UTILIZATION OF REMOTE SENSING TECHNOLOGIES IN THE DEVELOPMENT AND IMPLEMENTATION OF LARGE-SCALE SPATIALLY-VARIABLE INSECTICIDE EXPERIMENTS IN COTTON

Michael R. Seal, Kelly Dupont, Matthew Bethel, David Lewis and Jim Johnson
Institute For Technology Development, Spectral Visions
Stennis Space Center, MS
Jeffrey L. Willers
Genetics and Precision Agriculture Research Unit
USDA-ARS
Mississippi State University, MS
Kenneth Hood
Perthshire Farms
Gunnison, MS
Jay Hardwick
Hardwick Farms
Newellton, LA
Roger Leonard and Ralph Bagwell
Louisiana Agricultural Experiment Station
Louisiana State University, LA

Abstract

The Institute for Technology Development, Spectral Visions supports NASA's Commercial Remote Sensing Program, located at John C. Stennis Space Center in Mississippi, in various areas of agricultural research. During the 1999 growing season, Spectral Visions worked with USDA-ARS researchers and Perthshire Farms to conduct a large-scale spatially-variable insecticide (SVI) research experiment on 1023 acres of cotton in the Mississippi Delta. This experiment was designed to explore the role of remote sensing technology in precision farming to help improve profits and reduce chemical application costs by applying insecticides more efficiently throughout the field. Pesticide applications are one of the greatest costs incurred by a cotton producer. Past research suggests that vibrant cotton plants, as indicated by remotely sensed imagery, provide ideal habitat and are often infested by the tarnished plant bug (*Heteroptera: Miridae*). In addition, the plant bugs tend to infest cotton plants that are producing first squares and radiate outward as the cotton plants mature and increase in squaring rates. This research utilizes remotely sensed imagery to help identify vibrant cotton plants within a field, produce a SVI prescription (spray-ON or spray-OFF), and apply the prescription through GPS-controlled spray-rig equipment. The 1999 Perthshire Farms experiment resulted in five SVI applications with a 30-40% average reduction of insecticide applied and no negative impacts on yield. In building upon the 1999 results, the team designed a 2050-acre SVI experiment for the 2000 growing season at Perthshire Farms. The results of the Perthshire Farms experiments will be detailed in the following paper. In attempts to replicate this experiment on different geographical locations within the U.S. cotton-belt, a 1000-acre SVI experiment was attempted this year at Hardwick Farms in Newellton, LA. Both experiments utilized SVI and blanket-application fields ranging from 10-200 acres to further test the effectiveness of remote sensing technology to help improve profits through more efficient application of insecticides. However, low plant bug counts at Hardwick Farms negated the SVI experiment during the 2000 season. Even though no actual SVI experiments were conducted at Hardwick Farms, the implementation of the methodology, partnerships formed with the LSU research station scientists, and practical experiences gained will be invaluable for a successful implementation of a 2001 large-scale SVI experiment. The team also began studying spatial relationships within other cotton pests in addition to the tarnished plant bug. Development and implementation of these large-scale experiments produced many challenges throughout the season. These included efficient field scouting and sampling, timeliness of imagery collection, delivery, and turnaround, SVI development and application of prescriptions, GPS and controller communication problems, lead and lag times associated with product mixing and boom application, collection of yield data at harvest, and analysis of results.

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1010-1018 (2001)
National Cotton Council, Memphis TN

Introduction

Plant bugs are one of the most damaging insects to cotton production, infesting over 6 million acres and causing over $71 million in losses nation wide in 1998 (Williams 1999). Therefore, there is considerable cause to seek methods to help control yield losses. The tarnished plant bug feeds on developing squares and the stems of young plants (Ferreira 1979), resulting in hundreds of thousands of bales lost every year. Working on a farm in the Mississippi delta, USDA entomologists and ITD-Spectral Visions are exploring the use of remote sensing to identify areas likely to be infested with plant bugs, and creating spatially variable prescriptions to guide a GPS equipped ground sprayer. Beginning in 1997, ITD began providing entomologists with 3-band multispectral images captured using an RDACS camera system (Mao and Kettler 1995). Using these images in scouting efforts, patterns in the occurrence of insects in different states of crop development were observed (Willers et al., 1999). Multispectral imagery fitted with narrow-wavelength filters and processed with vegetation indices such as an NDVI (Normalized Difference Vegetation Index) can easily reflect different levels of crop vigor. By harvest 1998, we were convinced that there was tremendous potential to decrease insecticide cost to the farmer through spatially variable insecticide (SVI) applications. During the 1999 growing season, an experiment (covering 1023 acres) was conducted to test the hypothesis that plant bug infestations can be targeted and prescription maps can be developed to spray only those areas determined infested as an alternative to blanket spraying.

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 plant bug, 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 the plant bug 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. Current research in cotton insect management by Craig Kvien at the University of Georgia includes looking at sensor technologies for variable-rate insecticide, plant-growth regulator, and nitrogen. Other related research is being conducted by Nahum Gat of Opto-Knowledge Systems, who is researching hyperspectral imaging for insect-infestations in western cotton. Perhaps the most thorough basic research for remote sensing in cotton insect management has been done by Stephen J. Maas of the USDA-ARS, who has examined 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. Summy, et al (1998) 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, 1996). A similar prototype was developed by Jim Johnson of ITD-Spectral Visions for boll weevil eradication in Oklahoma in 1998.

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. Likewise, insecticide comparisons have been conducted, but not in the context of spatially variable application through remote sensing. The efficacy of various commercial insecticides against tarnished plant bugs, such as Orthene®, Vydate®, Baythroid®, and Provado® was reviewed by Robbins, et al (1999). These insecticides can be applied in the same spatially variable manner as described in this experiment. Upon careful review of the literature, we realized an opportunity to conduct groundbreaking applied experimentation in Spatially Variable Insecticide that may have a positive effect on both Southern cotton producers and the remote sensing industry.

Background

This experiment is a continuation of our spatially variable insecticide (SVI) work at Mr. Kenneth Hood's Perthshire Farms in 1999. The project is based on the concept that cotton insect pests respond to differences in crop phenology. Remote sensing imagery maps these differences in crop growth and development, facilitating on-the-ground scouting efforts that determine which areas of the field (or fields) need to be treated by pesticides to prevent economic loss to production. For example, tarnished plant bugs (*Lygus lineolaris*) are drawn to fast-growing, vibrant cotton. Remotely sensed imagery identifies these areas and provides a template 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. (1999), 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. Preliminary results indicate a potential for about 40% savings in insecticide costs compared to traditional blanket application (Dupont et al., 2000; Seal, 1999). Extensive scouting data are available to suggest that spatially variable sprays (including variations in the rate) were as effective in controlling pest populations of interest (namely, the tarnished plant bug) as broadcast sprays. The results from 1999 also suggest that SVI applications by ground and blanket sprays by air can be used concomitantly (i.e., SVI by ground cannot be accomplished due to recent rains and pest populations are present at economically damaging levels so application by air is warranted). Research is needed, however, to fully develop recommendations to determine which approach to use and in what combination. Due to limited resources in 1999, field data regarding yield maintenance (in both the SVI and neighboring blanket fields) was limited to about 32 test points. The analysis of these results suggest no loss in yield due to usage of SVI applications, or combination, compared to fields that were managed exclusively by broadcast applications. In 2000, we seek to expand this research—in terms of test points and acreage.

Remote sensing to support cotton insect control has been pursued by a number of researchers, mostly at the level of exploratory or basic research. 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. Current research in cotton insect management includes that by Craig Kvien at the University of Georgia, who is looking at sensor technologies for variable-rate insecticide, plant-growth regulator, and nitrogen, Nahum Gat of Opto-Knowledge Systems, who is researching hyperspectral imaging for insect-infestations in western cotton; and Paul Doraiswamy and James McMurtrey, who are looking at similar phenomena in Mid-South cotton. Perhaps the most thorough basic research for remote sensing in cotton insect management has been done by Stephen J. Maas of the USDA-ARS, Shafter, CA, who has examined effects of spider mites and other insects in cotton through a variety of data sets, including thermal imagery. Spider mite damage was also examined through multispectral imagery by Fitzgerald, Maas, et al (1999), with some promising results deriving from bit-error filtering on the near infrared band. Summy et al. (1998) 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, 1996) to locate cotton fields. Jim Johnson of ITD-Spectral Visions, in cooperation with McKinion and Jenkins of USDA-ARS Mississippi developed a similar prototype, for boll weevil eradication in Oklahoma in 1998.

Remote sensing in entomology in general 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 (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 over-wintering 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. Likewise, insecticide comparisons have been conducted, but not in the context of spatially variable application through remote sensing. The efficacy of various commercial insecticides against tarnished plant bugs, such as Orthene®, Vydate®, Baythroid®, and Provado® was reviewed by Robbins, et al (1999). These insecticides may be applied in the same spatially variable manner as described in this experiment.

Study Area

The research study area is a series of semi-contiguous fields totaling 2000 acres at Perthshire Farms In Gunnison MS about 80 miles south of Memphis TN. Much like Hardwick Farms, Perthshire is located on the floodplain of the Mississippi River, the region is noted for its fertile alluvial soils and high cotton yields. Mr. Kenneth Hood, a nationally known cotton producer, graciously allowed the research team to pursue this and other experiments on the farm, while also providing them with his expertise in progressive cotton production. In addition to Hardwick, Hood works closely with the National Cotton Council and Cotton Incorporated to ensure the research conducted on his farm is in line with AG20/20 priorities and any benefit from this research can be disseminated throughout the U.S. cotton-belt. **Figure 1** illustrates the Perthshire Farms study area.

Project Goal

The goal of the Perthshire Farms SVI experiment was to test the effectiveness of remote-sensing-based spatially variable insecticide in terms of (1) cost savings, (2) effectiveness in eliminating plant bugs, and (3) ability to maintain acceptable yield levels compared to traditional blanket application of insecticide. There was an additional parallel goal of verifying the utility of remote sensing as a tool to guide insect scouting on a stratified basis rather than a grid basis.

Hypotheses

We tested three interrelated hypotheses.

(1) Insecticide usage for SVI treatments is statistically significantly less than in traditional blanket treatments:

$$H_o: u_{\text{svi insecticide usage}} = u_{\text{blanket insecticide usage}}$$
$$H_A: u_{\text{svi insecticide usage}} \neq u_{\text{blanket insecticide usage}}$$

We hoped to reject the null hypothesis, with SVI insecticide use being less than blanket use.

(2) Effectiveness of SVI treatments (as measured through pre- and post-spray bug counts) is equal to traditional blanket treatments;

H_o: $u_{svi\ effectiveness} = u_{blanket\ effectiveness}$
H_A: $u_{svi\ effectiveness} \neq u_{blanket\ effectiveness}$

We hoped to fail to reject the null hypothesis, thus showing that effectiveness was the same for SVI and blanket. Alternately, we hoped to reject the null hypothesis if it can be shown that the difference in *u* was a matter of SVI reducing more bugs than blanket.

(3) Yields of SVI treatments are equal to traditional blanket treatments.

H_o: $u_{svi\ yield} = u_{blanket\ yield}$
H_A: $u_{svi\ yield} \neq u_{blanket\ yield}$

We hoped to fail to reject the null hypothesis, thus showing that yield was the same for SVI and blanket. Alternately, we hoped to reject the null hypothesis if it can be shown that the difference in *u* was a matter of SVI producing more cotton than blanket.

Experiment Design

The Perthshire Farms experiment was set up in a semi-randomized block design and was replicated 10 times.

- The experimental units were fields ranging from less than 10 acres to over 200 acres, selected for (1) contiguity, (2) size/scale, and (3) availability.
- The blocks comprised SVI/blanket pairs, at the field level.
- The two treatments (SVI and blanket) were allocated to their respective fields in a semi-randomized manner (see Figure 1). A coin toss was used to decide if we would start with SVI or blanket, then alternated between the two, field by field, according to the random label identification numbers that we had assigned to the various field polygons in Arc/Info.

Imagery and Field Data Specifications

Imagery Specifications

This experiment relied upon airborne three-band (840nm, 695nm, 540nm, +-5nm) multispectral imagery flown at 2-meter resolution and captured by the ITD-Spectral Visions RDACS camera. The 1320 x 1035 pixel array captures a footprint of 2640m x 2070m on the ground (1350 acres). The 2meter resolution was then resampled to 4 meter resolution to simulate Space Imaging ICONOS satellite imagery. The eventual utilization of satellite imagery for this application is an important long-term goal but was premature for the 2000 season.

Field Data Specifications

A stratified sampling strategy was utilized and fields were sampled according to the entomologist's discretion based on crop growth patterns revealed by the NDVI scout maps. At these sample locations, pre-spray and post-spray bug counts were measured through the drop-cloth method, net method, or similar approach recommended by Dr. Willers. Actual sampling techniques were based on the methods described by Willers (1999 and 1998), "Remote Sensing, Line-intercept Sampling for Tarnished Plant Bugs in Mid-south Cotton," "Perspectives on Sampling for Lygus in Cotton: Applications of Quadrant-Based Sampling Schemes," and others. The same strata used to select points in the SVI areas were also used to select points in the blanket areas.

Risk Mitigation

During the planning phase of the 2000 projects, the research team developed a risk mitigation section within each experimental design plan. The purpose of this section was to identify any potential problem areas that may interfere with the implementation and analysis of the experimental designs. There were four main topics of concern identified. Of these four, the Boll Weevil Eradication Program activity is the only risk that surfaced and proved to have a negative impact on the experiment.

Boll Weevil Eradication Program

The Boll Weevil Eradication Program (BWEP), beginning in 1978 in Virginia and North Carolina as a successful trial program, was a significant factor in the 2000 Spatially Variable Insecticide (SVI) experiment. The BWEP is a state and federally funded program to incrementally eradicate the boll weevil from the Southeastern United States.

Perthshire farms just recently completed its second year under the BWEP, with every field including the fields involved within our SVI experiment (blanket and SVI fields) receiving 6 to 15 mandatory blanket applications of Ultra Low Volume (ULV) Malathion, based on trap catches monitored by the BWEP. These mandatory Malathion sprays are significant to the experiment, because the Malathion used to kill boll weevils is also an effective insecticide against plant bugs, the insect of record for this study. However, these sprays are of an ULV meaning it is a weak amount of insecticide and likely would not kill all of the plant bugs in the ecological system, but most assuredly did keep overall plant bug counts lower than normal.

As the BWEP begins its third season at Perthshire Farms, coincidental control of the plant bug is expected to decline as the number and frequency of ULV Malathion treatments diminishes with economically significant numbers of boll weevils being drastically reduced after two years of rigorous eradication efforts. In fact, the plant bug is expected to assume a more significant role as the key pest of cotton when the boll weevil is declared eradicated (Layton et al, 1999). Also, while under the BWEP it may be a good opportunity for ITD to explore spatial relationships with other secondary insects such as tobacco budworms, beet armyworms, whiteflies, aphids, etc. which are reported to cause more of a problem during the program. Dr. Willers and other independent crop consultants reported possible correlations with some of these secondary insects to crop growth patterns revealed by RDACS multispectral imagery. These and other theories will be further studied as outbreaks of these insects are discovered in the 2001 growing season.

Methodology

The experiment began about 40 days after planting (first square), and continued throughout the growing season until it was no longer necessary to spray for plant bugs (mid-August). Dr. Willers and Perthshire Farm's private entomological team scouted the study area utilizing imagery collected early in the season as well as using imagery from the previous season. When they deemed that it was time to spray for plant bugs, they informed (1) Kenneth Hood and (2) ITD-Spectral Visions. Imagery was then collected over the study site and ITD Spectral Visions performed the image processing steps in **Image Processing Procedures** presented below. The resulting prescription files were then e-mailed to Perthshire Farms and Dr. Willers. With the assistance of ITD-Spectral Visions' field intern, Dr. Willers verified the prescription by sampling random sites within the study—SVI and blanket—and documented pre-spray and post-spray insect counts.

Perthshire Farms' precision farming specialist and operations staff applied the prescriptions with a GPS equipped CASE Patriot ground sprayer, with the assistance of Dr. Willers and the Spectral Visions team. It should be mentioned that a considerable amount of time was consumed early in the season in preparing the Patriot Sprayer to perform spatially variable applications of insecticide. Many things had to be designed, fabricated, installed, and verified to ensure effectiveness and reliability. The output spray amounts were calibrated (see **Figure 2**) to consistently apply the proper amount of carrier liquid (water). Lead and lag times had to be measured and calculated to be sure that the spray (on or off) would occur at the exact GPS location called for by the prescription.

The Patriot (see **Figure 3**) was also equipped with saddle mounted injection tanks to change chemical and/or chemical rate on-the-fly. These options were tested and it was found that the time required to charge the entire 90 ft. boom with product was far to slow and was not feasible for this experiment at this point in time. Travelling at 12 mph, too much ground is covered before the boom is completely charged, and likewise, the same amount of time (sometimes 2 minutes) was needed to clear the boom of product, applying chemicals to crops not scheduled to be sprayed. Ultimately it was decided not to use the injection tanks. The SVI spray process was achieved by mixing the insecticide directly in the carrier liquid tank. By doing this we were able to keep the boom pressurized with insecticide constantly at the spray tips and simply turn it on or off as directed by the prescription. The 90-ft. boom consists of a series of six 15-ft. booms. For the 2000 growing season we were limited to turning the entire 90 ft. boom on or off, greatly reducing our precision resulting in some over spray of areas (see **Automated Generation of SVI Prescriptions** below). Spectral Visions and Perthshire Farms hope to have control of each individual 15-ft. boom possibly in 2001, thus refining our precision six fold.

As-applied data was collected by the sprayer's on-board computer and later delivered to ITD-Spectral Visions. The as-applied data was useful to verify that the proper rate and location of the insecticide was broadcast over the fields. Also, the producer used this information to be certain that the correct fields have been sprayed at the proper rate.

After spraying, Dr. Willers/ITD-Spectral Visions then revisited near the same points in each field to collect post-spray insect count data. These data were delivered to ITD-Spectral Visions. This process (see **Figure 4**) was repeated several times between June and August at which time plant bugs were no longer a threat because of the maturity of the bolls. However, sampling did continue for other secondary insects (i.e., tobacco budworms, and white flies) to attempt to correlate their occurrence to different levels of plant vigor revealed by RDACS multispectral imagery.

At harvest all the fields within the study area were picked with CASE pickers and yield variability was mapped using Ag Leader yield monitors. The analysis began immediately after harvest and is explained in the **Results/Conclusions** section.

Image Processing Procedures

The multispectral data was collected using Spectral Visions' Real-time Data Acquisition Camera System (RDACS) at an altitude of 12,000 feet AGL, rendering 2m-spatial resolution imagery, and recorded onto 8mm tape. After arriving at the Spectral Visions Automated Data Processing (ADP) Lab and being immediately downloaded, a series of processing steps were performed on the data. In attempts to provide a near real-time product for the SVI experiment, most of these processing steps were automated through script and batch processing methods. Although most of the steps were scripted so that they could be performed automatically, some required interactive involvement by image analysts. This interaction helps ensure that a process runs smoothly and produces an error free data set.

Below is a detailed description of the processing steps involved in the scout map generation and delivery (see **Figure 5**):

- The data was downloaded to Erdas LAN format on disk, and analysts determined which image frames contained the research fields. A script was generated to convert one band of each of the data frames to jpeg format, and a jpeg viewer was used to display all of the jpeg files in the download directory at once. This allowed the analyst to quickly view the images and select the frames that covered the research fields.
- Since the cameras cannot be perfectly aligned, band to band misregistration must be corrected. Since the band to band misregistration is the same for each frame, the same control points were used for all frames within that particular flightline.
- Once a frame for a research field was band to band registered, an analyst began the georectification process. The result of the rectification process was a georeferenced, band to band registered image file in the Universal Transverse Mercator (UTM) coordinate system, WGS 84 spheroid, WGS 84 datum, Zone 15.
- Scripts to mask each study field out of the frame by using the frame number to index the file and the field name to index a corresponding field mask file were generated. The result was a dataset that only contained the field of interest for each research field.
- The RDACS data needed to be resampled to 4-meter data to simulate the spatial resolution of the Space Imaging IKONOS satellite data sets. A resample script performed this function by averaging four adjacent RDACS 2-meter pixels together to transform the data to a 4-meter spatial resolution.
- After the masked, resampled, jpeg images were generated, a script generated a Normalized Difference Vegetation Index (NDVI (NIR-Red)/(NIR + Red). The NDVI was saved to disk in two formats. One as an 8 bit version for display, and also as a floating-point format to be used in processing.
- Next, a script generated jpeg images of the masked and resampled images. These jpeg images were later incorporated into the Scout Map printout.
- After these processes were completed, the entire process was repeated again with the new frame/field pair. After all the frame/field pairs had been processed, the NDVI and composite (3-band) data images for the research field were safely stored on disk in the proper directories.
- At this point, an analyst opened a Scout Map template and inserted the NDVI and Composite images into the appropriate slides. After all the slides were filled, the Scout Maps were printed and overnight mailed and electronic versions were emailed to the research team. During the growing season, the Scout Maps were mailed within 24 hours of receiving the data from the aircraft.
- Next, a script created an ArcInfo grid from the NDVI data set, which was later used in the prescription generation process.

Automated Generation of SVI Prescriptions

The possible generation of prescriptions for all of the 32 test fields every 7 – 10 days required an automated process if the project's goal of rapid turnaround was to be met. The prescription shapefiles were created in ArcView using custom scripts and a graphic user interface (GUI) (see **Figure 6**). These shapefiles were imported into SSToolbox and controller-ready files were created.

Each prescription shapefile was imported into SSToolbox one at a time. From there it was converted directly into the file format of the appropriate controller. These files, along with the prescription shapefiles, were zipped into an archive file and emailed to Hood farms.

Analysis, Results, and Conclusions

Effectiveness Analysis

Pre and post-spray plant bug counts were conducted at several points in each research field. The pre and post-spray plant bug counts were used to test the effectiveness of Spatially Variable Insecticide treatments in eliminating plant bug infestations at the field level.

SVI fields T167-01 and T167-19 were used to test the effectiveness hypothesis. These fields were chosen because of the consistent and reliable plant bug count data that was recorded there. The data sets for both fields were balanced with the same number of observations for both the pre and post-spray insect counts (see **Figure 4**). In order to determine the probability that the difference in the means that was observed was due to chance, a nonparametric two-sample analysis of variance test was performed. 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).

Effectiveness Results/Conclusions

The results of the nonparametric analysis of variance tests on the pre and post-spray insect count datasets showed a statistically significant reduction in the numbers of plant bugs for both fields T167-01 and T167-19 at an alpha level of 0.05. The Chi-Square p-value for the T167-01 dataset was 0.0014 while the Chi-Square p-value for the T167-19 dataset was 0.0455. These results indicate that the effectiveness of SVI treatments (as measured through pre- and post-spray bug counts) are at least equal to that of traditional blanket treatments.

We can conclude that the effectiveness of SVI treatments was at least as good as the traditional blanket treatments in effectively controlling plant bug populations at the field level since there were no plant bugs found in the post-spray insect counts of either field. Therefore, this study suggests that blanket applications can only be as effective (100%) as the observed results of our SVI treatments in this year's research, and are viewed as non-efficient.

Yield--Analysis and Results/Conclusions

Yield Analysis

Yield data was collected by AgLeader yield monitors on each cotton picker in each research field. This yield monitor data was used to test the effectiveness of SVI treatments in maintaining or exceeding yield amounts commonly experienced with traditional pest management practices (a blanket insecticide treatment).

Unfortunately the boll weevil eradication program at Perthshire Farms this year impacted the original intent of the study to analyze the difference in yield data from the blanket and SVI fields. The implication of the boll weevil eradication program to the SVI research this year was that the producer did not need to apply blanket applications of Bidrin since the eradication program's Malathion sprays greatly reduced most insect populations. Field level research, such as the SVI study, is susceptible to the producer's farm management decisions since experiments at such a large scale may greatly impact the overall profit of the farm. Blanket sprays of an insecticide such as Bidrin over the hundreds of acres designated as blanket fields in this study when in fact there were no plant bugs present would be an unacceptable cost to a producer. This impact to the research is described in the Risk Mitigation section of this report.

Given that the fields designated at the beginning of the year as blanket were not actually treated with a blanket plant bug spray, we endeavored to convert some SVI fields to blanket that had SVI applications with prescriptions that called for at least 80% of the field to be sprayed. In the creation of the blanket fields from SVI fields to facilitate statistical analysis of yield, it was decided to convert three of the SVI fields to blanket fields by delineating a polygon around only the applied areas within each field. The "as applied" shapefiles created by the spray rig were used to define the polygons. These depicted the locations that were actually sprayed as opposed to the prescription shapefiles, which delineated the areas that needed to be sprayed. The shapefiles were displayed in an ArcView View with the spray and no spray areas assigned different colors. For each field, a polygon was manually drawn on the screen that encompassed only the sprayed areas. These polygons were overlaid over their respective yield surfaces and an average yield per acre for each new blanket field was extracted. **Figure 7** is an example of a blanket areas extracted from SVI fields.

SVI fields T167-19, T167-01, T1316-04 and converted blanket fields T1316-11, T1310-03, T167-10 were used to test the yield differences between the two groups. These fields were chosen out of the nine fields that had an actual SVI application this year based on similar planting practices and adjacency to one another. The yield data in pounds of seed cotton per acre for each SVI field was compared statistically to the yield data in pounds of seed cotton per acre from each blanket polygon created. As described in the Effectiveness Analysis section 2.2.11, a parametric t-test was not used to compare the means of the two groups for significant difference since the sample sizes were so small. The small number of observations made it difficult to assume a normal distribution of the data, so as in the Effectiveness Analysis section 2.2.11, a Wilcoxon rank-sum nonparametric test was used to analyze the data for significant difference in SAS.

Yield Results/Conclusions

The result of the nonparametric analysis of variance test on the yield data of the SVI fields and blanket polygon areas showed no statistical significant yield difference existed between the two groups at an alpha level of 0.05. The Chi-Square p-value for the yield comparison test was 0.5127. These results indicate that there is no significant difference in yield to a producer who utilizes SVI as opposed to the traditional blanket method of insecticide application. Given these results, a producer would benefit greatly from utilizing SVI applications in that input costs can be reduced while yield and effectiveness are maintained in respect to traditional blanket application methods. Please refer to the economic analysis below for more detail on potential savings utilizing SVI technologies.

Economic Analysis Results/Conclusions

Over all the SVI fields within the study, there was a 34% reduction in the amount of Bidrin sprayed by using the SVI method over the conventional method. However this doesn't take into account the additional costs associated with data collection, prescription generation, prescription application, or additional equipment needed for the SVI implementation. An analysis of the economics has been performed to determine the cost savings of using the SVI method over the conventional method. Dr. David Laughlin, Director of the Agriculture Economics Department at Mississippi State University assisted the Spectral Visions team in this effort.

The costs associated with implementing the conventional (Blanket) method include insecticide material cost and insecticide application costs. The insecticide application costs cover the cost of the spray rig with the 90' boom; the fuel consumption; diesel fuel cost; salvage, repair and maintenance costs; performance rate; and driver labor costs. It assumes a fully utilized machine. The summary costs are presented in **Table 1.**

The SVI 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. The remote sensing data acquisition costs include the costs of aircraft ferry time; data collection; and data delivery by a data acquisition company for 3 data collection dates. This analysis incorporates 3 data acquisitions in order to provide 3 NDVI scout maps during the June/July time period. This analysis also calls for one SVI application to be performed per field during this time frame. The value added processing costs includes costs for downloading data, band to band registration, georeferencing, masking fields, generation of NDVI images, scout map creation, 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 2, 3 and 4**.

The insecticide, Bidrin, has a cost of $6.80 per acre and is the same for the SVI and conventional methods. The insecticide application cost is $1.31 per acre for the conventional method and $1.55 per acre for SVI method. The remote sensing data collection and processing costs for the SVI method are $1.08 per acre. The service consultant costs for the SVI method are $0.16 per acre. This results in a total of $8.11 per acre cost for the conventional application and $9.59 per acre cost for the SVI application. These costs are presented in **Table 5.**

The entomologist or field scout used the scout maps based on the remotely sensed data to determine if an SVI application should be performed. Dr. Jeff Willers projected that after becoming familiar with the scout maps, the field scout should be able to perform the scouting task in 20% of the time required without the scout map. Traditionally the field scout visits a 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.

There were 10 field applications of SVI over the growing season. **Table 6** shows the total acres; the acreage and percentage of acreage sprayed by SVI; the acreage and percentage of acreage not sprayed by SVI. It also provides a total and average for these values over all the fields. The total acreage of the fields used in SVI applications was 1,293. The total amount of this area actually sprayed and not sprayed with the SVI method was 853.71 and 439.88 respectively. This means that the volume percentage of Bidrin savings was 33.96%.

The costs associated with the conventional and SVI applications are shown in **Tables 7 and 8.** The columns show the information for the conventional and SVI 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 the SVI has a cost savings of 21.96% over the conventional method. For the 1,293 acres in the SVI fields, the cost to perform the Bidrin application using the conventional method would have been $10,491.02; the cost of the SVI applications was $8,187.08; and the cost savings was $2,303.94. When extrapolated to 10,000 acres, the cost of the conventional method would be $81,100.00; the cost of the SVI method would be $63,289.60; and the 21.96% cost savings would be $17,810.40.

The economic analysis demonstrates that the SVI method is cost effective. The amount of Bidrin saved by utilizing SVI technologies is 33.96%. After integrating the application costs, data collection costs and prescription management costs, the cost of the SVI method as compared to the conventional method is reduced by 21.96%. Therefore, this economic analysis demonstrates that using SVI technology for application of Bidrin to treat plant bug infestations instead of today's conventional methods reduces the cost of insecticide applications to the American cotton producer.

Challenges – Lessons Learned

There were many challenges that arose during the implementation and analysis of the 2000 cotton experiments. Most of these challenges were overcome and solutions were generated due to lots of hard work and determination from an organized team effort of many disciplines and backgrounds.

Today's standard application equipment is not capable of SVI applications without some engineering modifications/fabrications and special software adjustments. Once these challenges were overcome, the issues of calibration, chemical mixing, lead and lag times of material through the spray boom, forward speed, etc,.... were addressed. Although solutions were implemented, the equipment industry realizes areas that could be improved upon to enable SVI technologies to be more efficient.

The low insect counts at both Hardwick and Perthshire Farms were largely due to the mandatory Boll Weevil Eradication Program's weekly spray schedule. These low insect counts created many obstacles during the implementation phase of the experiment. Many fields that were in the study never reached the insect count threshold needed to warrant an SVI or blanket application. In addition, low insect counts recorded during the season created difficulties in the final analysis of results.

The team also realized that conducting stratified or random insect sampling utilizing imagery as a guide can be somewhat challenging. It is very difficult for an entomologist to conduct an insect sample with a large GPS, antenna, backpack, notebook, RS scout map, water bottle and sweep net or drop cloth in hand. A GPS tagged sample point and reading is definitely a necessity but alternative methods must be explored to make the task less cumbersome to the entomologist or field scout. There were many samples taken that were not GPS referenced and may or may not have been recorded directly onto a field notebook or a scout map. Although these points were useful to the entomologist in determining overall insect pressures within a field, they were not useful in the final analysis.

Plans for Improvement

During the course of the 2000 season, ITD Spectral Visions has faced many challenges and learned many valuable lessons. These experiences although not all positive, have definitely been educational and informative to the team. There are many areas of improvement that the team will attempt to employ in the upcoming 2001 season.

The team is currently working to help equipment companies better understand the requirements and capabilities needed of spray equipment to efficiently conduct spatially variable chemical applications. Individual boom sections must have the ability to be independently controlled, injection pumps must be faster and the overall transfer of materials from concentrated holding tanks to the spray boom must be more efficient and more predictable.

As the BWEP goes into the 3rd year, experts anticipate a reduced number of boll weevils and therefore a reduction of blanket sprays needed in the program. This reduction of spray frequency will allow for a population increase of Lygus plant bugs. Although not positive for the producer, increased plant bug populations will allow for a more complete study of the use of remote sensing technologies in these SVI experiments.

The team must address the challenges of insect sampling and scouting with loads of heavy and cumbersome equipment. In order to do this, the team is exploring the use of hand-held pocket pcs, miniature GPS antennas, image-based software packages compatible with pocket pc's, and other electronic devices such as bar coding to allow the entomologist to collect, download, transfer, and archive valuable scout data with very compact equipment. We currently have a pocket pc that is working very effectively with a small GPS antenna and a version of ArcInfo's ArcPad software. The ability to collect field data without the need for bulky scout maps, notebooks, and clipboards will allow the entomologist to be much more efficient. These samples will be in digital format and much easier to transfer among team members for in season applications and post season analysis.

Acknowledgements

The ITD Spectral Visions team would like to acknowledge the following persons and companies that have contributed to the design, implementation, and analysis of the experiments conducted during the 2000 season. Without the gracious support of these individuals, this program would not have been possible.

The NASA CRSP Program, National Cotton Council, Cotton Incorporated, Mr. Kenneth Hood, Hood family and the Perthshire Farms staff, Johnny Freeman, Doug Cauthen, Russell Cauthen, Dr. Jay Hardwick and the Hardwick Farms staff, LSU Experimental Research Station staff, Dr. Roger Leonard, Dr. Ralph Bagwell, Dr. Jeff Willers, Dr. David Laughlin, Dr. Greg Carter, Quachita Fertilizer Co., Mid-South Ag Co., MidTech, John Deere, CASE-IH, Trimble, and Agricultural Information Management (AIM).

References

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

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*, vol. 2: 1022-1024 1999.

Layton, M.B., R.D. Bagwell and R.W. Seward, 1999. Insect Management in the Mid-South Eradication Zones: A Progress Report. *Proceedings of the Beltwide Cotton Conference,* pp 816-817.

Oklahoma Boll Weevil Eradication Organization, Website. www.obweo.org/keys.html

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

Riley, J.R. 1989. Remote Sensing in Entomology. Annual Review of Entomology, vol. 34:247-71.

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

Seal, M.R. 1999. Precision Insecticide Research Shows Potential Input Savings. Crop Decisions, October: 14-15.

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

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

Willers, J.L. Perspectives on Sampling for *LYGUS* in Cotton: Applications of Quadrat-Based Sampling Schemes, *Proceedings of the Beltwide Cotton Conference*, vol. 2:928-933 1998.

Willers, J.L. and D.C. Atkins. 2000. Sampling for Plant Bugs (Heteroptera: Miridea) in Mid-South Cotton. Southwest Entomologist.

Willers, J.L., D.C. Atkins, M.R. Seal and R.G. Luttrell. 1999 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.

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

Williams, M. 1998. Cotton Insect Losses. *Proc. Beltwide Cotton Conf*., Orlando, FL. Natl. Cotton Counc. Am., Memphis, TN. pp. 785-809.

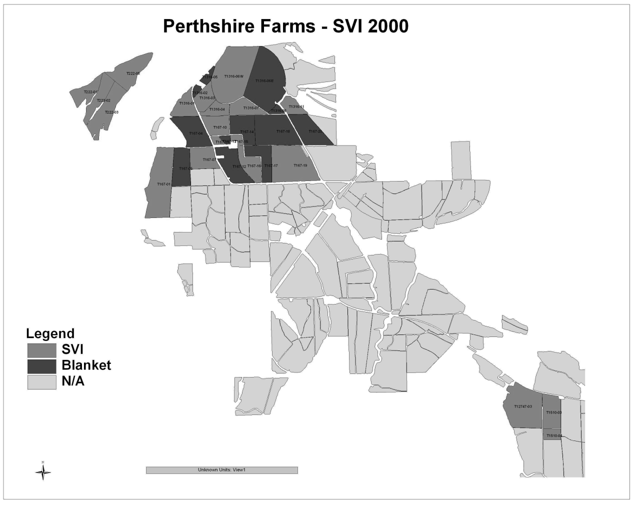

Figure 1. Perthshire Farms Study Area 2000.

Figure 2. Calibration and Testing of Patriot Sprayer.

Figure 3. Patriot Spraying SVI Prescription.

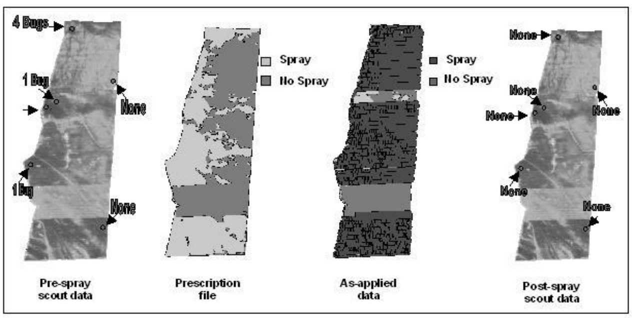

Figure 4. Sequence of Events To Implement and Verify SVI.

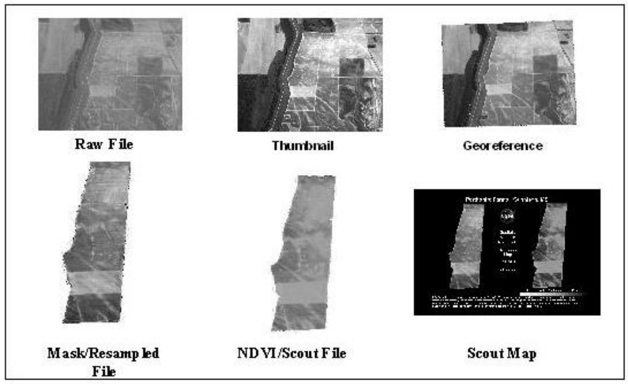

Figure 5. Steps to Generate SVI Scout Maps.

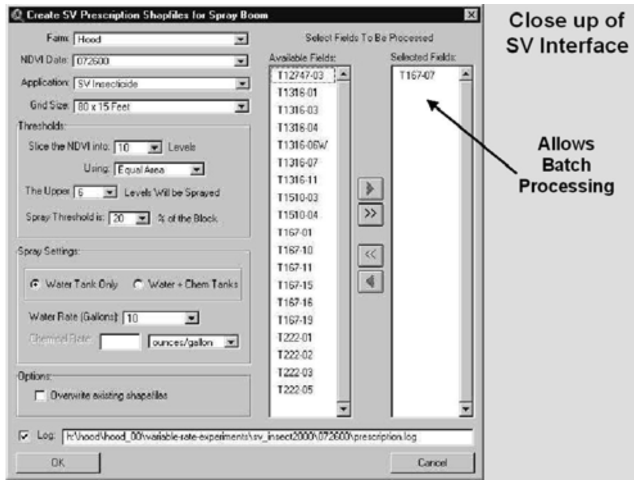

Figure 6. Graphical User Interface Used in Prescription Generation Process.

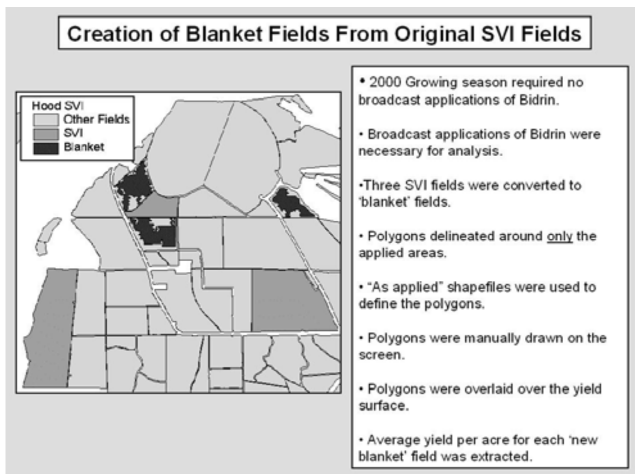

Figure 7. SVI Fields Converted To Blanket Polygons.

Table 1. Insecticide Cost for Conventional System.

	Unit	Price	Quantity	Cost	$/acre
Bidrin	1 oz	$0.68	10 oz	$6.80	$6.80
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 2. Insecticide Cost for SVI System.

	Unit	Price	Quantity	Cost	$/acre
Bidrin	1 oz	$0.68	10	$6.80	$6.80
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 3. Imagery Cost for SVI Method.

	Unit: Hours	Price	Acres	Cost	$/acre
1. Raw Data Collection	9	$400	10,000	$3,600	$0.36
2. Value Added Processing	12	$ 60	1,000	$ 720	$0.72
Total					$1.08

Note: Value Added Processing includes download data, band to band registration, georeference, mask fields, generate NDVI, create scout maps, generate data grids for service provider consultant.

Table 4. Service Consultant Cost for SVI 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 5. Perthshire 2000 SVI Experiment Conventional vs. SVI Summary Costs.

Item	Conventional $/acre	SVI $/acre
Insecticide material (Bidrin)	$6.80	$6.80
Insecticide application	$1.31	$1.55
Imagery	$0	$1.08
Service consultant	$0	$0.16
Total	$8.11	$9.59

Table 6. SVI Fields Insecticide Application Amounts.

Field	Total	Spray On	Spray Off	% Sprayed	%Not Sprayed
1316-01	49.00	38.30	10.70	78.16	21.84
1316-03	42.50	32.57	9.30	76.64	21.88
1316-04	32.60	21.40	11.20	65.64	34.36
1316-11	32.36	25.02	7.34	77.32	22.68
167-01a	170.57	86.50	84.07	50.71	49.29
167-01b	170.57	113.44	57.13	66.51	33.49
167-07	60.92	44.05	16.87	72.31	27.69
167-10	50.44	36.24	14.20	71.85	28.15
167-19	157.16	100.96	56.20	64.24	35.76
222-01	49.66	34.20	15.45	68.87	31.11
222-02	55.12	38.94	16.19	70.65	29.37
222-03	92.50	65.03	27.48	70.30	29.71
222-05	87.23	60.06	27.18	68.85	31.16
Keeler	242.96	157.00	85.96	64.62	35.38
Average	99.51	65.67	33.79	74.36	33.22
Total	1,293.59	853.71	439.27	66.00	33.96

Table 7. Cost Analysis for SVI Fields.

	Conventional	SVI	Savings
Cost/Acre	$8.11	$9.59	-1.48
Acres	1,293.59	853.71	439.88
Total Cost	$10,491.01	$8,187.08	$2,303.94
% Cost	100.00	78.04	21.96

Table 8. Cost Analysis for Extrapolated Acreage.

	Conventional	SVI	Savings
Cost/Acre	$8.11	$9.59	-1.48
Acres	10,000.00	6,599.54	3,400.46
Total Cost	$81,100.00	$63,289.60	$17,810.40
% Cost	100.00	78.04	21.96