CITRUS: CURRENT STATUS OF BIOLOGICAL CONTROL IN FLORIDA

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Successful biological control of cottony-cushion scale, Icerya purchasi, in Florida and California via the introduction of Rodolia cardinalis and Cryptochaetum iceryae around 1900 stimulated interest and continued research emphasis on classical biological control on citrus throughout this century. According to DeBach (1964), about 40% of the insects controlled biologically up to 1960 were soft scales, armored scales and mealybugs and these occurred mainly on citrus. However, other insects such as citrus blackfly and some species of whiteflies also have been controlled biologically, which implies a broader explanation for successful biological control on citrus. Certainly, the fact that citrus is a perennial host confers a degree of ecological stability that is advantageous to parasites, predators and pathogens. Additionally, subtropical and tropical climatic regions conducive to citrus production also favor survival of natural enemies. Whatever the reason(s), the bottom line appears to be, there is a high probability for success of classical biological control of pests on citrus.

If this hypothesis is incorrect however, future control of citrus pests promises to be costly. In both Florida and California, international commerce has flourished during the past two decades. This commerce involves areas of high population density, thereby increasing the likelihood of exotic pest introductions. According to Sailer (1983), at approximately three-year intervals a foreign pest of major importance becomes established in the U.S. Of these, Florida has more than their share as evidenced by the invasion of the citrus blackfly in 1976 and the Mediterranean fruit fly in 1980 and 1984. After an aborted eradication effort costing $15,000,000, the citrus blackfly was controlled through introduction of parasites, a program that cost less than $300,000. This example points to the very substantial benefits that result from successful application of classical biological control programs as well as the high cost of alternative methods having eradication as their objective. Fortunately, most of the potentially dangerous exotic pests of citrus not present in the United States are species against which classical biological control offers a high probability of success.

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In the past 40 to 50 years, the present 850,000 acre citrus industry of Florida has evolved into a highly complex monocultural system. The pest complex common to this system is rather typical of humid citrus-growing regions of the world. Numerous phytophagous mites, armored and unarmored scales, mealy bugs, whiteflies, aphids and some opportunistic insects represent the arthropod fauna common to Florida citrus (Griffiths & Thompson 1957, Knapp 1981, McCoy et al. 1976a). A number of chronic virus diseases and other microorganisms occur, amd three phytopathogenic fungi of the fruit and/or foliage are widespread in distribution and play a major role in IPM. The fungus, Mycosphaerella citri, is generally recognized as the most important pest requiring chemical control regardless of marketing objectives.

Classical biological control has realized a number of spectacular successes in this century (Table 1). In addition, augmentation of natural enemies within a defined IPM strategy has been successful in research and extension programs (Knapp 1981, McCoy et al. 1976a). Although integrated pest management is being used in some areas of citrus production today in Florida, the overall systems approach is generally ignored. Citrus growers are by economic necessity strongly oriented to the philosophy of the agrochemical world. This does not mean that they are oblivious to biological control and what it can do for them. Rather, they prefer that it function independently within the programmed three to four annual pesticide applications targeted primarily to control greasy spot and citrus rust mite. Fortunately, this situation does not present a crisis to the industry as a result of pesticide resistance or serious secondary pest outbreaks. Some environmental problems have developed in the past, however, and may occur from time to time in the future.

CURRENT STATUS OF BIOLOGICAL CONTROL

Phytophagous Mites

Citrus rust mite Phyllocoptruta oleivora has been an important pest to citrus since the inception of commercial production in Florida (Hubbard 1885). The injury caused by the rust mite is the result of intra-epidermal feeding on fruit and foliage (McCoy & Albrigo 1975). Leaf and stem injury will, on occasion, cause premature defoliation (McCoy 1976). Fruit injury appears as different forms of surface discoloration and can affect external fruit quality (McCoy & Albrigo 1975), internal fruit quality (McCoy et al. 1976c), fruit drop (Allen 1978) and fruit size (Allen 1979). Pesticidal spray costs per year for citrus rust mite are estimated at 50 to 75 million dollars.

Yothers & Mason (1930) observed a number of predatory insects feeding on the citrus rust mite. Muma (1967) observed Semidalis vicina and Coniopteryx westwoodi feeding on adult mites and found them abundant only at high population densities. Muma & Selhime

Table 1. Cases of biological control of citrus pests by natural enemies in Florida in citrus this century.

Scientific Name	Principal Natural Enemies: Common Name	Name	Type	Origin & Date	Control Results (C = complete, S = substantial, P = partial)	Reference
Chrysomphalus aonidum	Florida red scale	*Aphytis holoxanthus*	Parasite	Hong Kong via California 1960	C	Clancy et al. 1963 Selhime et al. 1969
Lepidosaphes beckii	purple scale	*Aphytis lepidosaphes*	Parasite	Unknown 1958	C	Clancy & Muma 1959
Unaspis citri	snow scale	*Aphytis lingnanesis* (HK-1)	Parasite	Hong Kong via California 1971	S	Selhime & Brooks 1977 Riehl et al. 1980
Icerya purchasi	cottony-cushion scale	*Rodolia cardinalis*	Predator	Australia, via California 1899	C	Muma 1969a
Dialeurodes citri	citrus whitefly	*Ascheronia aleyrodis*	Pathogen	Florida 1977	S	Berger 1921
		Encarsia lahorensis	Parasite		P	McCoy et al. 1980
Dialeurodes citri	citrus whitefly	*Delphastus catalinae*	Predator	California 1917	P	Denmark 1977
Aleurocanthus woglumi	citrus blackfly	*Amitus hesperidum*	Parasite	Mexico 1976	C	Hart et al. 1978
		Encarsia opulenta				Selhime 1979
		Encarsia smithi				Cherry & Pastor 1980
Planococcus citri	citrus mealybug	*Cryptolaemus montrouzeri*	Predator	Australia via California 1930	P	Muma et al. 1975
Aphis spiraecola	spirea aphid	*Leis dimidata quiquedecimmaculata*	Predator	California 1925	P	Denmark 1964
Anastrepha suspensa	Caribbean fruitfly	*Biosteres longicaudatus*	Parasite		P	Baranowski 1977

(1971) concluded that despite the ability of the predatory mite Agistemus floridanus to feed and reproduce on citus rust mite, it too was not capable of regulating this eriophyid. Recently, a new phytoseiid, Euseius mesembrinus, was observed feeding on citrus rust mite; however, its potential is unknown in Florida (Rakha & McCoy, unpublished data).

Although biological control of citrus rust mite with predators appears limited due to their high reproductive potential during the spring and summer, further research on importation of exotic predators should be encouraged in view of the economic importance of the citrus rust mite and the fact that it has virtually never been undertaken.

The fungal pathogen, Hirsutella thompsonii, appears to be the most important natural enemy of the citrus rust mite. It was first reported in association with this eriophyid by Spears & Yothers (1924). Fisher (1950b) described the fungus as H. thompsonii, while both Fisher et al. (1949) and Muma (1955a, 1958) recorded dead mites containing internal hyphae suspected to be the fungus from the field. McCoy & Kanavel (1969) isolated the fungus and confirmed pathogenicity.

In Florida, natural epizootics caused by the fungus occur regularly during the summer. Diseased mites can be found on fruit and foliage throughout the year. Mites move from the old to the new foliage, to small immature fruit in April and increase during May (McCoy 1979). By mid-June, a few diseased mites appear on the new growth. As mite populations reach peaks after mid-June, epizootics develop regularly, lasting two to three weeks. Two to six diseased mites per square centimeter of fruit surface are required to stimulate a decline in mite population density. However, 30 to 50 live mites per square centimeter of fruit surface must be present to obtain the above level of disease. Obviously, high population densities of citrus rust mites are required to initiate field epizootics by H. thompsonii. The epizootics, however, result in a high fungal residue that usually prevents further mite buildup during the fall and winter (McCoy 1981, McCoy et al. 1976b, Riehl et al. 1980).

In the last decade, H. thompsonii has been scrutinized extensively for its biological control potential against the citrus rust mite and other Acarina on citrus, turf, coconut, and greenhouse crops (Gardner et al. 1982, Gerson et al. 1979, Hall et al. 1980, Litvinova et al. 1979, McCoy & Couch 1982, McCoy & Selhime 1977, McCoy et al. 1971, Santos et al. 1981, Urueta 1980, van Brussel 1975, Yen 1974). In Florida, two avenues of biological control research with the fungus have been studied simultaneously: microbial control and habitat manipulation. Both large scale laboratory mass production and industrial methods were developed using semi-solid and submerged fermentation to produce mycelial and conidial formulations of the fungus (McCoy 1981; McCoy et al. 1971, 1975). In 1975-76, Abbott Laboratories developed the first diphasic fermentation method for the fungus. Concurrently, safety testing against non-target organisms pro-

vided a data base necessary for registration (McCoy & Heimpel 1980). This research led to the registration of H. thompsonii under the trade name Mycar; it received full registration status in 1981.

Since 1969, both fragmented mycelial and conidial formulations of H. thompsonii have been applied experimentally in the field (McCoy 1981, McCoy & Couch 1982) with encouraging results. Since H. thompsonii is absent from the newly-formed foliage and fruit early in the growing season and becomes regulatory only at high mite population densities, the fungus was applied as a prophylatic control agent early in the season against lower rust mite populations. The key to this strategy was to get the fungus to persist in an infective state on the foliage while the mites built up. Conidiation of the fungal inoculum on foliage generally began to appear after 48 hours as small patches of grey growth under optimum weather conditions.

Results of field trials with commercial preparations of H. thompsonii applied at two to four lbs per acre have been effective when weather conditions were optimum for the establishment of the growing fungal propagules on citrus fruit and foliage. In all field trials, applications rarely resulted in lowering the mite population below that of the standard chemical acaricide. However, there was no difference in the percent fruit injury at the end of the season. The addition of medium oil at 0.5-1.0% appears to improve overall knockdown of the mite population and has no apparent detrimental effect on the fungus.

Since H. thompsonii sporulates only moderately, it would appear that growth and conidiation from the residue is the key to improving the field performance of Mycar in the future. In addition, adjuvants that stimulate growth and conidiation should be included in the spray when feasible. Considerable research in the area of microbial formulation with highly virulent pathotypes is needed to improve persistence and performance of the fungus in the field.

In addition to Mycar, Avermectin B_1, a natural product macrocylic lactone derived from Streptomyces avermitilis, has demonstrated high toxicity to the citrus rust mite at dosages of 0.02-0.04 oz ai/100 gal (McCoy et al. 1982). This biological pesticide appears to be somewhat selective to natural enemies having no detrimental effect to H. thompsonii and other entomogenous fungi.

Coincident to studies on the development and evaluation of Mycar as a mycoacaricide, three pest control programs (conventional, integrated and no spray) were tested on Valencia oranges in central Florida (McCoy et al. 1976b, Riehl et al. 1980). Augmentation of H. thompsonii against the citrus rust mite was designed as part of the integrated control program to reduce spraying on processed fruit. Numerous assumptions were made in the experiment due to data gaps relating to the pests and their influence on the crop. Fungicides such as copper, which are known to cause increases in citrus rust mite populations in the

field (Griffiths & Fisher 1949, McCoy et al. 1976a) and benomyl, which is toxic to entomopathogenic fungi in the laboratory (McCoy et al. 1976a), were not used for greasy spot control. Medium oil, which is generally more innocuous to parasites, predators, and pathogens, was used exclusively. Acaricides known to be least disruptive were generally used to control citrus rust mite. Methidathion, a scalicide known to cause increases in citrus rust mite populations (McCoy 1977) and similar organophosphates, were not used in the study. The oxide form of manganese, which is known to affect the viability of conidia of H. thompsonii, was not used as a nutritional foliar spray (McCoy et al. 1976a).

During the four-year study, the use of selective pesticides and a simplified monitoring program reduced the need for chemical control of citrus rust mite and other arthropod pests. By reducing the number of sprays for citrus rust mite via monitoring, the activity of H. thompsonii was significantly increased in the summer and fall. As expected, the incidence of disease by H. thompsonii was highest in the no spray plots. Although rust mite populations were always higher in the integrated control program, no loss of yield was detected between the conventional and integrated programs after four years (McCoy et al. 1976a, b; Riehl et al. 1980).

Although many growers have applied the above strategy in their processed fruit program, data gaps relating to pest monitoring and long-term effects on the tree limit the biological control opportunities offered via environmental manipulation.

A citrus plant model is under experimental development (Allen 1977, Luck et al. 1980, Stamper & Allen 1979) and a predictive damage model for citrus rust mite damage has been developed for Valencia orange (Allen 1976, 1981). Intensified research is needed to test these models and add the natural enemy components to the total system. The use of H. thompsonii as a microbial insecticide and the augmentation of predators in the citrus system, whether introduced or otherwise, can be used most effectively only through the development of a complete model.

Texas citrus mite Of the species of spider mites found on Florida citrus, the Texas citrus mite, Eutetranychus banksi, is considered the most important today. Injury includes a scratching or etching of the leaves and, when tree moisture is critical, defoliation may occur. During heavy infestations, both fruit and leaves may experience russeting or bronzing. Injury thresholds are not known for any spider mite species.

Predators of the Texas citrus mite were reported by Kanavel & Selhime (1967) and Muma (1955a, 1965b). These included Galendromus floridanus, Paracheyletia bakeri, and Agistemus sp., generally considered to be ineffective as regulating natural control agents. Parasitic fungi were reported by Fisher (1954), Muma (1958) and Selhime & Muma (1966). These publications also dealt with a species described as Entomophthora floridana by Weiser & Muma (1966). According to Muma (1969), this fungus is the criti-

cal natural control factor affecting E. banksi populations on Florida citrus. Although its mode of infection is influenced by weather, it produces catastrophic and long lasting epizootics. Because of its localized importance, there are no current investigations on the biological control of Texas citrus mite.

Citrus red mite Panonychus citri occurs in most citrus growing areas of the world. Although its injury, which is similar to the Texas citrus mite, may cause defoliation, it has a narrower distribution than the Texas citrus mite in Florida.

The predators of the citrus red mite were studied by Kanavel & Selhime (1967), Muma (1955a, b, 1958), Muma et al. (1975) and Watson (1926). Although nine predators have been recognized, none, with the possible exception of some phytoseiids, were considered to be important in the natural control of the mite. No definitive studies have been made in Florida to establish more effective predators.

Parasitic fungi were recorded by Fisher (1951), Muma (1955a, 1958), Muma et al. (1975) and Selhime & Muma (1966). An undescribed species of Entomophthora sp. was reported to cause 70% mortality and produce natural control of citrus red mite (Muma 1955a). Selhime & Muma (1966) were successful in infecting citrus red mite with E. floridana. Attempts have been made to innoculate citrus red mite from Florida with a non-inclusion virus found in California with no success (A.G. Selhime, personal communication). Since citrus red mite populations are generally localized or developed because of pesticide misuse, no research is currently being conducted on the biological control of this mite.

Six-spotted mite Eotetranychus sexmaculatus is a sporadic problem on Florida citrus (Pratt & Thompson 1953). Mite populations generally reach a peak by May or June, then rapidly decline to noninjurious levels late in the early summer. They feed in restricted areas of the underside of the leaf nearly always along the midrib. The infested area becomes concave and yellow and the colony is covered with webbing. Leaf drop occurs with high populations.

Predators of the six-spotted mite were reported by Kanavel & Selhime (1967), Muma (1955a, 1958, 1965a), Muma et al. (1975), Selhime et al. (1963) and Watson (1926). Predators most commonly cited were Aleurodothrips fasciapennis, Chrysopa bicarnea, Paracheyletia bakeri, Scolothrips sexmaculatus, Stethorus utilis, and G. floridanus with the latter considered most important. Although destruction of six-spotted mite populations by predation was frequently observed, ecological studies indicate that temperature and humidity are also limiting.

Parasitic fungi were recorded by Muma et al. (1975) and Selhime & Muma (1966). Under grove conditions, an undescribed species of Hirsutella occasionally causes mycosis of six-spotted mites. In the laboratory, Entomophthora floridana was found to

infect the mite. Fungi are generally not considered important in the natural control of the six-spotted mite. There are no investigations on the biological control of this mite at this time due to its minor pest status.

Armored Scales A number of armored scale insects have been important pests of citrus in Florida. As previously mentioned, successful classical biological control of Florida red scale and purple scale have reduced their importance significantly today. Generally speaking, citrus snow scale, Unaspis citri, is considered the only armored scale on citrus not adequately controlled by beneficial insects, requiring additional research.

Florida red scale Prior to 1963, Florida red scale was of major importance in Florida. Heavy infestations caused defoliation and fruit injury.

A number of predators have been reported attacking Florida red scale, the more important being Chilocorus stigma, Microweisea coccidivora, C. bicarnea, and A. fascipennis (Muma 1955c, Muma et al. 1975 and Selhime et al. 1963). Although early researchers felt that entomogenous fungi contributed to control of Florida red scale, that is no longer the case (Fisher 1950a, Selhime & Brooks 1977). Prior to 1961, the parasitic wasps, Pseudhomalopoda prima and Aphytis chrysomphali were the most common parasites of Florida red scale, producing satisfactory natural control. In 1960, following reports of success in Israel, A. holoxanthus was introduced into Florida from Riverside, California where the parasite had been reared in large numbers. Five shipments totaling 15,500 adult parasites were received by the USDA and released in seven locations throughout Florida. By the summer of 1964, A. holoxanthus had become dispersed over the entire citrus area and had reduced Florida red scale populations to extremely low levels (Clancy et al. 1963). A. holoxanthus has essentially replaced P. prima in Florida as the predominant parasite of Florida red scale (Selhime et al. 1969). This example of classical biological control of an armored scale is recognized in Florida as a complete success (Table 1).

Purple scale This scale occurs in all citrus growing areas of Florida and at one time was considered a serious pest of both fruit and foliage.

Predators common to Florida red scale also have been found attacking purple scale (Muma et al. 1975, Selhime et al. 1963). Parasitic fungi were also reported attacking purple scale (Muma & Clancy 1961). Hirsutella besseyi and Myiophagus ucrainicus are considered to be the most important fungi affecting purple scale. The hymenopterous parasite, Aphytis lepidosaphes, was found fortuitously in Florida in 1957 and 1958 for the first time (Clancy & Muma 1959). Within a short time, it was established in all citrus areas and reduced purple scale populations to low densities (Selhime & Brooks 1977).

Citrus snow scale For many years, Unaspis citri was localized in Florida in a small area in Orange and Seminole Counties. The distribution of the scale increased rapidly during the late 1950's and throughout the 1960's. Heavy infestations cause twig dieback and loss of tree vigor.

Predators and fungi common to other armored scales have also been found attacking citrus snow scale (Muma 1969). Indigenous parasites of the snow scale are Aphytis sp. near lingnanensis and Aspidiotiphagus citrinus (Muma et al. 1975).

In 1971, through collaboration with Paul DeBach, Univ. of California, Riverside, exotic parasites from China were supplied to the USDA, Orlando in low numbers. Subsequently, a culture of A. lingnanensis designated HK-1 strain was established in the insectary at Lake Alfred (Selhime & Brooks 1977). From a modest beginning of nine adult parasites, the culture was expanded and releases were initiated throughout the state. Over 6.5 million parasites have been released in Florida. Although parasite establishment appeared widespread, biological control of the scale has been partial. In addition to the HK-1 strain of A. lingnanensis, two other strains have been released in Florida: A. lingnanensis found on California red scale and a hybrid (R^2-65-23) (a cross between A. lingnanensis native to Florida and R-2002 from Puerto Rico).

Since the A. lingnanensis strain native to Florida cannot be distinguished taxonomically from the HK-1 strain and other sibling species of the complex, a major limitation to this biological control campaign has involved the recognition of sibling species. Until better diagnostic methods such as biochemical techniques are developed for the separation of sibling species within the A. lingnanensis complex, a true measure of biological control of U. citri and other armored scales by the respective parasites will be difficult.

Other armored scale insects Glover scale, chaff scale, yellow scale, and a few less important armored scale insects have a few predators and entomogenous fungi common to all armored scales and these exhibit some degree of natural control. However, Aphytis citrinus, A. lounsburyi, A. lingnanensis, A. hispanicus, and A. chrysomphali appear to be the primary natural enemies controlling these scales (Selhime & Brooks 1977).

Unarmored Scales and Other Coccids Brown soft scale, green scale, Florida wax scale, and black scale have a wide distribution on the foliage of all citrus varieties. These species frequently generate enough honeydew to cause serious sooty mold buildup on fruit. Black scale appears to be the most important, particularly on grapefruit on the east coast where secretions of honeydew produce a seasonal buildup of sooty molds (McCoy & Selhime 1971).

Numerous predators, parasites and entomogenous fungi, many common to all soft scales, have been reported (Muma et al. 1975).

In 1970-71, the USDA Horticultural Laboratory, Orlando, FL, introduced Metaphycus helvolus, a primary parasite of Saissetia oleae, from Fillmore, California. Following the release of less than 2,000 parasites in five locations of Florida, the parasite failed to become established according to subsequent survey. On numerous occasions, however, encapsulated M. helvolus eggs were detected in second stage S. oleae. However, concurrent taxonomic studies of the Saissetia complex by DeLotto (1971) revealed that S. oleae was not the predominant black scale in Florida and therefore M. helvolus is the wrong parasite on the wrong host. Today, survey shows that S. negelecta is the predominant scale species on Florida citrus. In the future, parasites of S. neglecta should be introduced into Florida.

Citrus Mealybug Populations of citrus mealybug differ greatly in intensity from year to year. Scymnus flavifrons and Cryptolaemus montrouzeri, an exotic predator introduced into Florida in 1930, are among the more important predators (Muma et al. 1975). Two hymenopterous parasites are considered to be the most important natural enemies of the citrus mealybug. Because these parasites, Leptomastidea abnormis and Leptomastix dactylopii, are so effective little biological control research has been considered on mealybug.

Aphids Although aphids were considered to be major insect pests during the 1920's, they are of minor importance now even though tristeza is transmitted by the green citrus aphid, Aphis spiraecola, in Florida (Griffiths & Thompson 1957). Aphid injury is usually severe only during the period of spring growth on new leaves. Varieties such as Temple and tangerine are most susceptible.

Numerous natural enemies reduce aphid populations on citrus; ladybeetle predators being the most conspicuous. Cycloneda sanguinea is the most common followed by Hippodamia convergens and Scymnus spp. The chinese ladybeetle, Leis dimidiata quinquedecimmaculata, was introduced into Florida from California in 1925 (Denmark 1964). Lysiphlebus testaceipes is parasitic on adult aphids and the fungus, Entomophthora fresenii, is infectious under favorable weather conditions.

Whiteflies The citrus whitefly, cloudy-winged whitefly, and wooly whitefly are the major injurious species on Florida citrus. Other species are found but are seldom injurious (Muma 1969). A number of predators have been identified attacking the various whitefly species. The species mentioned most frequently are Delphastus catalinae, D. pusillus, C. bicarnea and A. fascipennis (Selhime et al. 1963). None of these predators appear to regulate either citrus or cloudy-wing whitefly. Parasitic fungi have been recorded by Berger (1921) as effective natural control factors of citrus and cloudy-wing whitefly. Species most frequently cited were Aegerita webberi, Aschersonia aleyrodis and A. gold-

iana. Some have felt that chemical control is generally not needed for whitefly because of the biological control exerted by Aschersonia sp.

Since Aschersonia generally become regulatory after citrus whitefly reaches high densities each year, the hymenopterus parasite Encarsia (= Prospaltella) lahorensis was introduced into the citrus-growing regions in the fall of 1977 and the winter of 1978 (McCoy et al. 1980). By the fall of 1978, the parasite was well-established in the Lakeland-Auburndale area on citrus and ornamental plants. Since that time, the parasite has spread throughout Florida. Although biological control with E. lahorensis has been successful on ornamental plants, it is premature to assess the degree of biological control on commercial citrus.

Interestingly, with the decline of citrus whitefly on ornamentals and citrus, cloudy-winged whitefly, Dialeurodes citrifolii, appears to be increasing in its more preferred southern area of distribution. An excellent opportunity for classical biological control exists for this species through parasite introductions from southeast Asia. Two species of parasitoids, Encarsia perstrenua and E. strenua, are known to attack cloudy-winged whitefly in this region.

Citrus Blackfly In January 1976, the citrus blackfly was detected for the second time in south Florida. The infestation was confined to urban areas of the Fort Lauderdale and Miami region. An eradication effort was conducted using acephate and malathion foliar sprays at the outer limits of the infestation while biological control was initiated in the center of the infestation (Reinert 1976). Between April and November 1976, several species of hymenopterus parasites including Amitus hesperidum, Prospaltella clypealis, E. opulenta, and E. smithi were introduced into the area. Approximately 22,000 A. hesperidum and 2,500 E. opulenta were released in the central area of the blackfly infestation. Although both A. hesperidum and E. opulenta were established initially, A. hesperidum was dominant and most widespread in its distribution during the first part of the program (Hart et al. 1978). It is interesting to note, however, that E. opulenta became predominant once blackfly populations reached low levels (Cherry & Pastor 1980, Dowell et al. 1981, Selhime 1979). Today, E. opulenta performs very well at low host densities even though A. hesperidum and E. smithi remain established.

Fruit Flies The Mediterranean fruit fly, Ceratitis capitata, has entered Florida and has been succesfully eradicated four different times since it was reported for the first time in Florida in 1929. Anastrepha suspensa entered Florida in the 1960's and have spread throughout the southern part of the citrus growing region. Although citrus is not a preferred host, A. suspensa will attack mature fruit.

Sterile insect releases, male annihilation and the use of

protein hydrolysate bait-insecticide sprays are the primary methods for control of tephritids infesting citrus (Baranowski 1977). Numerous attempts to reduce A. suspensa populations by release of the hymenopterous parasite, Biosteres longicaudatus, has been partially successful (Baranowski 1977).

Citrus Root Weevils In Florida, many species of root weevils occur on commercial citrus; however, six are considered predominant (Woodruff 1979). Although no accurate information is available on the annual economic loss caused by these weevils, larval feeding by the Fullers rose weevil, Pantomorus cervinus, the little leaf notcher, Artipus floridanus, the citrus root weevils, Pachnaeus spp., and the so-called West Indian sugarcane rootstock borer weevil, Diaprepes abbreviatus, will reduce tree vigor. The latter species, which also attacks sugarcane, is a more recent introduction into Florida and has received considerable attention from the standpoint of eradication and subsequent chemical control (Schroder & Beavers 1977).

Numerous natural enemies have been reported attacking all developmental stages of root weevils. Many species of ants (Buren & Whitcomb 1977), a predatory mite Blattisocius keegani (Beavers et al. 1972), and three species of parasites (Baranowski 1960, Beavers & Selhime 1975) attack the eggs of mainly D. abbreviatus. Other predatory arthropods and birds also prey on larvae and adult weevils (Schroder & Beavers 1977, Whitcomb et al. 1982). The entomopathogenic fungi Metarhizium anisopliae and Beauveria bassiana have been reported from the larvae and adult stages of D. abbreviatus in Puerto Rico and Florida (Beavers et al. 1972, Wolcott 1952). In a recent survey, M. anisopliae was frequently found infecting the larvae and adults of Pachnaeus spp., P. cervinus, Artipus floridanus, and D. abbreviatus. In addition, the fungi B. bassiana, Paecilomyces lilacinus, and Aspergillus ochraceous, in descending order of occurrence, were isolated from D. abbreviatus larvae and found to be pathogenic to the larvae of A. floridanus, P. litus, and D. abbreviatus. Nematodes of the genera Heterorhadditis and Steinernema (= Neoplectana) were also found parasitizing the larvae of Diaprepes. The fungi and nematodes were most abundant from June through August when weevil larvae are most abundant in the soil and seasonal rainfall highest (Beavers et al. 1982, 1983). Present biological control research is addressing the fungi attacking the larval and adult stages of the citrus root weevil complex. Particular attention should be given to the development of these fungi and nematodes as biological insecticides and devising an IPM strategy for root weevil larval control since no soil insecticides are registered for larvae.

Plant Nematodes Plant-parasitic nematodes co-exist with many other organisms in the rhizosphere, and together they form a complex ecological community in citrus groves (see Van Gundy, this volume). The soil organisms known to parasitize and prey on

nematodes include bacteria, viruses, fungi, protozoa, turbellarians, tardigrades, nematodes, collembola and mites (Stirling & Mankau 1977). Most of the interest in biological control of nematodes on citrus has centered on the nematode-trapping fungi. DeWolfe et al. (1954) observed Arthrobotrys oligospora and A. dactyloides preying on Tylenchulus semipenetrans, particularly in mulched citrus groves. In Florida, Tarjan (1961) applied nematophagus fungi and organic matter to citrus in pre- and post-plant treatments but failed to reduce the numbers of Radopholus similis in greenhouse and field tests. Predatory nematodes, mainly Mylonchulus spp., are capable of feeding on large numbers of citrus nematodes (Stirling & Mankau 1977); however their potential as biological control agents remain unknown.

In the future, it would appear that management of parasites of citrus will require the use of biocontrol agents as part of an integrated pest management system designed to minimize losses to Florida citrus. The loss of fumigants and ability of nematicides to enter groundwater make their long-term use somewhat tenuous.

Weeds Biological control of weeds of citrus in Florida has received very little attention. A classical program to introduce natural enemies of Lantana has been recommended by the citrus industry; however, the nursery industry recognizes Lantana as an ornamental and has discouraged the plan.

The milkweed vine, Morrenia odorata, is a major pest in many Florida citrus groves. A native pathotype of the parasitic fungus Phytophthora citrophthora has been developed as a biological insecticide by Abbott Laboratories under the trade name Devine (Burnett et al. 1973). This slow-acting mycoherbicide causes stem rot and decline of the plant and has been used in the citrus industry for nearly 10 years (see also Charudattan, this volume).

Recent biological studies have shown that allelochemics isolated from Lantana are toxic to Morrenia (Achhireddy & Singh 1984). The area of allelopathy appears to have excellent potential for biological control of weeds in the future.

Plant Pathogens Greasy spot, caused by Mycosphaerella citri, is the most important defoliating pest of citrus. This fungus causes lesions on the under surface of leaves of citrus and is particularly severe on grapefruit. No natural enemies are known to attack M. citri. As previously mentioned, some fungicides used to control greasy spot are also detrimental to the parasitic fungi that attack insects and mites. Obviously, one of the limitations to biological control of arthropod pests in Florida citrus is the disruption caused by fungicides used for greasy spot and other plant parasitic fungi. Development of a fungicide which controls phytopathogens without affecting entomopathogens may be difficult since most of the important ones are either ascomycetes or deuteromycetes. Melanose and scab, both fungal diseases that attack and cause lesions on the fruit, have no known natural enemies and no biological control studies have been

undertaken. Other more chronic diseases such as tristeza, blight, foot rot, and exocortis, that result in tree decline, are being researched biologically through use of resistant varieties, modification of cultural practice, and budwood certification programs.

RECOMMENDATIONS FOR RESEARCH IN BIOLOGICAL CONTROL OF FLORIDA CITRUS PESTS

1. Introduce exotic insect and mite predators for the biological control of the citrus rust mite.
2. Develop improved formulations and spray technology to maximize the field efficacy of the mycoacaricide, Mycar, for control of the citrus rust mite.
3. Develop novel selective acaricides, insecticides, and fungicides to maximize the conservation of indigenous natural enemies.
4. Determine the long-term effect of greasy spot disease and citrus rust mite independently on citrus varieties harvested for the processing market.
5. Develop models of the greasy spot-citrus rust mite-natural enemy interaction to better define key variables that can be manipulated to maximize alternative pest control by biological control agents.
6. Conduct biosystematic and fundamental genetic studies on specific natural enemies of key economic pests, particularly parasites of the Aphytis lingnanensis complex.
7. Introduce exotic natural enemies for the control of citrus snow scale, black scale, cloudy-winged whitefly and citrus root weevils.
8. Develop entomogenous fungi and entomophagous nematodes as biological control agents of citrus root weevils and determine the ecological factors that influence their survival in the soil.
9. Determine the long-term effect of key parasitic nematodes on citrus and expand biological control research particularly in the area of augmentation of existing natural enemies.
10. Investigate the role of allelopathy as a potential measure for the biological control of Lantana and other weeds.

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