SPATIALLY VARIABLE INSECTICIDE APPLICATIONS THROUGH REMOTE SENSING

J. K. Dupont, R. Campanella and M. R. Seal
ITD-Spectral Visions
Stennis Space Center, MS
J. L. Willers
USDA-ARS
Mississippi State, MS
K. B. Hood
Cotton Producer
Gunnison, MS

Abstract

With the price of everything in farming going up except the price of cotton, there is an urgency to develop ways to reduce rising costs of production. Many producers believe the answer to this problem will come through some method of precision farming, but early indications of what precision farming can offer remain vague. Research is being conducted at the Stennis Space Center, as part of NASA's Commercial Remote Sensing Program (CRSP) to address this issue. Supported by CRSP, Spectral Visions is exploring ways to use remote sensing in a large-scale production mode to predict where certain cotton pests (i.e., tarnished plant bugs, Heteroptera*:* Miridae) would gather and feed. Once identified, these areas can be represented in a prescription map to guide spatially variable insecticide applications. Working directly with researchers from the USDA, significant patterns have been detected in the way plant bugs respond to the non-uniformity of growth across cotton fields. Using certain wavelengths, multispectral imagery can routinely detect vegetation, and by using different vegetation indices, vigorous vegetation can be distinguished from less vigorous vegetation. Plant bugs prefer to feed on tender new squares found, at least early in the season, in the more healthy regions of a field and easily detected with remote sensing. These healthy areas are then rendered into an 'on/off' prescription map to be loaded into the controller of a GPS equipped ground sprayer. As the sprayer tracks across the field, the GPS signals its location to the controller and determines if it is in an area to be treated. The controller reacts accordingly by controlling an electronic valve that restricts or permits the insecticide flow. During the 1999 season, we achieved insecticide reductions of nearly 40%, saving money on insecticide costs and lessening the environmental impact.

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 are observed (Willers et al., 1999). Multispectral imagery fitted with the 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.

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Study Area

The research study area is a series of semi-contiguous fields totaling 1023 acres, ranging from 10 inches (ultra-narrow-row spacing) to 30- and 40-inch-row spacing of cotton, at Perthshire Farms in Bolivar County, Mississippi about 75 miles southwest of Memphis, Tennessee. Located on the floodplain between the Mississippi and Yazoo Rivers (i.e., the Mississippi Delta), the region is noted for its fertile alluvial soils and high cotton yields. Mr. Kenneth Hood, a nationally known cotton producer and co-owner of Perthshire Farms, graciously allowed the research team to pursue this and other experiments on the farm, while also providing them with his 40 years' worth of expertise in progressive cotton farming.

Methodology

As the crop approaches first square (usually about 45 days after planting) the need to address insect pressure becomes more urgent. Beginning in May 1999, imagery was acquired, on average, every 7-10 days. Using a recently acquired image to enhance our ability to determine sample sites and using a modified line-intercept sampling plan (Willers 1998; Willers et al., 1999), we began seeing the same patterns as previous years. The plant bugs are almost exclusively attracted to the more healthy regions of crop within the study fields. Since these areas are most likely to produce squares first and can be delineated by multispectral imagery, it is reasonable to use the 'image map' to spot spray these regions as an alternative to spraying an entire field (Fig. A). It should also be mentioned that, as on most farms, the soils are extremely variable across these study fields. These differences (along with elevation changes and poor drainage) result in differences in patterns of crop growth that are spatially non-uniform. With that in mind, across the 1023-acre study area, large areas have the potential to be less mature. These areas can be identified and mapped using remote sensing. A hard copy of the map can be used by field scouts to verify that these areas, lacking the tender food resources of the more healthy areas of the field, do not contain plant bugs in treatable numbers. Finally, a geo-referenced prescription map (based on feedback from both the scouting efforts and imagery) can be created to guide a GPS equipped spray rig. This is done by performing an NDVI on the 3-band image, and thresholding the output to exclude only those regions proven to be plant bug free, and recoding its digital values to zero. Areas shown to contain insects have their digital values recoded to one. As the GPS on the spray rig passes into one of these two areas, the controller reads its corresponding value; therefore, 1 = spray and 0 = no spray. This procedure was performed three to four times during the year, depending on the requirement of individual fields within the study site.

Another application issue that was explored during the course of the year was the application of plant growth regulator. This application came about as a result of the producer groundtruthing the insecticide prescriptions (Fig. B) and noticing that the areas our imagery picked out as insect habitat (i.e., the healthier and likewise taller cotton) were also areas that needed plant growth regulator. Plant growth regulator (PGR) is a chemical applied periodically during the growing season to inhibit vegetative growth (We also believe that proper use of PGR's to manage the canopy will also benefit insect control since a smaller canopy should be more easily penetrated by spray droplets). Upon instruction by the producer, we were able to mix the insecticide and the PGR together and apply the two using the same prescription map, adding yet another advantage, both economic and environmental, to spatially variable applications. By leaving slower growing areas untreated with plant growth regulator, these sparsely growing areas were able to catch up over the growing season and produce an average yield in places that, had PGR (e.g., PIX) been applied, would likely have been further stunted and produced little cotton. In the past, the producer would wait until most of a field was ready for PIX before distributing a blanket application. Consequently, the application would be too late in some areas and too early in other areas. With spatially variable applications it is possible to apply the full amount in the right places to manage canopy development. This is a very natural application of remote sensing that we intend to further explore in the 2000 growing season.

To assess the impact of the SVI vs. conventional approach to pest control several sites within each control strategy were selected for hand harvest. Using a GIS, sites were selected according to the following criteria: 1) irrigated or non-irrigated, 2) close to woods or far from woods, 3) SVI-sprayed or SVI-unsprayed, and 4) conventional-sprayed (or outside the SVI study areas). The UTM coordinates were posted by random selection of a point within the polygons that satisfied the above criteria. Thus, a site for yield assessment was objectively selected. Using a differentially corrected GPS, each site was located with the receivers navigation tool. At each site, all mature fruit were picked from 3 linear *ft* of row for each of 8 rows just prior to harvest, but after defoliation. Lint yield per acre was estimated for each site using the correction factors reported in Williams et al. (1995).

Omitting criterion (2) from above in the specification of the treatment structure used in the ANOVA, six yield classes were established with 5-7 observations (i.e., replications) per class. The classes were given the following labels: Class 1 = OUTSIDE SVI, NON-IRRIGATED; Class 2 = OUTSIDE SVI, IRRIGATED; Class 3 = SVI SPRAYED, NON-IRRIGATED; Class 4 = SVI SPRAYED, IRRIGATED; Class 5 = SVI, NO SPRAY, NON-IRRIGATED; and Class 6 = SVI, NO SPRAY, IRRIGATED. Each class was considered a fixed treatment effect in the ANOVA (Proc GLM, Littell et al., 1996). The yield expressed as bales/ac was the response variable. The rank transform procedure (Conover and Iman 1981) was applied to these yields prior to ANOVA. This transformation was deemed necessary due to the small sample sizes available per class and not as a procedure to stabilize variances (Mead 1988). A probability plot (King 1980) of the combined yields indicated that all samples were members of a similar population that was normally distributed.

Results and Discussion

Spatially variable insecticide approaches to pest control, driven by high-resolution multispectral imagery, offer several advantages. First, each application has the potential to achieve savings that range up to 40 – 60 % in amount of chemical applied, especially prior to peak bloom. Several times during 1999 large portions of the study fields required no protection against tarnished plant bugs. Sampling efforts confirmed that those areas of the crop where the imagery indicated least vigorous cotton plants, the plant bug population was far below economic levels (i.e., 545 plant bugs per acre). These areas also lagged far behind other areas of the crop with respect to the time of first square. Therefore, unsprayed areas used in the SVI prescription did not need chemical protection since squares were unavailable for plant bugs to feed upon. During June and July, areas that were sprayed in the SVI study area did have cotton that was vigorously growing and squaring rapidly. Also, scouting efforts found plant bugs present in these areas at economic numbers (i.e., in the range of 6-20 adults per 100 sweeps or nymphs that numbered more than 1500 per acre). For this study, populations of nymphs that numbered more than 1500 per acre were considered economic densities because during the three years prior to 1999 and in the same area used in this study, severe populations of plant bugs occurred soon after these densities were observed (Willers, unpublished). A decision was made prior to the first SVI application during 1999, that nymphal or adult populations more than 1500 per acre would result in a decision to treat. Neighboring fields on the farm that were not part of the SVI study would be managed according to traditional guidelines recommended in the Mississippi Control Guide (Layton 1999). During the season, only thrips reached economic levels prior to first square (requiring two applications with Orthene or Bidrin). During early July aphids reached levels that required a single application (Furadan). Thus, in this study only the tarnished plant bug was the cotton pest of record.

Many of the regions that through June and July were left unsprayed in the SVI study areas did produce squares after the first of August. However, by that time all fields on the farm, including the study sites, were managed by efforts related to the Boll Weevil Eradication Program. It was no longer necessary to employ any prescriptions for plant bug control once the eradication program began. Other pests, including Heliothines, remained below economic levels for the remainder of the year in nearly all areas of the SVI study sites.

There remain several analysis steps before a full economic evaluation of the benefits of SVI pest management can be fully evaluated. However, an early analysis comparing yield at selected locations within the SVI study area and within conventionally managed, nearby fields does indicate that a loss in yield did not occur using a reduced, spatially targeted approach to pest control. A one-way analysis of variance based upon the rank transformation procedure (Conover and Iman 1981) concluded that there is no significant difference in yield ($P = 0.9645$) among the treatment groups (Table 1). With this analysis, note that little use of the 'near or far' from woods criterion was made. In fact, a better criterion would have been soil textural classes. In future efforts this latter criterion will be employed. This preliminary data set, in both its acquisition and analysis portray the value (when available) of yield monitor data. We look forward to the dependable and widespread availability of spatially registered yield monitor data to evaluate most effectively alternate approaches to pest control of which SVI is a part.

Two additional figures also illustrate the difference between conventional and SVI approaches to pest control. We illustrate these issues using the 30-inch row spaced study area. In Fig. C, the timing of the broadcast applications during 1996 for tarnished plant bug control are stacked upon a gray scale image of a portion of the fields used during the 1999 SVI study. The figure illustrates at least four applications were applied and at intervals that were either far apart or close together. The last two applications occurred during the latter part of July 1996. Interestingly, the consultant records for these fields during 1996 indicated that the plant bug population was 'higher in the taller cotton'. The consultant was observing a spatial phenomenon in plant bug densities, but at that time had little recourse but to spray the entire field each time at a specified rate (i.e., Bidrin at 1 gal./ 20 ac. and at 5 gal./ac. [this rate is indicated by the thickness of each layer in Fig. C]).

The contrasting approach employed on the same area in 1999 is illustrated in Fig. D. The SVI pest management approach sprayed less acreage the first two times, slightly more acreage the third time, and accomplished a different timing and number of applications during a similar period of time (i.e., June and July). The evidence suggests that the SVI approach reduced by one the total number of applications and for the first two applications reduced the amount of area to be treated by at least 40%. The third application treated a larger area, not because the population was more severe, but because more areas of the crop were favorable for plant bug establishment. Scouting data at the time of this application indicated that the majority of the plant bug population at this time was comprised of teneral adults. Since we could not predict precisely where or how far these new adults would fly to become reproductive, the decision was made to be more liberal in the application. The small areas (shown as thin, gray areas) remained unfavorable for plant bug establishment. Overall, we believe the strategy worked better than the 1996 approach since there were no applications necessary during the latter part of July in 1999. Other fields on the farm under the conventional approach received at least one application during the last of July. However, it is of interest to note that, in contrast, these conventional fields were not treated as early during the first part of July. Therefore, both past and recent history strongly suggest that SVI pest management does result in a difference in the timing of applications. Similar results have been suggested by other authors (Fleischer et al., 1999) exploring similar novel pest control measures. The difference is due largely to the fact that the threshold for intervention was different than that used in the SVI study areas. Thus, addressing the issue of how thresholds need to be altered with a spatially dependent approach to pest control is a research topic of tremendous interest.

On occasion, different parts of the study area (i.e., the 40-inch study area) had to be blanket sprayed by air since rain made ground application too difficult. Insecticide applications are often time critical; here, the producer simply could not wait for the field to dry. This is an example of where research goals and production goals collide.

Conclusion

Early indications suggest that the implementation of spatially variable insecticide and possibly plant growth regulator are an excellent application of remote sensing. Yields were at least similar to those areas where conventional broadcast applications of insecticide and PGRs were used. This suggests that adequate insect control was accomplished with huge reductions in the amounts of chemical applied over the study area.

Acknowledgements

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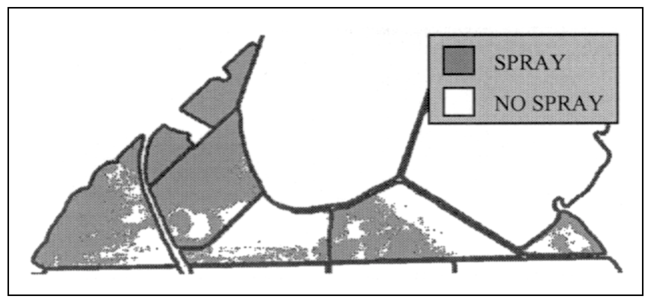

Figure A. Actual Prescription applied June 16, 1999 developed from multispectral imagery.

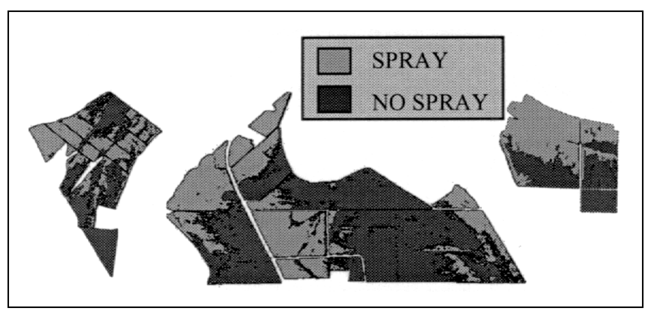

Figure B. Image representing the entire 1023 acre study site. This was an actual prescription used to apply insecticide and plant growth regulator.

Table 1. Average Yield (bales/acre) and standard error (SE) for the six treatment classes.

Class	MEAN	SE
OUTSIDE SVI, NON-IRR	1.69	0.246
OUTSIDE SVI, IRR.	1.85	0.269
SVI SPRAYED, NON-IRR.	1.81	0.246
SVI SPRAYED, IRR.	1.78	0.227
SVI, NO SPRAY, NON-IRR.	1.62	0.301
SVI, NO SPRAY, IRR.	1.45	0.269

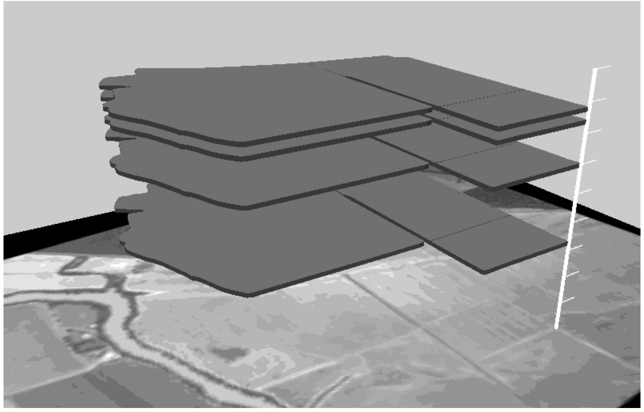

Figure C. Graphic illustrating the timing and number of applications for tarnished plant bug control in 1996. The time bar at the right represents days after crop emergence in 10-day increments.

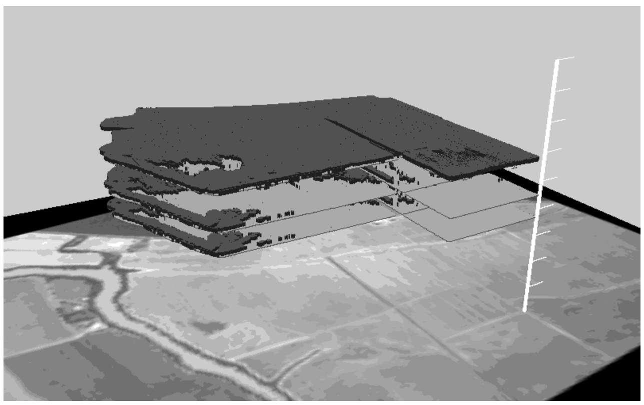

Figure D. Graphic illustrating the differences in timing and spatial extent of applications for tarnished plant bug control during 1999 using spatially variable insecticide applications. The time bar at the right represents days after crop emergence in 10-day increments. Thin, solid gray areas in each layer represent unsprayed regions; thick, dark gray regions were sprayed.