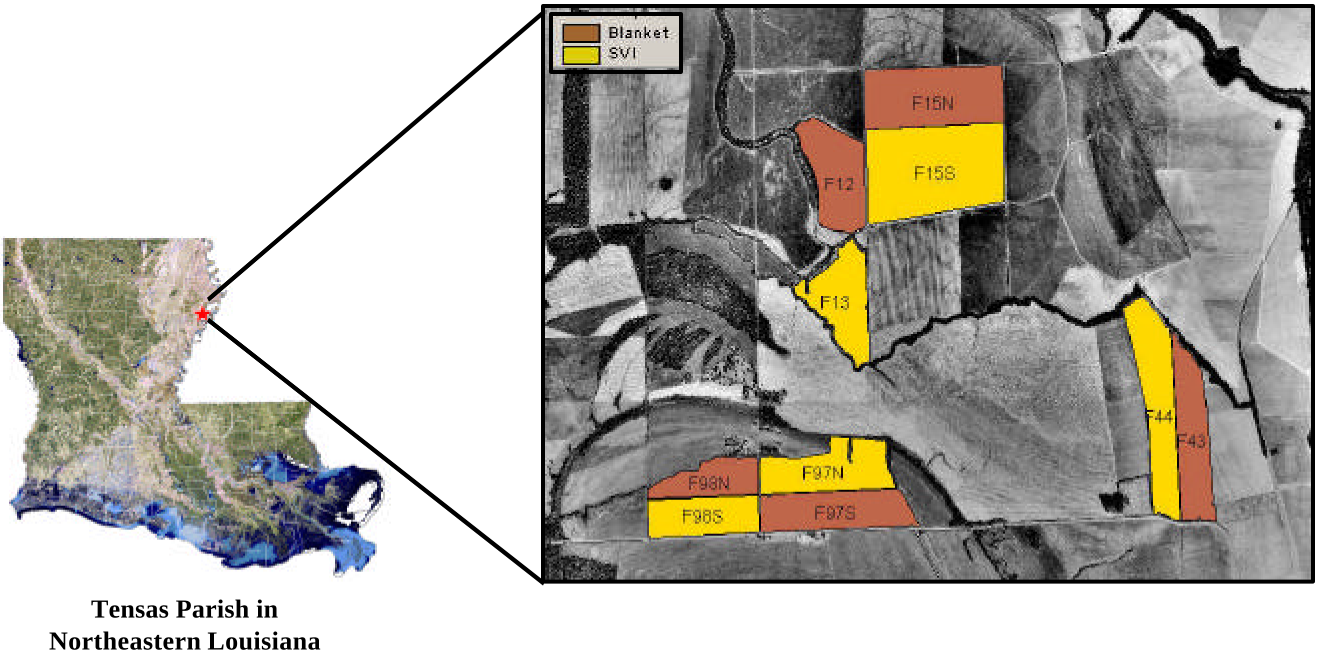
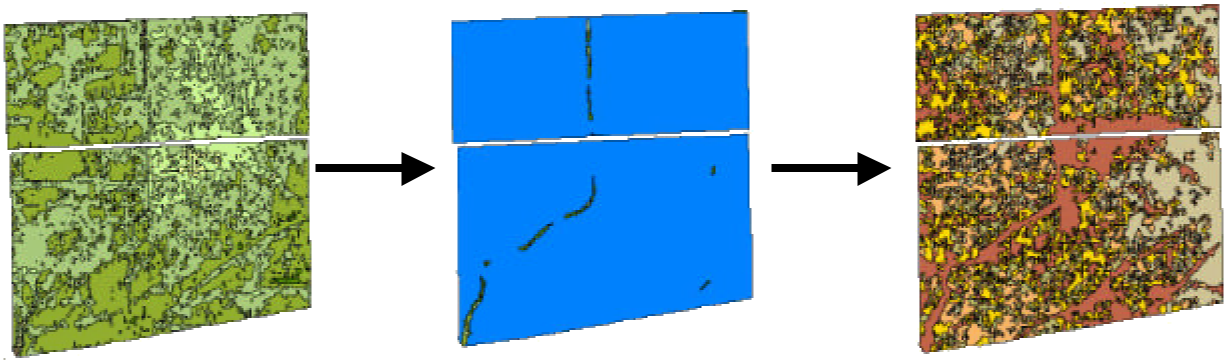


Figure 1. Hardwick Farms SVI 2001 Study Area Map.

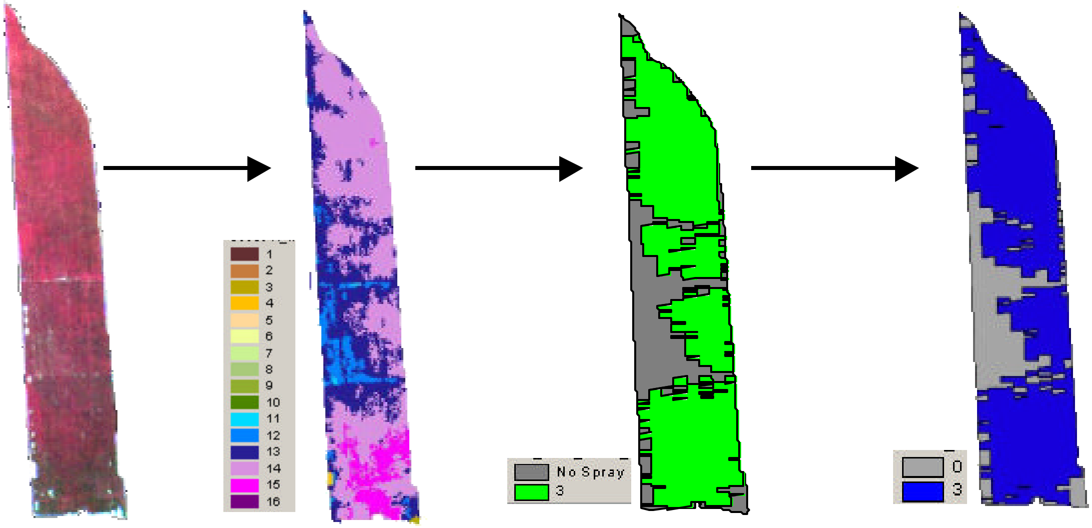


10 class NDVI classification of Field 15 from 06/17/01 image data

12 class NDVI classification of Field 15 from 07/15/01 image data

5 class equal-area NDVI classification of Field 15 from 07/15/01 image data

Figure 2. Various NDVI classification schemes used for scout files in determining the best approach with changing crop canopy conditions for SVI research at Hardwick Farms in 2001.



Multispectral composite image acquired on 08/02/01

NDVI classification produced from the composite image

Prescription map generated according to the field scout's parameters

As-applied map generated by the controller in the sprayer

Figure 3. Prescription generation and SVI application for Field 43 on 8/06/01 resulting in 71% of this field being sprayed.

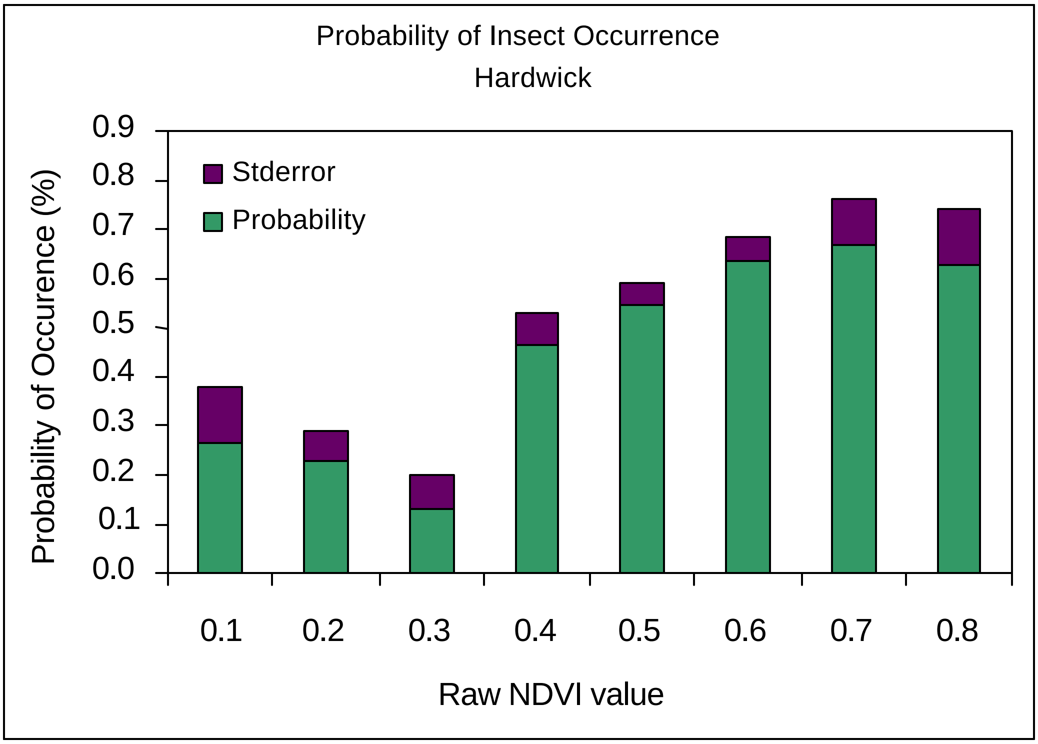


Figure 4. Probability of insect occurrence and raw NDVI value.

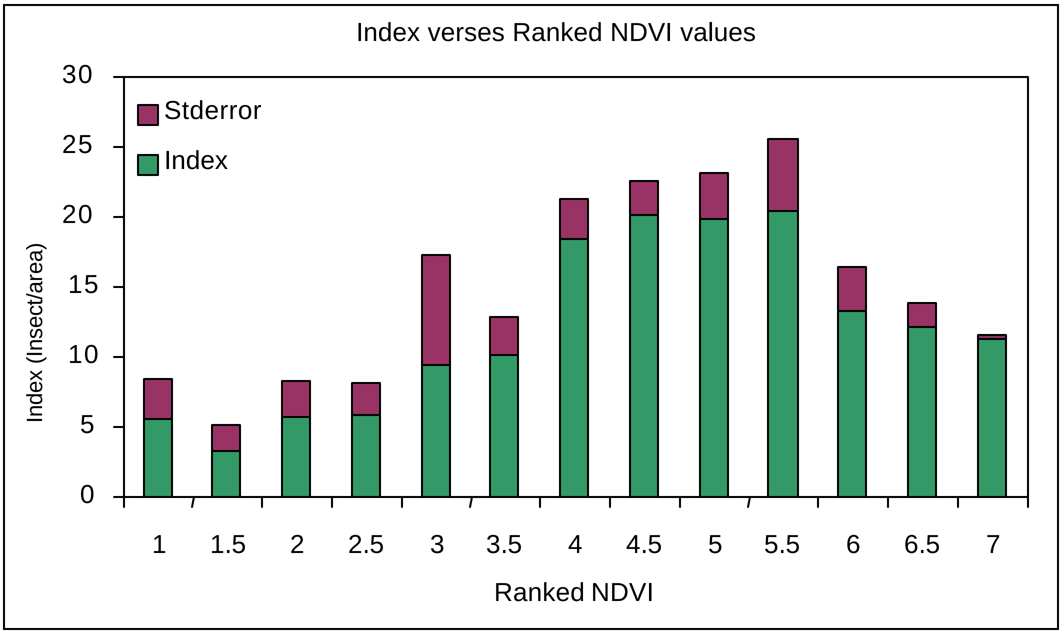


Figure 5. Probability of index and ranked NDVI value.