MAXIMIZING PINE TIP MOTH CONTROL: TIMING IS EVERYTHING

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INTRODUCTION

The impact of the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), has become of increasing concern as standard silvicultural practices have intensified in southern pine production. The associated silvicultural manipulations of site preparation, herbaceous weed control, release, bedding and fertilization have shortened rotation lengths and increased volume yields (Nowak and Berisford 2000), but have often elevated tip moth infestation levels (Nowak and Berisford 2000, Ross and others 1990). As a result, insecticide applications are now being considered as part of silvicultural prescriptions for intensively-managed pine plantations.

There are several insecticides registered for controlling tip moth infestations in forest plantations. The difficulty is that the availability of these compounds tends to fluctuate as older materials lose their registration (i.e., some organophosphates) and new compounds expand their labels to include forest plantations (i.e., spinosad). Therefore, a complete listing of registered insecticides is not provided here, but can easily be located in a current pest control handbook distributed by State Cooperative Extension offices.

Direct control with contact insecticides is effective if properly timed to target susceptible life stages of the pest. Timing is critical due to the non-systemic, relatively short residual nature of most insecticides currently registered for tip moth control. Spraying insecticides at about 30–80 percent egg hatch maximizes control, and corresponds with an abundance of first and second instar larvae exposed on infested shoots (Berisford and others 1984, Gargiullo and others 1985, Kudon and others 1988). These stages are most susceptible to control due to their small size, presence on the tree surface, and movement over sprayed areas when searching for new feeding sites. Insecticide applications should therefore target these life stages to maximize efficacy.

Several spray timing models are available to meet these objectives (table 1), and there continues to be a gradual evolution in the development of models for specific compounds and locations. Berisford and others (1984) first identified the need for spray timing as a way of reducing application frequencies in Georgia Christmas tree plantations. The first biological timing schedules were developed for dimethoate (Cygon®) and esfenvalerate (Pydrin®) insecticides using degree-day accumulations to predict optimum spray dates in the Georgia Piedmont (Gargiullo and others 1983) and Coastal Plain (Gargiullo and others 1985). In general, the procedure involves accumulating degree-day summations commencing on the date of first catch in pheromone-baited traps for each generation, and continuing until an experimentally determined sum is attained. This sum indicates the optimal spray date for each generation and is based on moth phenology. Most published models are based on variations of this theme with spray prediction values being derived from moth phenology distributions or insecticide spray timing trials (table 1).

Although largely effective, improper use of spray timing models has occasionally led to errors in spray date predictions. These models require a detailed knowledge of tip moth biology, proper pheromone trap deployment, intensive trap monitoring, knowledge of degree-day calculations, conversions and utility, and the ability to acquire daily maximum and minimum temperatures on or near the site. Scheduling problems may still arise from short-term advance notice of approaching spray dates or inclement weather patterns that limit insecticide spray opportunities. The development of an efficient method that permits prediction of spray dates in the absence of spray timing models is highly desirable.

PREDICTIONS OF OPTIMAL SPRAY DATES FROM LONG-TERM WEATHER RECORDS

Procedures

Mean maximum and minimum temperatures for each day of the year were obtained for selected weather stations in Virginia (n = 49), North Carolina (n = 58), South Carolina (n = 45), Georgia (n = 70), Alabama (n = 54), Mississippi (n = 52), and northern Florida (n = 26). Daily mean maximum and minimum temperatures for each weather station were placed in a spreadsheet program (Microsoft Excel, Microsoft Corp., Seattle, WA), and then transferred to a degree-day computational program (Degree-Day Utility, University of California Statewide Integrated Pest Management Program, Davis, CA). Degree-days were accumulated using the single-sine, intermediate cutoff computation method (Seaver and others 1990) with lower and upper developmental thresholds of 9.5 and 33.5 °C, respectively (Haugen and Stephen 1984). The annual number of degree-days accumulated at each station was divided by 754 degree-days °C (the minimum required for completion of a single generation) and rounded to the next lowest whole number to provide an estimate of the number of tip moth generations occurring annually at that location (Ross and others 1989). The weather station locations and the numbers of corresponding generations were then mapped for each state.

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Table 1—Papers published on the timing of insecticide applications for controlling tip moth infestations

Authors	Title	General description
Gargiullo and others 1983	How to time dimethoate sprays against the Nantucket pine tip moth	Spray timing model using pheromone-trap data and degree-day summations for a 3 generation phenology in the Georgia Piedmont
Berisford and others 1984	Optimum timing for insecticidal control of the Nantucket pine tip moth	Non-systemic chemical control must be directed toward early developmental stages
Gargiullo and others 1984	Mathematical description of Rhyacionia frustrana (Lepidoptera: Tortricidae) cumulative catches in pheromone traps, cumulative eggs hatching, and their use in timing of chemical control	Spray timing model for a 3 generation phenology in the Georgia Piedmont and validated and refined in Oklahoma and North Carolina
Gargiullo and others 1985	Prediction of optimal timing for chemical control of the Nantucket pine tip moth in the southeastern coastal plain	Spray timing model using pheromone-trap data and degree-day summations for a 4 generation phenology in the Georgia Coastal Plain
Kudon and others 1988	Refinement of a spray timing technique for the Nantucket pine tip moth (Lepidoptera: Tortricidae)	Two insecticide applications were necessary for adequate control of the third generation in the Georgia Piedmont
Malinoski and Paine 1988	A degree-day model to predict Nantucket pine tip moth flight in southern California	Prediction of optimum spray dates using trap catch data and a degree-day flight model for control of a 4 generation phenology in California
Pickering and others 1989	An automated system for timing insecticidal sprays for Nantucket pine tip moth control	Automated computer system that provided daily predictions of optimal spray dates for 70 stations in Georgia (obsolete)
Richmond 1992	Timing sprays by a heat unit model of spring flight of the Nantucket pine tip moth in North Carolina	A spray timing model developed for North Carolina
Fettig and others 1998	Revision of a timing model for chemical control of the Nantucket pine tip moth (Lepidoptera: Tortricidae) in the southeastern coastal plain	Corrected spray timing values are reported for data initially provided by Gargiullo and others 1985
Fettig and Berisford 1999	Nantucket pine tip moth phenology in eastern North Carolina and Virginia: implications for effective timing of insecticide applications	Spray timing model using trap catch data and degree-day summations for a 3 generation phenology in eastern North Carolina and Virginia
Fettig and others 2000a	Nantucket pine tip moth (Lepidoptera: Tortricidae) phenology and timing of insecticide applications in seven southeastern states	Optimal spray periods are provided for locations (354) with either 3 or 4 generation phenologies in the southeastern U.S.A. Allows for surprisingly accurate timing without using spray timing models
Fettig and others 2000b	Effects of Nantucket pine tip moth insecticide spray schedules on loblolly pine seedlings	An optimal insecticide spray schedule is identified that eliminates four sprays over a two year period when compared to standard applications
Nowak and others 2000	Efficacy tests and determination of optimal timing values to control Nantucket pine tip moth (Lepidoptera: Tortricidae) infestations	Optimal spray timing values are provide for permethrin, lambda-cyhalothrin, spinosad, and *Bacillus thuringiensis* Berliner in the Georgia piedmont

The length of winter diapause and the precise conditions required to break it are unknown for the Nantucket pine tip moth, and temperatures above the lower developmental threshold may occur throughout the year. Therefore, spray timing prediction values were accumulated from an arbitrarily established biofix of 7 January where four generations occur annually and 1 March where three generations occur annually. These dates are based on the time of average male moth emergence for the first generation. Three different sets of spray timing values were used to predict optimal spray dates. In portions of Virginia and North Carolina where three generations occur annually the values were 188, 784, and 1472 degree-days °C (Fettig and Berisford 1999). In remaining portions of the Southeast where three generations occur annually the values were 204, 968, and 1787 degree-days °C (Fettig and Berisford 1999). In locations where four generations occur annually the values were 237, 899, 1757, and 2513 degree-days °C (Fettig and others 1998). Spray timing values are not available for controlling populations with two or five annual generations and therefore are not provided for such locations. Degree-days were accumulated continuously for each weather station from the assigned biofix until the appropriate spray prediction value was reached for each generation. The corresponding date was designated the optimal spray date. Each optimal spray date was then located in an optimal spray period established by dividing the calendar year into 5-day increments.

To test the validity of spray period predictions, the predictions were compared to 44 spray dates determined at 16 different field sites during 1996–1998. The field-determined spray dates were calculated on site by monitoring moth flight with pheromone-baited sticky traps (Pherecon 1 C; Trece Inc., Salinas, CA) and accumulating degree-day totals using continuously recording biophenometers (Model TA51; Dataloggers Inc., Logan, UT). During this period, mean temperatures were generally normal (1996), below normal (1997), and above normal (1998) (Athens, GA June departure from normal: -0.06 °C, -2.33 °C, and 2.06 °C, respectively) throughout most of the Southeastern U.S.A.

Results and Discussion

Our phenology predictions indicated the moth would complete two to five generations annually in this region. Two generations occurred throughout the Mountain Province in Virginia and North Carolina and at some of the highest elevations of South Carolina and Georgia. Three generations occurred throughout the Piedmont Plateau and in the Coastal Plain of Virginia and parts of North Carolina. Four generations occurred in much of the remaining portions of the Coastal Plain to a northern limit apparently located in Craven County, North Carolina. Five generations were predicted for extreme southern portions of Alabama, Georgia and Mississippi, and in northern Florida.

Table 2 provides a brief example of how the optimal spray periods predictions are to be utilized. For example, if you wish to control tip moth in a pine plantation in the vicinity of Athens, GA with a pyrethroid insecticide, you would initially find the nearest weather station located to your vicinity on the maps provided in the original publication (see Fettig and others 2000a). After finding this location as site 7, you would look up site 7 on table 2. The optimal spray periods for this site are predicted for 16–20 April, 20–24 June, and 4–8

Table 2—Site number, location, and optimal spray period predictions for 15 weather stations located throughout Georgia

		Spray period			
No.	Location	1	2	3	4
1	Albany	March 17–21	May 21–25	July 10–14	Aug 19–23
2	Alma	— [a]	—	—	—
3	Alpharetta	April 21–25	June 30–July 4	Aug 24–28	
4	Americus	March 22–26	May 26–30	July 15–19	Aug 29 –Sept 2
5	Appling	April 11–15	June 20–24	Aug 9–13	
6	Ashburn	March 27–31	May 26–30	July 15–19	Aug 29 –Sept 2
7	Athens	April 16–20	June 20–24	Aug 4–8	
8	Atlanta	April 16–20	June 15–19	Aug 4–8	
9	Augusta	April 1–5	May 31–June 4	July 20–24	Sept 3–7
10	Bainbridge	March 12–16	May 21–25	July 10–14	Aug 19–23
11	Blairsville	—	—	—	—
12	Brunswick	—	—	—	—
13	Byron	April 1–5	June 5–9	July 25–29	Sept 8–12
14	Calhoun	April 16–20	June 25–29	Aug 14–18	
15	Camilla	—	—	—	—

[a] "—" refers to spray periods that are not applicable to spray timing because models have not been developed for populations with 2 or 5 annual generations.

August, and therefore treatments should be applied during these intervals. The lack of data in the column labeled spray period four indicates only three annual generations occur at this location.

Fourteen (31.8 percent) of the predicted spray periods agreed with field-determined spray dates, 21 (47.7 percent) differed by one spray period (i.e., a five day arbitrarily established interval), six (13.6 percent) differed by two spray periods, and three (6.8 percent) differed by three spray periods. Six (66.7 percent) of the spray predictions that differed by two or three periods occurred during the first tip moth generation and may reflect discrepancies between the arbitrary biofix date and the actual initiation of moth flight at these locations.

Spray timing values are typically determined experimentally by applying insecticide sprays at specified degree-day intervals, assessing damage levels for each spray, and using second degree polynomial regressions (parabolas) to determine optimal spray timing values. Although an optimal value exists, approximately 125 degree-days surround the optimal value in which little or no variation in damage levels is observed (from Gargiullo and others 1985). Assuming a typical mean daily temperature of 15.5 °C for the first generation, 20.5 calendar days of thermal units would occur during the 125 degree-day interval. In all cases, our predictions will meet this criterion. However, it also shows why spray timing becomes more critical in later generations. Assuming a mean daily temperature of 26.7 °C, the same 125 degree-day interval represents only 7.3 days of thermal units. Under these circumstances, our predictions would be effective 87 percent of the time.

EFFECTS OF INSECTICIDE SPRAY SCHEDULES ON LOBLOLLY PINE SEEDLING YIELDS

We are currently able to time insecticide applications accurately within a generation using either spray timing models or the optimal spray periods that were discussed above. However, it may not be necessary to treat each and every tip moth generation for the first two or three years following stand establishment as is the common convention. The objective of this study was to develop a tip moth control program that maximizes yield in loblolly pine, *Pinus taeda* L., with the minimum number of insecticide applications during the first two years following stand establishment (Fettig and others 2000b).

Procedures

In 1997, two newly-planted (1-yr old) and two 2-yr old plantations were selected as study sites in the Georgia Piedmont. Three randomized complete blocks were established in each plantation. Each block consisted of eight randomly assigned plots corresponding with the number of treatments and contained 12 randomly selected trees (N = 1152). In 1998, three additional 1-yr old and four additional 2-yr old plantations were selected as study sites in the Georgia Piedmont and North Carolina and Virginia Coastal Plain. Five randomized complete blocks were established in each plantation. Each block contained eight plots and eight randomly selected trees within a plot (N = 2560). All sites had received herbaceous weed control and were planted with 1-0 loblolly pine seedlings. It was previously confirmed that three tip moth generations occurred in each region.

The timing of insecticide applications was determined by monitoring male moth emergence for each generation with sex pheromone lures in Pherocon 1 C sticky traps (Trece Inc., Salinas, CA), and accumulating degree-days after the detection of an average of one moth per trap per day using continuously recording biophenometers (Omnidata T151; Dataloggers Inc., Logan, UT). Insecticides were applied at 188, 261 and 315 degree-days °C in North Carolina and Virginia, and 204, 308 and 293 degree-days °C in Georgia for each of the three tip moth generations (Fettig and Berisford 1999).

Applications included timed sprays of permethrin (Pounce 3.2 EC) with hand-pump backpack sprayers (Model 425; Solo™, Newport News, VA) at a rate of 0.6 ml of formulated product per liter of water. Treatments consisted of all possible combinations of insecticide spray schedules based on three annual tip moth generations, specifically: C) untreated control, 1) first generation, 2) second generation, 3) third generation, 1&2) first and second generation, 1&3) first and third generation, 2&3) second and third generation, and A) all generations. Applications were made during the first year only at three sites, second year only at six sites, and both the first and second year following stand establishment at two sites.

Damage estimates were taken on 30 randomly selected trees in Treatments C (untreated control) and A (all generations) for each site during the pupal stage of each generation. The total number of shoots (i.e., > 10 linear cm of apical stem containing foliage) and number of infested shoots were recorded in the terminal plus top whorl of each tree to assess insecticide efficacy. Growth statistics were taken in November 1997 and 1998 on each tree. Basal diameter (D) was measured with a caliper at 2.5 cm above ground surface. Height (H) was measured from the root collar to the tip of the terminal leader using a cm graduated height stick. These values were later used to compute a volume index (D^2H) for each treatment. The growth data were analyzed as a randomized complete block design and compared with the Tukey test for separation of treatment means (Sokal and Rohlf 1995).

Results and Discussion

Insecticide efficacy in both 1 and 2-yr old stands decreased throughout the year from 90.4 percent control in the first generation to 77.6 percent and 55.5 percent control in the second and third generations. Decreasing spray efficacy is commonly observed as the year progresses due to increasing asynchrony among susceptible life stages in later generations (Fettig and others 1998). Control of the first tip moth generation when insecticide efficacy is highest is also of particular importance in resistance management by limiting the proportion of insects that escape sub-lethal exposures.

Few significant differences were observed among treatment means when insecticides were applied to age 1 trees. Treatment A had significantly larger volume estimates than the untreated control. No other significant differences were observed among the remaining treatment means. This suggests that spraying tip moth infestations only during the first year following stand establishment is ineffective unless every generation is included in the control schedule. We observed a 63.1 percent increase in volume index by applying Treatment A.

More significant differences were observed among treatment means when insecticides were applied to age 2 trees. Treatment 1&3 (generations 1 and 3), Treatment 2&3 (generations 2 and 3) and Treatment A had significantly larger diameter, height and volume estimates than the untreated control. No significant differences were observed among Treatments 1&3, 2&3 and A. At least two insecticide sprays were required to produce a significant difference in all three growth measurements. An optimal insecticide spray schedule for controlling tip moth infestations in age 2 trees with insecticide applications applied during the second year includes either spraying the first and third or second and third generations thereby eliminating one spray without any significant effect on volume yield. We observed a 39.0 percent increase in volume by applying Treatment 1&3, and a 38.9 percent increase in volume by applying Treatment 2&3.

Significant differences were observed among treatment means when insecticides were applied to the same trees at both age 1 and age 2. Treatment 1 (first generation only) had a significantly larger volume index than several other treatments including the control. We observed a 74.5 percent increase in volume index by applying Treatment 1 during the first two years following stand establishment. This is the largest increase in volume index observed relative in this study.

The application of timed permethrin sprays during the first generation of both the first and second year following stand establishment appears to be the optimal insecticide spray schedule. Insecticide efficacy is greatest during the first generation, and coincides with the time when recurrent growth species such as loblolly pine typically have their largest growth flush of the year (Oliver and Larson 1996). Recently, it has been confirmed that control of the first generation has an extended benefit (Coody and others 2000). This suggests that previous tip moth attacks predispose trees to heavier attacks during subsequent generations, possibly due to bud proliferation from previous attacks, changes in host physiology, or simply that females emerging from infested trees mate and deposit eggs on the same trees. Control of the first generation may also be important in reducing recruitment from adjacent stands by reducing the number of suitable oviposition sites (i.e., bud proliferation resulting from tip moth attacks) and the number or density of calling females.

Currently, most tip moth control programs target at least the first and second year following planting and insecticides are repeatedly applied to control each generation. Our data suggest that it is unnecessary to control each generation to significantly increase volume yields. The optimal insecticide spray schedule program for a three generation tip moth phenology would include a single first generation spray during the first two years following planting. This would reduce the current practice by four sprays over the two year period, which would be both economically and ecologically beneficial, two important criteria for an integrated pest management program.

CONCLUSIONS

The application of insecticides to manage tip moth infestations is likely to become more common in the future as we attempt to increase fiber production. Spray timing is critical to successfully controlling these infestations. The questions remains as to what degree of accuracy is acceptable, and how inexpensively it can be obtained.

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