Sampling and Control Trials for Tilehorned Prionus (Coleoptera: Cerambycidae) and Broadnecked Root Borer (Coleoptera: Cerambycidae) in Commercial Pecan Orchards[1]

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J. Entomol. Sci. 51(3): 199–208 (July 2016)

Abstract Panel traps baited with prionic acid pheromone lures were effective in monitoring adult male *Prionus imbricornis* (L.) and *Prionus laticolis* (Drury) (Coleoptera: Cerambycidae) beetles in commercial pecan, *Carya illinoensis* (Wangenheim) K.Koch, orchards in southern Georgia and northern Florida. Pheromone lures with 30 mg of prionic acid trapped beetles for 6 to 7 weeks in the field. A soil surface application of chlorpyrifos solution at a concentration 1.25 ml/L and 0.6 L/m^2 had an efficacy of 92% against adult male beetles and persisted for 3 weeks. A matrix of lures made from 30-mg prionic acid–treated Isomate CP plastic-coated wire at 250 lures/ha prevented pheromone-baited panel traps from attracting male *P. imbricornis* beetles. One deployment of the matrix of lures prevented sentinel traps from collecting beetles for the entire 6-week flight period. The addition of LED lights to the pheromone-baited panel trap significantly increased the number of *P. imbricornis* male beetles trapped per trap per night by 8%.

Key Words Cerambycidae, *Prionus imbricornis, Prionus laticolis,* prionic acid, chlorpyrifos, Isomate lures

The tilehorned prionus, *Prionus imbricornis* (L.), and the broadnecked root borer, *Prionus laticolis* (Drury), (Coleoptera: Cerambycidae) are commonly found in pecan, *Carya illinoensis* (Wangenheim) K.Koch, orchards in the southeastern United States. As adult beetles, they are seen in flight, running on the soil surface, or digging in the soil and litter on the soil-surface larvae. The larvae are found in live roots of uprooted pecan trees or tunneling through the soil or chewing on the underground lines of drip irrigation systems (Fig. 1D). The injured roots often have exit sites (Fig.1B). Often, the gouge-like wounds will callous over (Fig. 1A). Apparently, the larva leaves the root it is feeding upon and will migrate through the soil to a different root. If the larva encounters an underground drip irrigation line on its way to the new root, it will cut through the line leaving a large elongate hole in the line (Fig. 1D). Infested trees topple over in high winds after the lateral roots are severed (Fig. 1C). Affected trees have lower production of foliage and nuts that is sparse at the periphery of the tree canopy. Infested trees are typically culled and replaced with a new tree when the old tree topples or ceases producing nuts, and infested orchards

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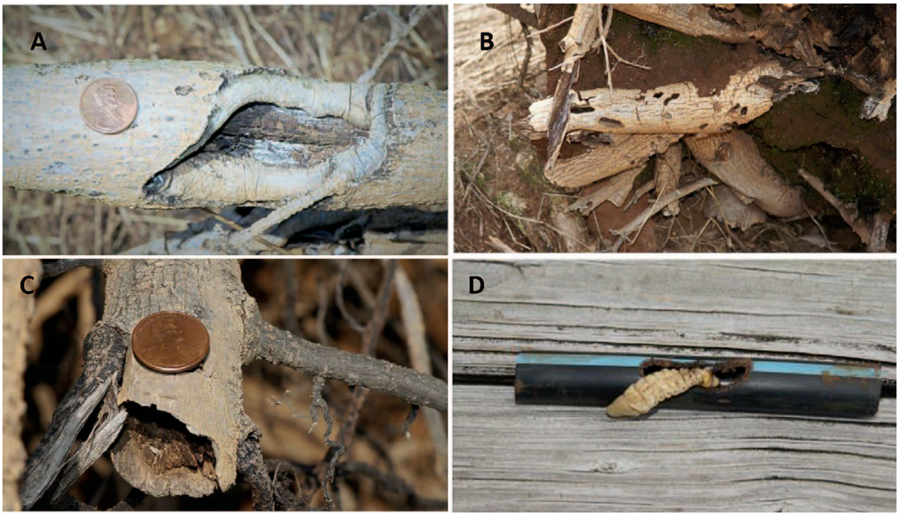

Fig. 1. ***Prionus*** **spp. root borer damage as a gouge wound to lateral root with callous tissue and new roots generated from the callous (A), multiple wounds to a single root beneath trunk base (B), feeding injury to a lateral root with new roots growing at the injury site (C), and holes created in underground irrigation pipe (D).**

will have uneven stands with trees of different sizes and ages. One benefit of this control method is that the orchard is usually replanted to a more recent and more productive pecan cultivar. The root injury is found on the tap root and the lateral roots, and borers hollow out the roots and often sever the root from the tree (Peterson 1990) leading to reduction of the root system by 75–90% over several seasons, resulting in reduced tree vigor and eventually tree death (Sparks et al. 1974). Other host plants include many common woody plants, such as oaks, poplar, apple, grape, and pine. At one time, American chestnut was a major host plant. The larvae also will feed on the roots of shrubs growing near the infested trees (Craighead 1942, Payne 1979, Solomon 1995, Wescott 1973).

The field biology and damage impact of *P. imbricornis* and *P. laticolis* in Georgia are well known (Payne et al. 1975, 1976a,b). Adult beetles are typically found in the pecan orchards from May through July. Males are attracted to black-light traps. Females are captured with pitfall traps (Dutcher et al. 2014). Ethanol and terpenes are attractive to cerambycid beetles (Miller 2006). The California prionus, *Prionus californicus* Motschulsky, has a 4- to 5-yr life cycle similar to that of *P. imbricornis* and *P. laticolis* and is distributed in the western United States (Eyers 1942), feeding on the roots of hardwood trees including, oaks, alder, and poplar, and various fruit, pine, and fir trees (Westcott 1973). A pheromone (isomer of 3, 5 dimethyl dodecanoic acid) called prionic acid that attracts males to females for *P. californicus* was discovered in 2009 (Rodstein et al. 2011). This pheromone was then found to be attractive to several *Prionus* species, including *P. imbricornis* and *P. laticolis* (Barbour et al. 2011). This discovery, plus the commercial availability of the

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synthetic pheromone and the ease of monitoring the male beetles with pheromone-baited panel traps, indicated that this trapping system may have some practical application in commercial pecan orchards.

Observations that injured roots generate callous tissue over the injury site (Fig. 1A), and research that demonstrates that mature pecan trees will regenerate a new root system after mechanical pruning of lateral roots from the tap root for the purpose of transplanting (Woodroof and Woodroof 1934) indicate that trees injured by root borers may recover if the root borers are controlled. These factors led to the field trials conducted in commercial pecan orchards in southern Georgia that are reported herein. The objectives of the field trials were to measure (1) the seasonal trap catch of the adult male beetles, (2) the efficacy of a soil-applied chlorpyrifos treatment as a control for the adult male beetles, (3) the duration of the attractancy of the pheromone-baited traps, (4) the effect of a matrix of pheromone lures on trap catch in sentinel pheromone-baited panel traps placed the center of the matrix of lures, and (5) the effect of adding LED lights to the pheromone-baited traps on trap catch.

Methods and Materials

The source for root borer panel traps and alpha pinene was Alpha Scents, Inc. (West Linn, OR). The source of the 30-mg prionic acid pheromone lures was ConTech Enterprises Inc. (Victoria, BC, Canada). In 2014–2015, the source of the 30-mg prionic acid pheromone lures was Alpha Scents. Male beetles were sampled with pheromone-baited panel traps (Fig. 2A). Pitfall traps for trapping root borer females were constructed by setting a 5-L plastic pail baited with two alpha-pinene lures (2 g/lure) were placed in a 120-ml plastic container with a screen top and suspended above the bottom of the trap with a piece of wood lathe (Fig. 2B). In this paper a “pheromone-baited panel trap” is an Alpha Scents panel trap with a 30-mg lure of synthetic prionic acid hanging in the center of the trap set out on inverted L-shaped stands of rebar, placed over the herbicided strip in the pecan orchard tree rows with the bottom of the trap at ground level, with a 1.2- $\times$ 5.1-cm piece of diclorvos insecticide strip (Hot Shot No Pest Strip, United Industries Corp. Spectrum Group, St. Louis, MO). The diclorvos insecticide strip killed the beetles after they fell into the collecting container, thus preserving the insects for identification and enumeration. Research has indicated that male beetles are attracted from as far as 244 m to the pheromone-baited traps (Barbour 2009). The distance between traps was maintained at 61 m or more to minimize the interference between traps and minimize the size of orchard needed to conduct trials. All data were analyzed with a Microsoft Excel spreadsheet amended with the add-in statistical program PopTools (Hood 2010).

Seasonal trap catch at commercial pecan orchards with known infestations of *Prionus* spp. was monitored with pheromone-baited panel traps retaining the same lure for the entire emergence period and monitored one time per week until the emergence period had ended at the end of July. Traps remained in the field at the end of July and were monitored one time for beetle catch in mid-September. Four commercial pecan orchards in Georgia—Mitchell County at Nilo Plantation with ~220 ha planted in pecans (31°29′ 47.6736″ N; 84°15′ 33.2784″ W), Lee County at Muckalee Plantation with ~190 ha planted in pecans (31°41′ 38.5152″ N; 84°6′

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Fig. 2. Traps used in the study included a pheromone-baited panel trap with rebar stand (A), a pitfall trap (B), and a pheromone-baited panel trap affixed to a cone-shaped screen wire trap over an observation arena for measuring the efficacy of soil treatment with chlorpyrifos to male adult tilehorned prionus beetles (C).

48.888″ W), Crisp County at Cannon Farm with ~150 ha planted in pecans (31°59′ 51.5724″ N; 83°55′ 47.784″ W), and Houston County at Lane Farm with ~12 ha planted in pecans (32°27′ 54.306″ N; 83°45′ 16.6896″ W)—were monitored for male beetles with pheromone-baited panel traps in 2014 with four traps per orchard. One pasture of ~8 ha in area with large (~18-m-tall), haphazardly planted seedling pecan trees in Union County, FL (Roberts Farm) (30°2′ 17.6352″ N; 82°22′ 38.3052″ W) was also sampled with 10 pheromone-baited panel traps placed next to the trees.

Duration of the attractancy was measured at a commercial pecan orchard in Mitchell County, GA. Five pheromone-baited panel traps were placed on three deployment dates (18 May, 8 June, and 20 June) and monitored for trap catch of male *P. imbricornis* and *P. laticolis* one time per week through August. All lures were purchased at the same time and stored in a freezer until placed in the field. On the dates when lures with differing deployment dates were present for comparison (after 8 June), the mean trap catches for the five traps in each deployment date group were compared with analysis of variance (ANOVA) (F test).

Efficacy of a soil-applied chlorpyrifos treatment was assessed against the adult male beetles with a field bioassay. An observation arena was constructed with a band of fiberglass lawn-edging material that was formed into a circle and

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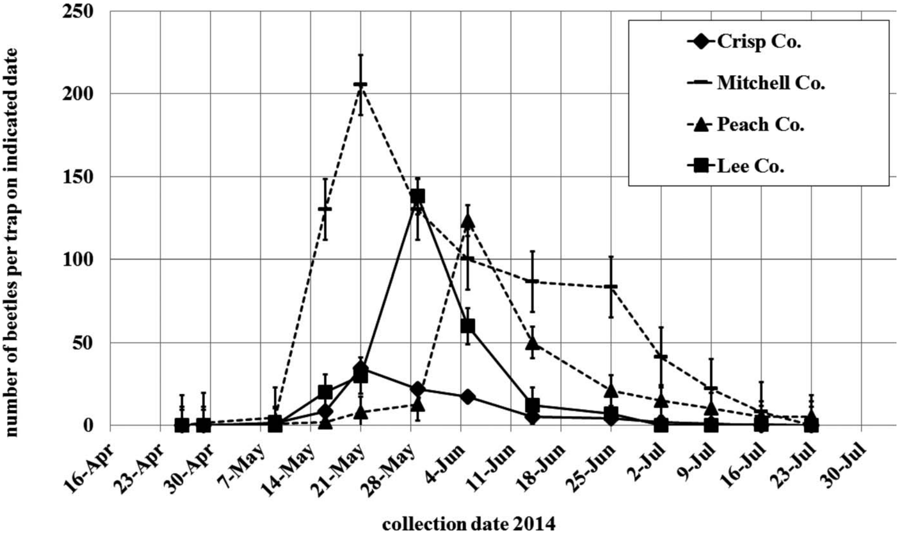

Fig. 3. Weekly seasonal trap captures of male *Prionus* spp. beetles at commercial pecan orchards in Albany (Nilo Plantation, Mitchell County), Leesburg (Muckalee Plantation, Lee County), Cordele (Cannon Farms, Crisp County), and Perry (Lane Farm, Peach County) in Georgia 2014.

placed on the ground in the orchard. The ground was cleared of vegetation and fallen leaves and debris. The soil surface within the arena was treated with a solution of chlorpyrifos (Lorsban Advanced, Dow AgroSciences, Indianapolis, IN) that was applied as a soil drench in a volume of 355 ml of final spray per arena (surface area, 0.89 m^2) with a handheld, hand-operated sprayer (Solo 430-3G, Solo USA, Newport News, VA) at 2,500 kPa through an adjustable brass nozzle in a cone pattern. Five arenas were treated with insecticide and five arenas were nontreated controls. Pheromone-baited panel traps with the collection container open at the bottom were affixed to the top of a cone-shaped trap made from 0.64-cm mesh hardware cloth (Fig. 2C). The number of male *P. imbricornis* beetles attracted to the panel trap and falling through the open collection container onto the surface of the arena were counted each day for a period of 3 weeks after the spray was applied. The beetles trapped in the arenas were then observed from the date of capture for mortality on the day after capture on the arena surface and then removed from the traps. Beetles falling onto chlorpyrifos-treated arena surfaces continued to die after the residue was 3 weeks old at a similar rate to the beetles exposed to the residue that was 1 d old, and efficacy was calculated based on the mortality of all beetles accumulated over the 3-week period.

The effect of a matrix of pheromone lures on trap catch in sentinel pheromone-baited panel traps was tested in the four orchards with one replication in each orchard during 2014. Isomate CP lures were used for the trial. The lures were supplied by Pacific Biocontrol Corp. (Wenatchee, WA) and formulated by Shin-Etsu

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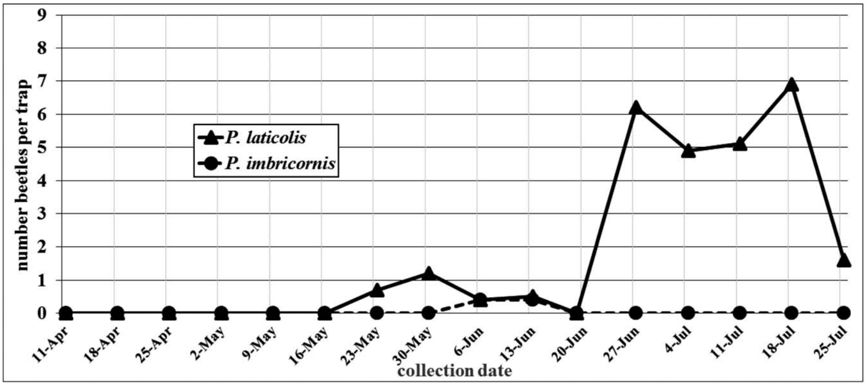

date	11-Apr	18-Apr	25-Apr	2-May	9-May	16-May	23-May	30-May	6-Jun	13-Jun	20-Jun	27-Jun	4-Jul	11-Jul	18-Jul	25-Jul
se *P. l.*	0	0	0	0	0	0	0.40	0.51	0.27	0.31	0	0.36	0.89	1.36	1.44	0.54
se *P. i.*	0	0	0	0	0	0	0	0	0.51	0.40	0	0	0	0	0	0

Fig. 4. Weekly mean trap captures at Roberts Farm, Union County, FL, in 2014. Standard error values for *P. laticolis* (SE P. l.) and *P. imbricornis* (SE P. I.) are shown for each sample date.

Chemical Co., Ltd, Japan (Lot No. CPS-60584) as 20-cm wire twist ties covered with plastic that was infused with 30 mg of synthetic prionic acid pheromone per lure. The lures were tied to four 110-m-long hemp strings placed on the orchard floor along the herbicided strip in the tree rows at a density of 240 lures/ha at three pecan orchards. A 2.4-ha block of pecan trees was used for the trial at each orchard. Each block was divided into two 0.8-ha (6 $\times$ 4 trees on 18.2-m squares) plots separated by one 0.8-ha plot in the center. One outside plot was treated and one outside plot was not treated, and the center plot served as a nontreated buffer between the treated and nontreated plots. Each orchard had one replication or one set of three plots. Two pheromone-baited panel traps were deployed as sentinel traps to monitor male beetles in the treated and nontreated plots at each orchard. The two traps were set out in the mowed alley between the two center tree rows of each of the two outside plots equidistant from the center of the alley (55 m apart). Traps were deployed from 29 May to 3 July 2014. Trap catch was counted as the number per two traps per plot five times at ~1-week intervals, and beetles were removed and identified. *Prionus imbricornis* male trap catch was summed over the five sampling dates to calculate season-long trap catch per two traps, and the means of the season-long trap catch per two traps were compared "within the matrix" and "outside the matrix" by analyzing the results with a one-way ANOVA. The same analysis was applied to the *P. laticolis* trap catch.

The effect of adding LED lights to the pheromone-baited traps on trap catch was measured by placing eight pheromone-baited panel traps at Nilo Plantation on 15 May 2015. Four traps were affixed with a solar-powered LED light with an automatic timer (Portfolio Brand LED Path Light, Lowe's Hardware, Model RS60M-F10-BK-C4) that switched the light on at night and off during the day. The lights turned on at

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~8:45 p.m. each night and turned off at ~6:15 a.m. each morning. The battery was sufficient to operate or power the light for the entire period of 9.5 h. All lights continued to work for the entire adult emergence monitoring period from 22 May to 21 July 2015. The pheromone-baited panel traps were placed 178 m apart in two rows of four traps per row, and lights were assigned to one of the traps at random. Lights were attached to the top bar of the L-shaped rebar stands with a steel wire.

Results

Seasonal trap catch. Female tilehorned prionus were attracted to pitfall traps baited with alpha-pinene in these trials. Emergence in middle Georgia (Perry) is about 2 weeks later than in southern Georgia (near Albany). Beetles emerge from the soil from May through July, with tilehorned prionus emerging earlier in the season and in higher abundance that the broadnecked root borer. In Georgia in 2014, *P. imbricornis* was the predominant species captured by the pheromone-baited panel traps (478 *P. imbricornis*; 15 *P. laticolis*) (Fig. 3), whereas in Florida, *P. laticolis* was the predominant species (275 *P. laticolis*; 8 *P. imbricornis*) (Fig. 4). Beetles were trapped earlier and over a longer period of flight activity at the Union Co., FL, orchard. Traps set out earlier on 11 April began capturing beetles on 17 May. The number of beetles trapped declined on 7 June, and no beetles were trapped on 13 June. All lures were replaced with new lures on 20 June, and trap catch increased significantly on 27 June, indicating that the lures were effective for 8 weeks (from 11 April to 7 June) in Florida.

Duration of the attractancy. In the Georgia orchards, traps were placed out in mid-May, and one lure in each trap collected beetles for the entire 6–7-week emergence period. The trap catch in traps set out at ~2-week intervals on 18 May, 8 June, and 20 June captured beetles at the same rate at the sixth week for *P. imbricornis* (Fig. 5A) and at the seventh week for *P. laticolis* (Fig. 5B). *F* tests of all comparisons between trap catch in traps with different lure deployment dates indicated that there were no significant differences among those deployment dates. At the Florida orchard, in anticipation of a potentially earlier and longer flight activity, traps were set out earlier, on 11 April and again on 20 June, after no beetles were tapped on 13 June. After the new lures were set out on 20 June, the trap catch increased significantly indicating that the first set of lures were no longer attractive after ~8 weeks of deployment.

Efficacy of a soil-applied chlorpyrifos. Treatment of the soil around the base of the tree trunk with sprays of chlorpyrifos at 250 ml formulation per 200 L of spray effectively controls the adult beetles. Nineteen and 22 male *P. imbricornis* beetles were trapped and observed for mortality in the treated and nontreated arenas, respectively, over the 3-week period. Two beetles survived in the chlorpyrifos treatment, and 22 beetles survived in the nontreated arenas for an efficacy of 92%.

Impact of pheromone matrix deployment. The effect of deploying a matrix of pheromone lures on trap catch was quite apparent. Overall catch of *P. imbricornis* was higher than trap catch of *P. laticolis*. Mean season-long trap catch per trap outside of the matrices was 4.5 *P. laticolis* males, 106 *P. imbricornis* males, 0.25 *P. laticolis* females, and 0.0 *P. imbricornis* females. Mean season-long trap catch per

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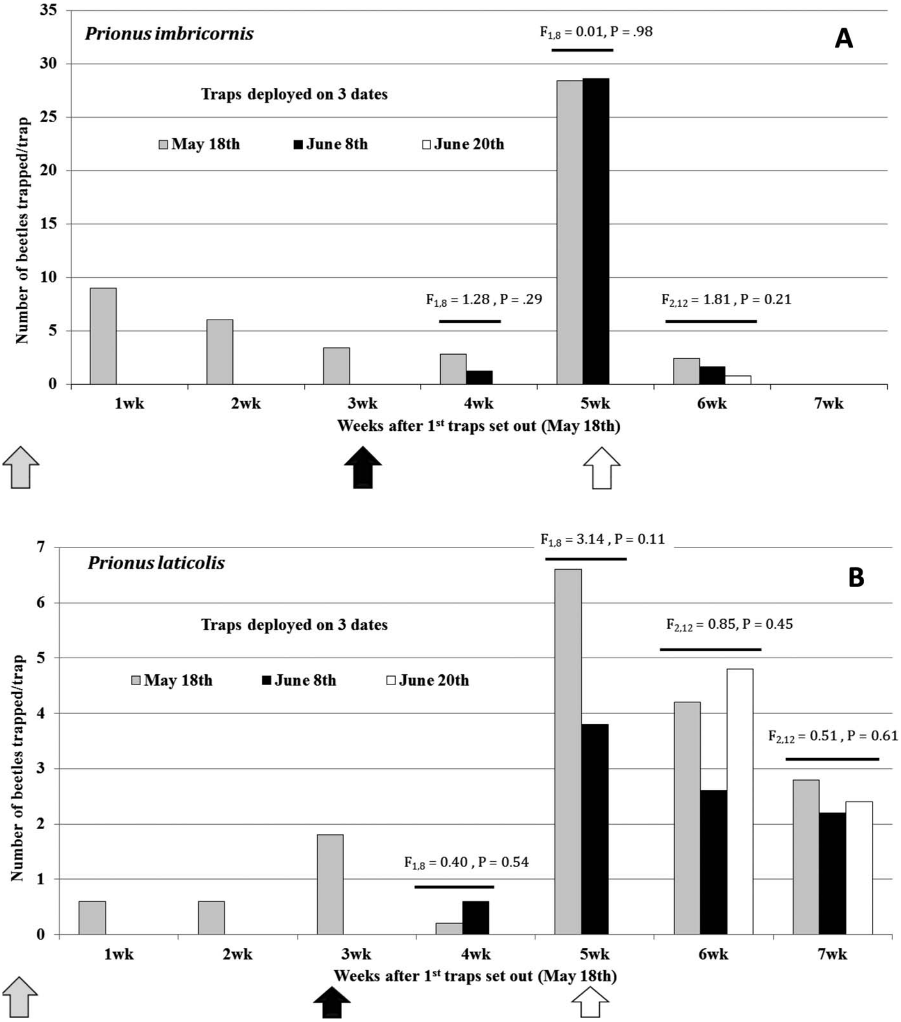

Fig. 5. Duration of pheromone lures in panel traps in the field for *P. imbricornis* (A), *P. laticolis* at the Nilo Plantation (Mitchell County) site (B). Mean trap catches are indicated by the vertical bars and means on the same sampling date under the same horizontal line are not significantly different ($P < 0.05$).

two traps inside the matrices was 4.25 *P. laticolis* males, 0.25 *P. imbricornis* male, 0.0 *P. laticolis* females, and 0.0 *P. imbricornis* females. The matrix of Isomate CP lures significantly reduced the catch of *P. imbricornis* by the sentinel traps (one-way ANOVA; $F = 26.4$; df = 1, 6; $P = 0.0021$). There was no significant difference between the trap catch of *P. laticolis* by the sentinel traps in the treated and nontreated plots at all three sites (one-way ANOVA; $F = 1.53$; df = 1, 6; $P = 0.2632$).

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LED light impact on trap efficiency. The effect of adding LED lights to the pheromone-baited traps on trap catch was apparent from the total trap catch of 417 male *P. imbricornis* beetles in the traps with lights and 290 beetles in traps without lights. Addition of LED lights to the top of the traps improved the trap catch of *P. imbricornis*. Chi square analysis of the total trap catch indicated a significant departure of the trap catch in the two trap types from the expected value of 353.5 beetles (equal trap catch in both types of traps). Only two *P. laticolis* male beetles were trapped in the trial and both were captured by traps without lights.

Additional casual observations of live *P. imbricornis* beetles during the daylight hours indicated that beetles were in contact with the soil surface during the daytime. Males released from pheromone-baited traps and set out on the ground in a nonbaited orchard were observed running along the soil surface, then digging below the leaf litter to the soil surface. One live female released from a pitfall trap in a nonbaited orchard was observed running directly to the tree trunk, digging in the soil for 18 min at the trunk base, then ovipositing 1–2 cm below the soil surface next to the root surface. Live female beetles were highly attractive to male beetles when set out singly in pitfall traps and monitored after 3 d in the field. On seven of these occasions, live females attracted a total of 538 males to the pitfall traps.

Discussion

The current research has investigated some properties of the pheromone-baited panel traps and an effective chemical control for the adult male beetles on the ground. Further research is needed to determine if control of the *Prionus* spp. beetles improves pecan tree health and nut production in infested trees. If beetle control is found to improve tree nut production, then a dense array of regularly spaced pheromone-baited traps coupled with soil application of chlorpyrifos may benefit pecan growers by controlling the male beetles with trapping and killing beetles that are not trapped at the soil surface. Two times when adult *Prionus* spp. beetles are vulnerable to control methods in commercial pecan orchards are when the beetles mate and when they are digging in the soil and leaf litter either to evade predators or as females preparing an oviposition site. The pecan trials reported herein found that the traps need to be deployed from April until August. One lure was attractive for 6–7 weeks, and two lures per season will be effective for a period that encompasses the male flight period in southern Georgia and northern Florida. A matrix of pheromone lures decreased catch, indicating that a mating confusion tactic may be effective as a control for *P. imbricornis*.

Acknowledgments

Thanks to cooperating Georgia pecan growers at Lane and Cannon farms and the Nilo and Muckalee plantations, and the Roberts Farm in Lake Butler, FL, for supplying research sites and assisting with the trials. Thanks to Dow Agro Sciences Chemical Company and the Georgia Agricultural Commodity Commission for Pecans for funding the research. Thanks to Scott Carlson and Doug Collins with the Georgia Cooperative Extension Service for initially locating the infested orchards and contacting cooperators. Thanks to Jamie Wilson, Josh Marchant, and Tzu-Chin Liu for assistance in the field work for the trials. Thanks to USDA National Institute of Food and Agriculture for support through Regional Hatch Project S-1048.

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