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# Evaluating precision agricultural technologies in a Louisiana cotton insect pest management system

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# EVALUATING PRECISION AGRICULTURAL TECHNOLOGIES IN A LOUISIANA COTTON INSECT PEST MANAGEMENT SYSTEM

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## ABSRACT

A variable rate pesticide application system was developed and tested during 2001 for an agricultural aircraft in Louisiana. Using technology available to the agricultural aviation industry, a variable rate prescription of insecticide was successfully applied to a cotton field in 2002. These studies compared the efficacy and value of spatially variable insecticide (SVI) applications based on yield maps to the producer standard, whole-field broadcast treatments. Insecticide prescriptions were created from historical yield and production data. Treatments included whole-field broadcast sprays, yield-based SVI sprays, and profit-based SVI sprays. Twenty-two SVI applications were made to test fields from 2002-2005 using two aircraft equipped with on-board computer systems. SVI technologies reduced crop input costs for insect pest management, but did not significantly impact yield or crop profit within the conditions of these tests. Insecticide costs were reduced by $12 to $35 per hectare depending on the application frequency and SVI strategy. There was a 13% to 32% reduction in hectares treated in the SVI treatment strategies compared to the whole-field broadcast (producer standard). These studies showed that variable rate application of pesticides can be accomplished using an agricultural aircraft. Intra-field management zones for reducing crop inputs (insecticides) were developed from yield and profit maps. SVI prescriptions can allow producers to manage crop production costs by restricting inputs in Louisiana cotton fields.

# INTRODUCTION

The United States agricultural industry is constantly developing new products, more efficient cropping practices, and innovative technologies to compete in a global market. Low commodity prices, higher input costs, and decreased government support are responsible for the gradual decline in profitability of United States agricultural products. Producers are constantly evaluating new tools and techniques to lower costs and increase the efficiency of their farm operations. One promising technology is the site-specific application of variable rate inputs (Srinivasan 2006). However, these tools must be adapted to address the specific plant protection needs of producers on a timely basis. Decision support systems based on precision agricultural technologies must be developed in a user-friendly format and transferred to producers, commercial pesticide applicators, and agricultural consultants.

Most precision agricultural technologies have focused on agronomic inputs to increase yields or reduce input costs (Srinivasan 2006). In an overview of precision agricultural studies Lambert and Lowenberg-DeBoer (2000) reported that over 70% of the research efforts focused on variable rate application of general agronomic inputs (nutrients, seeding rate, irrigation, etc.). Although remote sensing techniques have been used to monitor spatial and temporal changes in arthropod pest populations, the application of site-specific management tools for integrated pest management is limited. Very few references are available on site-specific insect pest management. Precision insect pest management was not addressed in *The Handbook of Precision Agriculture*, a review of current precision agriculture techniques and research around the world (Srinivasan 2006).

Integrated pest management (IPM) is a combination of cultural, biological, and chemical controls used to reduce insect pest populations to a manageable level while minimizing adverse affects on the environment or human health (NAS 1969). Prevention, detection, and suppression are the basic phases of cotton IPM. Economic injury levels (EIL) and economic thresholds (ET) were developed by Stern, Smith and Van Den Bosch in 1959 (Pedigo 1996). The EIL can be defined as the point where the loss caused by pests is equal to the cost of available control measures (NAS 1969). The ET is the level at which control measures should be applied to prevent an increasing pest population from reaching the EIL (Stern et al. 1959). The decision-making process of IPM that triggers a reactive control strategy, such as pesticides, relies upon ETs. Chemical control strategies are currently used as the primary tools for managing insect pest infestations in cotton, *Gossypium hirsutum* L. (Leonard et al. 1999).

Insect pest management currently represents one of the greatest variable expenses incurred by a cotton producer. Historically, cotton producers have been heavily dependant on insecticides to help manage arthropod pests. Chemical control strategies have allowed cotton production to remain a viable economic enterprise in areas of heavy insect pest pressure (Leonard et al. 1999). In Louisiana during 2005, foliar insecticides were applied an average of seven times per field (Fig. 1), and cost to producers was estimated to be 168 dollars per hectare (Williams 2006). In 2005, four applications were required to control tarnished plant bug, *Lygus lineolaris* (Palisot De Beauvois), and an average of 3 applications were needed to control other pests such as the heliothine complex; stink bug complex; thrips; aphids; cutworms; and spider mites. Over 90% of

Louisiana cotton acreage received insecticide applications using aerial and ground-based equipment in 2005 (Williams 2006).

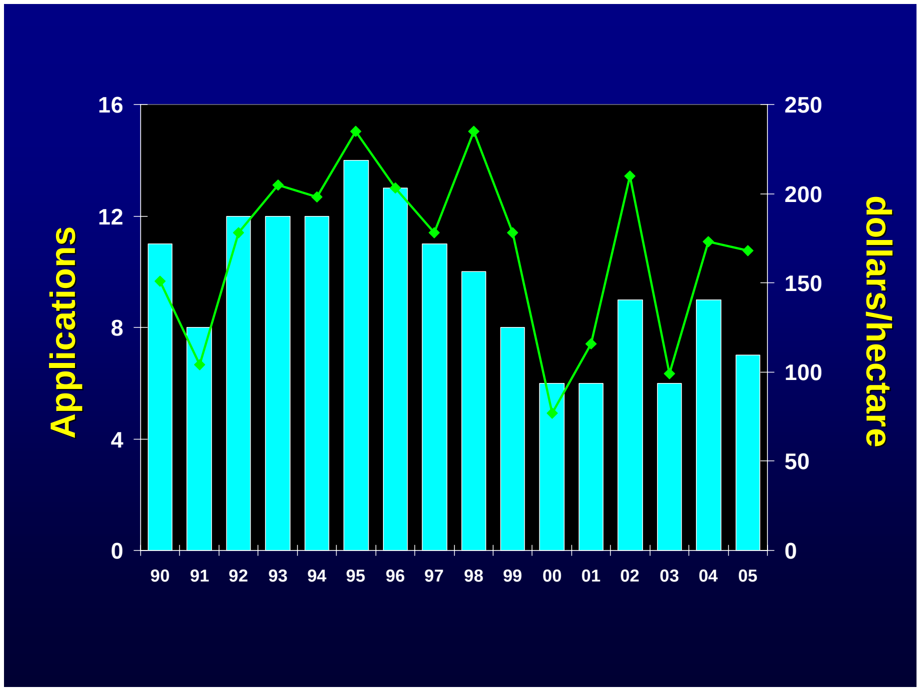


**Fig. 1. Historical annual application frequency and insecticide cost/hectare in Louisiana cotton production (Data adapted from Williams 2006).**

The current chemical control strategies in cotton are temporally restricted, and insecticides are applied when an action threshold level is exceeded. When crop consultants or producers detect insect pest densities above ET levels they initiate an insecticide application to the entire field (broadcast). A broadcast application refers to a treatment with a constant rate of product distribution across an entire field, or series of fields on a farm. In contrast, site-specific treatments are applied only to selected areas of the field or farm. The rate of the application may vary across the field as well.

A promising site-specific management technology that can reduce insect pest management inputs is based upon the concept of spatially variable insecticide (SVI) applications. SVI application research is currently in the developmental stages of commercialization. SVI applications are not only temporally restrictive and triggered only upon exceeding ETs, but also spatially restrictive. SVI applications are used when an ET is reached, but they are only applied to those areas of the field requiring treatment for the pest problem. Most prescriptions for a SVI application have relied upon remotely-sensed data used to generate vegetation indices related to plant health and are indirectly related to insect pest numbers. One such vegetation measurement, the normalized difference vegetative index (NDVI), has been used to develop prescriptions for SVI applications to the most vigorously growing zones of the field for control of tarnished plant bugs (Willers et al. 1999). SVI treatments based upon remotely sensed data have resulted in 20 to 40 percent reductions in insecticide use compared to whole-field broadcast applications (Dupont et al. 2000, Sudbrink et al. 2002, Fridgen et al. 2002).

Most agricultural fields have inherent variability due to soil type, nutrient availability, or drainage. Intra-field inconsistencies can result in yields that vary in quantity and/or quality and have considerable spatial changes in crop yields. Electronic yield monitoring equipment coupled with geographical information systems (GIS) has become an important tool in detecting and mapping intra-field variation. Historical geo-referenced yield data from fields can also provide producers with considerable information to make future crop management decisions. Researchers are currently attempting to define crop management zones within fields based on yield as well as topography, soil productivity characteristics, and remotely-sensed imagery (Sharp et al. 2003). Geo-referenced yield maps can delineate between field zones that contribute significantly to total yield for the entire field and those zones that are not productive.

Intra-field spatial changes in grain yields may vary 49 to 84% based on changes in topography (elevation and slope) in wheat fields (Lambert and Lowenberg-DeBoer 2000). In another study, excess differences in field topography created areas of excessive moisture saturated soils and resulted in yield loses up to 69% in the Mid-West U. S. (Lambert and Lowenberg-DeBoer 2000).

Extreme yield limitations in some field zones are defined by factors that likely cannot be overcome with insect pest management strategies. Attempting to manage insect pests in these areas of the field may only add to production input costs. By restricting insect pest management inputs to field zones that are producing profitable yields, producers should be able to more efficiently manage pests.

# REVIEW OF LITERATURE

## Precision Agriculture

The goal of precision agriculture technologies is to use global positioning systems (GPS)/geographical information systems (GIS) to improve farm efficiency with a more accurate distribution of crop inputs for optimum production. Site-specific management refers to the differential application of inputs across a production management unit (field or zone) (Hatfield 2000). Agricultural management systems that consider spatial variability are known as site-specific farming, prescription farming, precision agriculture, site-specific crop management, spatially variable farming, etc. Atherton et al. (1999) used the term "site-specific farming" to emphasize management decisions are based on local site-specific conditions that vary spatially. Precision agriculture goals include maximizing returns and/or managing risk efficiently by employing exact production and management practices (Oriade and Popp 2000). Precision agriculture has rapidly advanced in recent years from developments in GPS and GIS technologies. These systems provide the ability to automate data processing and management of spatial and/or temporal differences in resource levels using precision agricultural techniques (Oriade and Popp 2000).

Precision agriculture has the potential to minimize negative impacts of agriculture on the environment. Site-specific application of pesticides and nutrients based on sound ecological, agronomic, and economic principles, rather than whole-field broadcast applications, can reduce contamination of soil, water, and air resources (Daberkow and McBride 2000). In response to increasing environmental concerns and decreasing commodity prices, research has centered on precision agriculture over the past decade including site-specific applications of fertilizers, plant growth regulators, harvest aids, and herbicides in crops such as rice, wheat, grain sorghum, soybeans, cotton, and corn (Peters 2003).

Researchers and producers have long recognized that pest infestations, yield, nutrient levels, and soil types vary spatially across fields, farms, and regions. New technologies allow producers to: (1) quantify yield variability in small areas of the field; (2) spatially define areas with similar soil/crop productivity potential; and (3) apply inputs such as pesticides, fertilizers, and seeding rates in local prescriptions based on this intra-field variability (Atherton et al. 1999). The objectives of precision agriculture are similar to those in integrated pest management, sustainable agriculture, and environmental best management practices (BMPs). These goals focus on improving management strategies to increase production and profitability, protect the environment, and reduce adverse impacts from agriculture (Atherton et al. 1999). Precision farming has found acceptance as a crop management tool in the Midwestern Corn Belt, by reducing input production costs, and increasing yields of corn, wheat, and soybeans (Rains and Thomas 2000).

## Measuring Variability and Application to Precision Agriculture

Remote-sensing technologies have been used in precision agriculture to detect and/or quantify variation in crops, soils, water, and climate on field, farm, and regional levels (Hong et al. 2002). The first LandSat series of satellites were placed into orbit in 1972. Immediately, crop acreage, plant species identification, and yield estimates were monitored on a global scale using these technologies (Jackson 1984). Some of the initial inter- and intra-field applications of remotely-sensed data defined homogenous field zones for soil sampling, identified soil types, detected subsurface drainage tiles, monitored plant stresses, and forecasted crop yields (Covey 1999). Currently, there are remote-sensing research projects using satellite and aerial imagery data to create indices maps to estimate weed infestations and develop variable rate prescriptions of herbicides, harvest aids, and plant growth regulators in cotton. Similar projects are evaluating variable rate applications of fertilizers for field corn and wheat (Anonymous 2004).

Many of the remote-sensing studies use unprocessed, multi-spectral imagery to create maps that are defined as vegetation indices. These data estimate the relative abundance and activity of green vegetation in an area (Hong et al. 2002). The standard vegetative index used for agricultural applications has become the normalized ratio of the near-infrared (NIR) and red bands (NDVI). Other ratios available include the normalized ratio of the NIR and green bands (GNDVI), enhanced vegetative index (EVI), soil adjusted vegetative index (SAVI), and ratio vegetative index (RVI) (Clay et al. 2002).

A number of mobile devices have been developed to measure soil characteristics and can be used to create maps of intra-field variation. One of the most common measurements is soil electro-conductivity which is an indirect estimate of soil texture properties and is expressed as apparent soil electrical conductivity ($EC_a$). Sandy soils typically demonstrate low $EC_a$ values, silt soils exhibit medium $EC_a$, and clay soils have high $EC_a$ (Williams and Hoey 1987). Soil $EC_a$ data is obtained using a Veris (Veris Technologies, Salina, KS) EC mapping system. This system consists of a cart and GPS with at least four electrode coulters that contact the soil, inject an electric current, and measure the resulting voltage passing through the soil (Lund et al. 2002). Soil $EC_a$ data has been related closely to soil properties that influence crop yield such as carbon content, cation-exchange-capacity, soil depth, water holding capacity, and salinity (Lund et al. 2002). Similar correlations have been made in Germany using other EC mapping methods including the EM38 (Geonics Limited, Ontario, Canada) EC mapper (Luck 2002). Researchers are currently attempting to establish indirect relationships of soil $EC_a$ to the presence of plant-parasitic nematodes in cotton fields. The adverse effects of root knot nematodes, (*Meloidogyne spp*.), on cotton plants have been correlated with soil textural differences. However, it is currently cost-prohibitive to use conventional soil sampling and particle size analysis protocols to define zones of homogeneous soil textures within a field. Establishing a relationship between soil $EC_a$ and nematodes may provide the basis for a spatially variable nematacide application (Wolcott et al. 2005). On the Mississippi River alluvial soils of northeast LA, soil $EC_a$ was highly correlated to soil texture, and was produced accurate, detailed, and geo-referenced maps of soil zones for a site-specific nematode management program (Wolcott et al. 2006).

Soil characteristic data also can be obtained in other forms if $EC_a$ data collection is not available. Historical data sources with spatial components are available from the United States Department of Agriculture (USDA)-National Resource Conservation Service (NRCS). This information includes topography, elevation, digital ortho-quad images, land cover, and soil type maps for individual counties, and is available for public use through the USDA website (USDA-NRCS 2005). These data may be helpful in determining spatial variability in soil characteristics and defining crop input management zones.

## Crop Yield Monitoring Systems

Another system of capturing crop variability is to record site-specific differences in crop yield. A yield monitoring system includes a group of sensors installed on harvesting equipment that measures yield variability during the harvesting process (Vellidis et al. 2003). Crop yield variability can be spatially defined when yield monitors are combined with GPS. Knowledge of intra-field variability allows producers to identify site-specific management needs across fields or by defining intra-field management zones (Han et al. 2004). Mapping the spatial variability of crop yields and identifying homogenous zones is a relatively simple means of examining the interactions of abiotic and biotic factors influencing crop yields (Diker et al. 2002). Yield maps can estimate the extent of spatial variability across a field and determine the potential of precision agricultural techniques as profitable investments (Perry et al. 2004). Numerous sources of spatial yield variability including water stress, lack of nutrients, weed, disease, insect pest pressure, and poor drainage which may be identified and corrected with site-specific technologies (Rains and Thomas 2000).

Successful application of site-specific management practices will likely depend on understanding the spatial variability of crop yields and factors that may influence this variability (Ping and Green 2000). Site-specific yield data increases producers' knowledge of field variability and can help improve management decisions (Taylor et al. 2000). The accumulation of multiple years of yield data can allow producers to aggregate multi-temporal spatial information into one map and simplify the interpretation for sources of yield variability. Summaries of this type of data can provide producers with intra-field zones that exhibit similar productivity annually. In some instances, these zones produce static yields for several crops (Layrol et al. 2001).

The initial developments in yield monitoring technology occurred in grain crops harvested with combines. Due to the relatively constant flow of grain, yields were not difficult to measure (Ess et al. 1997). Cotton yield monitoring systems became available much later. The technology was similar to that for grain except seedcotton is measured by rate of flow through the harvesting equipment ducts. All commercially grown cotton is machine-harvested in the U.S. and is therefore, adapted well to machine-mounted yield monitors. Four commercial cotton yield monitors- Ag Leader®, Agri Plan®, Farm Scan®, and Micro-Trak® are currently available. These models use optical sensing techniques to measure flow rates to estimate yield (Vellidis et al. 2003). The sensors consist of two parts: a light-emitting component and a light-sensing component. Sensors are mounted directly opposite each other in the mechanical harvester delivery duct. Seedcotton passes between the emitter and receiver and reduces the transmitted light. Each yield monitor has a proprietary algorithmic formula that converts the reduction in measured light to pounds of seedcotton (Perry et al. 2004). Sensor data is then processed in an onboard computer that stores yield data with respective unique geographic locations (Vellidis et al. 2003). In 2005, John Deere introduced a cotton yield monitor (Harvest Doc Cotton, Deere & Co., Moline, IL) that uses microwave sensor technology instead of light emitters.

## Mapping Spatial Productivity with Crop Profitability

Spatial profit mapping incorporates GIS and economic analysis tools using crop production input records, geo-referenced crop yields, and estimated crop value. Rains and Thomas (2000) calculated profit as P=GI-I, were P= profit ($/hectare), GI= gross income ($/hectare), and I= fixed and variable cost ($/hectare). These calculations convert the yield map data into gross income based on crop sales, the total cost of production, and generate a spatially variable net profit map. Yield mapping data can provide a visual picture of homogeneous field zones, but crop profit/loss maps allow the producers to define profitable and non-profitable field zones. When producers can distinguish between profitable and unprofitable areas of a field, their decision-making ability is improved for the entire field. Managing non-profitable areas using zone management may include variable rate prescriptions of crop inputs, fallowing low yielding land, or correcting structural problems such as drainage or poor irrigation.

## Defining and Using Crop Input Management Zones

Crop management zones have been defined as geographical areas that can be treated as homogenous units for certain common characteristics (Velandia et al. 2004). These areas may be similar regions within a field or similar land areas across fields or farms. Production input applications can be managed differently for each zone using variable rate application technologies (Dillon 2002). Thus management inputs for homogeneous zones within fields that have variable yield potential can be executed uniformly within defined zones of specific fields (Whelan and McBratney 2003). Management zones may be developed using intra-field variation from field topography, soil types, soil fertility, crop yield, drainage, historical pest presence (weeds, nematodes, insects), or irrigation patterns. Producers can identify constant limiting factors among similar zones and vary inputs based on those factors to correct the problem. A number of techniques using intra-field variation have been utilized to develop management zones including: (1) hand drawn polygons on yield maps and imagery (Topography and DOQQ); (2) classification of remotely sensed imagery from satellite and aerial platforms; (3) identification of yield patterns across seasons; and (4) classification of soil maps and Veris data (Whelan and McBratney 2003). Proper delineation of crop management zones is the most fundamental issue associated with variable rate application technology (Dillon 2002). Layers of accurate, spatially dense, geo-referenced information are required to characterize reliable management zones and develop prescriptions of crop inputs (Whelan et al. 2002).

Creation of unique management zones has mainly focused on more static data sets, such as soil type surveys, yield data, and soil fertility from grid soil sampling. However, Boydell and McBratney (2002) used LandSat imagery crop vigor data to estimate stable yield zones in cotton fields in Australia. Multiple years of stable yield estimates from satellite data were sufficient to define yield zones within fields. Remotely-sensed crop yield estimates can provide the same information as three to five years of yield monitor data and provide producers with an alternative and more immediate source of data for management (Boydell and McBratney 2002). Fridgen et al. (2000) delineated field zones using $EC_a$ data, elevation, and slope to explain 10 to 35% of the variation in grain yields. Koch et al. (2003) defined three site-specific management zone classes (high, medium, and low) with three GIS data layers: bare-soil imagery, topography, and producer past management experience. In another study, $EC_a$ data was effective in identifying three distinct management zones, but showed that a combination of several data types may provide the most accurate generation of prescription application maps over a range of fields and environments (Fleming and Buchlieter 2002). Cabrera-

Davilia (2004) showed that the use of yield based management zones reduced production costs and increased profitability. In general, crop management zones for fields should provide greater efficiency in application of crop inputs based on spatial yield data (Moore and Wolcott 2000). The development of a prescription requires a data layer of interest, defining management zones, and developing a site-specific map for the application of variable rate inputs.

## Variable Rate Application Technologies

Variable rate technologies combine a computer, a rate controller, GPS equipment, software, and associated hardware to vary the delivery of crop production inputs such as fertilizers and pesticides (Rains and Thomas 2000). Electronic controllers can be described as the hardware and software necessary to read a prescription application map combined with a GPS coordinate to locate field position and a rate controller to vary the inputs based on a specific location within a field.

A variable rate application generally follows one of two general concepts. The simplest form of a variable rate application is an all (required standard) or none (0 rate, non-treated). In this concept of two management zones, an input is either applied to the recommended zone or it remains non-treated. This prescription is applicable to herbicides and insecticides because it takes a minimum rate to provide effective control; reduced rates may result in unsatisfactory control and excessive rates add unnecessary expense. The other example of variable rate applications is based upon a range of input rates (i.e. 0, 1x, 2x, 3x, etc.) across three or more crop management zones. This concept can be used when making variable rate applications of fertilizers, plant growth regulators, or harvest aids. Prescriptions for variable rate applications may be developed in an infinite number of ways depending on number of management zones and rate strategies. This process involves defining the optimum number of crop management zones and developing a logical rate strategy in a prescription that conforms to the needs of those zones for the required product or products.

Currently, software packages are available to generate variable rate application prescriptions based on data from several variables (crop yield, vegetative indices, soil characteristics, etc.). Three of the most common software packages include SST Toolbox™ (SST Development Group, Stillwater OK), SMS Advanced™ (AgLeader Technology, Ames, IA), and Farm Works Site Mate™ (CTN Data Service, Inc., Hamilton, IN). A number of on-board computers capable of using prescriptions to send rate change information to flow rate control equipment are available. The Raven Viper™ system (Raven Industries, Sioux Falls, SD), Ag Leader Insight™ system (AgLeader Technology, Ames, IA), John Deere GreenStar 2™ (Deere & Co., Moline, IL), Trimble Ag 170™ (Trimble, Sunnyvale, CA), Ag-Nav 2™ system (Ag Nav Inc., Newmarket, Ontario, Canada), a number of handheld computers [Dell Axim (Dell Round Rock, TX) and HP IPAQ (Hewlett-Packard Company, Palo Alto, CA)] are examples that can be used to communicate with flow controllers. Examples of companies manufacturing crop input flow rate control equipment include Midtech Technologies (Spraying Systems Co. Springfield, IL), Raven Industries (Sioux Falls, SD), Rawson Control Systems, Inc. (Oelwein, IA), and Houma Avionics (Houma, LA). Automated application technologies for agricultural aircraft are also available and were successfully tested by Smith (2001) using the Auto Cal II flow controller marketed by Houma Avionics. The Auto-Cal unit had an error rate of 0.64 to 1.60% of target volume in these tests. In 2002, Leonard et al.

(2003) reported the first successful prescription application of a pesticide with an agricultural aircraft in the U. S. using the Auto Cal unit and Ag Nav 2 computer system.

**<u>Successful Applications of Spatially Variable Crop Inputs as Prescriptions</u>**

Considerable research has been conducted with variable rate applications of fertilizers to improve nutrient management. Solohub et al. (1996) realized an economic return of 7 to 12 dollars per hectare using variable rates of nitrogen across crop management zones. The potential profitability of site-specific nitrogen management in corn was found to range from 11 to 72 dollars per hectare when compared to a uniform application (Malzer et al. 1996). Potato yields were increased by 8% using variable rates of phosphorous and potassium (Cambouris et al. 1999). Variable rate applications of nitrogen were shown to be more economically feasible than broadcast applications in corn. In the Koch et al. (2003) study, nitrogen fertilizer usage was reduced by 30 to 121 lbs/hectare with variable rate applications when compared to a broadcast treatment. The net return/hectare was $12 to 35 higher using variable rates of nitrogen when compared to the broadcast treatment (Koch et al. 2003).

Other studies have compared variable rate prescriptions for harvest aids, plant growth regulators, and herbicides. Lewis et al. (2002) reduced plant growth regulator (PGR) use by 40% using a variable rate strategy based on NDVI images as compared to whole-field broadcast treatments. In another study spatially variable PGR applications reduced pesticide usage by 51% when compared to a broadcast treatment in another study (Bethel et al. 2003). Remotely-sensed data when used as the basis for variable rate cotton harvest aid application reduced total pesticide requirements by 18% while maintaining yield and fiber quality (Fridgen et al. 2003). Peters (2003) conducted field experiments using a light activated sprayer (LAS) system to apply site-specific herbicides in cotton. The LAS system controlled weeds similar to a conventional sprayer and reduced herbicide cost, but there was no positive economic return from using the LAS system because of equipment costs. Goudy et al. (2001) reduced herbicide use by 59% while observing no differences in yield or weed control in a corn-soybean rotation when comparing a variable rate prescription to a conventional broadcast application.

Spatially variable insecticide (SVI) application research has demonstrated limited success. NDVI imagery has been researched as a basis for developing a prescription to apply SVI treatments to tarnished plant bugs (Willers et al. 1999). SVI treatments also reduced total insecticide use by approximately 40% when compared to broadcast applications in cotton (Dupont et al. 2000). Site-specific insecticide applications based on NDVI imagery were used by Sudbrink et al. (2001) to reduce insecticide inputs by 20 to 35% below that used in conventional broadcast treatments. Fridgen et al. (2002) used remotely-sensed imagery to create field maps detailing highly probable areas associated with tarnished plant bug infestations. SVI treatments reduced the total amount of insecticide (44%) without significantly reducing yields when compared to broadcast treatments. Sensor-actuated precision spray systems have reduced insecticides used in grapefruit orchards by restricting pesticide application only to areas where tree canopies were detected. Stover et al. (2003) reduced insecticide usage by 7% when compared to a conventional blanket spray by using a precision spray system. SVI was used as part of a management strategy against Colorado potato beetle, *Leptinotarsa decemlineata* (Say), infestations in potato (Blom et al. 2002). Perimeter sprays on approximately 25% of the field reduced mean numbers of Colorado potato beetle and reduced the amount of treated acreage by 75%. Khalilian et al. (2003) used variable application rates of aldicarb (Temik 15G, Bayer Crop Science, Research Triangle Park, NC) and 1,3-Dichloropropene (Telone II, Dow AgroSciences, Indianapolis, IN) using a prescription based on soil texture. Both treatments increased yields by 5% when compared to that in the non-treated areas. Temik and Telone use was reduced by 34 and 78%, respectively, when using the variable rate application strategies across a field.

The equipment used to apply site-specific insecticides has the ability to generate maps detailing the location of pesticide applications (as-applied maps). The as-applied maps contain valuable information such as date, time, and application rates that can be used as historical records of pesticide applications. These data may also be helpful when dealing with herbicide drift issues or off-target movement of insecticides. Read and Stevens (2002) used GPS technologies to generate detailed records of treatment locations when applying restricted use pesticides for the control of mosquitoes. Currently, the USDA Boll Weevil Eradication Program requires aerial applicators to use GPS-equipped computer systems that record the as-applied data of insecticide-treated fields (McNabb 2001).

**Spatially Variable Insecticide Applications and Integrated Pest Management**

Stern et al. (1959) revolutionized pest control methods with the concepts of economic injury level (EIL) and economic threshold (ET). Stern et al. defined EIL as the lowest population density that will cause economic damage to justify the cost of artificial control measures. The ET is the density at which control measures should be applied to prevent an increasing pest population from reaching the EIL. Headley (1972) re-defined the EIL as the density at which the cost of additional control is equal to the economic loss prevented by implementing the control tactic. Improvements in ETs are necessary for more effective and practical management solutions at a time when producers are seeking higher production efficiency and more profitable yields (Pedigo 1996). Currently, in cotton insect pest management insecticide treatments are usually applied broadcast to a field when ET levels are reached.

Presently there are no references using spatially variable yield data as a basis for decision making on chemical control strategies. Economic analysis of historical yield data may be used to define non-profitable regions of a field. Using actual ETs based upon crop value to apply an insecticide may result in many of those areas not receiving an insecticide application. SVI technologies provide producers with the ability to apply site-specific inputs to management zones which likely will result in economic benefits. In addition, the ability to selectively apply inputs to non-productive areas further provides an increase in production efficiency. SVI may allow producers to temporally vary insecticide use according to the principles of IPM by following an ET, but these technologies also can add a spatial component as well.

## Objectives

I. To evaluate the use of historical yield and profit data as the basis for developing site-specific insect management zones.

II. To use spatially variable insecticide (SVI) prescriptions and agricultural aviation equipment to apply insecticides to management zones in cotton fields.

## MATERIALS AND METHODS

These experiments were performed in fields of Hardwick Planting Co. at Somerset Plantation (32.18436, -91.23836), near Newellton, LA in Tensas Parish (Fig. 2). Hardwick Planting Co. is a progressive farm specializing in the production of cotton, field corn, soybean, and grain sorghum. Hardwick Planting Co. produces 500 to 800 hectares of cotton per year depending on crop rotation patterns. Hardwick Planting Co. includes many large fields (40 to 125 hectares/field) which were necessary for this research project. Large fields are needed to maximize areas of intra-field variability and to fully utilize the fixed-wing agricultural aircraft used for site-specific pesticide applications.

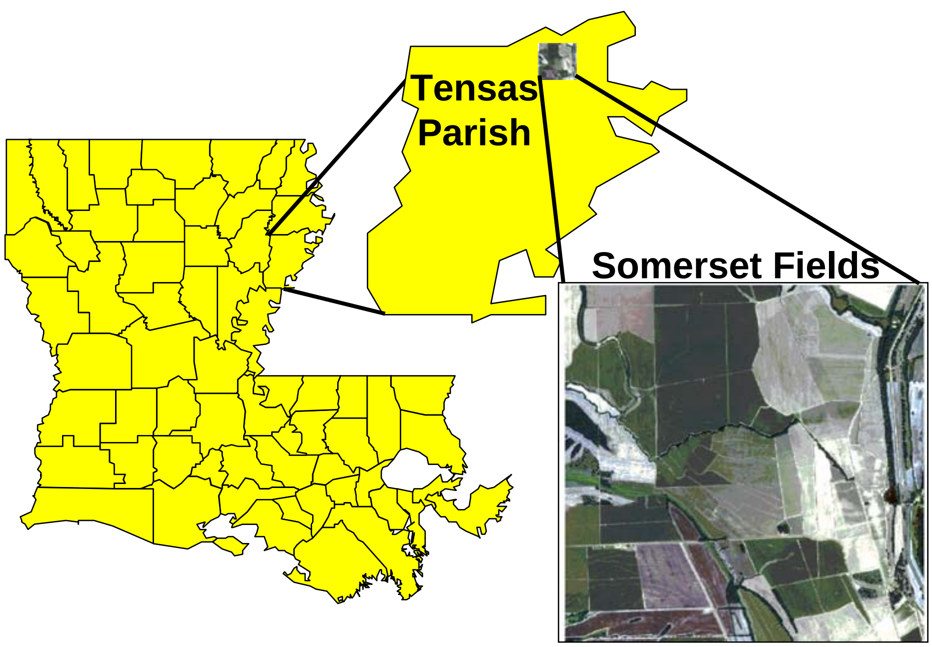


**Fig. 2. Test site for the spatially variable insecticide (SVI) application tests at Somerset Plantation, near Newellton, LA.**

Field boundaries were geo-referenced using a Trimble (Trimble, Sunnyvale, CA) backpack global positioning system (GPS) receiver enabled with Wide Area Augmentation System (WAAS) differential correction.  Three fields varying in size were used for these studies: 85 hectares in 2002; 110 hectares in 2001 and 2003; and 122 hectares in 2004 (Fig. 3).

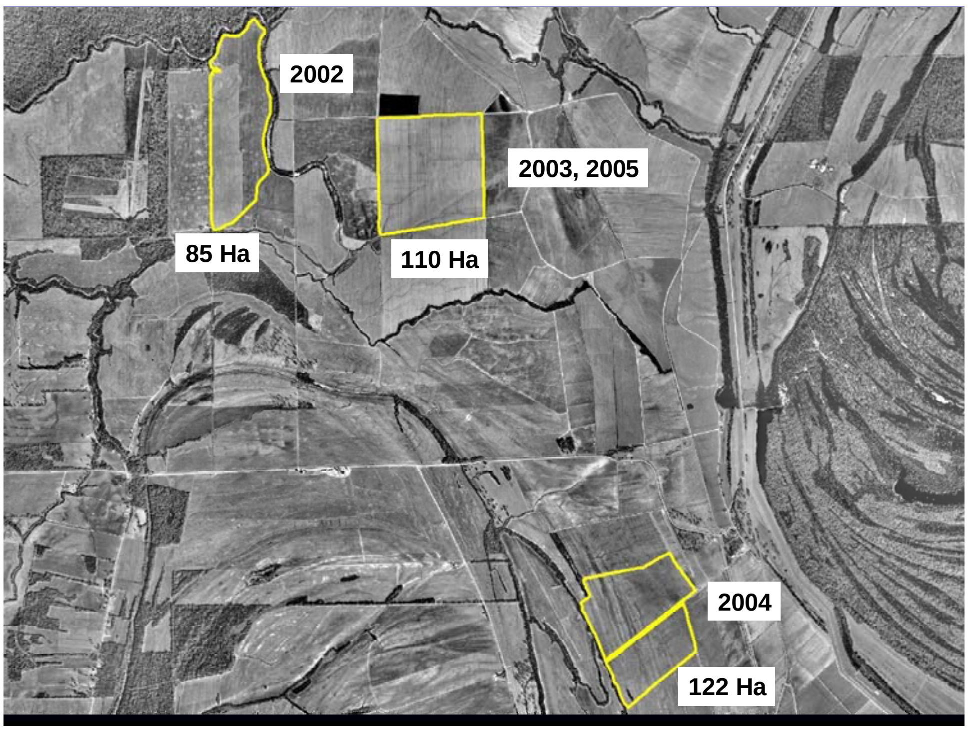


**Fig. 3. Aerial photograph of field locations used in SVI evaluations at Somerset Plantation.**

Historical yield data collected with Ag-Leader yield monitors on cotton harvesting equipment were analyzed using SMS Advanced and ArcView 3.3 (ESRI, Redlands, CA) software.   Unprocessed spatial yield data was imported into SMS Advanced, and a spatial shape file (Fig. 4) was created for analysis in ArcView 3.3.

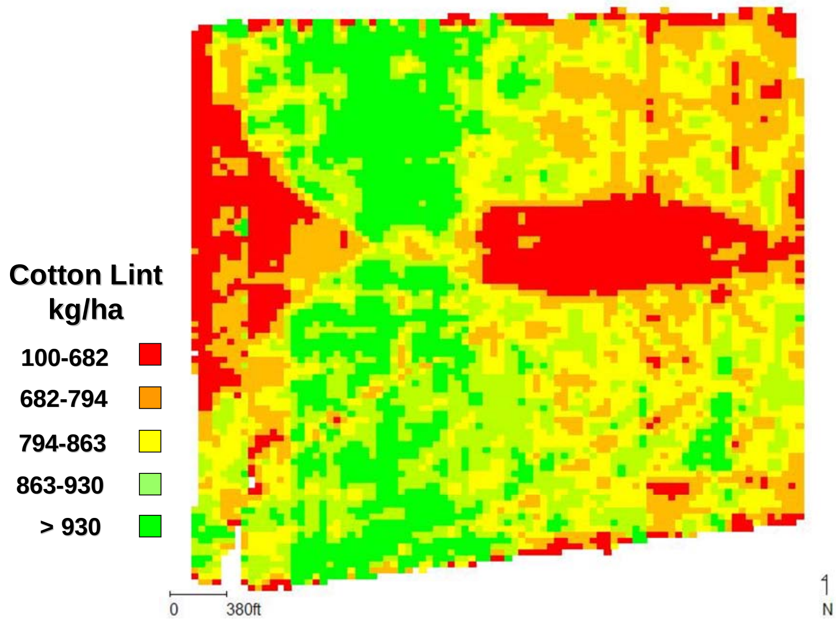


**Fig. 4. Historical cotton yield data used to develop the 2003 and 2005 SVI prescriptions.**

The yield data summary was divided into five natural break (this spatial distribution method minimizes within class differences and maximizes between class differences) classes with each class representing approximately 15-30% of the field. Cotton yield data was used in all years except 2002, because the data was not available. In 2002, grain data was the only data available for those specific fields. Yield data was further processed, and crop net profit maps were generated using ArcView 3.3. Average farm expenses for cotton production in Louisiana alluvial soils and a lint cotton price of $0.55 per pound (Paxton 2007) were used to facilitate creation of the profit maps (Fig. 5).

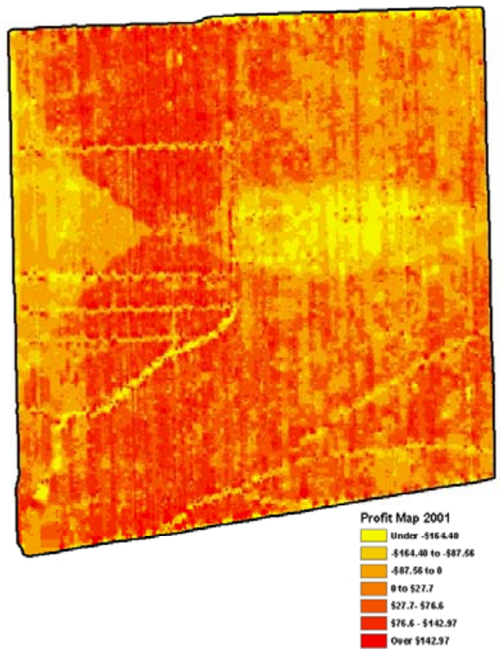


**Fig. 5. Crop net profit (dollars/hectare) map generated from 2001 cotton yield and crop input data.**

For each year, fields were partitioned into 18.3 m X 45.7 m blocks (spray on/off grids) using Enhanced Farm Research Analyst (Illinois Council on Food and Agricultural Research, Champaign, IL). Grids measuring 18.3 m X 45.7 m were selected to coincide with requirements of aerial application equipment. A swath (area treated during a pass) width of 18.3 m was required. Preliminary work with application equipment suggested that 45.7 m in length was necessary for rate changes using an aircraft (Temple et al., unpublished data). Fields were partitioned into randomized blocks, and treatments were replicated three times (Fig. 6). The SVI strategy was evaluated with two treatments (broadcast and SVI yield) in 2002 and with three treatments (broadcast, SVI yield, and SVI profit) from 2003-2005. The first treatment was a whole-field broadcast treatment (producer standard). The other treatments included a SVI application based on yield maps (SVI yield) and a SVI application based on profit maps (SVI profit). Grids of the SVI yield plots were not treated with an insecticide if yield data for those grids was in the lowest yielding (≤ 768 kg/hectare) class (approximately 15 to 30% of field). This was a conservative estimate since the break even yield on a farm of this size is around 900 kg/hectare (Paxton 2007). Louisiana's average yields for non-irrigated cotton in 2003 and 2004 ranged from 993 to 1055 kg lint/hectare and 1129 to 1183 kg lint/hectare for irrigated cotton. In 2004, those Louisiana cotton producers using harvest equipment equipped with yield monitors reported that average lint cotton yields for the lowest, middle, and top third zones of their fields were 743, 1016, and 1336 kg lint/hectare (Paxton 2007 unpublished data). Grids of the SVI profit plots were not treated with insecticides if those grids historically produced a negative net profit/hectare.

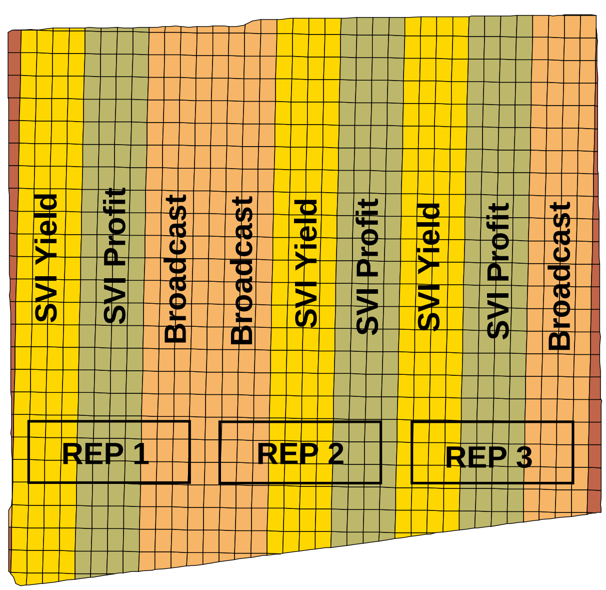


**Fig. 6. Experimental design and treatment arrangement for one field in this experiment.**

SVI prescriptions for aerial applications were generated at the beginning of each season using ArcView 3.3. The spatial grid file of the field was layered onto the yield and crop profit maps so that each grid included two layers of spatial data (crop yield and crop profit). Each individual grid received either a treat or no-treat designation. Grids in the SVI yield and SVI profit treatment plots received a no-treat designation when $\geq$50% of the area in a defined grid cell was classified as low-yielding or non-profitable.

All fields during the experiment were planted with transgenic cotton varieties (*Bacillus thuringensis* (Bt) var. Kurstaki insecticidal protein) to limit heliothine insect populations. Insecticide applications were initiated when recommended by the agricultural consultant, Howard Anderson (Anderson Consulting Co., Wisner, LA). Field prescriptions (Fig. 7) were used each time an insecticide application was recommended by the agricultural consultant. Economic thresholds for insect pest densities used in the tests were those recommended by the Louisiana Cooperative Extension Service (Bagwell et al. 2006). All insecticide applications in this study targeted tarnished plant bug. Insecticide applications were made on 30 Jul, 11 Aug, and 28 Aug in 2002. Insecticide applications were made on 21 Jul, 1 Aug, 7 Aug, 18 Aug, and 26 Aug in 2003. Insecticide applications were made on 25 Jun, 8 Jul, 15 Jul, 23 Jul, 3 Aug, and 12 Aug in 2004. Insecticide applications were made on 27 Jun, 5 Jul, 11 Jul, 18 Jul, 26 Jul, 2 Aug, 8 Aug, and 16 Aug in 2005.

Insecticide applications were made with either of two fixed wing aircraft (GA 200 and Turbine Thrush). The Gippsland Aviation (GA) 200 aircraft (Gippsland Aeronautics, Morwell Victoria, Australia) is a piston engine airplane with load capacity of 946 L.

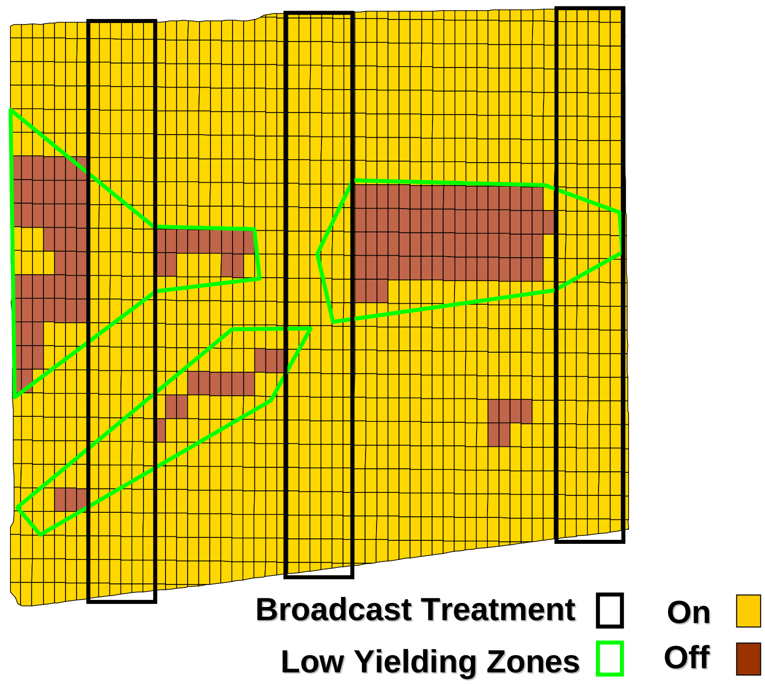


**Fig. 7. SVI prescription map illustrating the treated (on) and non-treated (off) grids, 2005.**

The GA (Fig. 8) was equipped with Davidon rotary nozzles (Davidon Inc., Unadilla, GA) calibrated to deliver 9.36 to 28.03 L of total spray volume per hectare, an AG-NAV 2 computer system, and a Trimble GPS. Flow rate on this aircraft was controlled by an Auto-Cal II unit (Houma Avionics, Houma LA). The AG-NAV 2 computer (Fig. 9) transmitted target flow rates to the Auto-Cal unit (Fig. 10) to vary application rates across the field based on prescriptions. Prescriptions were loaded onto the AG-NAV 2 computer using standard 3.5 disks (IBM Format). The GA was equipped with a variable electric fan pump to control the actual flow rate.

**Fig. 8. The GA 200 aircraft used to apply SVI treatments.**

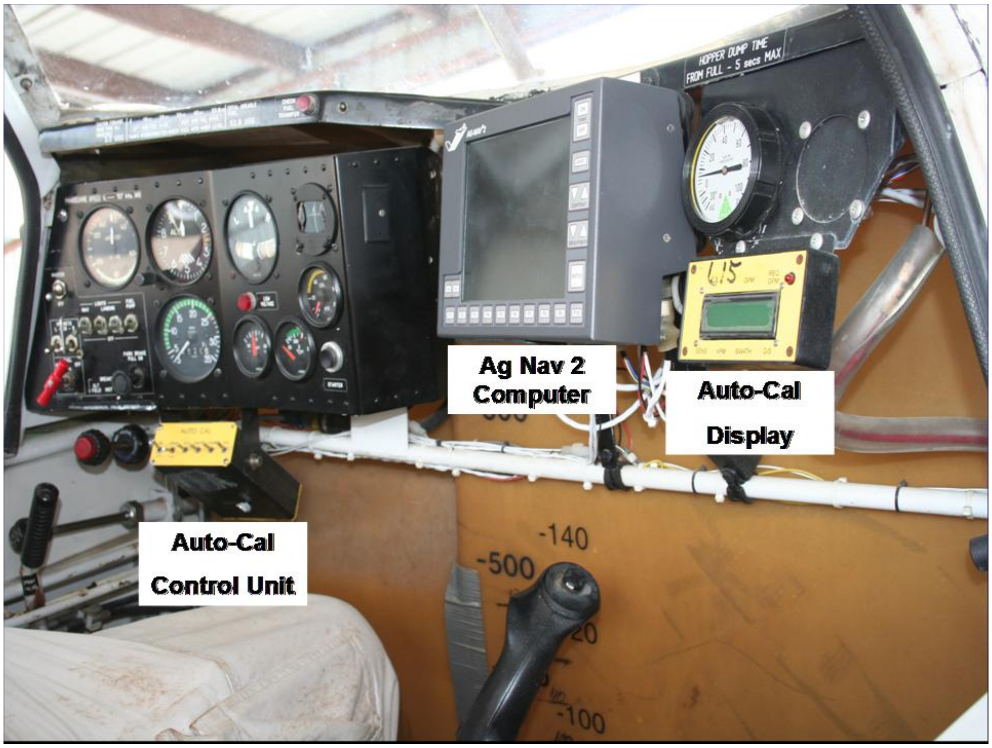


**Fig. 9. View of the GA 200 aircraft console illustrating the flow control unit, calibration display, and on-board computer.**

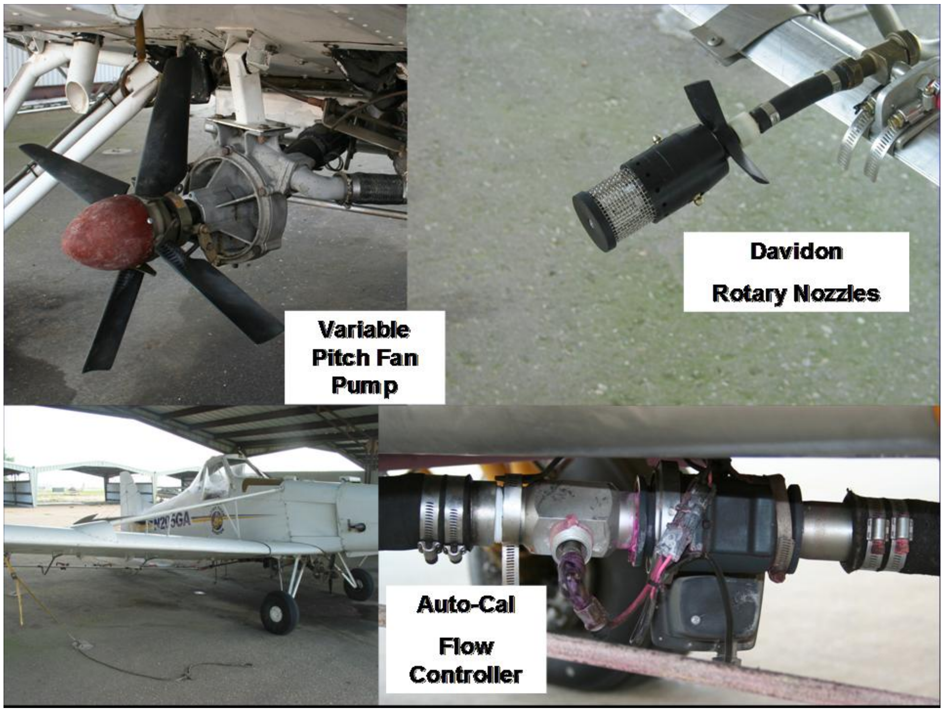


**Fig. 10. External views of the GA 200 aircraft illustrating the variable pitch fan pump, rotary nozzles, and Auto-Cal flow controller.**

The Thrush aircraft (Fig. 11) uses a turbine engine and has a payload capacity of 1500 L. The Thrush was equipped with Davidon rotary nozzles calibrated to deliver 9.36 to 46.93 L of total spray volume per hectare, a Trimble AgGPS 170 computer system, a Trimble GPS, an Auto-Cal flow controller, and a variable pitch electric fan pump. Prescriptions were loaded on to the AgGPS 170 computer system using standard compact flash (CF) memory cards. As applied data (Fig. 12) was downloaded after each insecticide application and compared to the actual prescription to verify proper function of the pesticide delivery system in the treated grids.

**Fig. 11. The Thrush aircraft used to apply SVI treatments.**

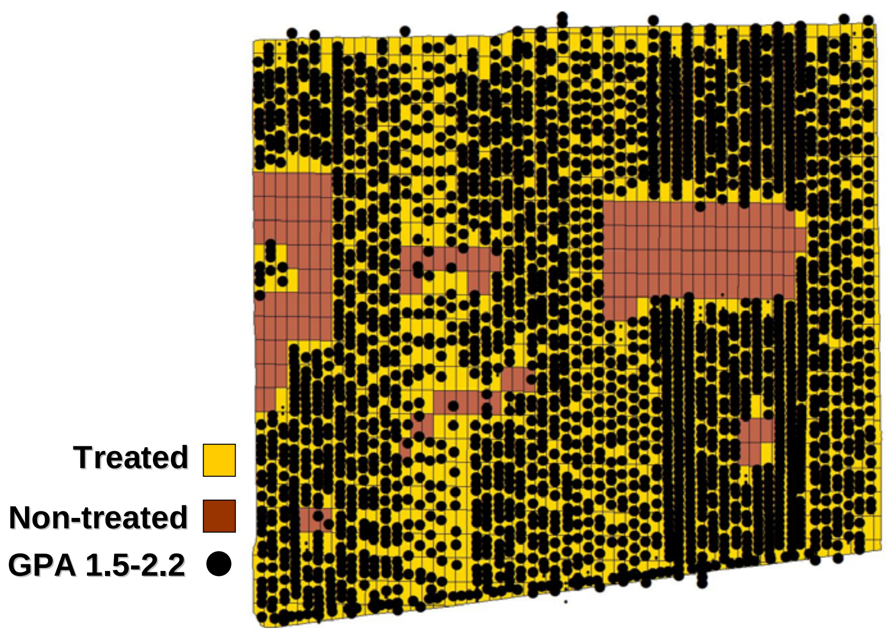


**Fig. 12. As-applied data recorded during one application of a SVI treatment.**

Treatment efficacy was determined with site-specific yield data collected from each plot using mechanical cotton harvesters equipped with yield monitors. Whole plot treatment means were analyzed using SAS 9.1.3. Data was subjected to analysis of variance procedures (ANOVA) (PROC Mixed, SAS Institute 1998) and means compared according to Tukey's Studentized Range Test (P=0.05). Post-harvest data was then further processed in ArcView 3.3 to remove all data points that were in the range of normal-yielding or profitable regions of the field (zones treated with insecticide in SVI-Plots) based on previous yield and crop profit data. Post-harvest yield data from the treatment grids defined as low-yield zones (Fig. 13) were compared among treatments using ANOVA and means were separated with Tukey's Studentized Range Test (P=0.05). The low yielding zones would not have been treated in the SVI yield treatments, but would have been treated in the broadcast treatment.

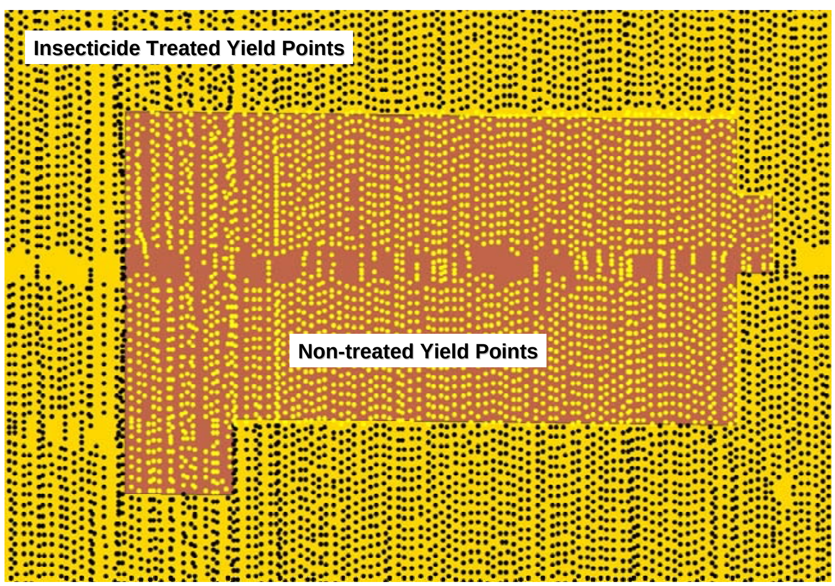


**Fig. 13. A portion of a yield map highlighting yield points that fell in a non-treated portion of the field.**

This analysis gives a direct comparison of yields for similar grids in a treated versus non-treated environment. The same procedure was followed for the zones considered unprofitable zones of the field. Yields were compared using ANOVA and means were separated with Tukey's Studentized Range Test (P=0.05). The zones defined as unprofitable would not have been sprayed in the SVI profit treatments, but would have been sprayed in the whole-field broadcast treatment. Post-harvest profit maps were developed and compared with historical maps.

Pre- and post-treatment insect pest numbers were documented and recorded using hand-held computers (Fig. 14) equipped with GPS receivers and Scoutlink software (Bayer Crop Science US, Research Triangle Park, NC). The primary pest sampled across the test area included tarnished plant bugs and numbers were determined using a standard 1 m X 1 m shake cloth.

**Fig. 14. Sampling for cotton insect pests and data entry into the handheld GPS computer.**

Tarnished plant bug samples consisted of two drops per field sample site for a total of 4 row m. Shake cloths were opened between two rows, and all plants on both sides of the row were shaken onto the cloth. This process was repeated, and total Tarnished plant bug numbers were calculated and recorded on the handheld-computer. GPS coordinates were recorded at each sample location. Site-specific navigation to insecticide-treated and non-treated grids was accomplished with prescription maps displayed on the handheld GPS computers. Tarnished plant bugs (Fig. 15) were sampled at sites in the normal and low-yielding grids of the broadcast, SVI yield, and SVI profit treatments. We were unable to sample post-treatment insect densities after all applications because of insecticide timing, irrigation schedules, weather events, and lack of sufficient scouts to check all plots thoroughly. The agriculture consultant was satisfied with application efficacy after all insecticide sprays though.

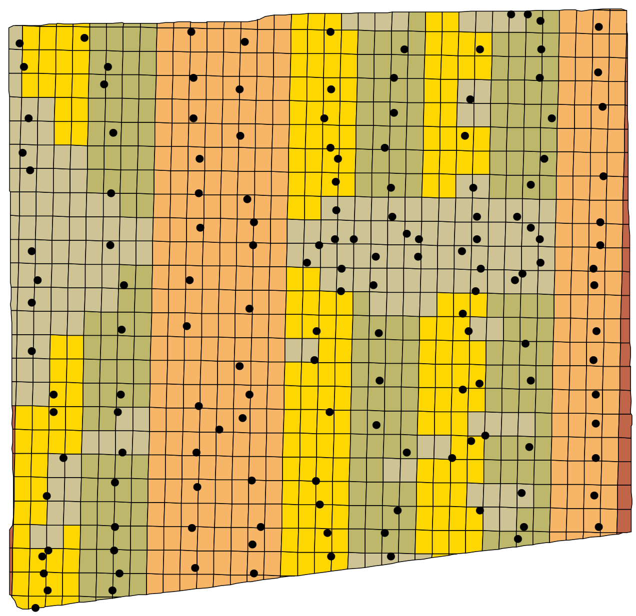

**Fig. 15. Map of sampling sites for tarnished plant bugs in the insecticide-treated and non-treated zones.**

Insect pest data was transferred to a desktop computer using Scoutlink 3.2 software. Data was then converted to a text file in Excel (Microsoft, Bellevue, WA). The text file data was imported into ArcView 3.3 and layered onto the field prescription. Samples sites were associated with the spray zone (on/off) and treatment zone (broadcast, SVI yield, and SVI profit). Data was exported in a tab-delimited text file format and imported into SAS 9.1.3. Insect data in the whole plots of each treatment were subjected to ANOVA. Treatment means were compared with Tukey's Studentized Range Test (P=0.05). Insect density data was further segregated based on insecticide treated or non-treated zones. Insect samples within the non-treated portions of the SVI yield/profit plots and in low-yielding/low-profit regions of the broadcast treatment (insecticide treated) were subjected to ANOVA. Treatment means were compared with Tukey's Studentized Range Test (P=0.05) to determine if non-treated zones had higher insect pest densities post-treatment.

## RESULTS

### 2002 Experiment

Three SVI applications based upon a site-specific prescription (Fig. 16) developed from historical yield data were successfully used to treat the test field during 2002. The prescription discriminated between zones considered high-yielding and zones that were low-yielding.

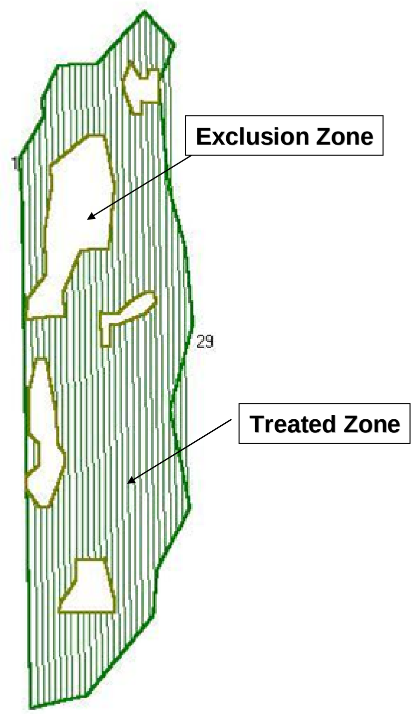


**Fig. 16. Ag-Nav prescription for 2002 applications.**

Approximately 30,000 yield points were analyzed to estimate whole-plot treatment means for cotton lint yield during 2002. There were no statistical differences ($F = 0.11$; $df = 1, 2$; $P = 0.77$) in whole plot lint yields between the broadcast and SVI yield treatments. Whole plot mean yields were 815 kg lint/hectare in the broadcast treatment and 807 kg lint/hectare in the SVI yield treatment (Table 1). The SVI prescription reduced the amount of insecticide-treated area by 20% compared with the broadcast treatment. The actual foliar insecticide cost for each treatment was $54/hectare in the broadcast treatment and $42/hectare in the SVI yield treatment. Post-treatment insect numbers were below measurable levels after each insecticide application in 2002.

**Table 1. Whole plot lint yields (mean±SE), percentage of hectares treated, and foliar insecticide costs per hectare during 2002.**

| Treatment | Lint yield kg/hectare[1] | % hectares treated | Cost ($)/hectare[2] |
|---|---|---|---|
| Broadcast | 815±10.99a | 100 | 54 |
| SVI yield | 807± 8.78a | 80 | 42 |

[1]Means within columns followed by a similar letter are not significantly different according to Tukey's Studentized Range Test (P=0.05).
[2] Total foliar insecticide cost for three applications.

**2003 Experiment**

Five insecticide applications were made to the test field using the SVI insecticide prescription and the aerial application system during 2003 (Fig. 17).

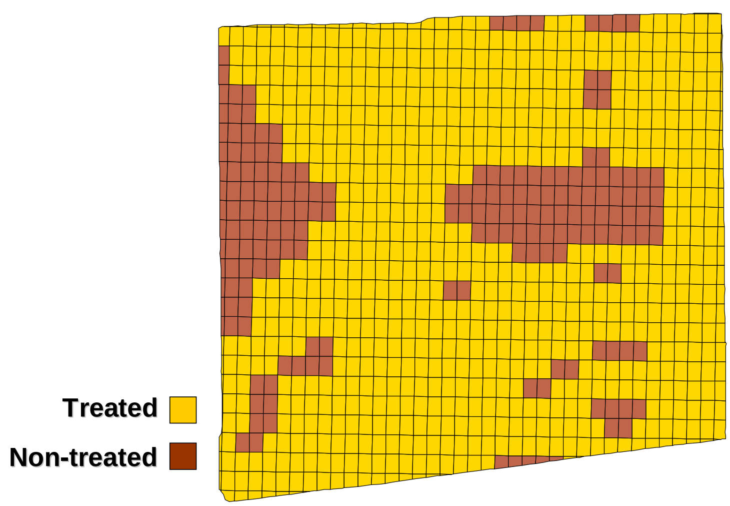


**Fig. 17. SVI prescription indicating treated and non-treated zones, 2003.**

Approximately 37,500 yield points were analyzed to estimate whole-plot treatment means for cotton lint yield during 2003. Lint yields for the whole-plot analysis were 983, 944, and 932 kg lint/hectare in the broadcast, SVI yield, SVI profit treatments, respectively (Table 2). There were no significant differences among treatment yields in 2003 (F = 1.24; df = 2, 4; P = 0.38). The costs of foliar insecticides for five applications of the treatments were $104, $69, and $77/hectare in the broadcast, SVI yield, and SVI profit treatments, respectively. Only 68 and 75% of the areas received sprays in the SVI yield and SVI profit treatments, respectively, compared to 100% of the area treated in the broadcast treatment (producer standard).

**Table 2. Whole-plot lint yields (mean±SE), percentage of hectares treated, and foliar insecticide costs per hectare during 2003.**

| Treatment | Lint yield kg/hectare[1] | % hectares treated | Cost ($)/hectare[2] |
|---|---|---|---|
| Broadcast | 983±15.21a | 100 | 104 |
| SVI yield | 944±48.10a | 68 | 69 |
| SVI profit | 932±36.51a | 75 | 77 |

[1]Means within columns followed by a similar letter are not significantly different according to Tukey's Studentized Range Test (P=0.05).
[2] Total foliar insecticide cost for five applications.

Additional analyses of lint yields were performed by isolating specific yield points within the low-yielding and non-profit zones within each treatment. This procedure allowed a direct comparison of yields from the insecticide-treated and non-treated areas among similar management (yield and profit) zones. For low-yielding zones, the SVI yield treatment produced 858 kg lint/hectare (Table 3) compared to 924 kg lint/hectare for the broadcast treatment (F = 3.09; df = 2, 4; P = 0.15). The zones defined as low-yielding in the SVI yield treatment received no insecticide sprays during the growing season. The broadcast treatment received five applications across all zones, regardless of yield potential. The non-profit zones of the SVI profit treatment produced 806 kg lint/hectare compared to 910 kg lint/hectare (F = 2.53; df = 2, 4; P = 0.20) for the non-profit zones of the broadcast treatment. The areas defined as non-profit zones in the

SVI profit treatment received no insecticide applications compared to five insecticide applications in the non-profit-zones of the broadcast treatment.

**Table 3. Treatment yields (mean±SE) for low-yielding and non-profit zones during 2003.**

| Low-Yielding Zones | | Non-Profit Zones | |
|---|---|---|---|
| **Treatment** | **Lint yield kg/hectare[1]** | **Treatment** | **Lint yield kg/hectare[1]** |
| Broadcast | 924±26.72a | Broadcast | 910±46.88a |
| SVI yield | 858±7.85a | SVI profit | 806±43.99a |

[1]Means within columns followed by a similar letter are not significantly different according to Tukey's Studentized Range Test (P=0.05).

Numbers of tarnished plant bug exceeded the ET according to the agricultural consultant and triggered all insecticide applications during 2003. There were no significant differences in post-treatment insect numbers among treatments on 24 Jul (F = 0.93; df = 2, 4; P = 0.39), 5 Aug (F = 1.58; df = 2, 4; P = 0.21), and 13 Aug (F = 1.63; df = 2, 4; P = 0.20) for the whole-plot samples (Table 4). There also were no significant differences in post-treatment insect numbers on 24 Jul (F = 1.06; df = 2, 4; P = 0.35), 5 Aug (F = 0.52; df = 2, 4; P = 0.60), and 13 Aug (F = 1.33; df = 2, 4; P = 0.29) when comparing non-treated areas in the SVI yield and SVI profit to insecticide-treated areas in the broadcast that were defined as and low yielding/non-profitable management zones (Table 5). Post-treatment insect numbers remained below action thresholds in all sampling dates in the non-treated zones of the field.

**Table 4. Post-treatment tarnished plant bug numbers (mean±SE) for whole-plot samples during 2003.**

| Date | Treatment | No. of Insects[1]/4 row m |
|---|---|---|
| 24-Jul | SVI yield | 0.63±0.17a |
| | SVI profit | 0.62±0.11a |
| | Broadcast | 0.44±0.01a |
| 5-Aug | SVI yield | 2.09±0.20a |
| | SVI profit | 2.23±0.57a |
| | Broadcast | 1.21±0.14a |
| 13-Aug | SVI yield | 1.38±0.22a |
| | SVI profit | 1.40±0.50a |
| | Broadcast | 0.56±0.27a |

[1]Means within columns followed by a similar letter within each sample date are not significantly different according to Tukey's Studentized Range Test (P=0.05).

**Table 5. Post-treatment tarnished plant bug numbers (mean±SE) for non-treated low-yielding and non-profit zones in the SVI strategies and treated low-yielding and non-profit zones of the whole-field broadcast treatments during 2003.**

| Date | Treatment | No. of Insects[1]/4 row m |
|---|---|---|
| 24-Jul | SVI yield | 0.85±0.30a |
| | SVI profit | 0.45±0.18a |
| | Broadcast | 0.29±0.14a |
| 5-Aug | SVI yield | 2.95±0.17a |
| | SVI profit | 3.30±0.69a |
| | Broadcast | 1.50±0.58a |
| 13-Aug | SVI yield | 2.00±0.14a |
| | SVI profit | 1.63±1.15a |
| | Broadcast | 0.34±0.28a |

[1]Means within columns followed by a similar letter within each sample date are not significantly different according to Tukey's Studentized Range Test (P=0.05).

## 2004 Experiment

Six insecticide treatments were applied using a site-specific insecticide prescription during 2004 (Fig.18).

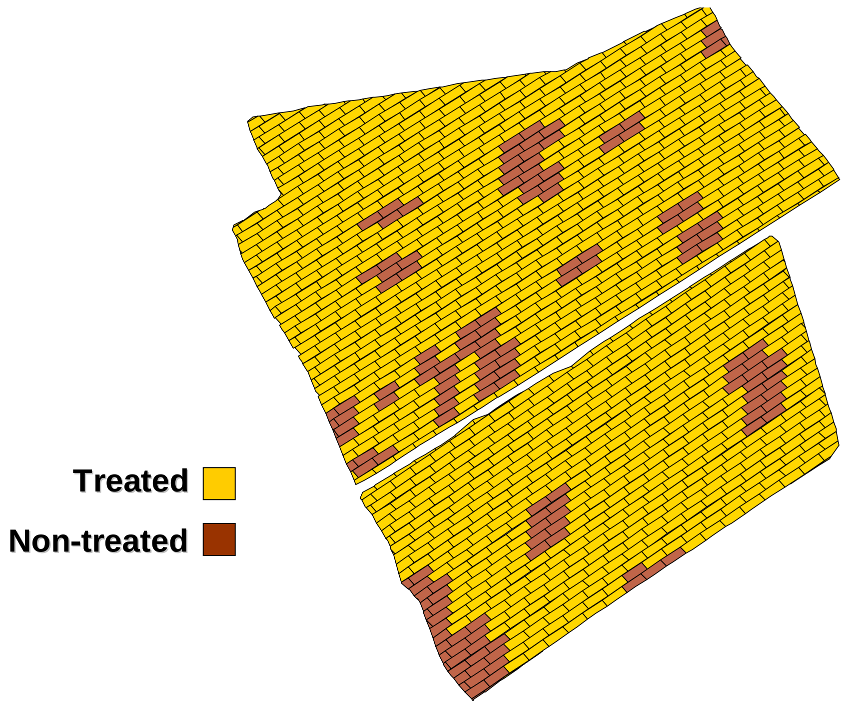


**Fig. 18. SVI prescription indicating treated and non-treated zones, 2004.**

The analysis of whole-plot treatment means for cotton lint yield included approximately 42,000 yield points. There were no significant differences among treatment yields in 2004 ($F = 0.22$; $df = 2, 4$; $P = 0.80$). Cotton yields for the whole-plots were 750, 744, and 765 kg lint/hectare in the broadcast, SVI yield, and SVI profit treatments, respectively (Table 6). The insecticide costs for the 2004 growing season was $102, $81, and $79/hectare in the broadcast, SVI yield, and SVI profit treatments, respectively (Table 6). Only 84 and 82% of the area received treatment with insecticides in the SVI yield and SVI profit plots, respectively.

**Table 6. Whole plot lint yields (mean±SE), percentage of hectares treated, and foliar insecticide cost per hectare during 2004.**

| Treatment | Lint yield kg/hectare[1] | % hectares treated | Cost ($)/hectare[2] |
|---|---|---|---|
| Broadcast | 750±12.89a | 100 | 102 |
| SVI yield | 744±14.02a | 84 | 81 |
| SVI profit | 765±33.18a | 82 | 79 |

[1]Means within columns followed by a similar letter are not significantly different according to Tukey's Studentized Range Test (P=0.05).
[2]Total foliar insecticide cost for six applications.

The specific analysis comparing results for the low-yielding and non-profit zones among treatments was similar to the 2003 test (Table 7). The low-yielding zones of the SVI yield plots produced 620 kg lint/hectare compared to 612 kg lint/hectare for the same low-yielding zones defined in the broadcast plots ($F = 0.88$; df = 2, 4; $P = 0.48$). These low-yielding zones in the SVI yield treatment received no insecticide during the growing season, but the similar classified zones received six applications. The non-profit zones in the SVI profit plots produced 684 kg lint/hectare compared to 668 kg lint/hectare for the broadcast plots ($F = 0.16$; df = 2, 4; $P = 0.86$). The zones defined as low profit in the SVI profit plots received no insecticide applications compared to six insecticide applications in zones of similar classification in the broadcast treatment.

**Table 7. Treatment yields (mean±SE) for low-yielding and non-profit zones of the field during 2004.**

| Low-Yielding Zones | | Non-Profit Zones | |
|---|---|---|---|
| Treatment | Lint yield kg/hectare[1] | Treatment | Lint yield kg/hectare[1] |
| Broadcast | 612±17.06a | Broadcast | 668±20.30a |
| SVI yield | 620±6.72a | SVI profit | 684±53.30a |

[1]Means within columns followed by a similar letter are not significantly different according to Tukey's Studentized Range Test (P=0.05).

Samples of tarnished plant bug exceeded action levels according to the agricultural consultant, prior to all insecticide applications in 2004. There were no significant differences in post-treatment insect numbers among treatments on 30 Jun (F = 0.28; df = 2, 4; P = 0.75), 12 Jul (F = 0.67; df = 2, 4; P = 0.51), and 19 Jul (F = 0.75; df = 2, 4; P = 0.47) for the whole plot samples (Table 8). There also were no significant differences in post-treatment insect numbers on 12 Jun (F = 0.56; df = 2, 4; P = 0.58) comparing insect pests in the non-treated zones in the SVI yield and SVI profit treatments to the same zones in the broadcast treatment (Table 9). No analysis was performed on data recorded from the non-treated zones on 12 Jul and 19 Jul, because insect numbers were insufficient (< 5 sample sites with insects present). Post-treatment insect numbers remained below action thresholds on all sampling dates in the non-treated zones in the SVI yield and SVI profit treatments.

**Table 8. Post-treatment tarnished plant bug numbers (mean±SE) for whole-plot samples during 2004.**

| Date | Treatment | No. of Insects[1]/4 row m |
|---|---|---|
| 30-Jun | SVI yield | 0.09±0.01a |
| | SVI profit | 0.13±0.01a |
| | Broadcast | 0.08±0.03a |
| 12-Jul | SVI yield | 0.75±0.14a |
| | SVI profit | 0.60±0.17a |
| | Broadcast | 0.90±0.18a |
| 19-Jul | SVI yield | 0.09±0.03a |
| | SVI profit | 0.08±0.03a |
| | Broadcast | 0.14±0.02a |

[1]Means within columns followed by a similar letter within each sample date are not significantly different according to Tukey’s Studentized Range Test (P=0.05).

**Table 9. Post-treatment insect numbers (mean±SE) for non-treated low-yielding and non-profit zones in the SVI strategies and treated low-yielding and non-profit zones of the whole-field broadcast treatments during 2004.**

| Date | Treatment | No. of Insects[1]/4 row m |
|---|---|---|
| 12-Jun | SVI yield | 0.80±0.29a |
| | SVI profit | 0.60±0.39a |
| | Broadcast | 0.21±0.09a |

[1]Means within columns followed by a similar letter are not significantly different according to Tukey's Studentized Range Test (P=0.05).

## 2005 Experiment

Eight insecticide treatments were applied to the test field using a site-specific insecticide prescription during 2005 (Fig. 19).

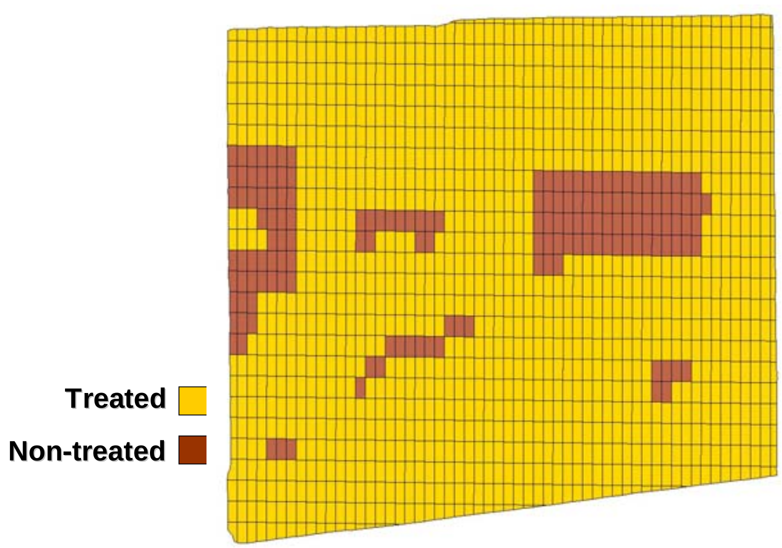


**Fig. 19. SVI prescription indicating treated and non-treated zones, 2005.**

The whole-plot treatment means for cotton lint yields were estimated using approximately 45,200 yield points. Lint yields from the whole-plot analysis were 1121, 1058, and 1109 kg lint/hectare in the broadcast, SVI yield, and SVI profit treatments, respectively (Table 10). There were no significant differences in yields among treatments (F = 1.72; df = 2, 4; P = 0.29).

Foliar insecticide costs for the 2005 growing season were $121, $94, $101/hectare in the broadcast, SVI yield, and SVI profit treatment, respectively (Table 10). In the broadcast treatment, 100% of the area was treated. Only 78 and 87% of the area received treatment with insecticides in the SVI yield and SVI profit treatments, respectively.

**Table 10. Whole-plot lint yields (mean±SE), percentage of hectares treated, and foliar insecticide cost per hectare during 2005.**

| Treatment | Lint yield kg/hectare[1] | % hectares treated | Cost ($)/hectare[2] |
|---|---|---|---|
| Broadcast | 1121±31.75a | 100 | 121 |
| SVI yield | 1058±44.92a | 78 | 94 |
| SVI profit | 1109±16.59a | 87 | 101 |

[1]Means within columns followed by a similar letter are not significantly different according to Tukey's Studentized Range Test (P=0.05).
[2]Foliar insecticide cost for eight applications.

The specific analysis comparing results for the low-yielding and non-profit zones was similar to the 2003 and 2004 experiments (Table 11). The low-yielding zones of the SVI yield treatment produced 901 kg lint/hectare compared to 1023 kg lint/hectare for the same low-yielding zones defined in the broadcast treatment (F = 3.91; df = 2, 4; P = 0.11). These low-yielding zones in the SVI yield treatment received no insecticide during the growing season, while the similar classified zones in the whole field broadcast treatment received eight applications. The non-profit zones in the SVI profit treatment produced 1036 kg lint/hectare compared to 1041 kg lint/hectare for the broadcast treatment (F = 0.16; df = 2, 4; P = 0.86). The zones defined as non-profit in the SVI profit treatment received no insecticide applications compared to six insecticide applications in zones of similar classification in the broadcast treatment.

**Table 11. Treatment yields (mean±SE) for low-yielding and non-profit zones of the field during 2005.**

| Low-Yielding Zones | | Non-Profit Zones | |
|---|---|---|---|
| **Treatment** | **Lint yield kg/hectare[1]** | **Treatment** | **Lint yield kg/hectare[1]** |
| Broadcast | 1023±59.36a | Broadcast | 1041±57.82a |
| SVI yield | 901±33.67a | SVI profit | 1036±23.84a |

[1]Means within columns followed by a similar letter are not significantly different according to Tukey's Studentized Range Test (P=0.05).

Samples of insect pests exceeded action levels according to the agricultural consultant prior to all insecticide applications in 2005. There were significant differences in post-treatment insect numbers among treatments on 30 Jun ($F = 3.97$; $df = 2, 4$; $P = 0.02$), 20 Jul ($F = 6.27$; $df = 2, 4$; $P < 0.01$), and 4 Aug ($F = 7.33$; $df = 2, 4$; $P < 0.01$) in the whole-plot analysis (Table 12). Tarnished plant bug numbers were higher in the SVI profit compared to the broadcast on 30 Jun. Tarnished plant bug numbers were higher in the SVI yield compared to the broadcast and SVI profit treatments on 20 Jul and 4 Aug, respectively. On these dates, the post-treatment tarnished plant bug numbers remained below action threshold in all treatments though.

There were significant differences in post-treatment insect numbers on 4 Aug ($F = 5.03$; $df = 2, 4$; $P < 0.01$) among the non-treated zones in the SVI yield and SVI profit treatments compared to those in the zones of the same classification that were insecticide-treated in the broadcast treatment (Table 13). Similar to the whole-plot results, post-treatment insect numbers remained below action thresholds. There were no significant differences in insect numbers on 30 Jun ($F = 1.28$; $df = 2, 4$; $P = 0.28$) and 20 Jul ($F = 0.92$; $df = 2, 4$; $P = 0.41$) among the non-treated zones in the SVI yield and SVI profit treatments to similar classified zones that were treated in the broadcast treatment.

**Table 12. Post-treatment tarnished plant bug numbers (mean±SE) for whole-plot samples during 2005.**

| Date | Treatment | No. of Insects[1]/4 row m |
|---|---|---|
| 30-Jun | SVI yield | 0.42±0.16ab |
| | SVI profit | 0.64±0.25a |
| | Broadcast | 0.10±0.10b |
| 20-Jul | SVI yield | 2.21±0.46a |
| | SVI profit | 1.00±0.21b |
| | Broadcast | 0.70±0.12b |
| 4-Aug | SVI yield | 0.90±0.30a |
| | SVI profit | 0.19±0.02b |
| | Broadcast | 0.15±0.01b |

[1]Means within columns followed by a similar letter within each sample date are not significantly different according to Tukey's Studentized Range Test (P=0.05).

**Table 13. Post-treatment tarnished plant bug numbers (mean±SE) for non-treated low-yielding and non-profit zones in the SVI strategies and treated low-yielding and non-profit zones of the whole-field broadcast treatment during 2005.**

| Date | Treatment | No. of Insects[1]/4 row m |
|---|---|---|
| 30-Jun | SVI yield | 0.52±0.24a |
| | SVI profit | 0.00±0.00a |
| | Broadcast | 0.15±0.08a |
| 20-Jul | SVI yield | 2.10±0.50a |
| | SVI profit | 1.33±0.32a |
| | Broadcast | 1.25±0.38a |
| 4-Aug | SVI yield | 1.35±0.41a |
| | SVI profit | 0.36±0.17b |
| | Broadcast | 0.22±0.06b |

[1]Means within columns followed by a similar letter within each sample date are not significantly different according to Tukey's Studentized Range Test (P=0.05).

## DISCUSSION

These studies are the first to evaluate SVI applications based on prescriptions developed with site-specific yield history and profitability of cotton. There were no significant reductions in cotton yields using SVI strategies (SVI yield and SVI profit) compared to broadcast whole-field applications (producer standard) of insecticides during the four years of experiments. A reduction in total insecticide use and insecticide cost relative to broadcast applications were accomplished with the SVI strategies at levels of 13-32% and $12-35/hectare, respectively. The average reduction in insecticide costs over broadcast applications was $24/hectare for these experiments. The opportunity to reduce production inputs with no adverse affects on cotton yields can significantly improve the profitability of cotton production and reduce the pesticide load in the environment. SVI technologies likely will be a valuable tool for cotton producers in the future.

These results suggest that insect pests are not the primary factor limiting cotton yields across the test fields. Zones of the field classified as low-yielding and low-profit did not appear to benefit from insecticide applications in broadcast-treated plots. Post-treatment insect pest numbers in non-treated zones were rarely higher than numbers in insecticide-treated areas of similar classified zones. Post-treatment insect numbers in these experiments appeared to be below the economic action thresholds for Louisiana cotton production (Bagwell et al. 2006). The non-treated zones in the SVI yield and SVI profit treated plots were embedded within insecticide-treated zones. Non-treated zones varied in size (0.25-8.15 hectares), and insect pest populations within these zones may have been influenced by the insecticide applications. Impact of sprays on insect pests in the non-treated zones could be partially attributed to the surrounding zones being sprayed and migration of insects into these areas from adjacent areas may have been reduced. Blom et al. (2002) reduced whole-field Colorado potato beetle densities by spraying only the borders of the field.

Insect pest behavior related to intra-field variability in plant development may also be related to effects on final yields. Insect pests may not prefer to infest or injure plants located in the cotton production zones defined as low-yielding or non-profitable. Plants in these zones are generally less vigorous, with reduced height, or fewer fruiting forms than plants from high-yielding zones. Willers et al. (2005) showed that tarnished plant bugs are least likely to be found in poor to marginal cotton growth zones compared to higher crop vigor zones. Willers et al. (1999) concluded that tarnished plant bugs were more commonly found in the most vigorously growing portions of cotton fields, and suggested that they selected these zones of the field over less vigorously growing areas. There are a number of yield-limiting factors that are not attributed to insect pests. These factors include water stress, lack of nutrients, weed or disease pressure, and poor drainage (Rains and Thomas 2000). The fields used in these studies were observed to have considerable variability in topography and drainage (Fig. 20). At least one of the yield and profit-limiting factors in these studies was lack of drainage in low-lying areas of the fields that restricted plant development. This problem likely magnified other crop production practices such as irrigation efficiency, nutrient availability, and disease susceptibility. This study relied upon intra-field variability of yield to generate prescriptions for insect pest management strategies. There are other types of data that estimate intra-field variability of plant growth that have been used to develop prescriptions for variable rate inputs of crop production products.

**Fig. 20. Aerial imagery of fields at Somerset Plantation showing the variability in topography.**

Several studies have used remotely-sensed imagery (NDVI) as a basis for SVI applications. NDVI maps have been successfully used in applying SVI treatments to tarnished plant bugs (Willers et al. 1999). Additionally NDVI-based SVI treatments have been shown to reduce total insecticide use by approximately 40% compared to broadcast applications in cotton (Dupont et al. 2000). Site-specific insecticide applications based on NDVI imagery were used by Sudbrink et al. (2002) to reduce insecticide inputs by 20 to 35% when compared to conventional broadcast treatments. Fridgen et al. (2002) used remotely-sensed NDVI imagery to create field maps detailing highly probable areas associated with tarnished plant bug infestations. SVI treatments reduced the total amount of insecticide (44%) without significantly reducing yields compared to broadcast treatments. Similar results were observed in this study by decreasing insecticide inputs from 13 to 32% using historical yield and crop profit data as the basis for the prescriptions without negatively affecting yields.

The concept of using insecticides in prescription applications should be compatible with IPM chemical control strategies. The principles of IPM require an effective sampling protocol and the use of insecticides when economic action levels are reached (Headley 1972). Therefore, these treatments must consider the temporal nature of pest populations as well as crop development stages. The economic action and injury thresholds also recognize cost of chemical control strategies, value of crop loss, and the estimated benefit of insect pest control with insecticides. The tools of precision agriculture can provide an economic analysis of historical yield data and define the non-profitable zones within a field. If economic action thresholds are used to apply insecticides, non-profitable zones would not receive treatments. The use of spatially-defined prescriptions and variable rate technologies allows producers to selectively apply inputs to areas of a field. This strategy can provide an economic benefit by not applying treatments to zones where no economic benefit is attainable. Using SVI prescriptions that do not treat non-profitable zones of the field may ultimately enhance profitability of those zones by reducing unnecessary input costs. This is possible even if yields in these zones remain unaffected.

The results of this study provide producers a short-term solution by reducing insect management input costs associated with cotton production. These studies may be applicable to decisions related to other crop inputs such as herbicides, fertilizers, nematicides, plant growth regulators, harvest aids, and seeding rates. The use of fewer inputs in historically non-profitable regions can potentially reduce the high cost of cotton production. Ideally, producers should attempt to identify underlying reasons for specific field zones producing low yields, and make attempts to rectify those problems. However, some field corrections may not be practical or cost-effective. An alternate option is for producers to leave fallow non-profitable zones that are incapable of production levels that will offset input costs.

One of the concepts of prescription applications that can be used to correct an agricultural production problem requires that sources of intra-field variability that can be spatially located and geographically defined. This study demonstrated that historical yield and crop profit data may be used as a basis for developing site-specific prescriptions for insecticide applications. These results show that SVI strategies, based upon intra-field variability of yields and/or profit, could be used as a feasible model to refine production inputs such as insecticides. Reducing insecticide-treated acreage improves environmental stewardship and supports the general principles of IPM by temporally and spatially restricting insecticide use strategies. SVI treatments can be used to moderate insect pest management costs and should contribute to the integration of precision agricultural technologies into current cotton IPM strategies.

## SUMMARY AND CONCLUSIONS

Louisiana cotton producers are constantly evaluating new tools and techniques to increase the efficiency, productivity, and profitability of their farming operations. Most agricultural fields in Louisiana have inherent variability in soil type, nutrient availability, or drainage that results in spatial variability of crop yields. Knowledge of this within-field variability allows producers to identify and characterize the site-specific management needs for an individual field or management zones within a field. Producers can quantify intra-field variability in crop growth and yield, characterize zones with similar productivity potential, and apply variable rates of inputs such as pesticides, fertilizers, and seeding rates based on this variability. Precision agricultural technologies and site-specific management strategies allow producers to differentially target crop production inputs to those fields or management zones that are likely to provide the greatest benefits.

Insect pest management still represents one of the greatest variable expenses incurred by a cotton producer in Louisiana. Cotton integrated pest management (IPM) utilizes chemical control strategies for insects by targeting only those populations that exceed an economic action level to initiate treatment. Currently, there are precision agricultural technologies available that can be adapted for site-specific management of insect pests and add a spatial component to cotton IPM. By restricting insect pest management inputs only to the management zones in a field that have the potential to produce profitable yields, producers should be able to more efficiently manage pests. A limited scope of previous research has attempted to develop prescriptions and implement site-specific strategies using precision agricultural technologies for cotton pest management. The goals of this project were to evaluate the use of geo-referenced crop yield and profit data in creating intra-field pest management zones, and to make spatially variable insecticide (SVI) applications to these pest management zones.

During 2002 to 2005, SVI prescriptions were developed from historical yield and crop profit maps of cotton fields located on Somerset Plantation near Newellton, Louisiana. Twenty-two site-specific applications were applied to pest management zones within those fields using two commercial aircraft equipped with variable rate application equipment. These studies compared the efficacy and value of SVI applications to conventional broadcast applications. The SVI treatments used site-specific prescriptions that discriminated between high (≥ 768 kg lint/hectare) and low yield zones (≤768 kg lint/hectare, and profitable (≥$0 hectare) and non-profitable zones (≤ $0 hectare). The SVI treatments reduced insect pest management costs compared to the cost associated with whole-field broadcast treatments, without significantly impacting crop yields. Lint yields in both of the SVI-treatments (yield- or profit-based) plots were not significantly different (P=0.11-0.86) from that in the whole-field broadcast-treated treatments. Lint yield for the four years of experiments ranged from 612-1121 kg lint/hectare. The SVI treatments reduced insecticide-treated hectares by 13% to 32% compared to the whole-field broadcast treatment. Insecticide cost reductions ranged from $12 to $35 per hectare depending on application frequency, and SVI strategy.

Post-treatment surveys of insect pests in the non-treated areas of the SVI-treated plots indicated the presence of insect pests, but population numbers were consistently below the economic action threshold for Louisiana cotton. The primary pest sampled in these test was the tarnished plant bug. Tarnished plant bug densities post treatment ranged from 0.01 to 2.20 bugs/4m row. Based on these results, insect pests were not the primary yield-limiting factor in the historically low yielding or non-profitable areas of these cotton fields. There are a number of yield limiting factors not associated with insect pests. These factors include water stress, lack of nutrients, weed or disease pressure, and poor drainage. The fields at Somerset Plantation used to compare the SVI and broadcast treatments have considerable variability in topography and drainage. Therefore, at least one of the yield and profit limiting factors was lack of drainage in low-lying zones of the fields. Other crop production factors such as irrigation efficiency, nutrient availability, and plant susceptibility to diseases were magnified by the drainage problem.

This research incorporated several tools of precision agriculture into a chemical control strategy for cotton insect pest. Variable rate applications of pesticides were successfully accomplished with an agricultural aircraft. Insect pest management zones for reducing insecticide requirements were successfully developed from crop yield and profitability maps. Site-specific prescriptions and SVI technologies were validated as tools that producers can use to manage crop production costs in Louisiana cotton fields. These studies support the development of a spatial component to sampling protocols that are used in conventional cotton IPM used to initiate insecticide applications.

## FUTURE RESEARCH TO IMPROVE SVI

Considerable more work needs to be done in the area of precision agriculture and southern crops including cotton. Our results show that the precision agricultural techniques were used to reduce insecticide inputs in cotton. These results were for specific fields, on one farm, in one cotton production region of Louisiana. These methods may need to be adjusted based on location, intra-field variability and local farm economic factors to produce similar results.

Limited literature is still available on commercial variable rate application systems for aircraft. Tremendous opportunities for research exist on the accuracy of these systems, the limitations, and methods for developing aerial application prescriptions. The present studies were done during the initial development of these systems. Many associated problems occurred with g the aerial application equipment to perform at a level sufficient for scientific research. The data analysis on the accuracy of the system in these tests demonstrated inconsistencies and limitations that were difficult to overcome. The actual amount of insecticide predicted for the treated areas and the amount of insecticide used was within ± 5%. However, drift of the spray and lag time in turning the system on or off may have influenced the distribution of the insecticide at the intersection of the treated and non-treated areas. Future studies may need to consider the use of transition zones between treatments that take into account the speed and target dose of application equipment.

There is also an opportunity for more research on variable rate applications of other agronomic crop inputs (fertilizer, plant growth regulator, harvest aids) in Louisiana cotton, as well as other row crops. The yield monitoring technology provides an invaluable tool to inform producers that there are portions of fields that are not making profitable yields. Future precision agricultural research in Louisiana should consider using yield monitoring data to document intra-field variability and develop site-specific management zones for increasing yields, reducing input costs, and increase overall farm profitability and efficiency. Another area of research should examine the spatial and temporal variability of insect pest populations in southern row crops using GPS/GIS technologies. There are an infinite number of ways to use this technology in crop production and the author hopes that this project may serve as a model for future work in the many disciplines associated with row crop production.

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