N O T E

Preliminary Tests of an Attracticide Formulation for Control of the Nantucket Pine Tip Moth (Lepidoptera: Tortricidae)[1]

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J. Entomol. Sci. 40(2): 240-245 (April 2005)

Key Words *Rhyacionia frustrana*, permethrin, trap catch, *Pinus taeda*

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), is an important pest of intensively managed loblolly pine (*Pinus taeda* L.) plantations in the southeastern United States (Asaro et al. 2002, J. Entomol. Sci. 38: 1-40). Repeated infestations of this multivoltine, shoot-boring insect can cause substantial growth reduction and poor tree form, resulting in significant economic losses (Cade and Hedden 1987, South. J. Appl. For. 11: 128-133; Berisford et al. 1989, Insects Affecting Reforestation: Biology and Damage, Forestry Canada, Pacific Forestry Centre, Victoria, British Columbia, pp. 130-136; Nowak and Berisford 2000, J. Econ. Entomol. 93: 336-341). Traditionally, control of this pest is achieved with conventional insecticides. Most applications are now made via spray timing models (Fettig and Berisford 1999, South. J. Appl. For. 23: 30-38; Fettig et al. 2000, USDA For. Serv. Res. Paper SRS-18). This involves the use of pheromone-baited traps to monitor adult emergence, providing a bio-fix point to begin accumulating degree-days. Spray timing models for most generations of *R. frustrana* in all southern states have been developed using degree-day development models combined with historical temperature records (Fettig et al. 2000a, USDA For. Serv. Res. Paper SRS-18; Fettig and Berisford 2002, J. Agric. Forest Entomol. 4: 1-5; Fettig et al. 2003, USDA For. Serv. Res. Paper SRS-32).

Despite the development of optimum spray dates and schedules for Nantucket pine tip moth, economic action thresholds for tip moth control remain elusive, while restrictions on pesticide use continue to grow. Therefore, there is an increasing demand for cost-effective and environmentally friendly tools to control these plantation pests. One potential tool is attracticide or "Attract and Kill" technology, which incorporates synthetic sex pheromones with a pyrethroid insecticide in a UV-stable paste. Such tools are an extension of pheromone-based mating disruption strategies, which

[1]Received 04 October 2004; accepted for publication 04 December 2004.

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have been applied to many lepidopteran pests with mixed success. Limitations to mating disruption against tortricid pests such as codling moth (*Cydia pomonella* (L.)) and oriental fruit moth (*Grapholita molesta* Busck) include: (1) lower efficacy in small or irregularly shaped treatment blocks (Judd et al. 1996, J. Entomol. Soc. Am. 93: 23-24; Charmillot et al. 2000, Entomol. Exp. Appl. 94: 211-216), (2) altered plume structure in response to variables such as crop canopy, wind speed and wind direction (Cardé and Minks 1995, Annu. Rev. Entomol. 40: 559-585), (3) adsorption and re-release of pheromone from the crop canopy (Karg et al. 1994, J. Chem. Ecol. 20: 1825-1841; Suckling et al. 1996, J. Chem. Ecol. 22: 325-341), and (4) the prohibitive costs of releasing large amounts of pheromone required by mating disruption in some crop systems. Attempts to control *R. frustrana* via mating disruption have been generally ineffective (Berisford and Hedden, unpubl. data).

Attracticide-based technologies have been developed for a number of lepidopteran pests to overcome some of these limitations (Butler and Las 1983, J. Econ. Entomol 76: 1448-1451; Haynes et al. 1986, J. Econ. Entomol. 79: 1466-1471; Miller et al. 1990, J. Econ. Entomol. 83: 1321-1325; Downham et al. 1995, Bull. Entomol. Res. 85: 463-472; Suckling and Brockerhoff 1999, J. Econ. Entomol. 92: 367-372; Charmillot et al. 2000, Entomol. Exp. Appl. 94: 211-216; Krupke et al. 2002, Environ. Entomol. 31: 189-197; Evenden and McLaughlin 2004, Environ. Entomol. 33: 213-220). For example, several novel attracticide formulations under the trade name *LastCall* (IPM Development Co., Portland, OR) have recently been registered in the U.S. against various tortricid pests: the codling moth—*LastCall* CM; the oriental fruit moth—*LastCall* OFM; and a complex of shoot boring moths, including the western pine shoot borer, *Eucosma sonomana* Kearfott, the eastern pine shoot borer, *Eucosma gloriola* Heinrich, and the lodgepole pine shoot borer, *Eucosma recissoriana* Heinrich—*LastCall* EucosmaAK. These products consist of a viscous paste incorporating moth-specific pheromones and the insecticide permethrin. Similar products are under development for a variety of pests in agriculture, horticulture, forestry, and urban settings. All of these products have identical ingredients except for the attractant compounds.

Our objective was to perform preliminary tests on the effectiveness of *LastCall* NPTM to control the Nantucket pine tip moth in loblolly pine plantations. This formulation was developed by Darek Czokajlo (IPM Development Co., Portland, OR) and consisted of a clear viscous paste consisting of a proprietary matrix plus additional inert ingredients (93.84% of the formulation), the insecticide permethrin (6%), and the pheromone of *R. frustrana* (0.16%). Nantucket pine tip moth pheromone used in the formulation was a two-component blend consisting of 95% (E)-9-dodecenyl acetate (Bedoukian Research Inc., Danbury, CT) and 5% (E)-9,11-dodecadienyl acetate (IPM Development Co., Portland, OR). The product is applied directly to trees as 50 µl droplets by depressing the plunger on a hand-held applicator, which consists of a pump head (white plastic with plunger and nozzle) attached to a tube containing the formulation. Once applied, droplets remain in place and contribute little or no insecticide runoff or residue to the soil regardless of subsequent weather conditions. *LastCall* NPTM was applied to trees at a rate of two drops per tree, or 3000 drops per ha. At this application rate, one applicator contains enough product to treat approximately 1 ha, utilizing 0.24 g of pheromone and 9 g of permethrin. By comparison, a traditional tip moth spray protocol with permethrin requires approximately 25× that amount of active ingredient per ha.

Because EPA restrictions prevented us from treating more than 4 ha of an unregistered product per year without an experimental use permit, we replicated our trials over numerous years, while replication within years was limited. Therefore, from 2002 to 2004, we established square or rectangular treatment blocks and adjacent control blocks (separated by a 30 to 60 m buffer) of varying sizes (0.8 to 4 ha) within 1-yr-old loblolly pine plantations at six sites throughout Georgia (Table 1). Among these sites, *LastCall* NPTM was applied to treatment blocks to control the first, second, third or fourth generation of *R. frustrana* (Table 1). Prior to treatment, three Pherocon 1C wing traps with red rubber septa baits (Trecé Inc., Salinas, CA) were placed in each treatment and control block at each site to monitor adult emergence throughout the study. Baits were replaced monthly to insure adequate pheromone release from the traps. Within each block, damage estimates due to *R. frustrana* were obtained before and after each treatment by determining the percentage of shoots in the top whorl that were infested for 25 trees along each of two diagonal transects (n = 50 trees per block; 100 trees were sampled in the 4 ha blocks). Infested shoots are identified by pitch mass accumulations and dry, brown needles near the terminal end of the shoot. Fettig and Berisford (1999, J. Entomol. Sci. 34: 203-209) demonstrated that top whorl damage estimates were well correlated with whole-tree estimates. Damage comparisons between treated and control blocks were performed using a Mann-Whitney rank sum test since normality or equal variance assumptions were not met. A non-parametric test was used because no single data transformation resulted in normality or equal variance in all cases.

At each site, wing traps within those blocks treated with *LastCall* NPTM caught few or no moths throughout the adult emergence period compared to control blocks (Fig. 1a-d). Such 'trap shutdown' is commonly observed during mating disruption efforts, although it is not in itself a guarantee that damage has been reduced. Trap shutdown occurred for a maximum of 8 wks during the entire spring adult emergence period, indicating that *LastCall* was actively releasing pheromone during this period. This length of time greatly exceeds the residual affect of conventional pyrethroid insecticides when applied directly to trees. Initial concerns that a second application of *LastCall* would be required to maintain control during this extended period of time were unfounded. Adult emergence periods during subsequent tip moth generations generally last less than 4 wks, so reapplication during the summer months was less of a concern.

Pre-treatment damage was similar ($P > 0.05$) in treated and control blocks at all sites (Table 1). Attracticide treatments were most efficacious at controlling damage by the first generation of *R. frustrana* compared to subsequent generations. First generation post-treatment damage among trees in the treated blocks was significantly lower than control blocks for sites in McDuffie Co. ($T = 22990$; $P < 0.001$), Jefferson Co. South ($T = 2097.5$; $P < 0.001$) and Jefferson Co. North ($T = 2222$; $P < 0.001$). Second generation post-treatment damage was lower in the treated blocks at four sites, but only significantly so at two of four sites (Oconee Co., $T = 2050.5$, $P = 0.042$; McDuffie Co., $T = 18655$, $P < 0.001$; Jefferson Co. North, $T = 1766$, $P = 0.161$; Jefferson Co. South, $T = 1747.5$, $P = 0.221$). Post-treatment damage due to the third and fourth generation was not significantly different among treated and control blocks (Effingham Co. East, $T = 482.5$, $P = 1.0$; Effingham Co. West, $T = 1015$, $P = 0.140$) (Table 1).

Trap shutdown, which occurred in all treated blocks regardless of tip moth generation, was not indicative of treatment efficacy. Indeed, past attempts at mating disruption against *R. frustrana* using synthetic baits or glandular extracts also resulted

Table 1. Average (±SE) percent of top-whorl shoots infested by tip moth in control versus treated blocks before and after each treatment. Within each control-treatment pair, means followed by the same letter are not significantly different ($P >$ 0.05)

Year	Site	Block size (ha)	Tip moth generation	Avg. pre-treatment damage (±SE)		Avg. post-treatment damage (±SE)	
2002	Oconee Co.	0.8	2	Control	26.99 (4.30)a	Control	24.13 (3.36)a
				Treatment	33.04 (3.79)a	Treatment	14.08 (2.64)b
	Effingham Co. East	0.8	3	Control	5.69 (2.27)a	Control	15.55 (5.67)a
				Treatment	5.95 (2.64)a	Treatment	31.11 (6.82)a
	Effingham Co. West	0.8	4	Control	20.2 (4.93)a	Control	37.1 (4.43)a
				Treatment	33.3 (6.93)a	Treatment	33.7 (4.58)a
2003	McDuffie Co.	4	1	Control	65.36 (2.15)a	Control	75.15 (2.65)a
				Treatment	61.88 (2.09)a	Treatment	8.24 (1.20)b
			2			Control	47.63 (2.48)a
						Treatment	29.20 (2.41)b
2004	Jefferson Co. North	2	1	Control	42.42 (4.30)a	Control	17.7 (2.66)a
				Treatment	43.05 (4.98)a	Treatment	2.20 (1.22)b
			2			Control	16.83 (3.40)a
						Treatment	8.83 (2.12)a
	Jefferson Co. South	2	1	Control	47.71 (4.75)a	Control	27.32 (3.60)a
				Treatment	44.94 (5.03)a	Treatment	0.71 (0.71)b
			2			Control	21.30 (3.88)a
						Treatment	14.25 (3.37)a

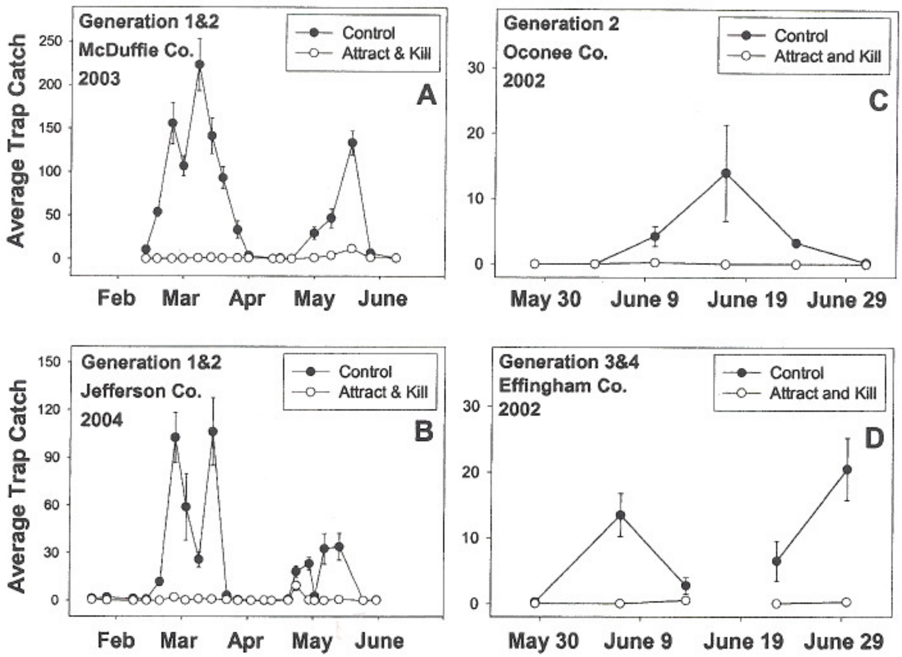

Fig. 1 Average *Rhyacionia frustrana* trap catch in control blocks versus *LastCall* NPTM treated blocks for A) generations one and two in McDuffie Co., B) generations one and two in Jefferson Co. (both sites averaged together), C) generation two in Oconee Co. and D) generations three and four in Effingham Co.

in trap shutdown (Berisford and Hedden 1978, Environ. Entomol. 7: 532-533) but no reduction in damage (unpubl. data). *LastCall* NPTM was highly effective at controlling damage by the first generation of *R. frustrana*, but only moderately effective at controlling damage by the second generation. Damage by later generations was not suppressed by *LastCall* NPTM.

It is not clear why *LastCall* was less effective for control of summer *R. frustrana* populations. However, these results are not surprising given that control of tip moth using conventional insecticide applications are also less effective during summer, particularly during the third and fourth generation (Fettig et al. 2000b, South. J. Appl. For. 24: 106-111; Fettig and Berisford 2002, J. Agric. Forest Entomol. 4: 1-5). During these intervals, tip moth development is more asynchronous than in spring, and targeting a specific life stage (first and second instar larvae) is therefore more difficult.

Furthermore, trap catches during summer almost always decrease compared to spring, even if tip moth population density remains relatively constant between generations (Asaro and Berisford 2001a, Environ. Entomol. 30: 776-784; Asaro et al. 2004, Environ. Entomol. 33: 397-404). We speculate that reduced adult life span during summer (Asaro and Berisford 2001b, Environ. Entomol. 30: 999-1005) along with a change in pheromone release rates, plume structure, and adult male responses to such changes, may be altering trap catch dynamics between spring and summer. These factors may also be responsible for reduced efficacy of *LastCall* NPTM at higher temperatures. Further studies will be required to elucidate how adult male tip moths differentially respond to *LastCall* droplets in the field during spring and summer.

Finally, treatment blocks during the third and fourth generation trials in 2002 were 0.8 ha, smaller than those of the other treatments of the first and second generation during subsequent years (Table 1). Smaller treatment blocks may have reduced product efficacy due to increased edge effects, with a greater likelihood of gravid females entering the treated area and overcoming the knockdown effect of *LastCall* on males.

Despite the limitations of *LastCall* NPTM described herein, these results are significant; current *R. frustrana* management strategies recommend targeting the first and/or second generation for control, because the growth flush of *P. taeda* during these generations is thought to contribute the greatest amount of annual volume gains (Fettig et al. 2000b, South. J. Appl. For. 24: 106-111; Asaro et al. 2002, J. Entomol. Sci. 38: 1-40). It is unlikely that controlling all generations of *R. frustrana*, particularly the later generations where damage control is more difficult and growth flushes less robust, will ever be economical. Therefore, this product has potential as another important tool for tip moth management, particularly in areas where pesticide use is restricted. However, for *LastCall* NPTM to be economical for tip moth management, development and eventual registration of this product will likely require additional studies addressing reduced application rates and more cost-effective means of application.

We thank Denise Bonnette, Scott Cameron, and Jimmy Seckinger, International Paper, for providing field sites and assistance with some aspects of this study. This research was funded by Richard Reardon, US Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, and the Pine Tip Moth Research Consortium.