# Pheromone Trap for the Eastern Tent Caterpillar Moth

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**ABSTRACT** The discovery that the eastern tent caterpillar *Malacosoma americanum* (F.) causes mare reproductive loss syndrome (MRLS), and thus has the potential to continue to result in major economic losses to the equine industry of Kentucky, has resulted in an intensive effort to identify practical means to monitor and control this defoliator, including these experiments to optimize a sex pheromone trap for this pest. A pheromone-baited delta trap with a large opening, such as InterceptST Delta, was more effective than other tested traps. Orange delta traps caught more moths than other tested colors. ETC males are caught at all tested heights within the tree canopy. For monitoring flights, setting traps at 1.5 m would allow easy counting of moths. A 9:1 blend of (*E,Z*)-5,7-dodecadienal (ETC-Ald) and (*E,Z*)-5,7-dodecadienol (ETC-OH) was most effective in capturing males. Increasing loading doses of a 3:1 blend (Ald:OH) resulted in the capture of increasing numbers of moths, but a 9:1 blend was more effective than 3:1 blend even at a nine-fold lower loading rate. Pheromone-impregnated white septa caught more moths than gray septa at the same loading dose. The advantages and limitations of using pheromone traps for monitoring *M. americanum* are discussed.

**KEY WORDS** *Malacosoma americanum*, mare reproductive loss syndrome, sex pheromone, population monitoring

The eastern tent caterpillar, *Malacosoma americanum* (F.) (Lepidoptera: Lasiocampidae), has been considered an esthetic or nuisance pest because of its early season defoliation of trees within the genera *Prunus*, *Malus*, and *Crataegus* (Neal et al. 1997). Because trees recover from this defoliation, insecticide treatments are usually not needed. In Kentucky, *M. americanum* is now recognized as a pest of great economic importance because it causes mare reproductive loss syndrome (MRLS), a disease causing both early and near-term abortions in horses (Webb et al. 2004). The prevalence of a preferred host, *Prunus serotina* Ehrhart (wild black cherry) throughout the Bluegrass region of Kentucky and particularly in fencerows surrounding pastures results in proximity between pregnant mares and caterpillars. In 2001 and 2002 combined, MRLS resulted in economic loss of more than several hundred million dollars (Webb et al. 2004). The need for tactics for monitoring and controlling outbreak populations of *M. americanum* has become apparent only since this outbreak.

The pheromone produced by the adult female had been determined to consist of (*E,Z*)-5,7-dodecadienal (ETC-Ald) and (*E,Z*)-5,7-dodecadienol (ETC-OH) (Kochansky et al. 1996). Our objective was to build on that identification and develop a pheromone trapping system that was easy to deploy and could be used to follow population trends over years, to map the occurrence of *M. americanum* over broad geographic regions, and to potentially help forecast trouble spots at the farm level (i.e., male flight in spring may be correlated to subsequent caterpillar population levels the following year). Because trap design, color, and height and pheromone blend and dose are known to influence the trapping efficiency in various species of moths (Subcev et al. 2004, Knight and Fisher 2006, Kovanci et al. 2006), this study was undertaken to refine these variables for *M. americanum*.

## Materials and Methods

**Common Trapping Procedures.** In Kentucky, pheromone traps were hung from 1.8-m T-posts that were driven into the ground every 10 m except where otherwise noted. The opening of each trap was ≈1.4 m above the ground surface except in the height study. Within a block of an experiment, traps were aligned with a fence row containing wild black cherry trees. Captured moths were counted and removed after every trapping period (1 or 2 d). The sticky surfaces of some types of traps were replaced as they became covered with scales or debris. Pheromone lures were hung from a paper clip located at the center of the trap and horizontally even with the trap entrance. These lures were replaced weekly. The position of each treatment was rerandomized within each block after

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each trapping period. Two to six blocks of each experiment were run simultaneously and were widely dispersed over the University of Kentucky's North Farm, Lexington, KY. Blocks were separated by between 20 m and 3 km.

Additional experiments were conducted in an outbreak region in Massachusetts with traps positioned in infested groups of wild black cherry trees along or near roadsides at several locations in an area east of the Connecticut River and south of Montague, MA. Baits were placed on the sticky surface at the center of sticky-type traps or suspended just above the opening of bucket/funnel traps. Trapping protocols were similar to those in Kentucky with trap types or baits randomly assigned to trapping locations in roughly linear blocks and rotated to the next trapping position each time they were inspected. Trapping intervals were 4–5 d. The distance between traps within a block was at least 15 m.

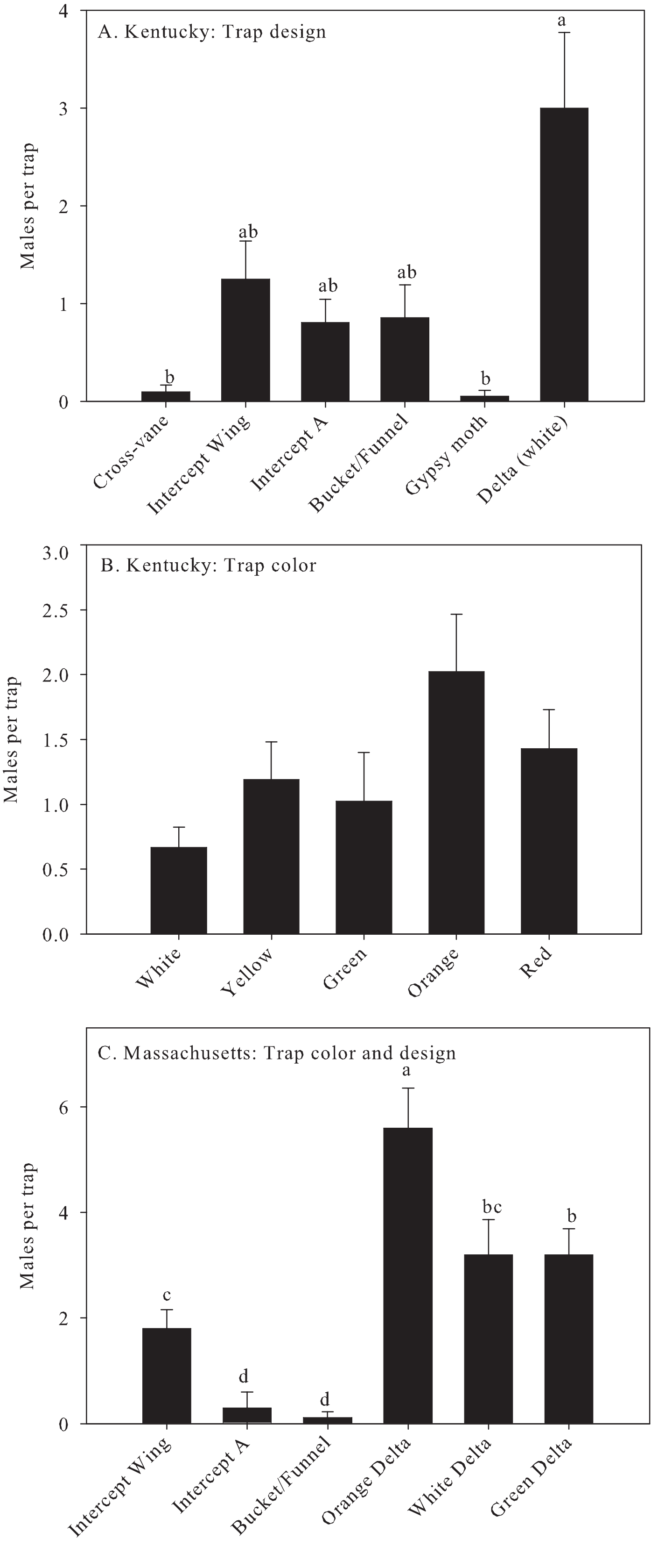
**Trap Design and Color.** Three experiments evaluated the impact of trap design and color on capture efficiency. The first experiment was conducted in Kentucky between 24 May 2004 and 1 June 2004 and included six types of traps: (1) cross-vane (black Intercept PT), (2) wing (white Intercept W), (3) A (white Intercept A), (4) bucket/funnel (green Intercept UNI-trap), (5) standard gypsy moth delta (green InterceptD), and (6) plastic delta (white Intercept ST Delta) traps (APTIV, Portland, OR). Moths were caught in 21 of 26 experimental blocks. The data set included a few missing values because of trap loss because of a tornado. A concurrently running experiment evaluated white, yellow, green, orange, and red delta traps (Intercept ST). Moths were caught in 42 of 60 experimental blocks. For these two experiments, traps contained hexane-extracted red septa loaded with 500 μg ETC-Ald and 100 μg ETC-OH. This blend caught male *M. americanum* in early studies (Kochansky et al. 1996, K.F.H., unpublished data). Hexane solutions used to load septa contained BHB, phenyl salicylate and Tinuvin-171 as stablizers at 1% of ETC-Ald and ETC-OH. Isomeric purity of the aldehyde and alcohol was 92%. The third experiment was conducted in Massachusetts between 2 June and 22 June 2005 and consisted of six traps: (1) white wing, (2) white A, (3) green bucket/funnel, (4) orange ST delta, (5) white ST delta, and (6) green ST delta traps. In this experiment, traps were baited with gray septa (West Pharmaceutical, Pittsburgh, PA) containing 300 μg ETC-Ald and 100 μg ETC-OH. This blend was within a range of blends that was effective (K.F.H., unpublished data). The pheromone was first diluted to 1:10 proportion (wt:wt) in hexane. The pheromone solution was dispensed into the well of each septum using a Hamilton 540 diluter/dispenser (Fisher, Pittsburgh, PA). Orange ST delta traps were used. The stabilizer BHB was present at 1% of the pheromone components. Isomeric purity of the pheromone components was 96%. Compounds of this higher purity were used in all subsequent tests. Concerns about the longevity of the red rubber lures based on preliminary data prompted the change to gray septa. Moths were caught in all 10 blocks.

**Height of Trapping.** A heavy duty slingshot (Big Shot; Sherrill, Greensboro, NC) was used to throw a baseball with an attached nylon cord over an accessible overhanging wild black cherry tree limb. The cord was used to pull up a line of three orange ST delta traps so that the trap openings were at ≈1.5, 4.5, and 7.5 m above the ground. At least 30 m separated these vertical lines of traps. Traps were baited with gray septa loaded with 300 μg ETC-Ald and 100 μg ETC-OH. Fourteen replicates of the experiment were conducted between 27 May and 8 June 2005, and an additional 13 replicates between 29 May and 9 June 2006.

**Blend Ratio and Loading Dose.** We evaluated the following blends on gray septa: (1) ETC-Ald only, (2) 9:1 blend, (3) 3:1 blend, (4) 1:1 blend of ETC-Ald and ETC-OH, and (5) ETC-OH only (300 μg). Except for the fifth treatment, ETC-Ald was present at 300 μg/septum. This experiment ran between 26 May and 8 June 2005. Moths were caught in 24 of 44 experimental blocks. Concurrently, in another experiment, the 3:1 blend was evaluated at different loading doses, 100, 300, 900, and 2,700 μg using both gray and white septa (West Pharmaceutical). Moths were caught in 43 of 55 experimental blocks. A similar experiment was conducted in Massachusetts between 2 June and 22 June 2005. This experiment did not include the 100-μg loading rate but did include an additional treatment of a 9:1 blend of ETC-Ald (300 μg) to ETC-OH on a gray septum. Moths were caught in all 10 experimental blocks.

**Statistical Analysis.** If no moths were caught in any trap within the block, the entire block was omitted from further analysis. Some experiments were conducted when *M. americanum* numbers were very low, which is the typical pattern in years after outbreaks; therefore, omission of the entire block eliminated many zeroes without introducing a treatment bias. No experimental blocks were omitted in Massachusetts using this criterion. For most experiments, the statistical analysis was based on a randomized complete block design using log-transformed ($\log[x + 1]$) numbers. Tukey's honestly significant difference (HSD) test was used for multiple comparisons. If the assumptions of analysis of variance (ANOVA) were not sat-

**Fig. 1.** Mean number of male eastern tent caterpillar moths caught in different types and/or colors of traps. (A) Trap design had a significant impact of the number of moths caught in a test conducted in Kentucky ($P < 0.05$; K-W ANOVA). (B) Trap color had a marginally significant affect the number of moths caught in Kentucky ($0.05 < P < 0.1$; K-W ANOVA) in Kentucky. (C) In Massachusetts, aspects of trap color and design were significant ($P < 0.05$; ANOVA). Means that share the same letter are not significantly different. Taken together, these results indicate that orange delta traps are most effective.


A. Kentucky: Trap design
Males per trap
0
1
2
3
4
b
ab
ab
ab
b
a
Cross-vane
Intercept Wing
Intercept A
Bucket/Funnel
Gypsy moth
Delta (white)
B. Kentucky: Trap color
Males per trap
0.0
0.5
1.0
1.5
2.0
2.5
3.0
White
Yellow
Green
Orange
Red
C. Massachusetts: Trap color and design
Males per trap
0
2
4
6
c
d
d
a
bc
b
Intercept Wing
Intercept A
Bucket/Funnel
Orange Delta
White Delta
Green Delta

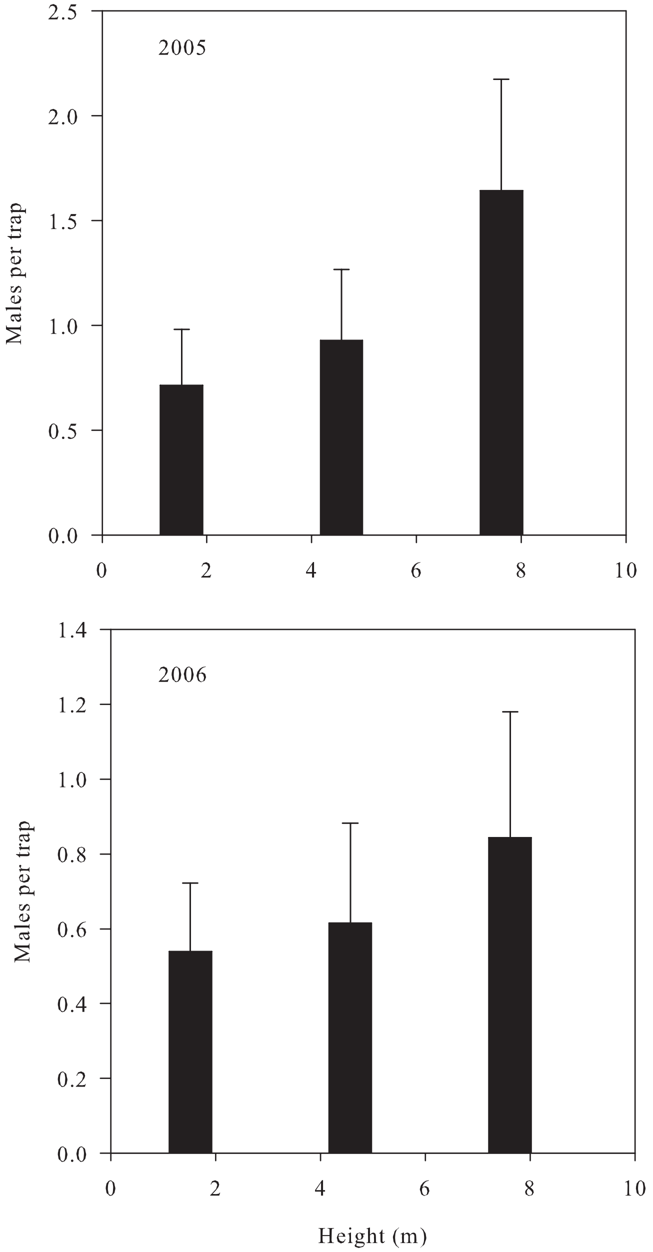



**Fig. 2.** Mean number of male eastern tent caterpillar moths caught at three heights. Although traps at 7.5 m caught the most moths in 2005 and 2006, there was no significant difference between heights ($P > 0.05$; K-W ANOVA).

isfied after this transformation, a Kruskal-Wallis nonparametric ANOVA was applied (K-W ANOVA). A two-way ANOVA on log-transformed data were used in experiments evaluating dose and septum type (dose, septum type, and dose × septum type interactions were considered). A paired *t*-test was used to contrast the 9:1 and 3:1 blends at 300 $\mu$g on gray septa for the dose and septum type experiment run in Massachusetts. All statistical analyses were done using Statistix8 (Analytical Software 2003).

## Results and Discussion

**Trap Design and Color.** In Kentucky, Intercept ST delta traps outperformed cross-vane traps and a smaller delta trap (Fig. 1A; K-W ANOVA, H = 29.9 $P < 0.05$). Trap color tended to affect trap capture, but the best trap color was not significantly better than the worst color of trap (Fig. 1B; K-W ANOVA, H = 7.8, $0.05 < P < 0.1$). In Massachusetts, there was a significant difference between traps (Fig. 1C; ANOVA; $F = 7.4$, df = 5,44, $P < 0.001$). Orange ST delta traps

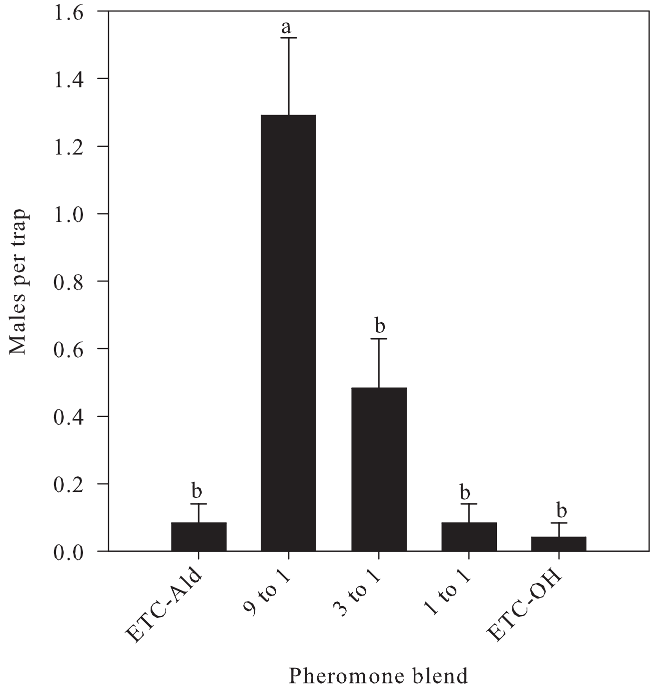



**Fig. 3.** Mean number of male eastern tent caterpillar moths caught per trap using different blend ratios of ETC-Ald and ETC-OH. Means that share the same letter are not significantly different ($P < 0.05$; K-W ANOVA).

outperformed all other trap designs and trap colors. Taken together, results from Kentucky and Massachusetts support the conclusion that orange ST delta traps would be the best choice. Other traps were probably inferior because of a combination of factors. The trap opening may be too small (small delta trap), the intensity of reflected light too high (most white traps), the contrast with the surrounding vegetation too high, the design incompatible with capture of a slow-flying moth (e.g., cross-vein and bucket traps), or some interaction between these factors. It is possible that differences between trap colors indicates perceived contrast with background foliage rather than color per se. Orange traps have an advantage of standing out to a human observer when hanging within a tree of green foliage during daylight hours; thus finding traps would be facilitated.

**Height of Trapping.** Male *M. americanum* were caught at every tested height (Fig. 2) in both 2005 and 2006. There was no significant difference among heights in either year (K-W ANOVA; H = 1.3 and 0.2 for 2005 and 2006, respectively). For the purpose of monitoring population trends, the convenience of placing traps at a height of 1.5 m seems reasonable. Because males were caught at every height, application of an attract and kill formulation may be most effective if the entire canopy is treated.

**Blend Ratio and Loading Dose.** A 9:1 blend of ETC-Ald and ETC-OH outperformed all other tested blends (Fig. 3; K-W ANOVA, H = 53.8, $P < 0.05$). Another experiment run in Kentucky showed that white septa caught more moths that gray septa when both were loaded with the 3:1 blend (Fig. 4A; ANOVA; $F = 11.0$, df = 1,336, $P < 0.001$). An increasing loading dose resulted in improved trapping performance on both white and gray septa ($F = 19.0$, df = 3,336, $P < 0.001$); thus, there was no interaction between septum type and loading dose ($F = 0.9$, df = 3,336, $P > 0.05$). In Massachusetts, the results paralleled those in Kentucky, with both septum type ($F = 65.3$, df = 1,45, $P < 0.001$) and loading dose ($F = 17.2$, df = 2,45, $P < 0.001$) showing a significant impact on capture rate, and there was no interaction between dose and septum type ($F = 1.3$, df = 2,45, $P > 0.05$). The 9:1 blend on gray septa was superior to the 3:1 blend at the same loading dose (300 $\mu$g ETC-Ald; paired *t*-test, $P < 0.001$). Results from Massachusetts and Kentucky were consistent and indicated that higher septum loading rates of the 3:1 blend improved trap performance, that white septa were superior to gray septa, and that a 9:1 blend was better than a 3:1 blend.

**Conclusions.** Monitoring *M. americanum* moth flights with orange ST delta traps baited with a 9:1 blend of ETC-Ald and ETC-OH could facilitate risk management for MRLS. The presence of tents in trees is a reliable indicator of the presence of caterpillars and thus experienced individuals can rely on this measure for feedback on the risks of MRLS. Egg sampling could give some measure of the risk of an oncoming outbreak, but it is labor intensive. Tracking moth abundance with pheromone traps gives a simpler approach of tracking population trends over years. The most effective use of traps would be to build a historical database that relates changes in number of males

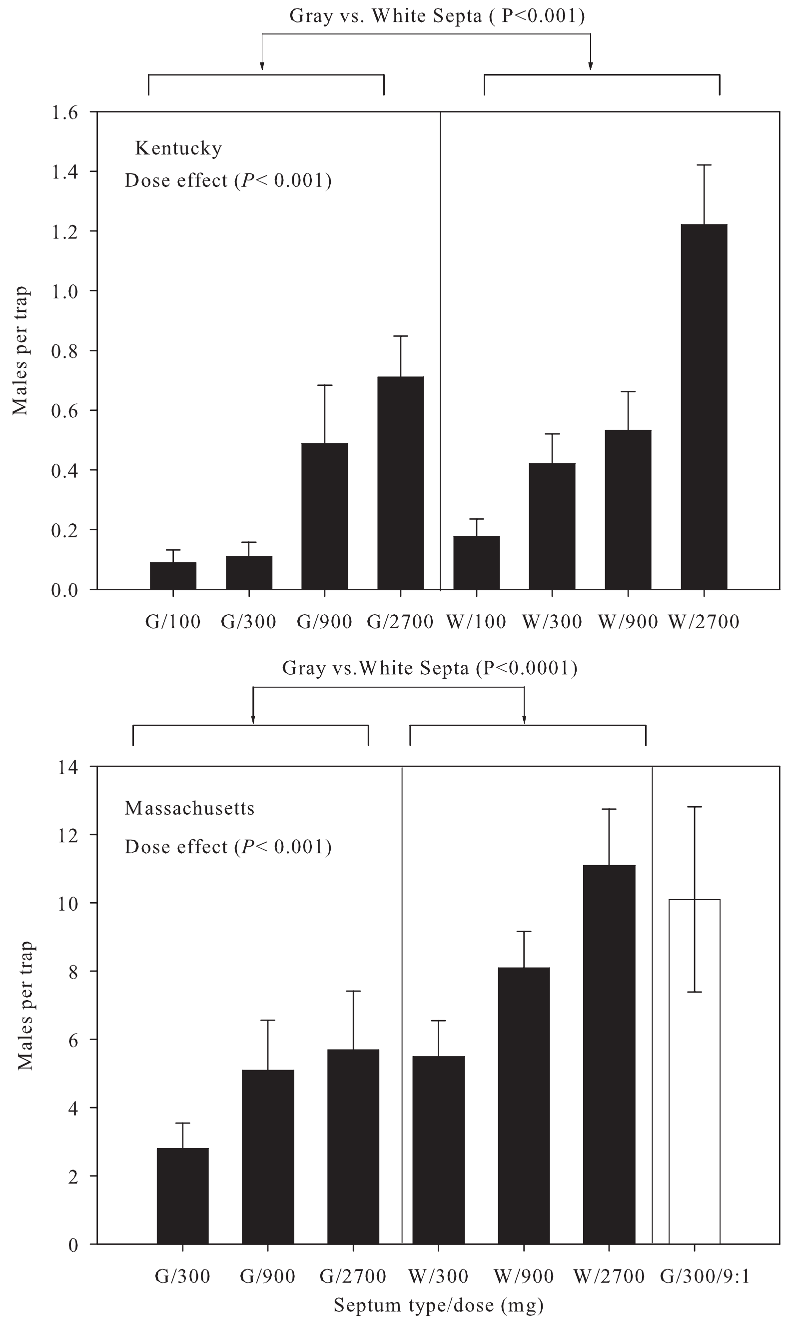



**Fig. 4.** Mean number of male eastern tent caterpillar moths caught per trap using different septa types G versus W and different loading doses of pheromone (100, 300, 900, and 2,700 $\mu$g). All traps were baited with a 3:1 blend of ETC-Ald and ETC-OH, except that illustrated with the white bar, which was baited with a 9:1 blend. There was a significant dose and septum type effect in Kentucky and Massachusetts (two-way ANOVA). A 300-$\mu$g loading of a 9:1 blend caught significantly more moths than a 3:1 blend (paired *t*-test, $P < 0.05$).

caught from 1 yr to the next to caterpillar density. An increasing trend in male captures from year to year may be correlated with upcoming outbreaks. In contrast, a decreasing trend could indicate that diseases, predators or parasitoids are having an increasing impact. Development of historical correlations between trapping results, egg masses, and population densities of caterpillars in the following year should be a research priority.

Management of MRLS involves reducing the risks that horses will be exposed to caterpillars. Control tactics that reduce this risk include the following: (1)

removing wild black cherry trees from around pastures, (2) winter treatment of eggs with pyrethroid insecticides, (3) foliar sprays targeting caterpillars, (4) trunk microinjection with systemic insecticides, (5) *Bacillus thuringiensis* targeted at neonate caterpillars, and (6) barrier treatment to prevent wandering caterpillars from entering pastures (Potter et al. 2005). Implementation of each of these actions would be facilitated by knowledge that an outbreak was likely. Specialized equipment (e.g., a cherry picker), trained personnel (e.g., an arborist), and insecticides would need to be available during a relatively short time frame. Within a season the abandonment of tents by caterpillars as they seek pupation sites may precede the reduced risk to horses. The detection of the first moths in a pheromone trap gives a reasonable time marker that it is safe for horses to be returned to pastures where exposure was a concern. In addition to predicting outbreak situations, traps could be used to facilitate mapping of the distribution of *M. americanum.* Recent verified cases of MRLS in Florida (http://pestalert.ifas.ufl.edu/jlf-0413b.htm) at the southern extremes of the *M. americanum* distribution (Fitzgerald 1995) suggest that it could be useful to know the distribution of *M. americanum* on a county by county basis. The effectiveness or practicality of using pheromone traps for monitoring and mapping distributions of *M. americanum* remains to be evaluated, as well as the potential of pheromones to be used more directly for population suppression, for example using mating disruption or attract and kill approaches.

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