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PAST AND CURRENT IPM STRATEGIES TO COMBAT THE SPREAD OF *DIAPREPES ABBREVIATUS* (L.) IN FLORIDA CITRUS

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ABSTRACT

During the past 30 years, the West Indian sugarcane rootstalk borer weevil, Diaprepes abbreviatus (L.) has spread from its original site of introduction to 15 counties throughout the Florida citrus industry where it is considered a major long-term threat. Approximately 25,000 acres of citrus have confirmed infestations of the weevil. Most of the infested acreage is exhibiting severe decline or is out of production. Currently, control methods for the larvae are limited and chemical control for the adults appears to be only partially effective in severely infested groves and threatens current IPM strategies. At this time, biological controls have had limited success.

INTRODUCTION

Several species of curculionid weevils representing 11 genera have been reported from citrus and other host plants in the Caribbean region (Fig. 1). The literature suggests that many of the genera are indigenous to the Lesser Antilles but have spread to other regions of the Caribbean over time (O'Brien and Wibmer 1982, Woodruff 1985). Most species have a wide range of host plants and different species within most of the genera can be found coexisting on citrus in many regions. From an economic standpoint, species within the genera. Exophthalmus and Diaprepes, appear to be most important. However, injury and economic thresholds for species within these genera are unknown for both citrus and sugarcane.

Nineteen species of Diaprepes are currently recognized; 17 of West Indian origin (Woodruff 1985). D. abbreviatus (L.) and D. famelicus (Olivier) are considered the most destructive species to citrus and sugarcane (Whitwell 1990). The latter species appears to be confined to the Lesser Antilles but can be found with D. abbreviatus on the same host plant. On the other hand, D. abbreviatus has a widespread distribution within the Caribbean region but interestingly is not found in Jamaica (Fig. 1). It was first reported as a destructive pest of sugarcane in the West Indies around the turn of the century (Watson 1904). Numerous reports of severe larval injury to the root systemof both citrus and sugarcane grown in the West Indies have been made by entomologists throughout this century. Both biological and chemical methods have been devised for larval and adult control (Wolcott 1936, Fennah 1942, Martorell and Gaud 1965, Mauleon and Madembe-Sy 1988). In the Dominican Republic, Martinique and other regions where citrus and sugarcane appear as mixed plantings in calcareous soils, larval feeding by Diaprepes spp. can be devastating to a grove. During the last 5 years, I have observed gradual decline and finally total destruction of a young citrus planting located adjacent to sugarcane in the La Romana region of the Dominican Republic. This destruction has occured even though both contemporary chemical and biological control methods against adults and larvae were applied as a regular management strategy. During peak adult emergence from sugarcane and citrus, as many as 100 adult D. abbreviatus were counted on a given citrus tree.

The sugarcane rootstalk borer weevil was first reported in Florida in 1964 in an ornamental nursery in Orange County near Apopka, Florida (Woodruff 1964). Since ornamental plants known to be hosts for Diaprepes were being imported into the USA from Puerto Rico, it is suspected that either immature and/or adult stages could have entered Florida undetected on ornamentals from that area. The purpose of this paper is to present a historical overview on the dispersal of D. abbreviatus throughout Florida since its introduction 30 years ago and to discuss various control strategies that are currently being used and others that are under development to combat this major pest of the Florida citrus industry.

DISPERSAL OF Diaprepes abbreviatus THROUGHOUT THE FLORIDA CITRUS INDUSTRY: A CASE HISTORY

Following its fortuitous introduction in 1964, 4 years passed before D. abbreviatus was detected again in the same citrus nursery (Jones 1969). A larva was recovered from damaged roots of a containerized plant. Further surveys within the immediate area produced a number of adults confirming establishment of the weevil. Within a few days, State and Federal regulatory agencies intensified their survey within the area which led to the definition of 8,000 acres in Orange County requiring immediate quarantine. Shortly thereafter, 70% of the regulated area, which included commercial citrus, received soil treatment for control of larvae using granular heptachlor or dieldrin. Subsequently, foliar chemical sprays with Sevin (carbaryl) for adult eradication were initiated in an attempt to eliminate the weevil. Within months after eradication was initiated, the use of the above chlorinated hydrocarbons was terminated at the request of the Federal government. Foliar spraying at 10 day intervals was continued thereafter, but was doomed to failure because of factors such as adult reinfestation fromalternate host plants, short residual of foliar chemical treatments and simply the inefficiency of the aerial sprays. Subsequently, soil-applied heptachlor and chlordane were used to control larvae of D. abbreviatus until their use was canceled in 1979.

In 1974 and 1975, the weevil was detected for the first time in Broward and Dade Counties, respectively (Fig. 2). It is unknown whether these new findings represented new introductions from the Caribbean or were the result of movement of plant material from Orange County. According to Griffith (1975), the regulated area in Orange County was now 32,640 acres. This area included 3,903 acres of infested commercial citrus and 113 infested ornamental nurseries. By 1980, the weevil had spread to the adjacent counties of Lake and Seminole and hopes for containment were virtually gone (Fig. 2). Then, in 1982 and 1983, catastrophic freezes destroyed greater than 80% of the commercial citrus acreage in Orange, Lake and Seminole Counties including most of the acreage infested with Diaprepes. The importance of the weevil declined significantly as the citrus industry began its recovery with an exodus to the noninfested southwestern region of the state.

Diaprepes survived the devastating freezes and was reported again in the Indian River area at Fort Pierce and in Polk County near Alturas in 1984 and 1986, respectively. However, its reemergence and continued dispersal was hardly noticed in the mid-eighties when the eradication of citrus canker received priority attention in citrus production. In 1984, use of Lorsban (chlorpyrifos) as a soil treatment for larvae was canceled by the manufacturer and chemical controls for larvae were reduced to zero. Within the last 4 years, Diaprepes has been detected in 7 new counties including newer plantings in Collier, Hendry and Glades Counties (Fig. 2), completing its dispersal to all major citrus growing areas of the state. 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.

CURRENT IPM STRATEGIES FOR THE CONTROL OF LARVAL AND ADULTS OF Diaprepes abbreviatus

During the past 25 years, numerous biological and chemical control methods have been evaluated by Federal and State agencies for each developmental stage of Diaprepes in Florida. In many instances, these research programs were designed after earlier work done by entomologists in the West Indies or they involved joint cooperation among scientists through the Caribbean Basin Administrative Group (CBAG) and other support agencies. In addition, environmental regulation has impacted significantly on the utilization of research on chemical and microbial methods, particularly asrelated to larval control and no doubt will continue to do so in the future. As the following review of past and current applied research will clarify, future research must be conducted in an IPM context where we use both nonchemical and chemical methods judiciously, but guarantee the grower acceptable crop protection. The major research effort must focus on the control of the developmental stage or stages that have a direct impact on the host plant. Since there is no published scientific information available on the economic impact of the different developmental stages of D. abbreviatus and such data is very difficult to generate, presently, we must speculate on this matter in view of the seriousness of the problem.

Biology and Control Strategies for the Adult Stage

In Florida, highest adult emergence by D. abbreviatus occurs from May through October with peak emergence either in June or September (Beavers and Selhime 1976). By comparison, highest adult emergence occurs from March through June in the West Indies (Wolcott 1934). Adults live for several months and never return to the soil from which they emerge. Adults 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. Leaf feeding by high populations of adult Diaprepes can be so severe that new flushes formed during the summer and fall are totally consumed.

Both invertebrate and vertebrate predators are known to feed on adult weevils during the arboreal time of their life cycle. Specifically, toads, birds and spiders have been observed preying on adults (Tucker 1940, Whetmore 1916, Whitcomb et al. 1982), however, the importance of adult predation is unknown and attempts have not been made to augment predator populations in the field through environmental manipulation.

The entomopathogenic fungi, Beauveria bassiana and Metarhizium anisopliae, are pathogenic to adult weevils (Wolcott 1952, Beavers et al. 1983). Adults can come in contact with these fungi during their exodus from the soil or through contact on the plant surface. When these fungi are applied as a foliar spray (Bullock et al. 1988) or to the soil surface beneath the tree canopy (McCoy 1989) at high conidial concentrations (> 1 x 10^6), adult weevil mycosis has been increased on both substrates. Although no reports of adult Diaprepes parasitism by entomogenous nematodes were found in the literature, there is a high probability of it occurring in the soil.

Chemical control of adult D. abbreviatus using foliar sprays applied during peak emergence are recommended to suppress adult populations, thereby reducing the number ofgravid females, egg deposition and larval entry into the soil (Bullock et al. 1988, Futch and McCoy 1994). Numerous pesticides are available to citrus growers for adult control (Knapp 1994); however, many have limitations and none of the products have greater than 4 weeks residual activity, even when applied with a necessary low rate of petroleum oil. Therefore, more than one application usually will be required during the adult emergence period. 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 Diaprepes is severe.

Biology and Control Strategies for the Egg Stage

Adult female D. abbreviatus lay eggs in clusters between leaves stuck together with an adhesive substance produced by the female. Oviposition begins 3 to 7 days after adult emergence from the soil and continues daily for several months. The number of eggs per cluster varies from 30 to 264 and a single female may lay more than 5,000 eggs during her lifetime (Wolcott 1936, Woodruff 1968). Eggs hatch almost uniformly in 7 days; hatch averages about 90% at 28°C in the laboratory (Beavers 1982).

A number of egg parasitoids of D. abbreviatus have been reported from the Caribbean region (Schauf 1987, Delvare 1988, Etienne et al. 1991, Etienne et al. 1992). Three eulophids, Aprostocetus (=Tetrastichus haitiensis (Gahan), A. gala (Walker), and Baryscapus fennahi (Schauff), as well as the trichogrammatids, Ceratogramma etiennei Delvare and Brachyufens osborni (Dozier) appear to be most widespread. Only three hymenopterous parasites have been reported attacking the egg stage of D. abbreviatus in Florida, namely A. (=Tetrastichus) haitiensis, B. osborni and an unidentified trichogrammatid (Beavers et al. 1980). Virtually nothing is known about the population dynamics of these egg parasitoids and how foliar pesticides effect their abundance and distribution from grove to grove.

From 1969 to 1972, T. haitiensis was introduced from Puerto Rico for the classical biological control of D. abbreviatus (Beavers et al. 1980, Beavers and Selhime 1976); however, only dead parasites were recovered from parasitized eggs. Recovery of only dead parasites from parasitized weevil eggs suggests effective host defense or lack of host specificity and the need for further introductions of different biotypes of the same species. Therefore, further classical biological control could improve overall natural control of eggs thereby reducing the larval population entering the soil. Researchers should be aware; however, that hyperparasites of Aprostocetus do occur in the West Indies (Schauff 1987).

Ants and spiders are known to prey on the eggs of D. abbreviatus. In studies conducted by Richman et al. (1986) in Florida and Puerto Rico, the ant species, Monomorium floricola (Jerdon) and Crematogaster ashmeadi Mayr, were observed consuming egg masses during the spring and summer.

Two chemical control strategies have been proposed for increasing mortality of the egg stage of Diaprepes. 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.

For years, oil sprays have been widely used in the summer during the weevil oviposition period for the control of greasy spot disease and phytophagous invertebrates of Florida citrus, so its benefits for Diaprepes egg suppression are being realized to some extent.

Insect growth regulators (IGR) such as Micromite (diflubenzuron) offer a second strategy. This acaricide has a Federal registration pending for control of the citrus rust mite and citrus leafminer 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). Since Micromite is not toxic to the adults, spray coverage and residual activity on the leaves during the summer will be critical to field performance or its use can be combined with a foliar adulticide.

Biology and Control Strategies for the Larval and Pupal Stage

After one week, the neonatal larvae of D. abbreviatus hatch from the egg and fall to the soil surface beneath the tree. Generally, they 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 8 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 the cortical layer. Larvae canremain 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.

Although there are no known parasites of the larval stage of D. abbreviatus, numerous species of ants and earwigs that forage on the surface of the soil have been reported as predators (Whitcomb et al. 1982, Tryon 1986). However, the efficacy of these predators is unknown. Earwigs were found to forage only at night and ants ceased to forage after rains. Recent studies by Jaffe et al. (1990) and Whitwell (1990) showed that ants were repelled by the neonatal larvae. Further research showed that neonatal larvae produce a defensive secretion identified as a sesquiterpene that repelled the fire ant, Solenopsis geminata (F) (Pavis et al. 1992). Novel methods of environmental manipulation are needed to enhance arthropod predation on the larvae.

The soil contains a number of entomopathogenic fungi and entomogenous nematodes that attack the larval stage of various soil insects. 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 throughout the Caribbean region (Beavers et al. 1983, Roman and Beavers 1982). 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 better biological control.

Currently, considerable attention is being given to the development of both nematodes and fungi as microbial control agents of D. abbreviatus larvae throughout the Caribbean region. 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 nematode cuticle, and therefore, can be transported in soil without infecting the nematode(McCoy 1991), suggesting that these pathogens can co-exist in tropical soils without negatively affecting each other.

Current research and field observations 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. Likewise, neither pathogen appears effective in achieving the high level of control (virtually 100%) needed for containerized plants in citrus and ornamental nurseries (Schroeder 1987). However, laboratory and field studies currently underway show that two nematodes, S. riobravis and H. bacteriophora, are more efficacious than commercially produced S. carpocapsae. Although encouraging, it remains to be seen whether more effective species or strains of nematodes can give reliable plant protection from Diaprepes under Florida conditions.

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 lb/treated acre), the fungal conidial density was always increased by 3 to 4 logs compared to the control but persistence in the surface soil has varied from 4 to 10 wk post-treatment (McCoy 1989). Larval mycosis in treated soil has varied from 60 to 80% shortly after treatment but then declined (McCoy 1989, McCoy, unpublished data). 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. Laboratory research is currently addressing the use of sublethal doses of certain pesticides and bacteria in combination with fungi for neonatal larval control.

There are no chemical pesticides currently available for controlling the larvae in the soil in either nurseries or the field. Currently, there are 3 compounds that are giving encouraging results. SuScon Green, a slow release polymer granule containing 10% chlorpyrifos, when incorporated into citrus potting mix and Candler soil has been effective in killing 100% of the neonatal larvae placed in containers each month for 7 months. However, when the product is broadcast on the soil surface, it is less effective. A registration for use in citrus nurseries is being pursued. Admire 2F (imidicloprid) has been effective as a soil drench for the control of neonatal larvae in greenhouse studies. The compound is systemic in the citrus plant and, although the larvae appear intoxicated in the soil, data suggest thatmortality occurs when larvae begin feeding on the fibrous roots.

Admire is currently registered as a soil treatment for citrus leafminer in Florida. Talstar 10WP and Capture 2EC (bifenthrin) are being tested both in the field and greenhouse against all stages of Diaprepes larvae. Preliminary studies show that this synthetic pyrethroid is active at 5 ppm or greater on neonatal larvae. A temporary registration (Section 24c) for use of Talstar in citrus and ornamental nurseries is pending. Field studies with Admire and Capture are under way.

CURRENT STATUS OF THE PROBLEM IN FLORIDA

Although total citrus acreage infested with D. abbreviatus appears very low (< 25,000 acres) in Florida based on a 1993 survey conducted by the Florida Department of Agriculture, the potential for further spread to citrus and sugarcane is tremendous in view of the fact that it is established in virtually all growing regions in the state and control methods are currently limited. It should be pointed out that current adult visual detection methods are insensitive and the infested acreage is most likely greater than the above estimate. Citrus growers with Diaprepes in their groves are experiencing major crop loss through severe tree decline and mortality. The pest is already a major problem to the ornamental industry in view of the number of infested nurseries and the lack of controls for the weevil. In addition, infested citrus and ornamental nurseries are a potential source for spreading the weevil via the sale of infested containerized and to a lesser extent bare rooted plants.

Because of the increased concern over the spread of D. abbreviatus and its devastating effect on the citrus tree in Florida during the past year, a grower-initiated Task Force was organized under the leadership of Mr. J. B. Pratt, Polk County citrus grower, and Ms. Connie Rieherd of the Florida Department of Agriculture and Consumer Services. This 27 member Task Force has as primary objectives: 1) establishment of a grower awareness program within the citrus industry to combat the spread of Diaprepes and 2) encourage both short- and long-term strategies for control of this pest through research and extension programs. The Task Force supports international development in any areas of agriculture that will lead to a solution to this devastating problem both in Florida and throughout the Caribbean region.

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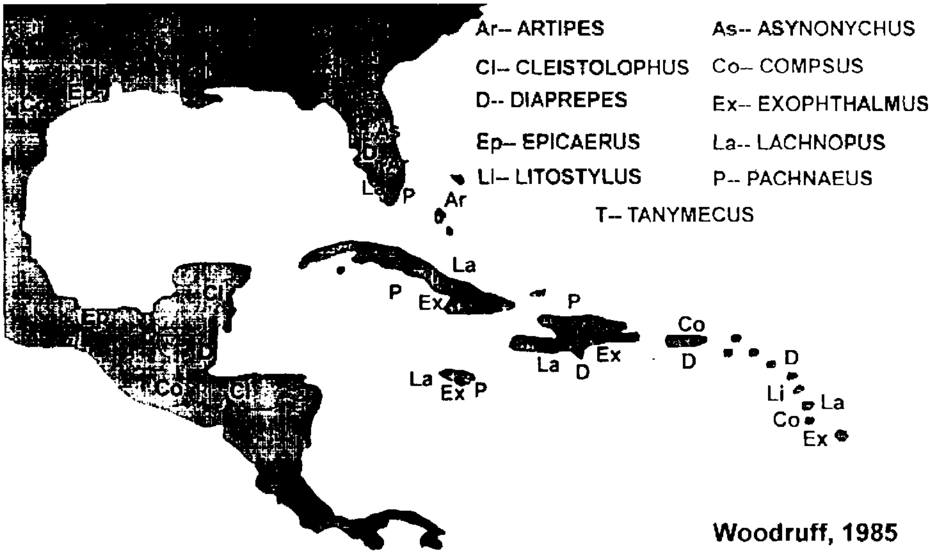

Fig. 1. Major Genera of the Curculionidae important to Citrus in the Caribbean Region.

☐ ORANGE	1964	☐ GLADES	1993
☐ BROWARD	1974	☐ HENDRY	1993
☐ DADE	1975	☐ MARION	1993
☐ PALM BEACH	1977	☐ VOLUSIA	1993
☐ LAKE	1980		
☐ SEMINOLE	1980		
☐ ST. LUCIE	1984		
☐ POLK	1986		
☐ INDIAN RIVER	1990		
☐ HILLSBOROUGH	1992		
☐ COLLIER	1993		

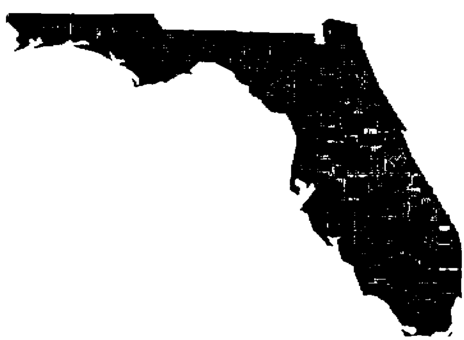

Fig. 2. Infestation by *Diaprepes* of Florida Counties by Year.