Efficacy Tests and Determination of Optimal Spray Timing Values to Control Nantucket Pine Tip Moth (Lepidoptera: Tortricidae) Infestations

J. T. NOWAK, C. J. FETTIG, K. W. McCRAVY, AND C. W. BERISFORD

Department of Entomology, University of Georgia, 413 Biological Sciences Building, Athens, GA 30602

J. Econ. Entomol. 93(6): 1708–1713 (2000)

ABSTRACT The Nantucket pine tip moth, *Rhyaciona frustrana* (Comstock), a common regeneration pest of loblolly pine, *Pinus taeda* L., has been shown to reduce tree volume yields through larval feeding. Chemical applications can be effective in protecting trees from the growth losses associated with this feeding, and optimum spray timing values are commonly used to reduce the number of necessary applications and to increase insecticide efficacy. Optimal spray timing values for the Georgia Piedmont were obtained for the following four insecticides available for use in loblolly pine plantations: permethrin (Pounce), lambda-cyhalothrin (Warrior T), spinosad (SpinTor 2 SC), and *Bacillus thuringiensis* variety *kurstaki* Berliner (Foray 48B). Optimal timing values were similar between the first and second generations for each of these compounds. All of the insecticides used in this study significantly reduced tip moth damage below the control treatment levels. Lambda-cyhalothrin was the most efficacious and had the longest spray timing window. *B. thuringiensis* was the least effective and had the shortest timing window. Spinosad and permethrin were similar in efficacy and spray timing values. This information is applicable to regions where there are three tip moth generations per year, as found in the southern Piedmont region and the coastal plain of Virginia and most of North Carolina.

KEY WORDS *Rhyacionia frustrana, Pinus taeda,* degree-days, spinosad, permethrin

THE NANTUCKET PINE tip moth, *Rhyacionia frustrana* (Comstock), is a common regeneration pest of loblolly pine, *Pinus taeda* L., plantations in the southeastern United States. This insect has been shown to reduce volume yields through larval feeding within shoots and buds (Young et al. 1979, Cade and Hedden 1987, Nowak and Berisford 2000). Chemical control of tip moth infestations has not traditionally been performed except in high value plantings such as Christmas tree plantations, seed orchards, and progeny tests (Berisford 1988). Recently, however, there has been an elevated interest in developing methods for reducing volume losses associated with tip moth damage in production forests. Chemical control is an effective method to achieve these results (Young et al. 1979, Fettig et al. 2000a, Nowak and Berisford 2000).

There are several concerns about the use of insecticides in commercial forests, including cost effectiveness, public perceptions, and impacts on nontarget organisms, including biological control agents. Methods that address these concerns and achieve acceptable control of tip moth infestations include the use of low volume insecticide applications and optimum spray timing values. Optimum spray timing values using degree-day models for the Nantucket pine tip moth were initially developed in the early 1980s and have been successful in increasing insecticide efficacy and reducing application frequency (Gargiullo et al. 1983). Several spray timing models have been developed for controlling tip moth infestations and vary depending on moth voltinism, geographic location, and the active ingredient used (Gargiullo et al. 1983, 1984, 1985; Kudon et al. 1988; Malinoski and Paine 1988; Fettig and Berisford 1999). 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 reached. This sum indicates the optimal spray date for each generation and is based on moth phenology and insecticide properties. Optimum spray timing values have not been determined for several important insecticides currently registered for loblolly pine stands and tip moth management. These include permethrin (Pounce), lambda-cyhalothrin (Warrior T), spinosad (SpinTor 2 SC), and *Bacillus thuringiensis* variety *kurstaki* Berliner (Foray 48B).

Permethrin, a third-generation pyrethroid, is currently the most commonly used insecticide for tip moth control. Permethrin has low mammalian toxicity and is effective in reducing tip moth damage (Fettig et al. 2000b). Lambda-cyhalothrin, a fourth-generation pyrethroid, has been given a special local needs designation (Section 24-C) in Georgia and is quite effective in reducing tip moth damage (C.W.B., unpublished data). Both of these pyrethroids are harmful to hymenopterous parasitoids and other beneficial insects (Theiling and Croft 1988) that are important regulators of tip moth populations (Berisford 1988). They are also detrimental to aquatic arthropods and fish (Douce and Hudson 1999). However, they are effective at low rates and are relatively inexpensive to use (Douce and Hudson 1999).

A relatively new biological insecticide available for tip moth control is spinosad. Spinosad is derived from a soil actinomycete bacterium, *Saccharopolyspora spinosa*, and is a mixture of spinosyn A and spinosyn D (Saldago et al. 1997). Spinosad has been shown to be effective against lepidopterous insects, has a very low mammalian toxicity, and is reported to be compatible with conservation of beneficial insects (Hendrix et al. 1997). It was first labeled in 1997 for cotton (Saldago et al. 1997) and has since been labeled for forestry use. Another microbial insecticide registered for loblolly pine plantations is *B. thuringiensis*. *Bacillus thuringiensis* contains bacterial spores and delta endotoxin crystals which are activated in the gut of susceptible caterpillars, and therefore must be ingested to be effective (Ware 1994). *Bacillus thuringiensis* has been shown to reduce tip moth damage and has little impact on tip moth parasitoids (K.W.M., unpublished data).

The objectives of this study were to compare the efficacy of these compounds for controlling tip moth infestations, and to determine spray timing values for these four compounds in the Georgia Piedmont where three generations occur annually.

Materials and Methods

This study was conducted during 1999 in two 3-yr-old loblolly pine stands located in Oglethorpe County, GA (site 1: 33° 49″ N, 83° 03″ W; site 2: 33° 47″ N, 83° 00″ W). The experimental design was a randomized complete block with five treatments and four replications per application date (two replications per site). Each replication contained 10 treated trees with 20 trees being sampled as control trees. The treatment compounds were applied with backpack sprayers (Solo, Newport News, VA) as the following formulations at the indicated rates: permethrin (Pounce 3.2 EC [emulsifiable concentrate], FMC, Philadelphia, PA) (0.17 kg [AI]/ha), lambda-cyhalothrin (Warrior T, Zeneca Agricultural Products, Wilmington, DE) (0.045 kg [AI]/ha), spinosad (Tracer and SpinTor 2 SC [soluble concentrate], Dow AgroSciences LLC, Indianapolis, IN) (0.098 kg [AI]/ha), and *B. thuringiensis* variety *kurstaki* (Foray 48B, Abbott, North Chicago, IL) (0.56 kg [AI]/ha).

The insecticides were applied on seven dates in the first generation and six dates during each of the second and third generations. Application dates were determined using a biophenometer (model T 151, Dataloggers, Logan, UT) to monitor the number of accumulated degree-days (°C). Temperature thresholds for degree-day accumulations were 9.5°C (lower) and 33.5°C (upper) (Haugen and Stephen 1984). Initial applications were made ≈75 DD (°C) after the beginning of each generation as determined by trapping male moths using a synthetic, commercially available tip moth sex pheromone in sticky wing-traps (Pherocon 1 C, Trece Inc., Salinas, CA). Degree-day accumulations began the day after detection of an average of one moth per trap per day. Subsequent applications were timed for approximately every 60 DD (°C) in the first generation and every 120 DD (°C) in the second and third generations. Longer intervals were used in the latter two generations to increase the treatment period (number of accumulated degree-days) and reduce the application frequency.

Tip moth damage levels were evaluated after each generation by counting the total number of shoots damaged relative to the total number of shoots on the whole tree. Compound efficacy, based on tip moth damage levels, was compared for all three generations combined and for the best three dates within each generation. Tip moth damage levels were arcsine square root (angular) transformed and subjected to an analysis of variance (ANOVA). The data were analyzed as a randomized complete block design and means were separated using PROC GLM and the Tukey studentized range test (SAS Institute 1989).

Second order polynomial regressions (parabolas) were developed by comparing the accumulated degree-day total for each spray date (independent variable) with the corresponding tip moth damage for trees treated on that date (dependent variable) (SPSS 1997). The lowest point of the regression curve, as determined by setting the first order derivative of the regression equation to zero and solving for degree-days, indicates the optimal spray timing value and corresponding optimal spray value (Thomas 1968, Gargiullo et al. 1985). The optimal spray dates for 1999 were calculated using the average daily degree-day contributions for the corresponding time periods.

Results and Discussion

Infestation Levels. Whole-tree damage averaged 23% in the control plots during the year (Fig. 1), and mean plot values ranged between 16 and 38% during the three generations (Figs. 2–4). Tip moth damage was highest during the first generation and then declined in the second and third generations. These infestation levels represent typical tip moth densities encountered in 3-yr-old loblolly pine stands in the Georgia Piedmont during endemic periods (C.W.B., unpublished data).

Insecticide Efficacies. Differences were detected in the ANOVA among the five treatments ($F = 43.92$; $df = 4, 12$; $P = 0.0001$). Significantly more damage was observed in the controls than in the insecticide-treated plots (Fig. 1). Lambda-cyhalothrin was the most effective insecticide, providing 83.1% control relative to the untreated plots (Fig. 1). Lambda-cyhalothrin has a large window of efficacy making application timing less critical than for the other insecticides tested. For example, applications reduced damage levels to <5% on the fourth, fifth and sixth spray dates during the first generation compared with 38% in the control (Fig. 2). This is a period of 14 d where little or no variation in damage levels was observed. For most insecticides, this large spray efficacy

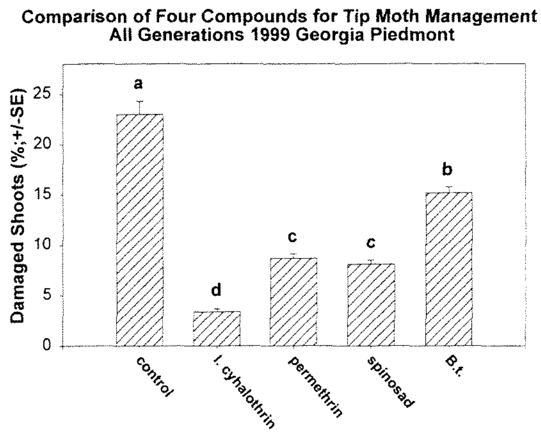

Fig. 1. Mean percentage (±SE) of loblolly pine shoots damaged by Nantucket pine tip moth in a study comparing the efficacy of the following compounds: permethrin (Pounce), lambda-cyhalothrin (Warrior T), spinosad (SpinTor 2 SC), and *Bacillus thuringiensis* variety *kurstaki* (Foray 48B). Bars with the same letter are not significantly different ($P > 0.05$; Tukey test).

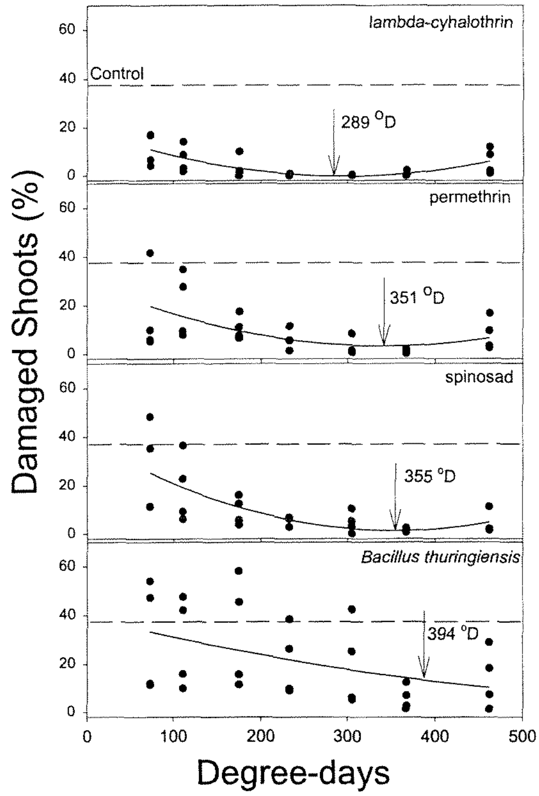

Fig. 2. Second-order polynomial regressions of percentage of Nantucket pine tip moth damage versus degree-day accumulations (commencing on the day after first trap catch). These regressions predict the optimal number of degree-days for the most effective insecticide applications in the first generation (denoted by arrow). Dashed line denotes average tip moth damage levels in control treatments. The optimal degree-days summation for the *Bacillus thuringiensis* treatment was estimated using only the fifth, sixth, and seventh spray dates.

window degrades during the third generation as life stage asynchrony increases making targeting of susceptible instars problematic (Berisford et al. 1984). As a result, timing becomes more difficult and a corresponding decrease in insecticide efficacy is commonly observed (Fettig et al. 2000b). However, during the first three lambda-cyhalothrin applications in the third generation, damage levels were <5% (Fig. 4). This large spray efficacy window would be highly advantageous for controlling third generation populations.

The efficacy of permethrin and spinosad was surprisingly similar, providing 62.3 and 64.9% control, respectively. There was no significant difference between their treatment means ($P > 0.05$) (Fig. 1), but they were significantly different from the control and *B. thuringiensis* treatments (Fig. 1). Because of their similar efficacy, spinosad could become an important alternative to permethrin if it is less detrimental to natural enemies as has been previously suggested (Thompson et al. 1995, Saldago et al. 1997; unpublished data). Spinosad also might be important in resistance management if permethrin becomes too widely used in production forests. Some lepidopteran insects have developed resistance to both lambda-cyhalothrin and permethrin (Brown et al. 1998).

Bacillus thuringiensis was the least effective insecticide examined in this study, providing only 34.2% control (Fig. 1). Damage levels in the *B. thuringiensis* treatment were significantly lower than the control treatment; however, there was some difficulty in finding the optimum timing value for this product. The spray efficacy window for *B. thuringiensis* is much shorter than for the other compounds examined in this study, making timing more critical. For example, during the second generation, *B. thuringiensis* damage levels were less than control levels in all plots only at the application date closest to the optimal spray date (Fig. 3). The shorter spray window for *B. thuringiensis* may be due to climatic effects, such as heavy rain and UV radiation, which have been shown to reduce the residual effects of its application (Cooke and Régnière 1996). However, its low impact on natural enemies may be advantageous when large areas are treated during multiple generations.

Comparisons for the three best spray dates were also significant for each of the three generations (generation 1: $F = 16.8$; df = 4, 12; $P = 0.0001$; generation 2: $F = 11.34$; df = 4, 12; $P = 0.0001$; generation 3: $F = 58.62$; df = 4, 12; $P = 0.0001$). Comparisons among treatments within each generation were similar to the overall analysis. Therefore, the data are not presented for the sake of brevity.

Spray Timing. In general, the polynomial regressions for each insecticide during the first and second generations show that efficacy gradually increased, reached optimal levels, and then decreased through time (Figs. 2 and 3). Optimal timing values for an insecticide varied little between the first two gener-

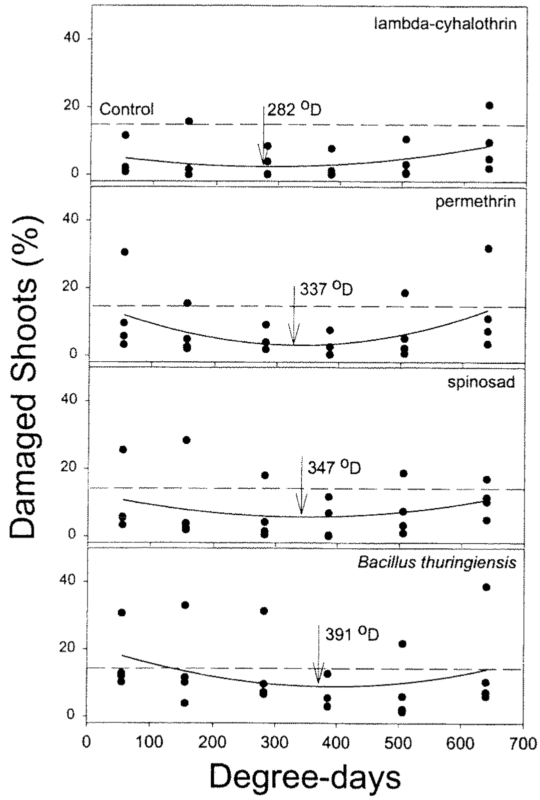

Fig. 3. Second-order polynomial regressions of percentage of Nantucket pine tip moth damage versus degree-day accumulations (commencing on the day after first trap catch). These regressions predict the optimal number of degree-days for the most effective insecticide applications in the second generation (denoted by arrow). Dashed line denotes average tip moth damage levels in control treatments.

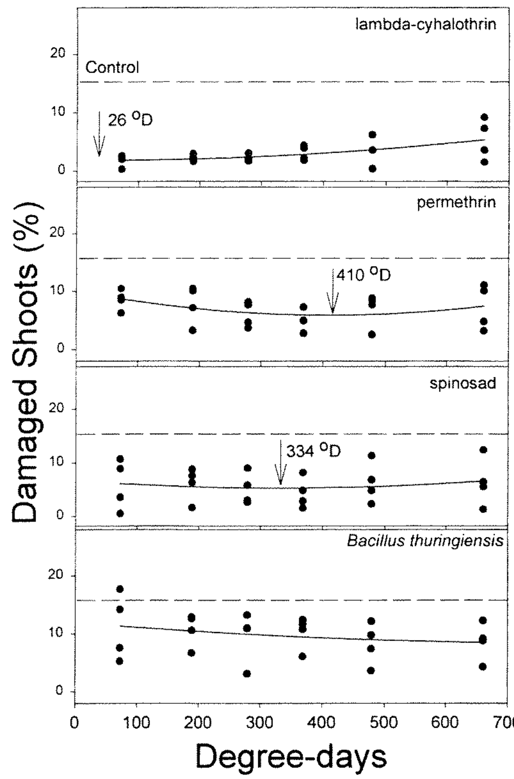

Fig. 4. Second-order polynomial regressions of percentage of Nantucket pine tip moth damage versus degree-day accumulations (commencing on the day after first trap catch). These regressions predict the optimal number of degree-days for the most effective insecticide applications in the third generation (denoted by arrow). Dashed line denotes average tip moth damage levels in control treatments. Optimal timing value for *B. thuringiensis* not presented because the degree-day summation was greater than the number of degree-days in a tip moth generation.

ations (Table 1). For each insecticide, the variation between generation 1 and 2 represented <1 d of degree-day accumulations. During these generations, the optimal spray timing values ranged from 282 DD (lambda-cyhalothrin) to 394 DD (*B. thuringiensis*) (°C) (Table 1). All of these optimal spray dates are within 9 d of the optimal spray periods listed by Fettig et al. (2000a) for these areas using historical climatic data. The lambda-cyhalothrin treatment had the earliest application date in the first two generations, followed by the permethrin and spinosad treatments, and finally the *B. thuringiensis* treatment. The permethrin and spinosad dates varied by <1 d from each other. Optimal timing values for *B. thuringiensis* were likely later than for other contact insecticides examined in this study because *B. thuringiensis* must be ingested to kill the target organism (Ware 1994). Cooke and Régnière (1996) developed a model predicting the efficacy of *B. thuringiensis* sprays on spruce budworm, *Choristoneura fumiferana* (Clemens), that suggested the applications worked best when the larvae were feeding the most. Second instars feed more frequently on the plant surface after exiting needle mines as second instars (Berisford 1988).

During the third generation, the lambda-cyhalothrin treatments worked well throughout the spray period, with efficacy decreasing slightly for the later spray dates (Fig. 4). The optimal timing value for this generation was 26 DD (°C) (Table 1). The permethrin and spinosad optimal timing values were similar to predictions during the first two generations. In the *B. thuringiensis* treatment, the regression equation predicted optimal degree-day timing values that were greater than the total number of degree-days accumulated during an entire generation (Ross et al. 1989, Fettig and Berisford 1999), and therefore are not useful for spray timing purposes.

This study was conducted in the Georgia Piedmont where three tip moth generations occur annually (Fettig et al. 2000a). Previous studies suggest that under most circumstances the spray timing values presented here are applicable on a more region-wide basis (Gargiullo et al. 1983, 1985); including, portions

Table 1. Number of degree-days and associated calendar dates for spray timing of four compounds used to control tip moth infestations in the Georgia Piedmont

Generation	No. of degree-days (°C) and predicted spray dates			
	Lambda-cyhalothrin	Permethrin	Spinosad	*B. thuringiensis*
1	289 (11 Apr)	351 (19 Apr)	355 (19 Apr)	394 (25 Apr)[a]
2	282 (14 Jun)	337 (18 Jun)	347 (19 Jun)	391 (23 Jun)
3	26 (25 July)	410 (14 Aug)	334 (10 Aug)	827 (—)[b]

[a] Optimal number of degree-days in this case estimated using only the fifth, sixth, and seventh spray dates.
[b] Predicted degree-day sum greater than total degree-days in a tip moth generation.

of the southeastern Piedmont, and coastal plains of Virginia and North Carolina, where three generations occur annually (Fettig et al. 2000a). The associated optimal spray dates will vary annually depending on geographic location and prevailing climatic patterns.

In conclusion, lambda-cyhalothrin, permethrin, spinosad, and *B. thuringiensis* are effective tools for controlling tip moth infestations. Lambda-cyhalothrin is highly effective and has a large spray efficacy window making timing less critical, but also has the highest mammalian toxicity and is potentially detrimental to tip moth parasitoids (unpublished data). Permethrin and spinosad both exhibited good efficacy and have low mammalian toxicity, but like lambda-cyhalothrin, permethrin is highly toxic to many parasitoids (Theiling and Croft 1988, Idris and Gratius 1993). There is also some concern that spinosad may also be deleterious to specific hymenopterous parasitoids (Hendrix et al. 1997). Still, spinosad may become increasingly important for controlling tip moth infestations because of the relatively low applicator risks and its potential to conserve other natural enemies, such as coleopteran predators. *B. thuringiensis* was least effective in controlling tip moth infestations and has a shorter application window than the other insecticides used in this study. However, carefully timed applications in the first and second generations could be effective in reducing tip moth damage levels and still maintaining natural enemy populations (Idris and Gratius 1993).

Acknowledgments

We thank J. Lyons and J. Hodges (erstwhile Champion International Corporation) for assistance in finding research sites and granting permission to conduct research on those sites. We also thank A. Coody, J. M. Gibbs, and R. Garland for their contributions to data collection and technical help. The authors thank J. N. All for providing some of the insecticide product. This research was supported in part by the University of Georgia Pine Tip Moth Consortium directed by C. W. Berisford.

References Cited

Berisford, C. W. 1988. The Nantucket pine tip moth, pp. 141–161. *In* A. A. Berryman [ed.], Dynamics of forest insect populations. Plenum, New York.

Berisford, C. W., P. M. Gargiullo, and C. G. Canalos. 1984. Optimum timing for insecticidal control of the Nantucket pine tip moth (Lepidoptera: Tortricidae). J. Econ. Entomol. 77: 174–177.

Brown, T. M., P. K. Bryson, D. S. Brickle, S. Pimprale, F. Arnette, M. E. Root, J. T. Walker, and M. J. Sullivan. 1998. Pyrethroid-resistant *Helicoverpa zea* and transgenic cotton in South Carolina. Crop Prot. 17: 441–445.

Cade, S. C., and R. L. Hedden. 1987. Growth impact of pine tip moth on loblolly pine plantations in the Ouachita Mountains of Arkansas. South. J. Appl. For. 11: 128–133.

Cooke, B. J., and J. Régnière. 1996. An object-oriented, process-based stochastic simulation model of *Bacillus thuringiensis* efficacy against spruce budworm, *Choristoneura fumiferana* (Lepidoptera: Tortricidae). Int. J. Pest Manage. 42: 291–306.

Douce, G. K., and W. Hudson. 1999. Forest and Ornamental Control, pp. 421–422. *In* P. Guillebeau [ed.], 1999 Georgia pest control handbook. Cooperative Extension Service, Athens, GA.

Fettig, C. J., and C. W. Berisford. 1999. Nantucket pine tip moth phenology in eastern North Carolina and Virginia: implications for effective timing of insecticide applications. South. J. Appl. For. 23: 30–38.

Fettig, C. J., M. J. Dalusky, and C. W. Berisford. 2000a. Nantucket pine tip moth (Lepidoptera: Tortricidae) phenology and spray timing predictions for seven southeastern states. SRS-18. Asheville, NC: U.S. Dept. of Agric. For. Serv. South. Res. 21 pp.

Fettig, C. J., K. W. McCravy, and C. W. Berisford. 2000b. Effects of Nantucket pine tip moth insecticide spray schedule sequences on loblolly pine seedlings. South. J. Appl. For. (in press).

Gargiullo, P. M., C. W. Berisford, C. G. Canalos, and J. A. Richmond. 1983. How to time dimethoate sprays against the Nantucket pine tip moth. Ga. For. Comm. For. Res. Pap. No. 44.

Gargiullo, P. M., C. W. Berisford, C. G. Canalos, J. A. Richmond, and S. A. Cade. 1984. Mathematical descriptions of *Rhyacionia frustrana* (Lepidoptera: Tortricidae) cumulative catches in pheromone traps, cumulative egg hatching, and their use in timing of chemical control. Environ. Entomol. 13: 1681–1685.

Gargiullo, P. M., C. W. Berisford, and J. F. Godbee, Jr. 1985. Prediction of optimal timing for chemical control of the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), in the southeastern coastal plain. J. Econ. Entomol. 78: 148–154.

Haugen, D. A., and F. M. Stephen. 1984. Development rates of Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae) life stages in relation to temperature. Environ. Entomol. 13: 56–60.

Hendrix, W. H. III, R. Huckaba, B. Nead, L. Peterson, D. Porteous, and G. Thompson. 1997. Tracer insect control: 1996 EUP results. Proc. Beltwide Cotton Conf. 2: 1086–1087.

Idris, A. B., and E. Gratius. 1993. Field studies on the effect of pesticides on the diamondback moth (Lepidoptera: Plutellidae) and parasitism by *Diadegma insulare* (Hymenoptera: Ichneumonidae). J. Econ. Entomol. 86: 1196–1202.

Kudon, L. H., C. W. Berisford, and M. J. Dalusky. 1988. Refinement of a spray timing technique for the Nantucket pine tip moth (Lepidoptera: Tortricidae). J. Entomol. Sci. 23: 180–186.

Malinoski, M. K., and T. D. Paine. 1988. A degree-day model to predict Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), flights in southern California. Environ. Entomol. 17: 75–79.

Nowak, J. T., and C. W. Berisford. 2000. Effects of intensive forest management practices on insect infestation levels and loblolly pine growth. J. Econ. Entomol. 93: 336–341.

Ross, D. W., J. Pickering, J. Berg, and C. W. Berisford. 1989. Mapping Nantucket pine tip moth phenology (Lepidoptera: Tortricidae) in Georgia. J. Entomol. Sci. 24: 405–412.

Saldago, V. L., G. B. Watson, and J. J. Sheets. 1997. Studies on the mode of action of spinosad, the active ingredient in tracer insect control. Proc. Beltwide Cotton Conf. 2: 1082–1086.

SAS Institute. 1989. User's guide: statistics, version 6. SAS Institute, Cary, NC.

SPSS. 1997. Sigmaplot 4.0, user's manual. SPSS, Chicago, IL.

Theiling, K. M., and B. A. Croft. 1988. Pesticide side-effects on arthropod natural enemies: a data base summary. Agric. Ecosys. Environ. 21: 191–218.

Thomas, G. B. 1968. Calculus and analytic geometry, 4th ed. Addison-Wesley, Reading, MA.

Thompson, G. D., J. D. Busacca, O. K. Jantz, H. A. Kirst, L. L. Larson, and T. C. Sparks. 1995. Spinosyns: an overview of new natural insect management systems. Proc. Beltwide Cotton Conf. 2: 1039–1042.

Ware, G. W. 1994. The pesticide book. Thomson, Fresno, CA.

Young, J. F., L. O. Warren, and F. M. Stephen. 1979. Pine growth and yield: influences of pine tip moth control. Ark. Agric. Exp. Farm Res. 28: 7.

Received for publication 1 February 2000; accepted 25 August 2000.