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MONITORING *DIAPREPES ABBREVIATUS* WITH TEDDERS TRAPS IN SOUTHWEST FLORIDA CITRUS[1]

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Abstract. **A pyramid trap known as the Tedders trap was used to monitor emergence patterns of the root weevil, *Diaprepes abbreviatus* (L.) in two citrus groves in Hendry County (southwest Florida) during 1996 and 1997. Two sizes (1 ft and 2 ft base) and colors (red and black) were compared with no significant differences. A well defined peak of weevil captures was seen in mid-April both years, as was a more poorly defined fall peak which continued into early winter. While the traps failed to detect treatment effects in single row plots, they did provide useful information for management planning. Soon after peak emergence in mid-April would seem to be an optimal time for foliar sprays directed against adults. Applications of nematodes against larvae might best be made to coincide with the first summer rains in June, when most of the current year's crop of eggs would have hatched and soil conditions would be favorable to nematode movement and survival.**

First detected near Apopka in central Florida (Woodruff 1964), the root weevil, *Diaprepes abbreviatus* (L.), has spread to many areas in central and southern Florida including 28,500 acres of citrus identified as infested (Anonymous, 1997) with the likelihood that the actual figure is much higher. On citrus and other perennial hosts (Simpson et al., 1996) adults feed on young foliage, the female ovipositing in masses between two older leaves sandwiched together by an adhesive secretion (Wolcott 1936, Schroeder & Beavers, 1981). Neonate larvae drop to the soil surface which they penetrate to feed upon fibrous rootlets, progressing to larger roots as larval development proceeds. The largest instars channel the cortex and often girdle scaffold roots and crown. Direct damage to citrus is compounded by secondary invasion of root rot caused by *Phytophthora* spp.

Current management tools are considerably less effective than the chlorinated hydrocarbon insecticides formally used to create a long-lasting chemical barrier against soil penetration by neonates. Today, broad-spectrum insecticides can be applied to foliage for adult control (Bullock et al., 1988), and entomophagous nematodes to soil for larval control (Schroeder, 1992). Both tactics require optimal timing for maximum effectiveness, necessitating accurate monitoring of weevil populations. However, subterranean stages are difficult to monitor, and sampling the long-lived adults provides little information on population age structure. One approach to avoid these shortcomings is to monitor emergence; the transition from soil inhabitation by feeding and resting stages to canopy inhabitation by reproducing adults. Emergence traps consisting of square or conical cages open at the bottom have been used for this purpose (Beavers and Selheim, 1975, Raney and Eikenbary, 1969). This approach captures only weevils emerging within cage boundaries, providing an estimate of weevil density per unit surface area. Normally, numbers are low, requiring large numbers of traps to achieve reliable estimates.

The pyramid or "Tedders" trap originally developed to monitor emergence of pecan weevil (Tedders and Wood, 1994), also captures at least 50 other weevil species (Mizell, personal communication). The Tedders trap consists of two slotted triangular vanes fitted together to form a pyramid (Diaprepes Task Force, 1996). A screen cone "boll weevil trap" open at the apex and fitted with a plastic "capture cylinder" is placed on top of the triangular vanes. The pyramid is thought to be perceived by the emerging weevil as a dark vertical form against the horizon mimicking a tree trunk, (Tedders and Wood, 1994). Current field studies in central Florida have established the superiority of Tedders traps to conical emergence traps with respect to numbers captured, if traps are dark colored and placed midway between trunk and drip-line (McCoy, unpublished data).

For the present study, a newly detected (1993) infestation of *D. abbreviatus* in the Ft. Denaud area of northwestern Hendry County was monitored using Tedders traps. Two trap colors: red and black, two sizes: a 1 ft base and a 2 ft base, and 2 materials: plywood and corrugated polyethylene, were tested. The trap was also used to evaluate the impact of management practices on weevil populations. The data depicted the phenology of *D. abbreviatus* in the southern flat woods and provided the basis for timing management practices.

Materials and Methods

Two adjacent groves in northwestern Hendry county were monitored. Both groves were located directly east of a citrus grove and nursery where *D. abbreviatus* was first detected (Fig. 1). Grove One consisted of 2 blocks, one planted in 1962 with 'Hamlin' orange budded to 'Cleopatra' mandarin rootstock and containing about 42% resets, and the other planted with 'Hamlin' orange on 'Carizzo' citrange with about 38% resets. The grower began root weevil management in 1994 after observing adults feeding in the west edge of the grove. An infor-

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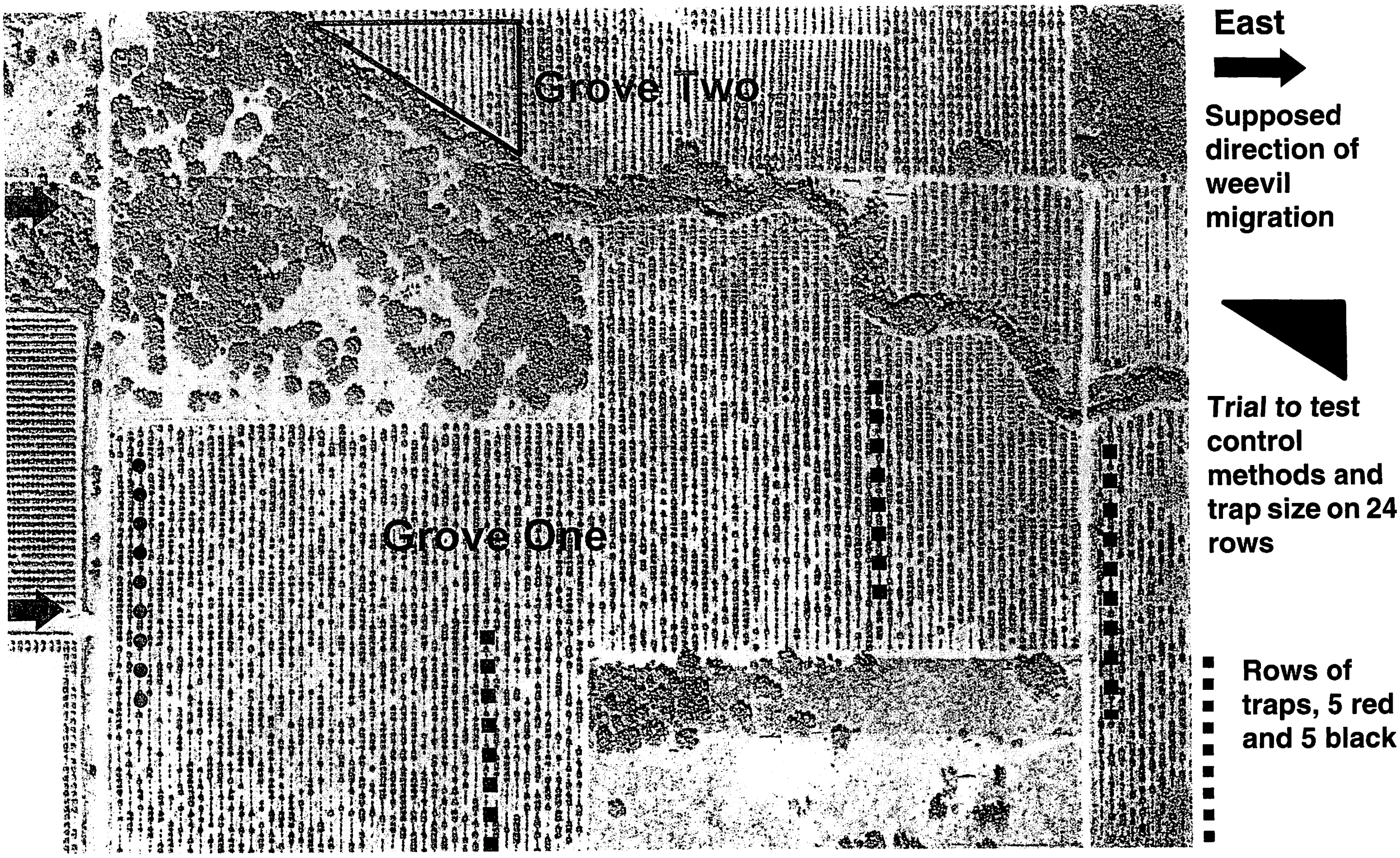

Figure 1. Study sites in northwest Hendry County.

mal survey carried out in October of that year indicated the highest concentration of adult weevils at the western edge with some weevils present throughout the grove. BioVector 350™, containing the nematode *Steinernema riobravis*, was applied by injection through a micro-sprinkler irrigation system at a rate 2×10^8 nematodes/acre to control larvae in July 1994, February 1995, and March 1995 and again in July 1996. In June 1997, the same rate was applied through a herbicide boom. Sevin™ (carbaryl) at 3 lb[ai]/acre mixed with FL-435 spray oil was sprayed twice over the whole grove in May and October 1994, and in the older and most infested block in March and July 1996. In addition, Micromite™ 25 W (diflurbenzuron) at 0.5 lb[ai]/acre plus FL-435 oil was sprayed in Aug. 1996 as an egg sterilent and Aliette™ (fosetyl-Al) at 4 lb [ai]/acre was sprayed in June and August 1997 to control *Phytophthora* spp aggravated by root weevil feeding. Grove Two was also 'Hamlin' orange, and roughly contemporaneous to Grove One but even more extensively reset. No controls were applied by the grower against root weevils in Grove One.

Forty Tedders traps were placed in Grove One on 22 March 1996, 10 in each of 4 blocks (Fig. 1). Traps were made locally of 3 inch Masonite, 2 ft high with a 2 ft base. Oil based enamel was used to paint half of the traps semi-gloss black and the rest 'Industrial' red (ACE™ Hardware). The two triangular vanes of each trap were bisected with a ¼ inch vertical saw cut, one from the base halfway to the apex and the other from the apex halfway to the base so the vanes could be slotted together to form a free-standing pyramid (Diaprepes Task Force, 1996). Screen cones and capture cylinders consisted of top portions of boll weevil traps (Great Lakes IPM, Inc., Vestaburg, MI). Traps were placed midway between trunk and drip-line, alternating red and black traps within each row. In Grove Two, 192 traps were placed in 24 adjacent rows, 8 traps to the row. Traps were made of ¼-inch plywood or ⅛-inch Masonite and placed halfway between trunk and drip-line of the southern-most 120 to 240 ft of each row, avoiding smaller resets. Half the traps had 2-ft bases and the other half had 1-ft bases, alternated within each row. All traps were 2 ft in height and painted with black glossy enamel. Wide traps were replaced on 23 October 1997 with narrow traps made of black corrugated polyethylene (PBE Graphics Warehouse, W. Palm Beach, FL). The 24 rows were assigned to 6 treatments in a randomized complete block design with 4 replications: (1) Foliar applications of AgriMek™ 0.16F (abamectin, Merck Ag-Vet, Rahway, NJ) at 10 oz/acre at peak emergence in spring and fall (2) foliar applications of Micromite™ 25W (diflurbenzuron, UniRoyal Chemical Corp., Brea, CA) at 0.1 oz per tree in spring and fall, (3) foliar application of Micromite 25 W at 0.1 oz per tree in spring followed by an application of entomophagous nematodes in summer, (4) only nematodes in summer, (5) Brigade™ 10 WSB (bifenthrin, FMC Corp., Philadelphia, PA) applied to the soil below the canopy as a barrier at 5 lb/acre in spring and fall, (6) untreated control. Applications were made to the first 25 trees in each row (the trapped area) using a 4-wheeled ATV-pulled sprayer supplied by a gasoline powered diaphragm pump. Foliar applications in 1996 were applied on 19 April and 10 October with the ATV sprayer equipped with an atomizing spray gun and the pump operating at 400 psi and calibrated to deliver 150 gal/ac, and in 1997 on 4 April and 31 October at 200 psi calibrated to deliver 220 gpa. Brigade™ 25 WSB was applied to the soil inside the drip line 12 April and 9 October 1996, 10 April and 28 October 1997 using the same ATV sprayer equipped with a herbicide boom fitted with 3 nozzles containing Albuz ceramic fan (110 degree) spray tips. The pump was operated at 50 psi and calibrated to deliver 150 gal/ac in 1996 and at 50 psi to deliver 37 gpa in 1997. Weeds were cleared with a weed whip prior to the application to facilitate passage, but leaf litter was left on the ground under canopies. BioVector 355™ (*Steinernema riobravis*, Biosys, Palo Alto, CA) was applied in the rain on 19 August 1996 using the ATV sprayer equipped with a herbicide boom. The boom was fitted with one nozzle containing an inverted TeeJet 16 mesh strainer for a spray tip to drench a 6 ft band around the trunk. The pump was operated at 10 psi and calibrated to deliver 150 gpa. *Heterorhabditis bacteriovora* (Integrated BioControl Systems, Inc., Aurora, IN) was applied 22 August 1997 at the rate of 350 million/acre. The ATV was clocked at 1.5 mph with the pump operating at 20 psi and calibrated to deliver 106 gpa through a 6-nozzle boom equipped with Albuz® 110 degree flat fan tips. Nozzles were placed at 10-inch spacing except for two closest to the trunk which were spaced at 6 inches, providing a 4⅓ ft swath. Nematodes were applied in 2 passes, one from either side of the tree, followed by 2 passes of water.

All traps were checked weekly and the number and sex of *D. abbreviatus* recorded. Sex was determined by observing the end of the abdomen which is straight-sided and pointed in females, curved on the sides and blunt in males. Paired t-tests were used to compare trap colors, trap sizes, trap materials and groves. Emergence data from the two groves were also compared using correlation analysis. Analysis of variance was used to compare mean post-treatment captures (from 17 October 1996 through 4 December 1997) among treatments in Grove Two (SAS Institute, 1988). For this analysis, the treatment × replicate interaction was used to test treatment effects over time (Freund et al. 1986). In addition, changes in weevil captures during the same period were analyzed with respect to a pretreatment baseline derived from the number of captures during the period 29 March 1996 through 31 May 1996 as percentage change [100 × (late/early)] or difference (late-early).

Results

Temporal and Spacial Patterns. Distinct peaks in trap captures of adult *D. abbreviatus* were observed in both groves on 18 April 1996 and 24 April 1997 (Fig. 2 or 3). Mean captures recorded on these dates and maximum for their respective years were 0.63 and 0.61 weevils per trap per week in 1996 and 1997. Subsequent captures dropped off rapidly, especially in 1997, declining to less than 0.1 per trap by May or June of 1996 or 1997 respectively. Captures remained low throughout the summer but increased to a secondary peak in November-December of 1996 and October-December of 1997. Catches were down during late winter, increasing again in March to the April peak. Sex ratio was .914:1 ♂:♀ (611 ♂: 659♀) and not statistically different from 1:1 ($\chi^2 = 1.81, 0.5 > P > 0.1$).

Patterns of trap captures in Groves One and Two were similar with respect to the features described above (Fig. 4). Paired comparisons between the two were not significantly different ($P < 0.41$, $t = 0.83$, $df = 170$), and captures between groves were correlated $R = 0.67$, $P < 0.0001$). However, there did seem to be a tendency toward fewer captures in Grove One during fall 1997 that may represent effects of management practices initiated since 1994.

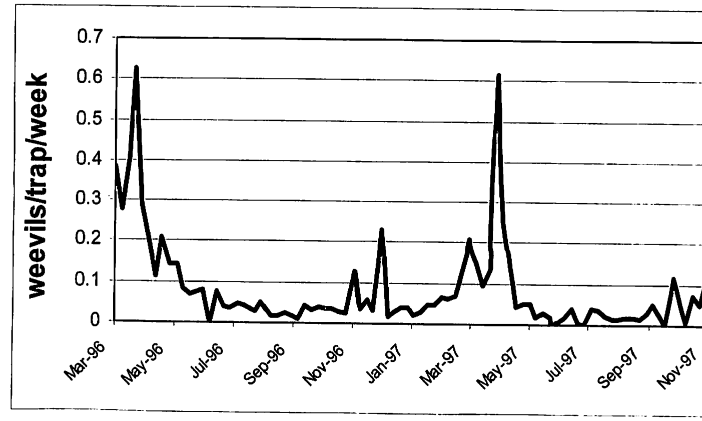

Figure 2. Mean captures of *D. abbreviatus* per trap per week in groves One and Two combined.

The pattern of captures in both groves was aggregated as indicated by indices of dispersion (variance to mean ratio, Sokal and Rohlf, 1969) in excess of 1 (2.03 for Grove One and 2.21 for Grove 2). Spacial variation in capture pattern was noted in both groves with a tendency for captures to increase in Grove One from west to east (Table 1), the supposed direction of colonization (Fig. 1). In the much smaller block of Grove 2, most weevils were caught in the second replicate toward the west side. These differences were probably due to interactions between tree condition and colonization patterns.

Treatment Results. There were no significant differences observed between black and red traps, wide and narrow traps, or corrugated plastic and plywood traps (Table 2). In spite of a 6-fold difference among the two most divergent treatments (Table 3), treatment effects on number of captures were not significant ($F = 1.96$ $df = 5.15$, $P < 0.14$). The difference between base line numbers and post-treatment numbers was likewise not significant ($F = 1.51$, $df = 5.15$, $P < 0.24$). However significant differences were observed among treatments using the criterion of percent change post-treatment over baseline (Table 3). However, the order of treatments with the untreated control on the very bottom, was hardly conducive to an interpretation of significant treatment effects. We can only conclude that aggregation and consequent variability among plots (rows) obscured differences among treatments.

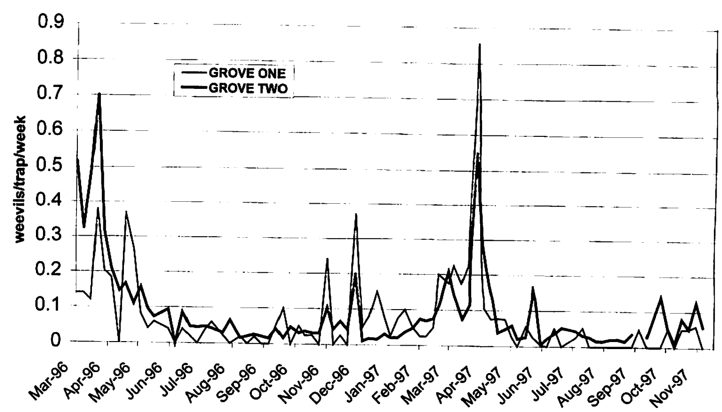

Figure 3. Mean captures of *D. abbreviatus* per trap per week in groves One and Two shown separately.

Table 1. Distribution of captures of *D. abbreviatus* in Groves One and Two; 1996 and 1997 data combined.

Grove	Location	Captures (No./Trap/Week)
One	West	0.035 c[1]
	West Middle	0.061 cb
	East Middle	0.078 b
	East	0.148 a
Two	West	0.063 b
	West Middle	0.209 a
	East Middle	0.026 c
	East	0.030 c

[1]Means for different locations in the same grove followed by the same letter are not significantly different (Fisher's protected LSD, $P < 0.05$).

Table 3. Mean number of weevils captured per trap per week from 17 October 1996 through 4 December 1997, percentage change in weevil captures during same period compared to captures during the period 29 March 1996 through 31 May 1996 [100 × (late/early)], and difference in captures during these two periods (late-early).

Treatment	Weevils per trap per week (No.)	(% Change)	(Difference)
AgriMek	0.88	117.1 a[1]	-0.048
Brigade	0.15	111.8 ab	0.06
Micromite	0.36	44.1 bc	-0.049
Micromite & BioVector	0.35	23.8 c	-0.112
BioVector	0.25	24.0 c	-0.200
Untreated	0.45	19.3 c	-0.260

[1]Means in the same column followed by the same letter are not significantly different ($P < 0.05$, Fisher's protected LSD).

Possible movement of weevils among rows may have further confounded treatment effects.

Discussion

While the objectives of this study were not specifically to test the hypothesis that the Tedders trap attracts primarily emerging adult weevils, this appears to be the case, based on the distinct peak of captures observed in April. Otherwise, one would expect a high capture rate extending further into the season from adults (which can live for more than 4 months, Wolcott, 1936) attracted to traps from the tree canopy. Nevertheless, disturbed weevils were observed to drop immediately to the ground from where they must have occasionally crawled into traps because marked weevils released into the canopy were retrapped on various occasions (data not shown). This behavior could explain some of the non-treatment variation observed among replicates of our field experiment. Clearly, these results suggest that larger plots would be necessary to detect effects of control treatments using Tedders traps.

Given that the salient features of the capture cycle represent emergence patterns, how can these patterns be explained? Development time of *D. abbreviatus* approximates 1 year, but varies between 10 and 16 months due primarily to larval diapause prior to pupation and adult quiescence in the pupal cell prior to emergence (Wolcott, 1936, Beavers and Selhime, 1975b, 1982). Thus, it would seem that much of the population is univoltine, although 2 generations per year or less than one per year may also occur. Wolcott (1936) did not believe that environmental conditions exerted much control over development time, although consistence in the spring emergence pattern we observed suggests some environmental synchronization. Beavers and Selhime (1975) suggested soil moisture as an environmental trigger for emergence, but April is normally the driest month in Southwest Florida with least rainfall and high evapotranspiration (Fig. 4). Furthermore, the irrigation systems typically utilized in Florida citrus, including the monitored groves, serve to maintain soil moisture relatively constant within the root zone. In Vero Beach (central east coast region of Florida) maximum emergence occurred in May, although peaks were not as well defined as we observed (Adair, 1994). It seems likely that factors in addition to soil moisture triggered the release of weevils from winter quiescence, driving spring emergence. Future research should perhaps focus on direct effects of temperature on emergence or indirect effects via root growth or other plant responses.

Table 2. Captures of adult *D. abbreviatus* by trap color, size, and material with t statistic, probability that differences are due to random variation, and degrees of freedom.

	Color: Red	Color: Black	Base: 1 ft	Base: 2 ft	Material: Wood	Material: Plastic
Weevils (No./trap/week)	0.077	0.072	0.090	0.082	0.066	0.059
t =	0.33		1.03		0.36	
P <	0.74		0.31		0.72	
df	3673		14140		1146	

Adult captures in fall may represent weevils that began as eggs in early spring and developed quickly under optimal conditions, or slow-developing weevils from the year before. The fall emergence peak was more poorly defined than the spring peak, with a tendency to extend into early winter. Mean minimum air temperature was 3°F above normal during December 1996, and mean minimum soil temperature was 4°F above normal during December 1997. Furthermore, December 1997 rainfall was at least 4 times greater than normal. These meteorological factors may have contributed to the prolonged emergence observed. Lack of definition in the pattern of fall emergence would seem to reflect variable de-

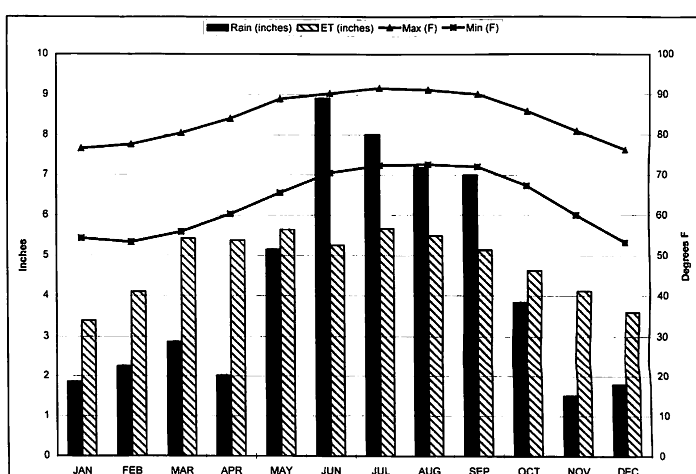

Figure 4. Mean (1989-1996) annual maximum and minimum temperatures and total Penman Evapotranspiration for Immokalee (Collier County), and 30-year average rainfall for LaBelle (Western Hendry County).

velopment time acting in the absence of environmental factors that tend to synchronize spring emergence. In contrast to the spring generation, weevils emerging in the late fall would find a paucity of young flush for feeding and might tend to disperse. Given lack of food, the contribution of the fall generation to reproduction is likely to be minimal. Walcott (1936) believed that off-season emergence in Puerto Rico was a response to parasitization by the eulophid wasp *Tetrastichus haitiensis*, an egg parasite which caused high levels of mortality. However, we have not detected egg parasitism at the study site (data not shown). Regardless of the possible role of parasitism in selecting for development scenarios in some populations of *D. abbreviatus*, adjustments in emergence patterns might be expected with time in southwest Florida as this newly-implanted population continues to adapt.

Our ability to monitor adult emergence patterns has facilitated management decisions for *Diaprepes*. Most egg production is likely to occur around peak emergence in the spring. Therefore, foliar sprays at this time would maximize impact on adults and consequently on egg production. At the full rate, carbaryl, one of the commonly used insecticides, has residual activity up to 4 weeks against *D. abbreviatus* (Bullock, et al. and McCoy, unpublished data). Therefore, an application made at peak emergence in mid-April could be effective through mid-May when emergence would be greatly decreased (Fig. 3).

Insecticide treatment of the soil as a barrier to penetration by neonate larvae would best be applied before peak emergence, but no such options are currently registered in Florida. Optimal timing for nematode application directed against larvae would appear to be most effective after peak emergence, possibly co-incidental with the first summer rains in early June when most of the year's egg crop would have hatched and soil conditions are favorable for nematode movement and survival. However, nematode survival in soil following application is at best 2 weeks (Duncan et al., 1996), so multiple applications may be necessary. There may be fewer benefits from controlling the late fall generation in southwest Florida, given its smaller size and probable lower reproductive potential. Thus, the Tedders trap appears to be a valuable tool for monitoring annual cycles of citrus weevil populations to aid in management decisions.

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