CHAPTER 14

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Arthropod Pests of Citrus Roots

The major arthropods that are injurious to plant roots are members of the classes Insecta and Acari (mites). Two-thirds of these pests are members of the order Coleoptera (beetles), which as larvae cause serious economic loss in a wide range of plant hosts. Generally, the larvae hatch from eggs laid by adults on plants or in the soil and complete part of their life cycle chewing on plant roots, and in many cases as adults they feed on the foliage of the same or other host plants. A number of arthropods inhabit the rhizosphere of citrus trees, some as unique symbionts, but few are injurious to the roots. Only citrus root weevils, termites, and ants, in descending order of importance, are root or stem herbivores. These insects are found in both arid and humid citrus-growing regions of the world. Because of their sporadic distribution among groves in a given area, they are categorized as pests of minor economic importance to citrus. However, in an infested grove, they can be devastating to the vitality and productivity and even the survival of trees of all ages. In addition, these soil insects are often associated with root diseases.

Citrus Root Weevils

Adult Identification

Citrus root weevils are beetles with specialized prognathous (snoutlike) mouthparts, in the family Curculionidae (Fig. 14.1). The snout extends forward of the eyes and bears a pair of clubbed antennae toward the end. The front wings are modified to form heavily sclerotized elytra (wing covers), which protect the hind wings at rest. Most citrus root weevils are polymorphic as adults; that is, members of the same species may be distinctly different in appearance. For example, many of the brilliantly colored tropical species exhibit wide variability in the number and color of stripes or spots on the elytra. The genetic plasticity of both temperate and tropical species of citrus root weevils has caused many unresolved and poorly understood taxonomic problems.

Geographical Distribution

Citrus root weevils are predominantly tropical; however, a few temperate species are important pests in the United States, Chile, Argentina, Australia, and New Zealand (Table 14.1). The northern blue-green citrus root weevil, *Pachnaeus opalus;* the Fuller rose beetle, *Asynonychus godmani;* and related species in the genus *Pantomorus* are found in temperate areas. Approximately 150 species have been recorded in the Caribbean region, including Florida, Central America, and South America, feeding as larvae on the roots of all species of the genus *Citrus*. No reports of root weevils on citrus in Europe, Africa, and southeast Asia have been published, although they are likely present in those regions. Currently, species in the genera *Diaprepes* and *Pachnaeus* pose the greatest threat to the citrus industry of Florida. *Exophthalmus* species pose a greater threat if introduced from the Caribbean. Other citrus root weevils of lesser importance to Florida are the little leafnotcher, *Artipus floridanus; Tanymecus lacaena;* and *Epicaerus fermidolosus.*

Generalized Life History and Injury

Most citrus root weevils are univoltine species; that is, they produce one generation per year. Soil conditions greatly influence the amount of time required to complete a life cycle. Both adults and larvae are polyphagous; that is, they feed on a wide range of host plants, in many cases totally unrelated to citrus. All citrus root weevils have a similar life cycle (Fig. 14.1). They have three immature stages: egg, larva, and pupa. Adult weevils emerge from the soil and lay eggs on host plants aboveground; the larvae enter the soil to feed on roots, and the pupa and teneral adult stages are spent belowground. Adults emerge beneath citrus trees or alternate host plants throughout the year. Peak adult emergence varies within and among species and by region but normally occurs in spring and late summer. Adults are attracted to the nonreflective silhouette of the citrus trunk and crawl up the trunk or fly short distances to the tree canopy. They prefer to rest in the shaded interior foliage of the canopy when the sun is shining, but they aggregate on new leaf flushes in subdued light or darkness to feed, mate, and oviposit. Most weevils are bisexual, with females constituting about 60% of a local population. The Fuller rose beetle and a few less important species do not produce males and reprodnce by parthenogenesis. When disturbed, adults of all species drop from their resting or feeding positions to the ground.

The most apparent visible injury caused by adult weevils is notching of the leaf margins of young, tender shoots (Plate 59E). Severe leaf injury can decrease water use efficiency and photosynthesis. However, leaf injury appears to be only a minor problem associated with nonbearing trees and has no apparent effect on the yield of mature trees. Adult weevils feed less on citrus leaves as the leaves mature, and some of them migrate to alternate host plants. They live for several months and never return to the soil.

Except for the Fuller rose beetle, which prefers to lay eggs in masses beneath the fruit calyx or, less commonly, in cracks and crevices in the bark or foliage, citrus root weevils normally lay eggs in clusters between two leaves, which are secured by an adhesive substance secreted by the female during oviposition. The egg masses vary in number, shape, and color and are distributed throughout the tree canopy.

Upon hatching, first-instar larvae fall from the leaf to the soil beneath the tree and enter the soil. The behavior of the larvae in the soil is poorly understood, but their size appears to dictate the site of root feeding. Tiny hatchlings (0.5 inch long) feed on feeder roots, whereas later-instar larvae feed on the larger lateral roots, forming deep grooves as they consume the outer bark, including the cambium layer (Plate 59F). The larvae remain on the roots for eight to 15 months, depending on the species, reaching a length of 0.5–1.0 inch. Larger larvae can remove the outer bark from the crown area of the root system or girdle the trunk, thereby killing the tree. The abovegrou symptoms associated with extensive damage to roots are sim lar to other tree declines caused by root maladies, includi leaf yellowing or leaf drop, twig dieback, off-blooming, setti a very heavy crop of fruit, and (in the later stages of mo bundity) fruit drop. The protracted period in which larvae fe in the soil is followed by an inactive pupal stage of two to fo weeks. Following pupation, the adults either remain in the so for a short period or ascend to the soil surface.

Species of Major Economic Importance

Sugarcane Rootstalk Borer Weevil

The sugarcane rootstalk borer weevil, *Diaprepes abbreviatus*, one of 17 species native to the Lesser Antilles, was introduced into Florida in 1964. It has been recognized as a major pest of citrus in the Caribbean region for over a century. Currently, Florida is the only state in the United States where this weevil is present. It is found in 19 counties, including all those growing citrus commercially.

The adult weevils, commonly referred to as *Diaprepes*, are the largest of the Florida weevils, with a length of 0.37 to 0.75 inch. The females are generally larger than the males. Both males and females are highly variable in color, having black wing covers with stripes that vary from white to gray to yellow to orange (Plate 59A).

Adults are slow-moving and are capable of flying short distances, usually displaying nocturnal or crepuscular activity. Males are thought to emit an aggregation pheromone in frass

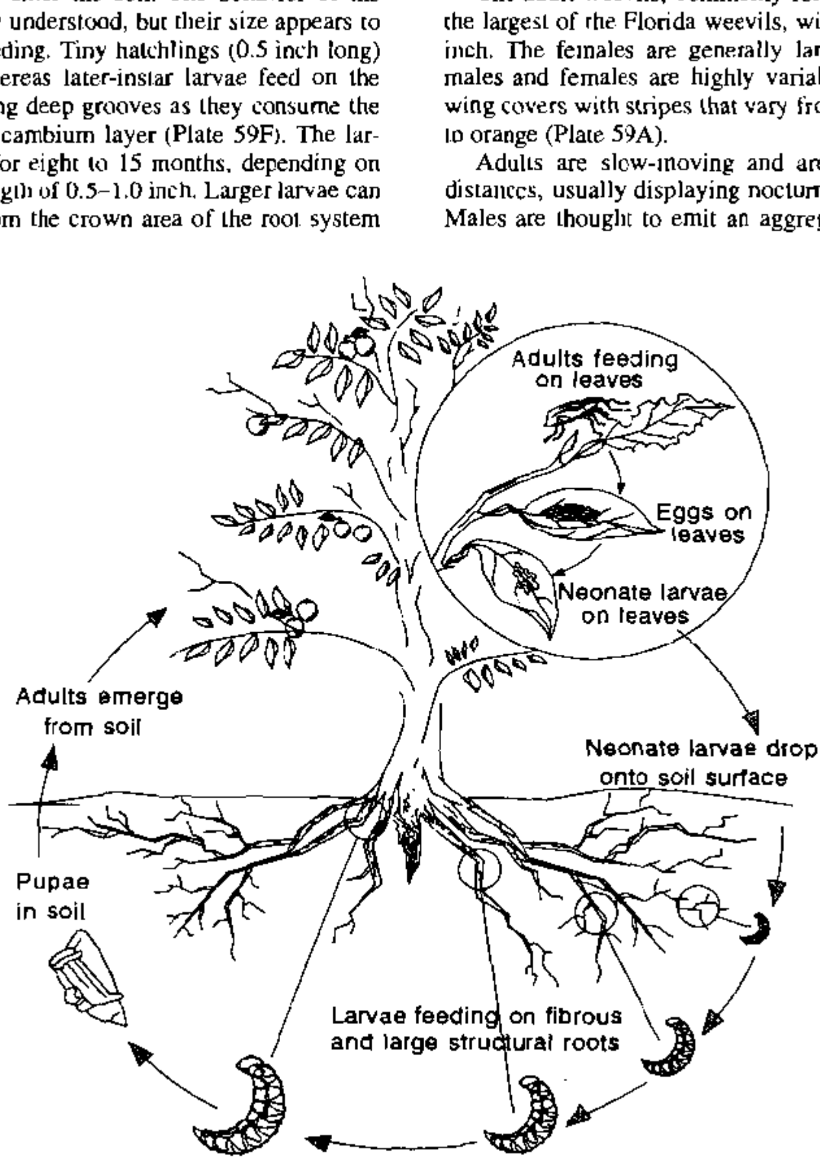

Fig. 14.1. Life cycle of *Diaprepes abbreviatus*, the sugarcane rootstalk borer weevil, on citrus. The life cycle is typical of citrus root weevils. (Drawing by Diana Drouillard)

deposited on the host plant. The pheromone attracts both sexes, resulting in a congregation of weevils on newly formed leaf flushes. This phenomenon might partially explain the aggregation of adults frequently observed on particular trees in a citrus grove.

Neither larvae nor adults are specific to citrus; they feed on a wide range of native and introduced host plants in Florida and the Caribbean region. Of the 270 plant associations recorded, many involve agricultural plants, including citrus, sugarcane, pineapple, corn, peanut, potato, and yucca, as larval hosts. In addition, many woody plants are hosts, including mahogany, live oak, dahoon holly, silver buttonwood, Brazilian pepper, pigeon pea, and *Gliricidia sepium* (quick stick, commonly grown in the Caribbean as a living fence or windbreak). Quick stick is often the preferred host, and it serves to attract weevils to the vicinity of other commercial crops. No citrus rootstock is known to be resistant to larval feeding, and rootstock research showed no inhibition of feeding on rough lemon, sour orange, Carrizo citrange, Milam lemon, Cleopatra mandarin, and many monogeneric hybrids.

Adult emergence is most frequent during the spring or late summer and lasts 10–12 weeks. The beginning of adult emergence appears to be associated with periods of frequent rainfall and peak leaf flushing in some areas, although little empirical information is available to support these observations. The female weevil can live approximately four months, slightly longer than the male, and will lay up to 5,000 eggs in masses of 30 to 250 during a lifetime. Oviposition begins three to seven days after newly emerged females feed. The eggs are smooth, white, oblong-oval, and about 0.5 inch long by 0.016 inch in diameter after deposition. They become tan with age and hatch in seven to 10 days at 78°F.

Table 14.1. Root weevils known to reproduce on and damage citrus[a]

Genus	Common name	Geographical location
Major pests		
Asynonychus	Fuller rose beetle	United States, Australia, New Zealand, Chile, Argentina
Diaprepes	West Indian sugarcane rootstalk borer	United States, West Indies
Exophthalmus	Fiddler beetle	West Indies
Naupactus	. . .	South America
Pachnaeus	Blue-green citrus weevil	United States, West Indies
Pantomorus	. . .	Central America, South America
Minor pests		
Artipus	Little leafnotcher	United States, West Indies
Campsus	. . .	Central America, West Indies, Texas
Cleistolophus	. . .	West Indies
Epicaerus	. . .	Mexico, Central America, Florida, Texas
Eutinophaea	Citrus leaf-eating weevil	Australia
Lachnopus	. . .	West Indies
Litostylus	. . .	West Indies
Maleuterpes	Spine-legged citrus weevil	Australia
Orthorhinus	Elephant weevil	Australia
Tanymecus	. . .	North America

[a] Major pests are those known to cause significant economic losses to citrus in more than a single, isolated region of the world.

The larvae are white and legless and have highly sclerotized chewing mouthparts. The larval stage is variable in length, lasting from eight to 15 months. First-instar larvae emit a defense pheromone that repels ant predators while the larvae are at the soil surface. The larvae cannot penetrate dry soil. The optimum soil moisture for penetration of sandy soils is 9% of its moisture-holding capacity. As they feed and grow, larvae molt at least 11 times, attaining a length of 0.8–1.0 inch before pupation. They move readily in sandy soils, having been found at depths of 8–10 feet. Larger larvae are particularly destructive to the crown region of the root system, frequently killing trees. This feeding behavior by late-instar larvae distinguishes *Diaprepes* from other weevils (except *Exophthalmus*) as a serious economic pest. Larvae in the last instar stop feeding and enter a variable period of quiescence; the larva then forms a naked pupa in a chamber in the soil. The pupal period lasts 15–30 days. A single generation from egg to adult in the field requires about 1 to 1.5 years, depending on soil conditions and the availability of host material on which the larvae can feed.

Fiddler Beetles

The genus *Exophthalmus* comprises 76 species of fiddler beetles, found in many countries in the Caribbean and Central America (Plate 59D). None is known in the United States. However, fiddler beetles are present in Puerto Rico, Cuba, and Hispaniola and thus pose an immediate threat to the citrus industry in Florida. In Jamaica, six species of *Exophthalmus* feed on citrus, causing severe root injury. *E. vittatus* is the most widespread on the island and is considered a major problem in commercially grown citrus. Biologically, fiddler beetles are closely related to *Diaprepes* species, feeding on similar host plants and having similar feeding behaviors and natural enemies. Fiddler beetles also prefer peanut, jackfruit, star apple, yam, mango, avocado, sugarcane, and cocoa as host plants, in addition to citrus.

Adult fiddler beetles are generally larger than *Diaprepes*, about 0.5 to 1.0 inch long, with some variation in size among species. They exhibit strong color polymorphism; the elytra (wing covers), in particular, are marked with different patterns of stripes and spots, varying from brown to blue, green, yellow, rosy, tawny, or white on a black body. The shape of the body and the genitalia vary among species.

Unfortunately, detailed studies of aspects of the biology of *Exophthalmus* have not been conducted. In Jamaica, two distinct emergence cycles have been identified, concurrent with the rainy seasons (May and October). Adult emergence starts a few days after the rains begin, when adequate moisture has percolated down to infested roots. The last-instar larvae appear to be triggered by the changing environmental conditions, and they move toward the soil surface to pupate. After about 30 days, adults begin to emerge from the soil and move to the tree canopy.

Adult fiddler beetles mate in the tree canopy shortly after emergence. After a brief preoviposition period, egg laying begins. The eggs are creamy white or grayish and oval with rounded ends. They are laid in masses of about 60, in a manner similar to that of *Diaprepes*, but in fewer numbers. One female will lay an average of 2,000 eggs over her life. Embryogenesis in *E. vittatus* takes seven to eight days. Adult females live about 110 days and males 103 days in the field.

The neonate larvae spend a brief period on the leaves before dropping to the soil. Larval behavior in the soil is similar to that of *Diaprepes*; larvae in the first two instars feed on adventitious roots and then move to lateral roots. *E. vittatus* has 10 larval instars, which complete their development on roots after

30 weeks. The last larval instar moves to the crown of the root system, where it actively feeds for about four weeks before forming a pupal chamber away from the roots, near the soil surface. The pupal period lasts three to four weeks, and the total life cycle requires about 9.5 months.

Blue-Green Citrus Root Weevils

The genus *Pachnaeus* comprises seven species of blue-green citrus root weevils, which are found on citrus in the Caribbean region and the southeastern United States. Two species, the southern citrus root weevil, *P. litus* (Plate 59B), and the northern citrus root weevil, *P. opalus*, are present in Florida, and the former also in Cuba. Adults are large, 0.30 to 0.55 inch in length, but smaller than *Diaprepes*. The coloration of the adult ranges from gray to gray-green to bright aqua. These two species are indistinguishable to the average person, because of their similarity in color and shape, but they can be readily distinguished by the degree of sinuosity of the suture between the pronotum and the elytra. *P. litus* has a visible notch on the pronotum, and *P. opalus* has a smooth pronotal edge. *P. litus* is confined mainly to coastal and interior plantings in south Florida. *P. opalus* is a more temperate species, found throughout central and north Florida and as far north as New Jersey. Where distribution overlaps, both can be found in the same citrus grove. A third species, *P. citri*, is an important citrus pest in Jamaica.

Like other citrus root weevils, the *Pachnaeus* species are polyphagous. Adult *P. opalus* has 27 known host plants, and *P. litus* has 70. Both prefer citrus but are also found on oaks, Australian pine, and woody ornamentals, such as roses. *P. litus* and *P. citri* have been observed feeding on citrus fruit in Cuba. Host plants of *P. citri* include mango, avocado, pimento, cacao, peanut, and star apple.

No detailed studies of the life cycles of these three species of *Pachnaeus* have been conducted, but from what is known they are quite similar. Both *P. litus* and *P. opalus* adults emerge from the soil continuously; peak emergence is generally from mid-May to mid-July in Florida. The emergence of *P. citri* adults is triggered by the rainy season. Adult feeding and mating behaviors are similar to those of other citrus root weevils. Adults live for up to 120 days. The female lays 30–75 whitish, elongate cylindrical eggs in a mass and can produce as many as 4,000 eggs during a life span. Hatching of *P. litus* and *P. opalus* begins after seven to 10 days and is affected by moisture. The larvae are white and legless and have well-developed, brownish black chewing mouthparts. Larvae of all species exhibit similar feeding behavior. They develop over a period of eight to 10 months. The neonate larvae of *P. litus* are highly sensitive to low soil temperatures, in the range of 60–70°F, with a survival rate up to 25% lower than that of other weevils in Florida. Root injury caused by *Pachnaeus* species is typical of that due to other weevils described previously. Injury to the crown area of the root system is generally less serious than that caused by *Diaprepes*.

Fuller Rose Beetle

The Fuller rose beetle, *Asynonychus godmani* (Plate 59C), is a ubiquitous species, native to South America. It has been reported on citrus in the United States, the Mediterranean region, South Africa, Australia, and New Zealand and on other deciduous fruit trees, numerous woody ornamentals, and other plants, such as roses and grasses. It is found on a wide range of plants in both coastal and interior areas of Florida, where it was first reported in 1916. It is very localized in citrus-growing areas of the state and frequently coexists with other weevils in infested groves. Adult feeding damage to citrus foliage and larval injury to roots generally cause little tree decline.

The Fuller rose beetle has a propensity for laying eggs under the calyx of the fruit. This habit has increased its importance as a postharvest pest, because fruit harboring eggs is considered a quarantine problem in some countries, notably Japan. In California, where the Fuller rose beetle is widespread on citrus, fruit destined for export to Japan is regularly fumigated with methyl bromide. Fumigation is expensive and is especially damaging to lemons.

The Fuller rose beetle is parthenogenic. Adult females are about 0.33 inch in length, smaller than the species mentioned above. They are brownish to gray and have a faint crescent-shaped mark on each side of the wing covers. The wing covers are fused, and the insect is flightless.

In Florida and California, the beetle produces one generation per year. Adults emerge from the soil throughout the year, but peak emergence occurs from July until the end of November. Females oviposit for about four months, depositing yellow, flattened eggs in masses of 70–100. Eggs hatch in 15–17 days, with maximum hatch occurring at high ambient relative humidity. The hatchling larvae are cream-colored except for the yellowish head capsule. They can survive soil temperatures as low as 21°F. In feeding behavior and development, the Fuller rose beetle is similar to other root weevil species. Mature larvae are about 0.4 to 0.5 inch long at pupation. The pupal period lasts about 15 days.

Economic Importance

Generally, leaf feeding by adult root weevils (Plate 59E) is of no economic importance to either young or mature trees; however, they occasionally defoliate young trees, particularly replant trees in mature groves, causing retardation of tree growth. The larvae of various key species of citrus root weevils, discussed previously, cause an estimated annual loss of \$75–100 million in citrus production as a result of tree mortality and yield reduction in commercial citrus groves in the major growing regions of Florida, Jamaica, Puerto Rico, the Dominican Republic, Dominica, Martinique, and Cuba. In addition, an estimated \$3 million is spent annually to fumigate fruit contaminated with eggs of the Fuller rose beetle and bound for export to Japan. Economic estimates are not available for other countries.

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Management

As will be pointed out in the following sections, a repertoire of historical and contemporary methods for managing citrus root weevils has been developed. They include numerous cultural, mechanical, natural, sanitary, biological, and chemical methods for the suppression of citrus root weevils at all developmental stages. No single method of control has been totally effective. The multiphasic approach of integrated pest management (IPM), utilizing both chemical and nonchemical methods, will be necessary to achieve acceptable control and, at the same time, satisfy environmental concerus into the next century.

One major deficiency in the aggressive use of chemical and nonchemical control methods is our lack of injury thresholds and economic thresholds for root weevil larvae in relation to the age and health of trees in various regions of the world. Techniques for monitoring adults of some species are in development, but none has been nsed to generate ecological data vital in determining injury thresholds. Preliminary research suggests that ground traps have potential in monitoring seasonal adult emergence. Snch data should be helpfnl in timing foliar treatments for adnlts and soil treatments for neonate larvae invading the soil.

In California, the following monitoring program is recommended when groves are infested with adult Fuller rose beetles. Growers should sample fnr adult beetles from July to November by shaking or beating branches to induce beetles to drop onto an apron or tray. If beetles are found, fruit should be sampled for egg masses, especially in areas where adult feeding damage is evident. A minimum of 500 fruit in a 10-acre block, five fruit per tree from 10 trees per acre, should be sampled. Fruit at chest height is selected from different quadrants of the canopy. The stem is clipped 2 inches from the fruit; then the stem is held and twisted off the calyx. The underside of the button end and the part of the fruit that was covered by the button should be examined for the presence of egg masses. If the fruit is to be exported, the infestation level should be less than one fruit infested with a viable, unhatched egg mass per 1,000 fruit sampled at harvest.

Nursery Sanitation and Control

With their broad host range and limited mobility as adults, citrus root weevils have historically been disseminated between countries as eggs or adults on plant foliage or as larvae on the roots of container-grown nursery plants. In Florida, spread withiu the state has most frequently occurred by the movement of infested budded trees from the nnrsery to the grove. Citrus root weevil management in nurseries begins with purchasing plant material that is certified weevil-free and maintaining a weevil-free nursery. It is important to randomly inspect the canopy of all plants for leaf injury (notching), eggs, and adults. In addition, container-grown plants showing symptoms of decline should be bare-rooted and examined for larvae and feeding injury.

Sanitation is vital to any nursery. Greenhouses and shadehouses mnst be kept insect-proof through careful preventive maintenance. The following management program is recommended for either enclosed or outdoor nurseries subject to weevil invasion from the surrounding area. Plants should be inspected weekly for adnlt weevils. In outdoor nurseries, a few gronnd traps, snch as the pyramid-shaped Tedder's trap, can be placed on the soil surface at random locations near the base of snspected host plants, to attract adults moving on the soil. Foliar chemical sprays should be applied as needed to kill adult populations on the foliage at the time of detection and thereby reduce the nmmber of gravid females laying eggs on the plant. In nurseries with a history of weevils, soil insecticides should be applied as a liqnid drench or as granules fully incorporated into the potting mix for the control of first-instar larvae invading the soil. Residual control lasts a minimum of 10 weeks but has no effect on larvae beyond the first instar. Natural enemies attack weevils at various developmental stages in nurseries, and the entomogenons nematode *Steinernema riobravis* is effective in snppressing weevil populations in containers or field soil, but eradication is reqnired to avoid plant loss and satisfy certification requirements in Florida. In any case, pesticides shonld be rotated and used judicionsly to prevent resistance and avoid disrupting natural enemies.

Certification programs are effective in reducing the spread of citrus root weevils from nnrseries to groves. For example, the Florida Department of Agriculture and Consumer Services regulates the movement of all nursery stock originating from nurseries known to be infested with *Diaprepes*. All weevil-infested nurseries operate under a compliance agreement that allows nursery stock to be moved from the nursery only when all conditions in the agreement are met. Regnlatory reqnirements include 1) the removal of all foliage or chemical treatment of eggs and adults and 2) larval control by approved chemical treatment of potting media in containers or by shipment of plants bare-rooted. It is imperative that nurseries do not sell liners infested with weevil larvae.

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Cultural Control

Improving the drainage of the soil appears to be the most fundamental strategy for minimizing root injury due to citrus root weevil larvae. Drainage ditches and raised planting beds in lowlands reduce the amount of standing water in orchards and lower the water table. As a result, the rhizosphere is larger and better-drained and favors rapid, healthy root growth free of water stress and disease. Although citrus root weevil larvae feed readily on roots growing under these improved conditions, the tree generates new roots at a more rapid rate, so that less overall tree decline occurs over time. It has been observed bnt not proved scientifically that improved drainage also appears to reduce the incidence of diseases caused by soilborne fungi associated with larval injnry to roots. The combination of root disease and larval feeding can be devastating to a tree. Where drainage has been improved in declining groves, the regular use of a combination soil fnngicide-insecticide can significantly improve canopy leaf density and productivity, particularly when declining trees are also rejuvenated by aggressive canopy pruning and regular tree care.

Bare rooting is another method of limiting crown injury caused by *Diaprepes* larvae, practiced in the Caribbean and occasionally in Florida. The upper 4–6 inches of soil is removed, by means of water under pressure, in an area extending 2 feet from the base of the trunk, to expose the crown region of the root system and thereby prevent larval feeding on this vulnerable part of the tree. This tactic has been used mainly to prevent tree mortality in declining young groves. Unless combined with effective control of adults and larvae on other parts of the tree, this labor-intensive practice will likely fail. Also, the formation of a basin over the rhizosphere can lead to overwatering and drainage problems. In Jamaica, where bare rooting has been widely practiced, nursery trees have been selected for lateral root development, and trees are planted on mounds before the crown is exposed.

Fertigation at monthly intervals has been successfully used by a few growers in Florida to promote the growth of fibrous roots near the soil surface after weevil larvae have destroyed the taproot and inner crown of the tree. The promotion of fibrous root growth can significantly improve tree health and average fruit production in declining groves. This strategy also will be effective for only a short time unless weevil adults and larvae are controlled by other means.

Skirt pruning can be effective in controlling the Fuller rose beetle and other flightless weevil species. In California, tree skirts are pruned and mechanical or chemically treated trunk barriers are used to prevent the invasion of trees by adult weevils. Weed control is also needed, to prevent movement into trees from the stems of grasses and other weeds.

Cover cropping has been practiced in a number of countries in the Caribbean since the beginning of the century; however, from the literature, it is difficult to determine its success. Early in the century, the leguminous plant *Tephrosia candida* was planted between rows or around citrus trees to repel adult *Diaprepes* species, but it is no longer used as a cover crop. Observations in Jamaica suggest that citrus root weevil adults are attracted to *Gliricidia* species (quick stick) more readily than to adjacent citrus trees, so that quick stick may have potential as a trap crop. However, other reports suggest that it attracts *Diaprepes* species to citrus, on which they lay eggs, and larvae hatching from the eggs are carried by the wind to infest citrus groves. Further research should resolve this contradiction reported in the literature. In Puerto Rico, another leguminous plant, pigeon pea, appears to be effective as a trap crop for adult *Diaprepes* species around citrus plantings.

In the past, deep tillage was practiced in the Caribbean to expose larvae to predators in the soil beneath the tree. However, mechanical root injury to the tree was always a concern. This cultural practice is rare today and is impractical in most commercial citrus-growing areas.

Mechanical Control

In the Caribbean, where agricultural labor is less expensive than in the United States, the large, brightly colored adult citrus root weevils in the genera *Diaprepes* and *Exophthalmus* are conspicuous enough in the tree canopy for hand-picking. It is common today to see teams of workers hand-collecting weevils from leaves or from white cloth sheets spread beneath the canopy, which catch weevils that fall from the tree when the branches are shaken. The weevils are usually collected in containers and then killed in a kerosene bath or burned. The economic benefit gleaned using this mechanical control to reduce adult populations is unknown.

In parts of the Caribbean and in Florida, some growers spread strips of black plastic, approximately 3 feet wide, on the soil on opposite sides of the trunk beneath the canopy to trap newly hatched citrus root weevil larvae as they drop from the leaves. During the heat of the day, larvae can be killed within minutes as they land on the hot plastic, or they are forced away from the tree to the row middle, where they are killed on the hot, dry sand or consumed by predators. When used over a large area, this mechanical barrier can aid weed control, but it causes problems in routine grove maintenance, particularly irrigation and fertilization. Wind can also be a limiting factor in maintaining an effective barrier.

In summary, a number of cultural and mechanical control methods have been developed to combat citrus root weevils, with different degrees of success. Most of these methods have been grower-driven and lack empirical data to support observations.

Natural and Biological Control

At least 50 species of parasites, predators, and pathogens are known to attack citrus root weevils at one or more developmental stages. Insect parasitoids have been observed attacking adults of some species and eggs of virtually all species of citrus root weevils.

Two parasitic wasps—a *Microctonus* species (an internal parasite) and the digger wasp, *Cerceris watlingensis*—deposit eggs on the body of adult *Artipus floridanus*. The larvae kill the host by invading the body cavity to feed on internal tissues. They subsequently emerge from the dead host as adults.

The hymenopterous egg parasitoids differ widely and are quite host-specific. Different species lay eggs externally on a host egg mass or internally, inside the eggs of a host species. The parasitoid larvae then develop as predators on or in the host eggs. Egg parasitism appears to vary greatly from species to species and for a given species within a citrus-growing area. Of the 13 species of egg parasitoids reported in the Caribbean region, *Aprostocerus haitiensis* (synonym *Tetrastichus haitiensis*) is most widely distributed on citrus. Virtually nothing is known about the population dynamics of these egg parasitoids and their potential as regulatory agents in the field; however, reports of egg parasitism as high as 90% in some locations have been published. There are no known parasitoids attacking citrus root weevil larvae in the soil.

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A number of attempts have been made to introduce egg parasitoids into one country from another as classical biological control agents. Recent attempts in Florida have involved the introduction of *A. haitiensis* from Puerto Rico to control *D. abbreviatus* and the introduction of *Fidiobia citri* from California and *Platystasisus asinus* from Chile to control the Fuller rose beetle. Limited surveys suggest that none of these has become established in Florida.

Both invertebrate and vertebrate predators are known to feed on adult weevils during the arboreal portion of their life cycle. Birds, reptiles, spiders, ants, and mammals have been observed preying on adult weevils. Tree-inhabiting ants, particularly predatory species in the genera *Monomorium* and *Crematogaster*, and various spiders have been observed consuming eggs of citrus root weevils. The importance of egg and adult predation is unknown, and no attempts have been made to rear and release these predators as biological control agents or to augment their population in the field by environmental manipulation.

Numerous general predators, such as ants, ant lions, earwigs, and mites, forage for neonate weevil larvae on the soil surface beneath the tree canopy. Some larvae can repel ant predators by releasing defense pheromones. On small farms in many Caribbean countries, chickens and guinea hens are kept in groves to reduce larval numbers. Predation by insects, mites, and vertebrates can have a significant effect on larval populations, and it may be possible to enhance this form of biological control of weevil larvae by environmental manipulation (mulching, for example).

Citrus soils around the world contain microscopic nematodes that are obligate parasites of soil insects (Plate 59H). Five species of entomogenous nematodes, belonging to the families Steinernematidae and Heterorhabditidae, are known to attack emerging adult citrus root weevils and, more often, larvae in all stages. The nematodes carry mutualistic bacteria (*Xenorhabdus* or *Photorhabdus* species) that are toxic to the larvae after invasion by infective juveniles through external openings of the body. The bacteria kill the host within three days. The nematodes then feed on the bacteria, reproduce in the host, and return to the soil to resume parasitic activity. *Steinernema carpocapsae, Heterorhabditis bacteriophora,* and *H. indica* have been identified in citrus root weevil larvae in different Caribbean countries and Florida.

Fungal and protozoan pathogens have been found attacking both adult and larval stages of citrus root weevils. Viral and nonmutualistic bacterial infections have not been described. Unicellular gregarines and microsporidial protozoans infect the alimentary tract of adult *Artipus floridanus.* These nonspecific microbes rarely kill their host but will reduce the fecundity of the weevil. Entomopathogenic fungi are ubiquitous in nature. Citrus root weevils at all developmental stages except the pupa are susceptible to fungal conidia found on or in the vicinity of a dead host in soil or on plant surfaces. Upon contact with a host, a conidium attaches itself to the host cuticle and subsequently germinates. An infection peg (modified hypha) is formed and penetrates the host cuticle. Upon entry into the body cavity, hyphae proliferate within the body cavity, killing the host. In subtropical and tropical citrus areas, three species of fungi infect adult citrus root weevils: *Beauveria bassiana* (Plate 59G), *Metarhizium anisopliae,* and *Stilbella buquettii.* The first two of these species also infect larvae, as do a few species in the genera *Paecilomyces* and *Aspergillus.*

While entomopathogenic fungi and entomogenous nematodes can reduce weevil populations in the soil under natural conditions, their spatial distribution and persistence in the soil is variable. Soil texture, soil temperature, soil moisture, ultraviolet light, and various natural and artificial antagonists are important abiotic and biotic factors that influence populations in space and time. In Florida citrus soils, entomopathogenic fungi appear to be most prevalent before the summer rainy season. During the rainy season, nematodes are predominant.

Natural control of citrus root weevil larvae by entomogenous nematodes and entomopathogenic fungi is limited by abiotic and biotic factors in Florida, California, and some Caribbean and South American countries. Research on biological control is therefore focusing on the supplementation of naturally occurring fungi and nematodes with selected strains that are amenable to mass production and are applied as biopesticides for short-term pest control. In the United States and other developed countries, fungi and nematodes are produced and formulated as commercial products for sale to growers. In some Caribbean countries, cottage industries exist to produce nematodes and fungi for control of citrus root weevil larvae.

Numerous laboratory and field studies of different species of nematodes have been conducted in Florida to determine their potential as biological control agents of citrus root weevil larvae. From this research, *Steinernema carpocapsae* and *Heterorhabditis bacteriophora* were developed as commercial products and were sold to citrus growers for about 10 years for larval control. *S. riobravis,* an exotic species collected in south Texas, has since replaced *S. carpocapsae.* Laboratory and field studies clearly showed that *S. riobravis* is the superior nematode in sandy loam ridge soils, killing over 90% of root weevil larvae in some experimental trials. Although the overall survival rate of the nematodes is generally low, they are capable of sufficient vertical movement in the soil to reduce the larval population in the rhizosphere.

S. riobravis and *H. bacteriophora* are currently the only soil treatments used for the control of citrus root weevil larvae in Florida. Nematodes are applied either by microjet irrigation or with a herbicide applicator, at the rate of 200 million per treated acre, regardless of tree age and planting density. Pre- and post-treatment irrigation is required to minimize nematode mortality and ensure that nematodes move to the root zone. A minimum of two applications per year should be made, in early June (at the beginning of the rainy season) and in mid-September, after adult weevils have begun to emerge, to ensure a high nematode population density at the time when most larvae are invading the root zone. Nematodes should not be applied within four weeks of nematicide use.

In Puerto Rico, Jamaica, and other Caribbean countries where citrus is planted in soils that are either calcareous or high in clay, nematodes are not used regularly as biological control agents. It is not clear whether soil conditions or other factors are the reason. In California, some suppression of Fuller rose weevil larvae was obtained using *S. carpocapsae.*

In Florida, the fungal biopesticide Mycotrol WP, a conidial preparation of *Beauveria bassiana* formulated in medium oil, has been tested experimentally at a rate of 1×10^6 conidia per gram in combination with a sublethal dosage of the insecticide imidacloprid, as a soil treatment to control neonate larvae and emergent adults at the soil surface. Previous research, using virulent strains of *B. bassiana* and *M. anisopliae* formulated as conidial and mycelial preparations, respectively, determined that high dosages of fungi (1×10^8 conidia per gram) are necessary to achieve 70% control of the larvae and, therefore, are not cost-effective. In the Caribbean, mass production of *B. bassiana* conidia on rice has become a cottage industry. Rice granules harboring the fungus are applied directly to the soil beneath the tree to control citrus root weevil larvae.

Chemical Control

During the last century, chemical control has frequently been used to reduce populations of citrus root weevil larvae and adults in the field. Over 30 different chemicals have been applied as liquid sprays on foliage to control adult weevils, as soil drenches to control neonate larvae, and as granules or fumigants in soil treatments to control larvae and emergent adults. To control the Fuller rose beetle, chemicals have been applied as sprays to the trunk of the tree and in a band around the tree trunk to form a barrier against adults.

Until their cancellation, the chlorinated hydrocarbons aldrin and dieldrin were widely used as a soil treatment to kill neonate larvae falling to the soil surface. In recent years, organochlorines, carbamates, growth regulators, and on occasion even certain nematicides have been used against root weevil larvae and adults, but residual control has generally been short and unreliable.

A number of chemicals are recommended as foliar sprays to reduce adult populations in the tree during peak emergence from the soil. The purpose of adult suppression is to limit the number of gravid females and egg deposition and thereby reduce the number of larvae entering the soil. Foliar sprays should include a spreader-sticker adjuvant, such as medium oil, to improve coverage of new flushes. Even then, the residual activity of the chemicals begin to decline significantly after three to four weeks. Because of their short residual activity, two sprays may be necessary to maintain low adult populations during the peak emergence period, which can last 10 weeks.

Multiple pesticide applications, particularly during the summer, can interfere with the efficacy of natural enemies. Therefore, foliar sprays should be applied only when adults of the most important species are readily visible on the foliage or in ground traps.

Petroleum oil is widely used for both arthropod and disease control in Florida citrus. When sprayed on citrus foliage alone or in combination with another pesticide, medium petroleum oil appears to affect the bonding characteristic of the substance holding the leaves together around an egg mass. It alters the protection provided by the folded leaf and exposes the egg mass, thus increasing the natural mortality of the eggs through predation and desiccation.

Termites

Termites are small to medium-sized, white to yellow insects in the order Isoptera. They are similar to ants. They live in social groups and have a highly developed caste system. Some termites live in moist subterranean habitats, normally in wood buried beneath or in contact with the soil. A number of subterranean species are important to citrus, especially the eastern subterranean termite, *Reticulitermes flavipes,* in California and Florida. In the past, trees were routinely banked (that is, soil was piled to about 1 foot deep around the trunk) in the fall for cold protection, and any wood that was carelessly left in the soil served to attract termites. Termites often would colonize the soil around the tree and feed on the bark of the trunk, sometimes girdling the tree.

In Florida, pine-palmetto woodlands are a natural habitat of subterranean termites. When these areas were planted with citrus, the wood residue accumulated during clearing was often buried rather than burned, creating an ideal refuge for termite buildup and persistence. Under these circumstances, eastern subterranean termites have increased in numbers and can be found feeding on living bark of young trees both above and below the surface of the soil. They strip bark from the trunk in a ring between the soil line and the crown roots, frequently girdling the tree. Once the tree dies from girdling and the wood dries, termites return to consume the seasoned wood, which is a preferred food. Fresh bark and wood are hardly normal food for termites; however, the consumption of the wood source by a large population of termites may force them to eat fresh bark and wood to avoid starvation. The soilborne pathogen *Phytophthora nicotianae* often infects trees wounded by termites.

Management of termites in citrus groves should begin with the removal of wood residue, preferably before planting. Secondly, shallow planting is a desirable practice, to expose upper scaffold roots. After planting, tree wraps for cold protection should be avoided in infested areas. Infested groves should be regularly monitored for termites; wood bait blocks or wooden stakes should be used in monitoring. Soil should be removed to expose the base of injured trees. Granular chlorpyrifos applied to the surrounding soil at the rate of 2 ounces per tree will give about three months of protection. Cellulose baits treated w[...] hexaflumuron have been used experimentally to elimi[...] colonies of *R. flavipes* from groves.

Ants

Ants are a large group of ubiquitous social insects in [...] family Formicidae. About 300 species have been collec[...] from citrus groves throughout the world, many having a b[...]havioral association with the soil. Ants may play an importa[...] role in the dynamics of citrus production and successful pe[...] management in one or more of the following ways. Some spe[...]cies of ants are extremely disruptive to IPM. As they forage fo[...] food within the tree, they prevent parasitoids from engagin[...] their host. They also protect honeydew producers, mainly ho[...]mopterous insects, such as aphids, soft scales, mealybugs, and whiteflies, from their natural enemies. This is particularly true of the Argentine ant, *Iridomyrmex humilis,* and the native gray ant, *Formica cinerea,* in California. On the other hand, some ants are beneficial; species in some genera are strictly predaceous. Some ants are omnivorous, and their role in citriculture is often complex. Other species, such as leaf-cutting ants and fire ants, cause foliar damage or sting and bite humans so severely that they interfere with production and harvest. In Florida, the red imported fire ant, *Solenopsis invicta,* frequently builds nests in disturbed areas in proximity to citrus trees, often near surface irrigation lines or beneath wraps attached to the trunks of young trees for cold protection. This species often feeds so intensely on the bark and tender new leaf flush of young trees planted near ant mounds that the trees are killed, usually by trunk girdling. Severe ant infestations can cause significant tree loss in localized areas of a grove.

Although ants can be a localized pest by injuring trees, interfering with the natural enemies of honeydew-producing insects, or biting grove workers, their role as effective predators preying on other pests in the citrus ecosystem must not be overlooked. These factors must be carefully considered from an ecological perspective when chemical control in citrus groves is under consideration. For example, multiple applications of broad-spectrum chemicals are recommended for the control of fire ants on the soil in Florida. Such recommendations must carry a caution as to the effect of the treatment on nontarget pests and natural enemies. Growers can monitor their groves for honeydew-producing insects. Ants feeding on honeydew can be readily identified by examining the abdomen to see if it is swollen and translucent. Fire ants can also be identified by their sting.

In California, cultural controls such as skirt pruning of trees, removal of branches within 12–30 inches of the ground, and application of sticky materials to the trunk to prevent access to the tree are recommended for both the Argentine ant and the native gray ant. Sticky material can be used against the Fuller rose beetle, too. However, sticky barriers should be used with caution, because they can lead to sunburn under certain field conditions.