CITRUS ROOT WEEVILS: BIOLOGY AND CURRENT IPM STRATEGIES IN FLORIDA

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INTRODUCTION

Several species of curculionid weevils from 11 genera have been reported from citrus in the Caribbean region. Most species have numerous host plants, and different species within or among genera coexist on citrus in many regions. The literature suggests that many genera are indigenous to the Lesser Antilles and have spread to other regions of the Caribbean (O' BRIEN and NIBNER, 1982; WOODRUFF, 1985).

Currently, there are eight described species of root weevils known to infest citrus in Florida (WOODRUFF, 1968, 1981, 1982; WOODRUFF and BULLOCK, 1979; SCHROEDER and BEAVERS, 1977; TARRANT and McCOY, I985a; FUTCH and McCOY, 1994). Larvae of these species are of significant economic importance in both nursery and commercial situations because of the severe root injury to the tree caused by their feeding These species are: the southern blue-green citrus root weevil, *Pachnaeus litus* (Germar); the blue-green citrus weevil, *P. opalus* (Olivier); Fuller rose beetle, *Asynonychus godmani* (Crotch); the little leaf notcher, *Artipus floridanus* Horn; and the West Indian sugarcane rootstalk borer weevil, *Diaprepes abbreviatus* (L.). Other lesser important species include *Tanymecus lacaena* (Herbst), *Epicarerus fermidolosus* Boh. and *Parapantomorus fluctuosus* Boh. These and other species are found in other parts of the world and are a major production problem in the Caribbean region and some areas of South America.

GENERALIZED LIFE HISTORY OF CITRUS ROOT WEEVILS

All citrus root weevils have a similar life cycle. Adults emerge from the soil beneath their host plant throughout the year. They prefer to rest on shaded interior foliage of a citrus tree canopy during full sun; however, they aggregate on the new leaf flush in subdued light to feed, mate, and oviposit. The most apparent visual plant damage resulting from adult feeding is notching of the margins of leaves of young, tender shoots. The amount of leaf consumption differs between species and food requirements of the adult, and more than one weevil may feed on a leaf. Laboratory studies by SYVERTSEN and McCOY (1985) showed that severe leaf injury can decrease water use efficiency up to 20% and decrease photosynthesis. However, injury from notching of the leaf appears to cause no subsequent economic effects on yield from mature trees. Once the leaf has matured, feeding is either reduced or expanded to include alternate host plants. Adults live for several months and never return to the soil from which they emerged.

Except for the Fuller rose beetle, female root weevils usually lay their eggs in clusters between two leaves on new leaf flush. The female secretes an adhesive substance at the time of egg laying that holds the leaves together (WOODRUFF, 1968; FUTCH and McCOY, 1994). The egg masses of each species differ in number, size, shape, and color (Table 1).

After 10-20 days at 80-86° F, neonate larvae hatch from eggs, fall to the soil surface, and immediately begin moving into the soil where, we assume, they begin feeding on the fibrous feeder roots of the plant. Feeding damage by late instar larvae may be seen on major lateral or pioneer roots when a tree is removed from the soil. Preferred feeding sites by weevil larvae are listed in Table 2. Larvae cause damage by consuming the outer bark tissue (cortex), including the cambium layer, to the woody portion of the root, or by girdling a root, thereby causing root death. In addition to the damage done to the root itself, channeling on the outer portion of the root could conceivably allow for pathogen invasion. Considerable tree decline and mortality has been observed in commercial groves, particularly young groves infested with both *Diaprepes* and the fungus, *Phytophthora* (foot rot). The length of time that larvae feed on the root system varies depending on the species and soil conditions (Table 3). This protracted period of time in the soil includes an inactive pupal stage of 2-4 weeks. Following pupation in the soil, the adult can emerge or remain in the soil for at least 3-4 weeks.

Table 1. Estimated number of eggs and total eggs per lifetime of the five major root weevil species.

	Number of eggs per mass	Approximate number of eggs in lifetime	Egg size in mm	Egg color
Pachnaeus spp. Southern blue-green weevil, Blue-green weevil	50-75	4000		
Asynonychus godmani Fuller rose beetle	70-1000	3000	Flatten 0.035 long 0.01 wide	Pale translucent yellow
Artipus floridianus Little leaf notcher	12-130	800-1000	0.03 long 0.01 wide	White to yellow
Diaprepes abbreviatus Sugarcane rootstalk borer weevil	30-264	5000	0.05 long 0.016 wide	White when laid, brownish before hatching

Table 2. Characteristics citrus root feeding behavior by root weelis

Root part	Weevil genera			
	Diaprepes	*Asynonychus*	*Pachnaeus*	*Artipus*
Crown	+	-	-	-
Major lateral	+	+	+	-
Tap (vertical)	+	+	+	-
Pioneer	+	+	+	+
Fibrous	+	+	+	+

+ Indicates feeding on root part by weevil genera.
- Indicates no known feeding on root part by weevil genera

Table 3. Approximate larval developmental time in the field

Weevil genera	Time
Diaprepes	6-24 months
Pantomorus	9-12 months
Pachnaeus	9-12 months
Artipus	35-40 days

BLUE-GREEN CITRUS ROOT WEEVILS

Southern blue-green citrus root weevil (*Pachnaeus litus*) and the northern blue-green citrus root weevil (*Pachnaeus opalus*) have the most widespread distribution of all weevil pests in Florida, occurring on numerous woody ornamental plants such as oaks, Australian pine, and roses (WOODRUFF, 1981). The southern blue-green citrus root weevil is commonly found in flatwoods citrus plantings in south central and south Florida, on the east coast as far north as Brevard County, and on the west coast to Sarasota County. The northern blue-green citrus root weevil is commonly found in north and north central Florida. Both species can be found in the same grove in some central Florida counties.

The adult of both species is 8-14 mm in length, usually with a pale grey-green color but occasionally is bright aqua (KNAPP and BULLOCK, 1981). The two species may be distinguished by the presence (*P. litus*) or absence (*P. opalus*) of a notch in the anterior portion of the elytra. Adults emerge from the soil every month, but peak emergence is generally from mid-May to mid-July. Average adult longevity is 100-120 days during which mated females can deposit up to 4,000 eggs (KNAPP and BULLOCK, 1981). About 50-75 elongate whitish eggs are laid in masses between two leaves, and hatch in about 2 weeks (Table 1). Percent egg hatch appears to be affected significantly by saturation vapor pressure deficit (TARRANT and McCOY, 1989). The larvae are white and legless with well-developed brownish-black chewing mouth parts. The duration of larval feeding on the roots of their host is poorly documented; however, the total life cycle is approximately one year, and the larval stage can be estimated at 9-12 months (Table 3). The neonate larvae of *P. litus* are highly sensitive to low soil temperatures; that is, at 15-20 C, survival is 10-25% lower than that of other species (TARRANT and McCOY, 1989). Root injury by *Pachnaeus* spp. is typical of that described above for other species of root weevils. Although larval feeding will severely damage the crown of the tree, particularly in container grown trees, injury is generally less severe than from *Diaprepes* (Table 2).

FULLER ROSE BEETLE (*Asynonychus godmani*)

The Fuller rose beetle was originally described as a pest of tea roses in 1874 (RILEY, 1879). It was first reported in Florida in 1916 and can be found on a wide range of plants in both coastal and central Florida, and as far north as the Panhandle counties and south to Homestead (KING, 1958). It is the only citrus root weevil of economic importance found in temperate areas of the world (HELY, 1948). Adults are brownish to grey in color and are about 0.33 inches long. There are two whitish marks on either side of the body, a diagonal one near the center of the abdomen and one on the posterior angle of the prothorax.

The wing covers are fused. Being apterous, its dispersal is passive because it is parthenogenetic without males; however (SMITH, 1935), one female can produce an entire new colony. Adult beetles emerge from the soil throughout the year, but peak emergence is from May through September. After emergence, they move to the tree by crawling up low lying branches, the trunk of the tree, or weeds that have grown into the tree canopy. Adults are nucturnal feeders on new leaf flushes. Within the tree, females deposit about 80% of the eggs beneath the calyx of the fruit, and lay the remainder in cracks formed by the leaves or on the bark of the tree (COATS and McCOY 1990). Adults will lay about 70-100 yellowish eggs per mass over a 4-month period (Table 1). Eggs hatch in about 15-17 days. Egg survival is reduced significantly as ambient humidity declines at temperatures ranging from 20-35 C (TARRANT and McCOY, 1989). The neonatal larvae are white except for a yellowish head capsule. After falling to the surface of the soil, the larvae move to the rhizosphere to feed. Larvae can be found at depths of 60 cm causing typical injury to the roots. Neonate Fuller rose beetle larvae can tolerate lower soil temperatures (-5 C) than the other weevil species (TARRANT and McCOY, 1989). Mature third instar larvae move near the soil surface to pupate within an earthen cell (KNAPP and BULLOCK, 1981). The pupation chamber cannot be formed in dry soil.

Root injury to citrus by *A. godmani* is similar to that of the blue-green citrus root weevil; however, because of its limited ability to disperse, less acreage is infested by the beetle.

In the last 10 years, the Fuller rose beetle has become a postharvest pest of citrus in California and Florida (MORSE and LAKIN, 1987), because of its propensity for laying eggs under the calyx of fruit. Whenever viable eggs have been found under the calyx of fruit grown for the fresh market that are being exported to Japan (where the beetle is absent), Japanese quarantine inspectors have required entire shipments of fruit to be fumigated.

LITTLE LEAF NOTCHER (*Artipus floridanus*)

Little leaf notcher was reported in Florida as early as 1876, when the insect was first described from weevils collected on limes in the Florida Keys (Leconte and HORN, 1876). The genus *Artipus* contains nine described species, eight found exclusively on islands in the Caribbean (O' BRIEN & NIBNER, 1982). Since *A. floridanus* is common in the Bahamas and is the only species known to occur in the continental U.S. (WOODRUFF, 1982), it probably has an origin in the West Indies. It is presently found mainly along Florida's east coast from Volusia County to Key West, however, adults have been collected from interior counties on the central ridge and west of Lake Okeechobee (TARRANT and McCOY, I985a; WOODRUFF, 1982).

This species can be found on approximately 150 host plants including salt tolerant species as well as other hosts such as teaweed, ragwsed, carpet grass, and Australian pine (WOODRUFF, 1982). Adults and larvae have been frequently observed in citrus groves on both the tree and on ground cover plants such as teaweed and carpet grass (TARRANT and McCOY, I985b). Larval populations taken from the soil beneath the plant were significantly higher on the above weed hosts compared to citrus and there was no correlation between adult populations on the tree and adult emergence from the soil, suggesting that adult leaf notchers feed and rest more readily in the citrus tree canopy, but oviposit on adjacent host plants.

The adult is the smallest of the common weevils, measuring about 5-6.5 mm in length. They are usually grayish-white in color; however, it is common to find isolated populations with metallic pink, gold, or green scales on the elytra. Like Fuller rose beetle, adults are flightless and female. Laboratory studies (McCOY et al., 1985) showed that newly emerged females begin to lay eggs within II-20 days and continue for 165 days. Peak oviposition is about 8 eggs per day. Like other weevils, eggs are laid between the leaves of the host plant in masses containing 12-130 eggs. Eggs are elongate (0.8 x 0.35 mm), range in color from white to yellow, and hatch in 7-9 days. Differences in saturation vapor pressure deficit appear to affect egg hatch (TARRANT and McCOY, 1989). Larval development requires a period of 45 days at 28°C. At 35°C, larvae died at ecdysis to the last instar (TARRANT and McCOY, 1989). At 25°C, 1412 degree days were required to complete development. Larvae held at 15°C had not pupated after 8 months. Mature larvae form a pupal chamber within the soil where they remain for about 2 weeks before pupation. The pupal period lasts 14-20 days at 28°C. Unlike other species, the total developmental time from egg to adult ranges from 70-120 days, averaging 100 days, with 3-4 generations per year. In the field, adults can be found throughout the year, with peak emergence in April-May, August-September, and November-December (SIMANTON,.1976). Two to three generations per year may be possible in Florida.

Adult injury to the leaf can severely defoliate young trees and, on occasion, cause tree mortality if adult populations are high for a long time. However, larval injury to the citrus tree rhizosphere appears to be less than for other species, with injury confined to mainly the fibrous roots (Table 2).

SUGARCANE ROOTSTALK BORER WEEVIL (*Diaprepes abbreviatus*)

The sugarcane rootstalk borer weevil was introduced into Florida from Puerto Rico in 1964 on ornamental plants (WOODRUFF, 1964). It is one of several species of *Diaprepes* that are pests of citrus, sugarcane, and other crops grown throughout the Caribbean area. During the past 30 years, *D. abbreviatus* has spread from its original site of introduction to 15 counties where citrus is grown and it is considered a major long-term threat. Within the last 4 years, it has been detected in seven new counties including newer plantings in southwest Florida (McCOY, in press). Weevils discovered in the Moore Haven area in an ornamental nursery in 1993 place the pest within the northwestern edge of the sugarcane growing area in Glades County.

D. abbreviatus has a wide range of host plants available to both the adult and larval stages. Adults feed on at least 75 species of plants in Puerto Rico (MARTORELL and GAUD, 1965), many of agricultural importance. Larvae can feed on the roots or tubers of many important agricultural crops such as sugarcane, yams, and pineapple and a wide range of ornamental plants. No citrus rootstock appears to be resistant to larval.feeding; rootstock research showed no feeding preference for rough lemon, sour orange, 'Carrizo', 'Milam', or 'Cleopatra' (NORMAN et al., 1974).

The West Indian sugarcane rootstalk borer weevil is the largest adult weevil found on citrus, ranging in length from 9.5-

19.0 mm. Adults have colored scales on the wing covers which range from white to orange on a black background. In Florida, adult emergence occurs from May through October, with peak emergence either in June or September (BEAVERS and SELHIME, 1976). Adults live for several months, females longer than males, and never return to the soil from where they emerge. Adults prefer to rest on shaded interior foliage of the citrus tree canopy during full sun; however, they aggregate on the new leaf flush in subdued light to feed, mate, and oviposit. Leaf feeding by high populations of adult *D. abbreviatus* can be so severe that new flushes formed during the summer and fall are totally consumed. Oviposition begins 3-7 days after adult emergence from the soil and continues daily for several months. The egg is smooth, white, oblong-oval, and about 1.2 mm long by 0.4 mm in diameter. The number of eggs per mass varies from 30-264 and a single female may lay more than 5,000 eggs during her lifetime (WOLCOTT, 1936). Eggs hatch almost uniformly in 7 days; hatch averages about 90% at 28°C in the laboratory (BEAVERS, 1982).

After one week, the neonatal larvae of *D. abbreviatus* hatch from the egg and fall to the soil surface beneath the tree. They tend to remain active on the soil surface for a few hours before entering the soil (JONES and SCHROEDER, 1983). At this time, they appear to be most vulnerable to predators (WHITCOMB et al., 1982) and surface applied pesticides: As neonate larvae age their ability to enter the soil increases. Larvae cannot enter dry soil (< 2% soil moisture). Once in the soil it is assumed that the larvae feed initially on the smaller fibrous roots of citrus and subsequently move to the lateral roots. The number of larval instars completed in the soil is highly variable; WOLCOTT (1934) suggested eight instars before the onset of the inactive period before pupation. The late instar active larvae are particularly injurious to the crown area of the tree where they literally strip away 12 the cortical layer. Larvae can remain partially inactive for up to a year (WOODRUFF, 1968). The whole larval period lasts from 250-350 days in the Caribbean and Florida. Prior to pupation a vertical chamber is formed in the soil in which the larvae compacts the soil by spinning on its caudal end. This chamber appears to protect the pupae from natural enemies and physical factors. Pupation occurs within 15-20 days after the chamber is formed. Adults exiting the pupal chamber remain in the soil for up to 120 days before moving to the surface.

DETECTION AND SAMPLING CITRUS ROOT WEEVILS

The best way to determine the presence of weevils in a citrus grove is to examine.the most recent leaf flush for the typical notch-like feeding pattern along the margin of the leaves. If notching is present, then examine the same foliage for adult weevils and/or egg masses. Since weevils are nocturnal, the best time to scout for adults are in the early morning or late evening hours on the outer portion of the tree. When the adults are disturbed they will usually fall to the ground, faking death. For easier detection scouts can use a "beating apron" to gatch the adults as they fall to the ground (COATS and McCOY, 1990).

To estimate time and intensity of seasonal adult emergence from the soil various types of emergence traps placed on the ground beneath the tree canopy have been used to capture the adults as they ascend from the soil (COATS and McCOY, 1990). These traps can be circular or square in shape and usually cover an area of 0.25-0.50 square meters. Monitoring ground traps in time is labor intensive since a minimum of 50-100 traps per infested grove is required to obtain an adequate sanple. Two cages should be placed near the trunk under each tree and traps should be checked on a weekly basis. Grower caution must be used when working with machinery, so as not to disturb or destroy the traps. When weevils are detected initially in April or May, this signals the beginning of a major emergence period that can continue throughout the summer for most species (Table 3). Both adult and neonate larval control using foliar and soil treatments, respectively, can be timed according to adult emergence.

NATURAL CONTROL OF CITRUS ROOT WEEVILS

Numerous parasites, predators, and pathogens have been reported as attacking one or more developmental stages of citrus root weevils in Florida. Specifically, parasitic hymenoptera appear to be important mortality factors of the egg stage (BARANOWSKI, 1960; BEAVERS et al. 1980, BULLOCK, 1984; TARRANT and McCOY, I985a; SCHAUFF, 1987). *Brachyufens osborni* has been reported from the eggs of *P. litus* in Florida (BARANOWSKI, 1960), but not from *D. abbreviatus*, in a host in the Caribbean region (ETIENNE et al., 1992). An eulophid parasite has been found attacking the eggs of *A. godmani* (BROWNING, personal communication) and two exotic species, *Fidiobia citri* and *Platystasius asinus* from California and Chile, respectively, have been released in Florida for the classical biological control of Fuller rose beetle (Browning, personal communication). At this time, the extent of field colonization is unknown. Although numerous parasitoids of *D. abbreviatus* have been reported from the Caribbean (SCHAUFF, 1987; ETIENNE et al., 1992), only isolated recovery of *Aprostocetus* (= *Tetrastichus*) *haitiensis*, *B. osborni*, and an unidentified trichogrammatid have been reported in the literature (BEAVERS et al., 1980). The former species was introduced into Florida from Puerto Rico (BEAVERS et al., 1980). Although egg parasitism has been detected in *A. floridanus* eggs (Browning, personal communication) no species determination was made from limited material. An undescribed species of trichogramma was recovered from *P. opalus* a that parasitized little leaf notcher eggs in the laboratory (TARRANT and McCOY, I985a). A hymenopterous parasite, *Microctonus* sp. has been recovered from adult little leaf notcher in numerous locations (BULLOCK, 1984).

Numerous general insect predators such as ants and earwigs as well as birds, spiders, and mites have been reported to attack eggs, larvae, and adults of citrus root weevils in Florida (WHITCOMB et al., 1982; RICHMAN et al., 1986; BROWNING, personal communication). Ants appear to be the most aggressive predators of all developmental stages, particularly the neonate larva at the time they drop from the tree to the soil surface beneath the canopy.

Various pathogens have also been found attacking both the adult and larval stages of the different citrus root weevil species in Florida. Most prevalent are the entomogenous fungi and nematodes found in the soil (BEAVERS et al., 1983). *Beauveria bassiana*, *Stilbella buquettii*, and *Metarhizium anisopliae* are pathogenic to adult weevils (WOLCOTT, 1936; BEAVERS et al., 1983; TARRANT and McCOY, I985a). Adults can come in contact with these fungi during their exodus from the soil or through contact on the plant surface. Frequently, dead infected adults are observed attached to the leaf or stem of a host plant. In the case of *S. buquettii*, the fungus appears to be specific to the little leaf notcher. When either *B. bassiana* or *M. anisopliae* are applied as a foliar inoculum (BULLOCK et al., 1988) or to the soil surface beneath the tree canopy (McCOY, 1989) at high conidial concentrations ($> 1 \times 10^{6}$), adult weevil mycosis has been increased on both substrates. Virus and bacterial infections of root weevils have not been reported; however, adult *A. floridanus* are frequently infected with gregarine and microsporidia protozoans (TARRANT and McCOY, I985a). Neither protozoan parasite shows high virulence to the adult weevil.

The fungi, *B. bassiana*, *M. anisopliae*, *Paecilomyces lilacinus* and *Aspergillus ochreaceous* in descending order of occurrence, were isolated from *Diaprepes* larvae in Florida soils (BEAVERS et al., 1983). In addition, nematodes of the genera *Heterorhabditis* and *Steinernema* have been found infecting larvae of *D. abbreviatus* (BEAVERS et al. 1983). Fungi and nematodes appear to be most prevalent in citrus soils from June through August in Florida; however, the distribution and abundance of these organisms is variable because of many interacting physical and biological antagonists that occur in all natural soils. As research improves our understanding of entomogenous fungi and nematodes in natural soils, practical ways to manipulate and/or augment soil conditions in favor of the survival and proliferation of these natural enemies may lead to improved biological control.

CURRENT IPM STRATEGIES FOR CITRUS ROOT WEEVILS IN FLORIDA

No information exists on an economic threshold level for either adult or larvae of citrus root weevils. As previously mentioned, larval injury to the tree is a major concern, particularly for species such as *D. abbreviatus*, that destroy the cortical layer of the crown area of the root. system. Prevention or exclusion is the first line of defense when planting or replanting a grove with new reset trees. Careful inspection will assure a grower that replants used in the grove are free of any weevil eggs, larvae, or adults. Grove maintenance is critical to dealing with a weevil infestation in time. It is essential that both adequats fertilization and irrigation are applied regularly to maximize root growth and reduce tree stress (KNAPP, 1985). Root invading soil pathogens should be controlled regularly to prevent any secondary effect from disease. Soil drainage is important to avoid stress caused by water damage to the roots.

A number of factors should be considered when making decisions to control adults and/or larvae of citrus root weevils: the grower should identify the weevil infesting the grove and know its general life cycle to determine the correct time to apply control measures; the age of the citrus planting must be considered because young trees have smaller root systems and therefore cannot tolerate the same level of adult and larval feeding damage as a mature tree; if Fuller rose beetle is the problem and fruit is for export, adult control may be a consideration, if chemical control measures are to be used, an understanding of their effect on nontarget organisms on the tree and in the soil should be a consideration. The following strategies are currently available to the commercial grower to combat citrus root weevils in Florida: 1) foliar insecticides to control adults and eggs on the tree, 2) entomogenous nematodes to control larvae in the soil, and 3) cultural practices which minimize the impact of larval feeding injury to the tree.

ADULT AND EGG CONTROL OF CITRUS ROOT WEEVILS

A number of chemicals are recommended as foliar sprays to reduce adult populations in the tree during peak emergence from the soil (BULLOCK, 1985; BULLOCK et al., 1988). The purpose of adult suppression is to reduce the number of gravid females and egg deposition, thereby reducing larval entry into the soil. If a foliar spray is applied, it should be applied 2-3 weeks after the beginning of adult emergence from the soil. The residual activity of the various chemicals does not exceed four days; therefore, a second application may be necessary from time to time. Since multiple pesticide applications can interfere with the efficacy of natural enemies and/or lead to resistance, foliar sprays for adult control are discouraged and should be used only in groves where citrus root weevils are severe.

The following pesticides are recommended as foliar sprays for mature trees to reduce adult root weevil populations in the field.

Pesticide	**Rate per acre**	**Weevil species**
Carzol 92S	1.0 lb/100 gal	All species
Guthion 35W	3.5-6.0 lb	All species
Kryocide 96 WP		Fuller rose beetle
(cryolite)	50 lb	blue-green weevil
Orthene 75S	2.6-5.2 lb/100 gal	All species
	(Nonbearing citrus only)	
Sevin 80S	1.25 lb/100 gal	All species

When the above chemicals are used with oil at 0.25% as a sticker spreader, residual control can be increased by approximately one week.

Cultural control can be use to disrupt the adult behavior of the little leaf notcher and the Fuller rose beetle, thereby affecting their ability to oviposit on a preferred site. Since these species are flightless, by raising the tree skirts through pruning away the lower branches of the tree and removing weeds that reach the lower branches, one can inhibit the movement of the adults upward into the tree. In the case of the little leaf notcher, preferred weed hosts for oviposition should also be removed to eliminate sites for oviposition within the grove. Trunk wraps have also been used to prevent movement of Fuller rose beetle into the tree (GRIFFITHS, et. al., 1986).

Two chemical control strategies have been proposed for increasing mortality of the egg stage of *D. abbreviatus*. The first strategy involves the use of petroleum oil as a foliar spray which appears to weaken the bonding characteristics of the adhesive substance responsible for the attachment of the eggs to leaf or leaf to leaf (SCHROEDER et al., 1977). By altering the natural protection afforded by the folded leaf, egg mortality is increased via physical exposure and predation.

Insect growth regulators (IGR) such as diflubenzuron offer a second strategy. This acaricide has a Federal registration pending for control of the citrus rust mite and citrus leaf miner in florida citrus and state approval for use as a ovicide against *Diaprepes* on nonbearing citrus. When this IGR is applied with petroleum oil to the tree it reduced the reproductive potential and egg viability of female *D. abbreviatus* exposed to treated leaf flush in the field (SCHROEDER et al., 1976; SCHROEDER and SUTTON, 1978).

As previously mentioned, there are numerous hymenopterous egg parasites found in the Caribbean and other countries that offer excellent opportunity for classical biological control of most species of citrus root weevil.

LARVAL CONTROL OF THE CITRUS ROOT WEEVILS

Currently, no chemical control methods are recommended for the control of citrus root weevils in commercial citrus; however, imidacloprid used for citrus leaf miner at 475-946 ml./ grove acre also has activity against neonate larvae of *D. abbreviatus* (McCOY, in press). The pyrethroid, bifenthion, is only recommended as a soil treatment at 25 ppm for control of weevil larvae in container grown citrus in nurseries.

Since August 1, 1994, the biological Insecticide, BioVector 355, a commercial preparation of the entomogenous nematode, *Steinernema riobravis*, has been used in citrus groves for the control of the larvae of *Diaprepes* and *Pachnaeus*. The nematode is commercially mass produced via fermentation and is marketed by Biosys as a water dispersible granular formulation. The product should be applied to moisten soil over the root zone between the tree trunk and the drip line at 2 million nematodes per tree, using various application methods. Continued irrigation for a minimum of 1 hour is required after application. It is imperative that the nematode reach the root zone where the larvae are found. The juvenile nematode enters the root weevil larvae through external openings in the cuticle, and release a symbiotic gram-negative asporous rod-shaped bacterium which is lethal to the host. The nematodes do not appear to infect the neonatal larvae. A nematicide should not be applied within 14 days before or after a nematode treatment.

Currently, considerable research attention is being given to the development of both nematodes and fungi as microbial control agents of *D. abbreviatus* larvae. The potential exists to supplement naturally occurring levels of existing fungi and nematodes with commercially- produced strains during favorable seasonal conditions for control of the weevils. In Florida, focus is on the use of fungi for the control of neonatal larvae on the soil surface (McCOY et al., 1984; McCOY, 1991) and nematodes for the control of larvae beyond the first instar in the soil rhizosphere (SCHROEDER, 1990; SCHROEDER, 1992). Preliminary data show that fungal conidia will attach to the nematods cuticle, and therefore, can be transported in soil without infecting ths nematode (McCOY, 1991), suggesting that these pathogens can co-exist in soils without negatively affecting each other.

Current research and field observations also suggest that both pathogens are limited by numerous environmental factors that affect their reliability as biopesticides, and no research data are available as to how their performance protects the root system of the tree in time. However, laboratory and field studies currently underway show that two nematodes, *S. riobravis* and *H.*

bacteriophora, are more efficacious than commercially produced *S. carpocapsae*.

In the case of fungi, virulent isolates of *B. bassiana* (McCOY and BOUCIAS, 1989) and *M. anisopliae* (STOREY et al., 1990) have been selected for *D. abbreviatus* and have been applied to citrus soils as conidial and mycelial preparations, respectively. In field tests where *B. bassiana* has been applied as a conidial powder at practical rates (18-20 1b/treated acre), the fungal conidial density was always increased by 3-4 logs compared to the control, but persistence in the surface soil has varied from 4-10 weeks post-treatment (McCOY, 1989). Larval mycosis in treated soil has varied from 60-80% shortly after treatment but then declined (McCOY, 1989). In the case of *M. anisopliae*, mycelial granules applied at 5 g/m^2 give similar results; however, the cost of fungal production at this use rate exceeds $ 1000 per acre (SCHWARZ, 1994). Further field studies are needed to determine if *Beauveria* can achieve reliable control of neonatal larvae at the soil surface to adequately protect the root system of the tree.

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