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Crop Protection 24 (2005) 821–828
Crop Protection
www.elsevier.com/locate/cropro

Management of the mahogany shoot borer, *Hypsipyla grandella* (Zeller) (Lepidoptera:Pyralidae), through weed management and insecticidal sprays in 1- and 2-year-old *Swietenia humilis* Zucc. plantations

Elizabeth Goulet[a,*], Alfredo Rueda[b], Anthony Shelton[c]

[a]*Department of Entomology, Cornell University, Ithaca, NY 14853, USA*
[b]*Escuela Agrícola Panamericana (El Zamorano), Honduras*
[c]*Department of Entomology, Cornell University, New York State Agricultural Experiment Station, Geneva, NY 14456, USA*

Received 26 August 2004; received in revised form 10 October 2004; accepted 4 January 2005

Abstract

Field trials of three weed management methods and three insecticide treatments were evaluated for use in controlling *Hypsipyla grandella* in small-scale plantations of Pacific mahogany (*Swietenia humilis*) in Honduras. Weed row, weed-free, and maize taungya methods were evaluated in 1-year-old plantations. Two-year-old trees were treated with deltamethrin, *Bacillus thuringiensis*, or neem seed extract. Leaving weed rows between tree rows significantly decreased the proportion of mahogany trees attacked by *H. grandella* compared to either weed-free or taungya methods. Deltamethrin provided complete control while Bt and neem provided significantly better control than untreated plots. Based on these findings, weed management has been modified and insecticide spray management has been incorporated in control of *H. grandella* at the research site in Honduras. The information gathered in these studies has the potential for furthering the development of broader scale integrated pest management programs in small-scale commercial plantings of several rare Neotropical hardwood species.

Keywords: *Hypsipyla grandella*; *Swietenia* spp.; Deltamethrin; Neem; Bt; Mahogany

1. Introduction

The mahogany shoot borer, *Hypsipyla grandella* (Zeller) (Lepidoptera: Pyralidae), is the major pest of several of the most valuable commercial hardwood timber species in the Neotropics. These include Pacific mahogany (*Swietenia humilis* Zucc.), big-leaf mahogany (*S. macrophylla* King), West Indies mahogany (*S. mahagoni* Jacquin) and Spanish-cedar (*Cedrela odorata* L.). Efforts at growing these species in plantations have been largely unsuccessful due to the shoot borer (Alegría and Lanuza, 1996). The life cycle of the insect is well documented (Griffiths, 2001). The larvae feed on new growth, tunneling internally and causing death of the terminal shoot. Young trees are particularly vulnerable to damage since only one larva in the apical stem can kill the tip and cause excessive branching and deformation, making the tree unmarketable. Yet intensive control of *H. grandella* to limit deformation and branching may only be necessary for 4–8 years, until trunks reach a merchantable height (Mayhew and Newton, 1998).

Research suggests that volatiles emitted by new mahogany shoots attract the females (Gara et al., 1973; Grijpma and Gara, 1970; Holsten and Gara, 1977; Schoonhoven, 1974). Leaving weed rows between tree rows in young plantations could serve the two-fold purpose of decreasing mobility of *H. grandella* females

*Corresponding author. Tel.: +1 6072554404.
E-mail address: ejg25@cornell.edu (E. Goulet).

0261-2194/$ - see front matter
doi:10.1016/j.cropro.2005.01.007

during search by creating a physical barrier between trees and also increasing the number of odors, thus confusing the females. Leaving weed rows can also reduce both the time and labor needed to maintain a weed-free mahogany plantation. Mahogany plantations are often kept weed-free due to concerns about plant competition, in spite of evidence that suggests that mahogany is more weed tolerant than many other plantation tree species (Mayhew and Newton, 1998).

Another management option could be to develop a system of successful intercropping in young plantations so that the land planted in mahogany continues to produce an annual cash crop. Taungya, a planting practice that combines tree seedlings and agricultural crops, has been utilized in management of mahoganies since the 1940s with mixed results, and is often abandoned after the annual crop is harvested (Mayhew and Newton, 1998).

Research on insecticidal control of the *Hypsipyla* spp. shoot borers has been conducted for over 80 years throughout the tropics, with 51 different insecticides from eight different classes evaluated in greenhouses, laboratories, nurseries and plantations (Wylie, 2001). Although some products, particularly systemic insecticides such as carbofouran, have shown mixed results in field trials (Allan et al., 1970; Mayhew and Newton, 1998), no economically and environmentally acceptable management strategy exists for control of the shoot borer using insecticides alone. The cryptic nature of the larvae presents challenges for controlling them when using foliar sprays. However, these sprays may still prove a useful component in an integrated pest management program.

Since in Central America small farmers are familiar with insecticides and behavior modifying products (e.g., repellents) that they use in various crops and can often use a single chemical in more than one crop, they are likely to accept such products for mahogany shoot borer control. This could save both time and effort in application. Preferred products would be those that are effective, short-lived in the environment, and readily available. Although deltamethrin is a broad spectrum insecticide, the fact that it has low human toxicity makes it a favorable synthetic insecticide alternative in Central America, where pesticide safety regulations and recommendations are not always rigorously followed.

Laboratory studies have identified the toxic effects of the microbial insecticide *B. thuringiensis* subsp. *kurstaki* (Bt) on *H. grandella* larvae (Hidalgo-Salvatierra and Palm, 1973). Advantages of this Bt are that it affects only Lepidoptera, is non-toxic to humans and generally considered safe to natural enemies. Although the same problems with access to cryptic larvae exist in the use of Bt as with any insecticide, preventative applications at sufficient frequencies and concentrations may lead to enough of the product being present between hatch and entry into the main stem to cause mortality. Effectiveness of low-volume applications of Bt applied to other forest pests have been improved by increasing exposure concentrations (van Frankenhuyzen, 1990). In spite of its effectiveness against other lepidopteran pests in agricultural crops in the tropics (Gallegos-Morales and Sanchez-Novoa, 1992), no information on the use or testing of Bt for control of *H. grandella* in field experiments has been reported.

Applying substances that act as antifeedants to newly hatched larvae could work to decrease damage as well. Though the larvae are internal feeders, the eggs are laid on the surface of the plant and first instar larvae wander for up to a day before boring into the plant (Ramirez Sanchez, 1964). Hence topical sprays of a non-systemic substance such as neem (*Azadirachta indica* A. Juss.) may still be effective for control. Neem seed extract is a known antifeedant for various insects (Gahukar, 2000) and has also proved to be an ovipositional repellent in laboratory tests against *Earias vittella* (Fabricius), a lepidopteran pest in cotton (Gajmer et al., 2002). Laboratory studies also show its effectiveness as both a toxin and growth disrupter in *H. grandella* larvae (Mancebo et al., 2002). A small scale field study showed decreased frass production by the shoot borer in *S. mahagoni* trees treated with azadirachtin (Howard, 1995). Many small farmers in Central America already have neem trees on their property, and some make their own homemade extracts to control insect pests in other crops (Rueda, personal communication).

This paper describes research that examines the effects of three methods of weed management in 1-year-old Pacific mahogany (*S. humilis*) plantations on infestations levels of *H. grandella*. We also evaluated the effectiveness of deltamethrin, Bt, and neem seed extract for control of *H. grandella* in 2-year-old plantations. These studies were conducted to develop an integrated pest management program for *H. grandella* in small-scale commercial plantings of mahogany.

2. Materials and methods

2.1. Research site

Research was done over 7 months with weed trials during June–August 2001 and insecticide trials from May to August 2002. The *S. humilis* plantations used in the study are located within 5 km of the Escuela Agrícola Panamericana (Zamorano) campus, in the municipality of San Antonio de Oriente, Francisco Morazán, Honduras. The Zamorano valley, at 800 m, is a dry tropical forest habitat. Four different plantation locations (blocks) were used in the weed study. The plantations were established in 2000. The first block, San Nicolás, was located approximately 5 km south of campus. Two of the blocks were located in the La Florencia plantations, located approximately 2.5 km to the north and west of the campus, and the final block was located in El Burro, approximately 1.5 km north of campus. All locations receive between 1000 and 1200 mm of rain per year. All plantations had spacing of 3 m between tree rows and 2 m between trees within a row. All had been cultivated for maize and sorghum production previous to planting mahogany except El Burro, which had mixed pasture grasses and canavalia legumes. All insecticide trials were conducted in the San Nicolás plantation.

2.2. Experimental design

A randomized, incomplete block design was used in the weed management trials. Fourteen plots of 0.125 ha with approximately 200 Pacific mahogany trees each were established in each of the four locations in June 2001. One each of the weed-free, weed row and weedy control plots (in which no weeds were cut) were randomly assigned in each of the four blocks. In addition, the taungya treatment was randomly assigned within the two blocks where mahogany was intercropped with maize. All plots within a given block had similar tree growth characteristics, weed cover, and topography, though these factors varied between blocks. The study included a total of 2560 trees ranging in height from 2 to 139 cm with an average height of 31 cm at the start of the rainy season. The shortest trees had been attacked by leaf-cutter ants (*Atta* sp.), which had removed the new growth earlier in the season, making these trees much shorter than others in the study.

Insecticide trials, all which were conducted at the San Nicolás plantation, included a 0.35 ha section that was separated from other plantation blocks by at least 10 m on all sides. Twenty plots of 20 trees each were used in a randomized complete block design for the three insecticide treatments plus the untreated control with five replicates (plots) for each treatment. The 400 trees in the study also had $3\,m \times 2\,m$ spacing. Trees in the study ranged in height from 18 to 227 cm with an average height of 110 cm. Weed rows were left between the tree rows throughout the insecticide study.

2.3. Weed management treatment descriptions

Weed-free plots were established by cleaning weeds to ground level by manual cutting with machetes. Weed-row treatments had 0.5 m on each side of the tree cleaned of weeds, leaving weed rows to grow between the tree rows. The taungya treatment was an intercropping of maize in completely cleaned and tilled soil. In the control treatment weeds were left uncut. Weed-free and weed row plots were maintained by two cuttings during the 9-week study and the intercropped areas were maintained by local farmers in exchange for the maize produced in the plots. For the duration of the study, farmer maintenance included weeding and applications of nitrogen fertilizer but no insecticide applications to control *Spodoptera frugiperda* (J.E. Smith), a major pest of maize.

The most common weeds in La Florencia were *Panicum maximum* Jacquin, *Cynodon nlemfuensis* Vanderyst, *Hyparrhenia rufa* (Nees), *Lantana camara* Linn and *Mimosa tenuiflora* (Willd.) Poiret. In San Nicolás they were *P. maximum*, *C. nlemfuensis*, *Sorghum halepense* (L.) Pers. and *Hyptis pectinata* (L.), and in El Burro *P. maximum*, *M. tenuiflora* and *L. camara*.

2.4. Insecticide treatment materials and application methods

The products selected for the study are readily available and widely used in Central America against lepidopteran pests in agricultural systems. We tested the synthetic insecticide Decis 2,5 EC (Deltamethrin 2.5%, Aventis Crop Science, Bogotá, Colombia), the microbial insecticide DiPel 6.4 WG (*B. thuringiensis* var. *kurstaki* 6.4%, ABBOTT Laboratories, Chicago, Illinois) and the neem product, Nim Aceite Natural 0,15 EC (Azadirachtina 0.15%, in *Azadirachta indica* seed oil, 84.85%, Investigaciones Orgánicas, SA, Managua, Nicaragua). The Decis and DiPel were mixed at the lowest recommended doses for any pyralid moth pest listed on the labels. These were 1.9 g Decis/L of water, and 5 mL Nim/L of water. The Bt was applied at a volumetric concentration twice that of the recommended dosage of 125 g Bt powder/ha to potentially increase the effectiveness of the insecticide as indicated by van Frankenhuyzen (1990). The treatments were applied weekly using a CO_2 pressurized portable backpack sprayer, with a Spraying Systems Company Trigger Tee Jet nozzle and a quick T-Jet nozzle head (#25607) with a bronze Split Spray Jet G-1 nozzle tip. A nozzle pressure of 60 psi was maintained during spray applications on the same morning in any given week to limit variation in spray effectiveness due to weather conditions. For the first 3 weeks of applications, treatments were applied without a sticker (adherent); due to unusually heavy rains, the commercial sticker Bayer ADHERENTE 810 (Tuliglicoleter) was added at 1 mL/L to all treatments from the fourth week onwards for the duration of the study. The entire tree, including the stem, was sprayed.

2.5. Data collection

In the weed management test, weekly visual counts were made of larval attacks, which were identified by the entry holes and characteristic frass. A tree was recorded as attacked if it had one or more of such signs of mahogany shoot borer attack. Data were recorded for 9 weeks, with the number of new larval attacks each week recorded for each plot. Damaged trees were pruned below the lowest larval entry point, and were then pruned directly above each node below the entry point until the larva was encountered or the end of the larval tunnel was reached.

Visual counts of larval attacks were made for the trees in the insecticidal study during the 11 weeks. Each tree that was damaged by larval attack constituted a data point. Pruning of attacked trees took place at the time data was recorded.

2.6. Data analysis

The weed management data were analyzed with a mixed model, binary logistic regression (GENMOD procedure, SAS version 8e, 2001) to test for effects of treatment. The dependent variable was the proportion of trees attacked in each plot throughout the 9-week survey. Differences among the three, non-control treatments were analyzed using a comparison of least squares means. The random effect of blocks was included in the covariance structure of the model. Responses from different blocks are assumed to be statistically independent and responses within blocks are assumed to be correlated.

The insecticide treatment data were analyzed using a binary logistics regression (GLIMMIX macro procedure, SAS version 8e, 2001) to test the effects of treatment (fixed categorical) and tree height (fixed continuous). The binary response variable was whether a tree was attacked (response = 1) or not attacked (response = 0). The random effect of block was accounted for in the model. Since in the deltamethrin treatment no attacks were recorded in the entire 11 weeks, the actual analysis was done by changing one observation to a positive response in order to generate a very low estimate of attack since otherwise no parameter estimates were possible. The modified data were included in the model only after the analysis was performed both with and without the attack added to the deltamethrin treatment and it was determined that the parameter values were modified only slightly, and that the addition made no change in determinations of significance. To assess whether significant differences existed between this treatment and the Bt, neem and control we used a least squares means comparison for all treatments.

3. Results

3.1. Weed management trials

The mean proportion of trees attacked in the different treatments is summarized in Tables 1 and 2. The proportion of trees attacked in both the weed-free treatment and the taungya were significantly higher than the control (weedy) plot (both treatments $p<0.0001$), whereas the proportion of attacked trees in the weed row treatment was not significantly different than the control ($\chi^2 = 2.50; p = 0.114$). In the least squares means analysis, the weed row treatment was found to be significantly different from both the weed-free ($p = 0.008$) and the taungya treatments ($p<0.0001$). In addition, the weed-free treatment was significantly different than the taungya treatment ($p = 0.044$).

Table 1
Proportion of trees attacked by *H. grandella* in weed-free, weed row, taungya and weedy (control) treatment plots in one year old *S. humilis* plantations

Treatment	Number of trees	Proportion attacked	SD
Weedy (control)	731	0.008	0.007
Weed row	730	0.018	0.018
Weed-free	750	0.052	0.073
Taungya	349	0.140	0.087

The standard deviation in all the treatments is large relative to the proportion of trees attacked, indicating high variability in attack rates between the blocks for any given treatment (Table 1). The logistic regression model, with its ability to decouple the treatment effect from the block effect with covariance, was used for the analysis of significant differences (Table 2).

3.2. Insecticide trials

All treatments resulted in significant decreases in attack rates compared to the control treatment in which 44% of the trees were attacked over the course of the study (Fig. 1). The deltamethrin treatment, with no attacks, resulted in complete control. The Bt and neem treatments resulted in only 17% and 12%, respectively, of the trees attacked (Fig. 1). The comparison of least squares means showed significant differences between all paired treatments except the Bt and neem, which were not significantly different from each other ($p = 0.628$). Since some trees were attacked multiple times, the mean number of larval attacks per tree differed considerably from the percent of trees attacked in the control. An average of 0.73 attacks per tree in the control was recorded, with the averages for Bt and neem at 0.18 and 0.13, respectively.

Of the five control plots, each with 20 trees, the range in total number of attacks on trees during the 11-week study ranged from 3 to 30. The variability in attack rates between blocks was controlled for in the model. All measures of significant differences among treatments were determined from the logistic regression analysis and the least squares means comparison. The parameter estimates and summary statistics for the logistic

Table 2
Parameter estimates and summary statistics for proportion of 1-year-old *S. humilis* trees attacked by *H. grandella* in weed-free, weed row, and taungya treatments relative to a weedy control

Treatment	Degrees of freedom	Estimate	SE	χ^2	Prob.$>\chi^2$
Intercept	1	−4.099	−5.7196	136.79	<0.0001
Weed row	1	0.784	0.496	2.50	0.114
Weed-free	1	1.918	0.441	18.92	<0.0001*
Taungya	1	3.006	0.438	47.21	<0.0001*

*Indicates treatment difference is significant at $p = 0.05$ level.

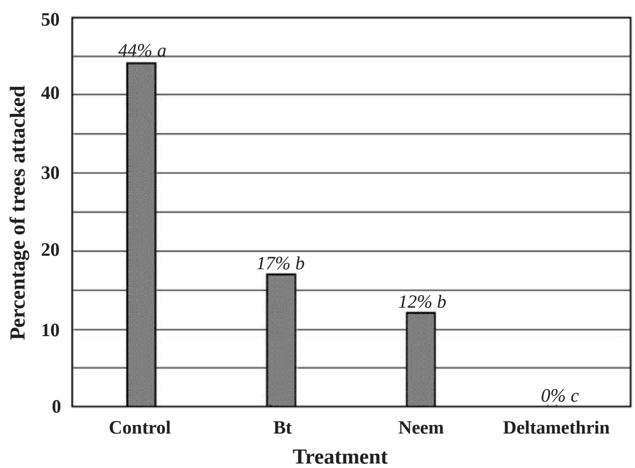

Fig. 1. Percentage of 2-year-old *S. humilis* trees attacked by *H. grandella* in untreated control, Bt, neem, and deltamethrin treated treatments in 11-week study ($n = 100$ trees for each treatment). For each treatment, bars with same letters are not significantly different ($p \geqslant 0.05$).

regression model are shown in Table 3. Because some trees were attacked multiple times, and the purpose of the study was to estimate the overall attack rates in plantations under different treatments, the variable used in the logistic model was whether a tree was attacked at all (hence causing damage), but did not include information on the total number of attacks in the plots. This is based on the assumption that once a tree is attacked, damage has occurred. Including all attacks would artificially inflate the actual number of trees damaged during the study.

Height (t-value 4.03, $p = 0.0001$) also had a significant effect on likelihood of attack. The average heights of the trees did not vary significantly among treatments. The average tree height was 109.9 cm, with standard deviations among treatments ranging from 38.7 to 51.1 cm. The effect of height alone on attack rates was addressed in a different study (Goulet, 2003). The combined height and treatment effects can be described by the logistic regression equation:

$$\mathrm{logit}(\pi_{hi}) = -1.93 - 0.016\mathrm{height} - 1.94\mathrm{Bt} - 4.69\mathrm{Decis} - 2.14\mathrm{neem},$$

where π_{hi} is the probability that a tree of height h in the ith treatment type will be attacked. The regression analysis curves for the treatments, with one attack added to the deltamethrin treatment for analysis purposes, are shown in Fig. 2.

Shoot borer attack on the mahogany was cyclic, as expected and observed in other studies (Yamazaki et al., 1992). The number of trees attacked on a weekly basis for each treatment and all treatments combined throughout the 11-week study is shown in Fig. 3. The majority of attacks occurred in the control, with a greater proportion of the total attacks occurring in the control during the second attack cycle than in the first.

4. Discussion

4.1. Weed management

Significant differences in attack rates among treatments were observed with the highest percentage of trees attacked being 14% in the taungya. Attack rates by *Hypsipyla* spp. tend to be lower if infested trees are not close by (Mayhew and Newton, 1998). The closest known population of *H. grandella* to the Zamorano plantations was more than 60 km away at the time of planting (Darío Mejía, Zamorano plantations manager, personal communication).

The fact that only one larval attack on the terminal shoot of a tree can break apical dominance and thus cause forking and excessive side branching makes the threshold for economic injury very low (there are no known estimates of economic injury levels in plantation mahogany production). The cumulative effect of attacks over time must also be considered. Annual attack rates ranging from 30% to over 80% are common in trees over 3 years old, even in managed plantations (Howard, 1991; Newton et al., 1998). Although this study used only 1-year-old trees and was not repeated in 2002, the plantation manager indicated that overall attack rates did go up considerably in the plantations in the second year after establishment.

The lower incidence of attack in the weed row treatment used in this study has resulted in adoption of this method throughout the plantations by the

Table 3
Parameter estimates and summary statistics for effects of tree height, Bt, deltametherin, and neem treatments compared to an unsprayed tree for *H. grandella* attacks in 2-year-old *S. humilis* trees

Effect	Parameter estimate	SE	Degrees of freedom	*t*-value	Prob. > |*t*|
Intercept	−1.934	0.623	4	−3.10	0.0362
Height	0.0157	0.004	391	4.03	<0.0001*
Bt	−1.937	0.388	391	−4.99	<0.0001*
Neem	−2.144	0.398	391	−5.38	<0.0001*
Deltamethrin	−4.694	1.012	391	−4.64	<0.0001*

*Indicates effect is significant at the 0.05 level.

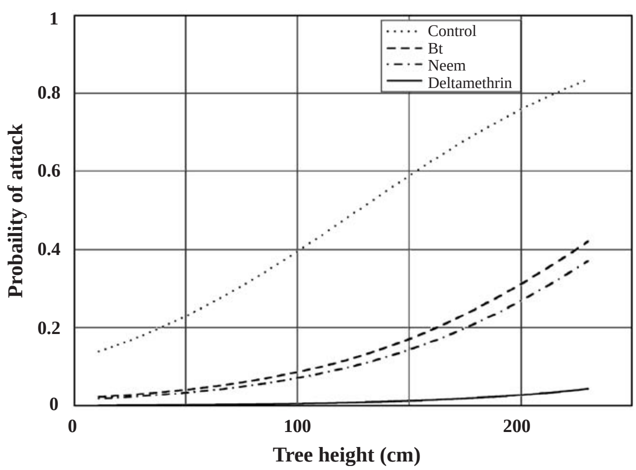

Fig. 2. Probabilities of *H. grandella* attack rates in 2-year-old *S. humilis* trees subject to treatments of Bt, neem seed extract, and deltamethrin, and an untreated control. The logistic regression equation logit (probability of attack) = −1.93 − 0.016tree height − 1.94Bt − 4.69deltamethrin − 2.14neem describes the response.

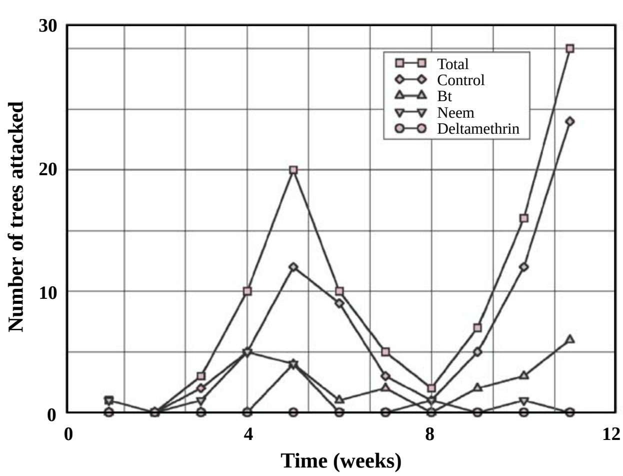

Fig. 3. Time course of *H. grandella* attack in 2-year-old *S. humilis* trees for 11 weeks (May 14–July 23, 2003), with number of trees attacked each week for the untreated control, Bt, neem and deltamethrin treatments along with the total number of trees attacked in all plots.

current plantation manager, Carlos Orellana, at Zamorano. Both student workers and hired farm laborers from the local area help maintain the plantations. The use of weed rows and other promising control methods will hopefully limit the amount of damage occurring in the next 6–7 years in the mahogany plantations at the school and, if successful, will encourage other landholders in Central America to include these valuable hardwoods in their long term land use plans.

4.2. Insecticide treatments

The fact that all three products decreased damage significantly indicates that development of a spraying program might be an effective means of controlling shoot borers. Further studies on the neem might clarify if it is acting as a repellent or an insecticide. The neem used in this study is a commercially prepared product. Farm-made extracts of neem for control of the shoot borer are worth exploring as a means of not only decreasing the cost to low income farmers, but possibly providing a source of income if the farmers can prepare an effective product in large enough quantities. However, because extraction techniques can strongly influence the activity of the various biologically active compounds in neem, care must be taken in standardizing extraction techniques and quantifying biological activity. Additionally, any safety concerns about possible detrimental health effects due to topical contact at high concentration must be addressed.

Most of the attacks in the neem treatment (9 out of 13) occurred in the 4 weeks before the sticker was added. In contrast, the Bt attacks actually increased after the addition, but so did attacks in the control treatment and overall throughout the plantations. This indicates that the neem is probably more effective with the addition of the sticker, whereas the Bt is either adversely affected or not affected by its addition. Further investigations on the use of sticker with Bt should be undertaken in order to determine whether efficacy of the product is compromised by its addition.

Besides its feeding deterrent properties, neem seed extract might prove more valuable in control of shoot borer if it actually decreases the incidence of oviposition by either masking the volatiles of the new mahogany shoots or by serving as a repellent to ovipositioning females.

Treatments in this study were applied weekly. Applying products for control immediately before new ovipositional cycles begin for maximum effect and saving time and money by not applying during non-attack periods in the cycle may be possible. Work at Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) in Costa Rica indicates that prediction of emergence of adult moths from pupae may be possible by a degree day model (Macarrulla, 1999). The ability to predict the emergence of the insect could aid in the effectiveness and efficiency of spray applications.

The use of neem, Bt, and deltamethrin on a rotational basis, especially if coupled with other techniques such as the use of weed rows between tree rows in plantations, may help form the basis of an economical management program for *H. grandella* in small stands of mahogany. Both the weed row technique, which significantly decreased shoot borer attacks relative to other weed management methods, and the rotational use of the products evaluated in this study are being used at Zamorano now. A study on the cost effectiveness of these methods is the next logical step in development of a program that may allow small growers to successfully incorporate high-value mahogany into their planting regimes with decreased risk of devastation by shoot borer.

The continued harvest of precious hardwoods from native forests perpetuates an unsustainable system that ultimately leads to damaged soils, degraded environments, and impoverished people. The research at Zamorano shows promising methods of mahogany plantation management that may provide opportunities for small farmers, and can be part of the solution to the increasingly urgent environmental and economic problems in Central America.

Acknowledgments

We thank the students at Zamorano for their labor, and Carlos Orellana and Darío Mejía, plantation managers at Zamorano. Financial support for this work came from the Andrew W. Mellon Foundation, the Cornell International Institute for Food, Agriculture, and Development (CIIFAD), the Cornell University Latin American Studies Program, the Rawlins Endowment, and the G. Burke Wright Foundation.

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