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Do Mound Disturbance and Bait Placement Affect Bait Removal and Treatment Efficacy in Red Imported Fire ant (Hymenoptera: Formicidae) at Different Seasons?

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Abstract: This study provides empirical evidence that disturbing mound immediately before application, as opposed to label recommendation, did not reduce foraging activity of the red imported fire ant, *Solenopsis invicta* Buren, except for about 10-min delay in foraging. Despite the delayed foraging, there was no significant difference in the amount of baits foraged between disturbed and undisturbed colonies. Eventually, >96% of the baits were foraged, with the maximum removal occurred by 2 and 3 h, respectively, in summer and spring trial. The fastest and great amount of bait removal 1 h post-treatment occurred to baits placed on mound, followed by 0.18–0.3-m from mound base, and the slowest 1.08–1.2-m from mound base. All treatment gave 100% control 1 mo later, regardless of the season, without colony relocation or new colony invasion in the test plots.

Keywords: *solenopsis invicta*, individual mound treatment, bait application, season effect

The red imported fire ant, *Solenopsis invicta* (Buren) (Hymenoptera: Formicidae), is a major constant pest in agricultural and urban sectors in the southeastern United State[1,2] and has substantial impact on humans, wildlife, and agriculture.[3,4] One approach to manage fire ants is the use of toxic baits in which a toxicant, a food attractant, and a carrier are combined into granular bait and applied broadcast or to individual mounds. Baits are often promoted to the public as the most practical, economic and effective component in integrated fire ant management programs because they allow the dissemination of the active ingredients to an entire colony via social feeding behavior.[5,6]

Registration labels on commercial fire ant baits generally suggest, with no research-based data, not to disturb fire ant mound and to place baits on the ground in a circle <1.2 m around the mound but not directly on mound. Despite the labels, homeowners and some pest control professionals still claim that applying bait on and around pre-disturbed mounds via foot-kicking or racking or shoveling provides better control. Up to date, research on baits has focused on what makes the best active ingredients[5,7,8–13] or bait formulations.[14,15] The only research on the impact of not following label suggestions reported no significant effect on mound disturbance concerning the total amount of bait removed by fire ants. The research was conducted in winter season when foraging activity was low.[16] The resulting bait consumption was <44% regardless of whether the colonies were disturbed. Additionally, that study did not evaluate treatment efficacy.

Fire ants are known for seasonally changing foraging activity[17,18] and bait preference.[19] We conducted this study in spring and summer seasons of the year 2008. Our objectives were to determine: 1) whether disturbing mound before bait application reduces fire ant foraging activity; 2) whether bait placed on mound is less accessible, as opposed to that around the mound; 3) whether mound disturbance will reduce treatment efficacy; and 4) whether the results are consistent in spring and summer, in comparison to previous results in winter.

Materials and Methods

Study plots and fire ant mounds

Spring trial was conducted in a nongrazed permanent pasture where grass was cut short (about 5 cm) in December of the previous year (2007) at E.V. Smith Research Center of Auburn University in

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central Alabama. Summer trial was conducted in a roadside mowed-lawn on Auburn University campus in Auburn, AL (Lee Co.). All fire ant colonies were monogyne. One day before bait application, fire ant mounds were surveyed for activity. Mounds were designated as active when at least 20 fire ants exited mounds or crawled up a metal rod (2.5 mm in diameter) inserted to the mounds within 2 min of probing to create light disturbance.

Plots consisting of 8 active mounds that were comparable in size and at least 10 m from each other were selected. The spring plot measured 1,010 m^2, and the mound sizes ranged from 31 to 46 cm in diameter. The summer plot measured 2,400 m^2, and the mound sizes ranged from 46 to 60 cm. The plots were carefully searched and any possible colony (no visible mound) was treated individually with the fast-acting indoxacarb bait.[12]

For each active individual mound, 12 sampling areas of 12×12 cm^2 were marked using color paint on different areas on and around the mound: on the slope of the mound, and the ground with the outer edge 0.3 m or 1.2 m from the mound base (Fig. 1). Grass in the sampling areas was hand cut to ground level for easy inspection.

Bait application

The bait we used was Extinguish Plus (Wellmark, Schaumburg, IL), which comprises soybean oil as attractant, corn grit as carrier, and a combination of a fast-killing insecticide (Hydramethylnon, a trifluoromethyl aminohydrazone) and a slow-acting (S)-methoprene (insect growth regulator) as active ingredients.

A randomized complete block design was used in which the eight mounds were used for the two treatments with four replicated blocks, and each mound was used for the three bait location treatments. Mound disturbance was made by opening the top ½ of the mound with a shovel immediately before bait application. The mound soil was placed aside the clasped mound without covering any of the sampling areas. Baits were hand-applied uniformly on and around each individual mound up to 1.2 m from mound base (Fig. 1), at the label rate of 5 level tablespoons per mound.

The spring trail was conducted on March 28, 2008 from 0830 through 1430 with air temperature ranging between 19.2 °C–23.1 °C. The summer trial was conducted on July 2, 2008 from 0630 through 1030 with air temperature ranging between 28.4 °C–32.2 °C. Hourly observations were made until 2 h after fire ants ceased foraging in the treated areas. Fire ant workers were observed active before, during, and after application of both tests.

Data collection

Bait density in each sampling area was monitored through visual counting and reaffirmed by comparing photos. Each sampling area initially received 65 ± 4 (mean ± SE) bait particles. Treatment efficacy was evaluated 4 wks after bait application. The same method aforementioned was used to determine whether a mound was active or inactive. Additionally, all inactive mounds were confirmed

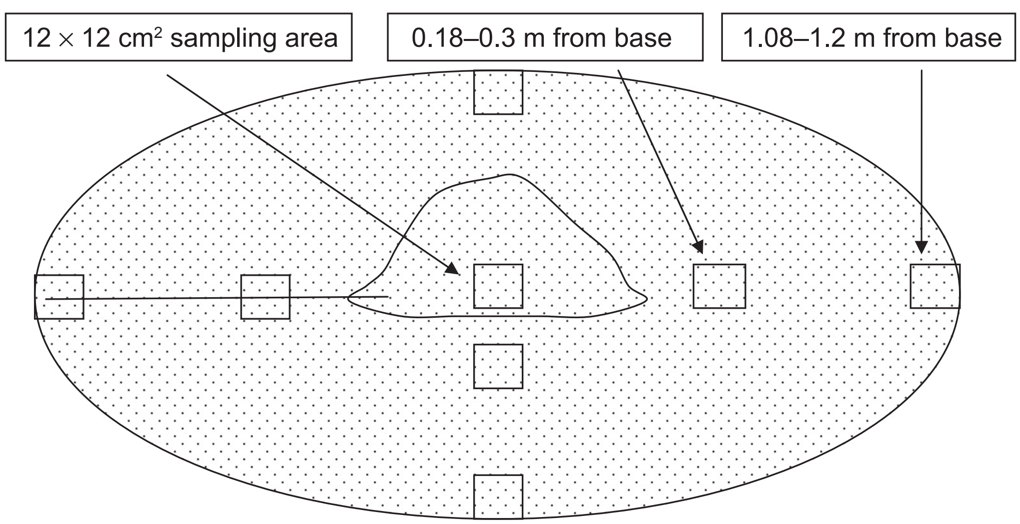

Figure 1. Diagram of individual mound treatment with bait and sampling areas.

by digging into each mound 60 cm deep to look for the absence of any castes. A mound was considered to have relocated if a new active mound appeared within 10 m of the active mound which had been treated and had since become inactive.[20]

Statistical analysis

Hourly counts were recorded as percentage of reductions in bait particles relative to initial amount. Data are reported as mean ± SE. The percentage data were arcsin-square root transformed to reduce heterogeneity among variances before analysis. Data was analyzed by using split-split-plot ANOVA, with disturbance (vs. non-disturbance) as the main-plot factor, bait placement (on mound, 0.18–0.3 m, 1.08–1.2 m) as the subplot factor, and the post-treatment hour as the sub-subplot factor. Total reductions of bait were then compared between disturbed and undisturbed treatments in each season using two-way analyses of variance (ANOVAs). Because of the significant post-treatment hour effect, we further compared the data from the first hour between disturbed and undisturbed treatments from each season using two-sample T test. Means were separated with Tukey's honestly significant difference tests.[21] A significance level of $\alpha = 0.05$ was used for all analyses.

Results and Discussion

Effect of mound disturbance immediately before bait application

The test results from different treatments and seasons are presented in Figures 2 and 3. In contrast with the control colonies that began bait foraging immediately after application, disturbed colonies exhibited ≈10-min delay in foraging that was followed by an intensified bait foraging. As a result, the total amount of bait foraged was not statistically different ($T < 1.38$, df = 1, $P > 0.05$) between the disturbed and undisturbed colonies, despite the fact that the average bait removals were 81.0% and 85.24% (in spring and summer, respectively) for disturbed colonies, and 78.00% and 81.29% for undisturbed colonies during the first h post-treatment. Additionally, the highest rates of bait removal occurred during 1 h after application, regardless of the treatments.

Comparison of the total percentage of bait removal overtime also revealed no significant difference (spring: $F = 1.01$, df = 1, $P = 0.38$; summer: $F = 0.03$, df = 1, $P = 0.87$) between the disturbed and undisturbed treatments. More than 96% of the bait applied were foraged, with the maximum removal occurred by 2 and 3 h, respectively, in summer and spring trial. After that, fire ants for some reason ceased foraging in the sampling areas, even though there were still a few baits left. This could be due to the extremely high ground temperature (>46 °C) at and after that time, but the group temperatures (24 °C–28 °C) could not be held accountable in the spring trial, because they are in the suitable range for fire ant foraging.[17] With the understanding that toxic baits usually degrade quickly after field application,[22,23] the peaked bait removal within 2 or 3 h could be very important in bringing out the best control result of bait.

As a territorial insect, fire ants often switch to defense mode in response to disturbance caused by animal or environmental factors. Such disturbance-induced behavior was evidenced by the 10-min delay

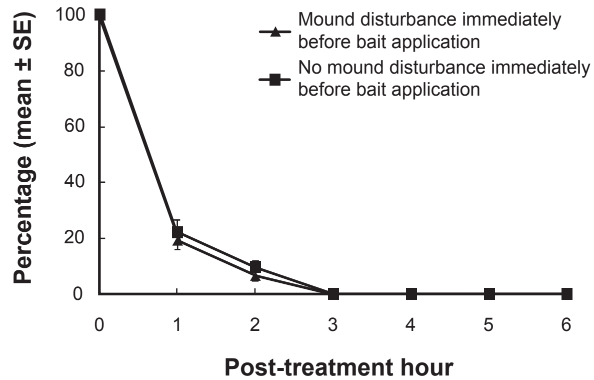

Figure 2. Percentage of remaining bait applied on and around fire ant mound in spring trial.

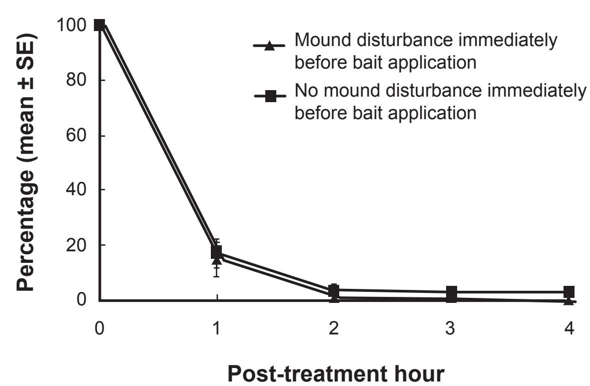

Figure 3. Percentage of remaining bait applied on and around fire ant mound in summer trial.

in foraging in our study. Immediately after the mounds were disturbed, masses of fire ant workers rushed to the opening, bustled around while displaying impulsive defensive gestures, rescuing brood, or simply moving under harborage. However, behaviorally, most of the alerted workers quickly reversed back to foraging once they encountered baits and even recruited more workers to the baits. This is not surprising because fire ants are also consummate opportunists and will certainly explore food items when they are encountered.

Effect of bait placement

There was a statistically significant difference detected only in the summer experiment (Fig. 4: $F = 18.2$, df = 2, $P = 0.003$) not in spring (Fig. 5: $P > 0.05$). Despite this difference, it is clear that the placement of baits relative to mound had an influence on the speed of bait foraging and the amount of bait foraged during the first post-treatment. Regardless of whether the colonies were disturbed pre-application or not, the fastest bait removals were consistently on mound (83%–99.27%), followed by 0.18–0.3 m from mound base (78%–88%), and the least at 1.08–1.2 m from mound base (68%–72.8%). However, the trend became inconsistent as the experiment progressed through the 6-h test and >96% of bait was foraged from all locations.

Fire ant foragers usually leave and return to the nest from underground foraging tunnels that radiate from the nest mound.[24,25] The mound is often at or near the center of the colony's foraging territories.[26] Therefore, it has been speculated that baits placed on the mound may be less accessible to fire ant foragers, as opposed to those placed around the mound. This might be the rationale of manufacturer labels. However, this speculation is without a comprehensive understanding of disturbance-induced behavior changes in fire ant colony. As we aforementioned, fire ants are often on the mound surface in response to nest disturbance and, if they find food conveniently placed right there on their doorstep, they certainly explore it.

In our study, the heavy disturbance created by shovel-opening mound drew more workers to the mound surface. Applying baits on mound could create a light disturbance to the mounds that were not disturbed before bait application, during the application of baits, and thus also drew some workers to mound surface. After baits were encountered, they recruited more workers to the site.[14] Therefore, it is not surprising that baits placed on the mound were located and foraged faster than baits placed around the mound. Indeed, foragers from baits placed on the mound is used as a key tool for fire ant territory mapping[27] despite an early report by Horton et al[28] which indicated that the speed of recruiting increased with the distance of the food source from the mound.

There are other possibilities to the on-mound foraging phenomenon. Disturbance could have forced workers to expend energy in alarm responses such as defense and brood rescue and in-nest repair labor. Presumably, they were hungry and hungry workers not only forage more food but also recruit more workers.[29] Additionally, the urgent need for defense and nest repair could have stimulated a great number of workers from distant foraging territory to mound site who later engaged in bait forage.

However, this result does not mean to recommend using bait only on the mound. Bait placed on mound is only available to that particular colony.

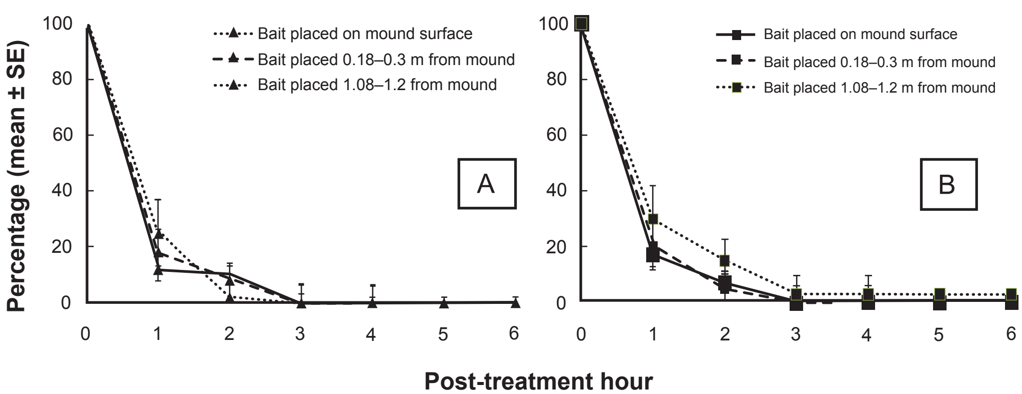

Figure 4. Percentage of remaining bait in spring trial (**A**: disturbed coloneis; **B**: undisturbed colonies).

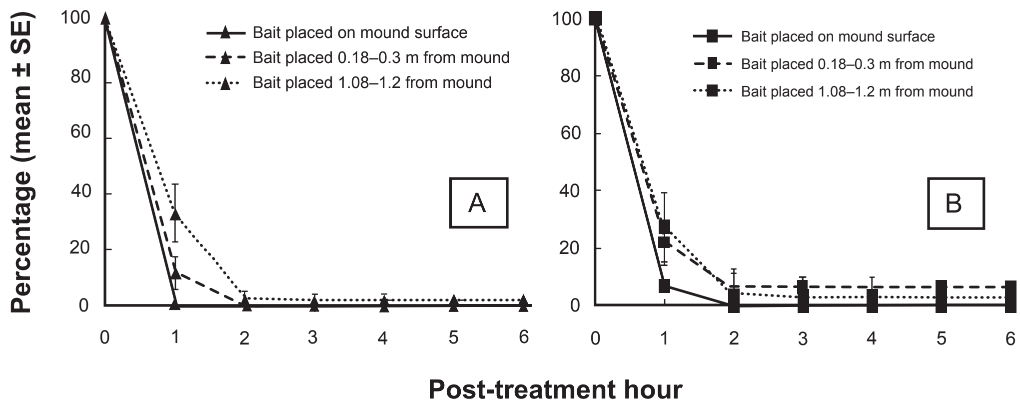

Figure 5. Percentage of remaining bait in summer trial (**A**: disturbed coloneis; **B**: undisturbed colonies).

Bait placed around mound can be also foraged by surrounding colonies in areas polygene colonies exist.

Treatment efficacy

One month after treatment, all the treated mounds became inactive, regardless of the season and type of treatment. Furthermore, no new active mounds were observed in the study plots. This is evident that disturbing mound immediately before bait application did not induce movement or satellites of colonies from their original mounds and was equally effective as the label method for controlling fire ants. Some early works reported that colony fragments or satellites were induced by trenching, which involved disturbing individual mound with conventional liquid insecticide.[7,20,30,31] Williams and Lofgren[7] compared different fire ant products and reported the smallest colony movement was associated with toxic bait application. The movement was even less than the control (water-only treatment). In fact, colony relocation may be a natural process for no apparent reason.[32,33]

Effect of season

Neither the periods of disturbance-induced foraging delay, nor the percentages of bait foraged throughout the test period or the treatment efficacy displayed a significant difference between spring and summer tests ($P > 0.05$). The 96%–100% removal of bait is higher than the 34% reported in winter trial.[16] This was expected because fire ant foraging and recruiting activities were lower in winter than warmer seasons.[14,17,18,34]

The time for maximum bait removal was 2 h in summer (test period temperature 28.4 °C–32.2 °C) and 3 h in spring (test period temperature 19.2 °C–23.1 °C), compared to the 3 h reported in winter test.test period temperature 13 °C–20 °C,[16] The period of disturbance-induced delay was 10 min in both seasons, compared to the 20 min reported in winter test.[16] These patterns were not well correlated with the season or temperature. We do not have a better explanation than what Porter and Tschinkel[17] and Vogt et al[18] pointed out, that some unexplained variation in foraging activity during season often occurs. Therefore, temperature and season may not be used alone to predict optimal foraging.[18]

Treatment efficacy depends on ant foraging activity. Which season allows optimal control when bait is used? Early works are not in agreement with each other: Hillman[30] had a better control in spring and fall of the year than hot summer months; Vogt et al[18] noted poor control in early-season (April); Ferguson et al[34] suggested later-summer or fall be the optimum time; and Collins[35] recommended spring treatment for rapid population suppression but summer and fall treatments for gradual population suppression over a more extended period of time. According to our data, 100% control was achieved within 1 m in both spring and summer trials. The reason for the differences in treatment efficacy could be due to a number of factors; however, the bait application times of early morning in summer and morning in spring for bait application may count for the similar result in the two seasons. In southern and central Alabama, fire ants forage year-round, as long as temperatures are suitable for activity.

In summary, the results of our study do not corroborate the recommendations of bait labels. In the contrast, except for a short-term delay in foraging, disturbing mounds immediately before bait application did not reduce fire ant foraging activity. In fact, baits placed directly on mound were equally or even more accessible to fire ants as/than that placed around mound. Furthermore, when bait product was used, disturbing mounds before treatment did not decrease treatment efficacy. The results of spring trial were consistent with that of summer trial. In addition to explaining the good control of mound disturbance claimed by homeowners and professionals, this study provides research-based data to bait product manufacturers for future refining labels. At a very basic level, knowledge of the effects of mound disturbance and bait placement on bait foraging is important, considering that mound disturbance is inevitable in home lawns, landscape and pastures where frequent mowing are required. Further research is necessary to investigate the fate of baits in disturbed vs. undisturbed colonies.

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Disclosure

The authors report no conflicts of interest.

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