Insect pests and their control

Louis A. Riehl, Professor of Entomology, Emeritus, Department of Entomology, and
Paul DeBach, Professor of Biological Control and Entomologist, Division of Biological Control, Department of Entomology

University research on insects and mites on citrus began in southern California in 1906 with the appointment of H.J. Quayle to the U.C. Plant Disease Laboratory at Whittier. In 1916 he correctly attributed resistance of black scale and California red scale to fumigation with HCN—one of the first reports of resistance. Quayle moved to Riverside in 1917, and the Division of Entomology of the Citrus Experiment Station was formed in 1918. Professor Quayle's studies on citrus insects and mites and their control brought worldwide recognition.

Control problems spurred research on petroleum oil, a little-known and unpredictable material. The first breakthrough came in 1914 with the discovery that acute injury to foliage could be prevented by treating the oil with sulfuric acid; this was the basis for the specification of 92 percent minimum unsulfonated residue (U.R.) that has been the standard of safety to fruit trees for spray oils since 1932. The formulations in use created "tight" emulsions with low rates of deposit that required concentrations of 10 to 13 percent oil. In 1927 the quick-breaking concept of formulation with higher deposit rates was developed; this gave better control with reductions of nearly tenfold in the concentration of oil in the dilute spray mixtures. This concept is still basic to spray oil formulation. Then came the classic work on the relation of oil distillation data to pest control and effect on trees. These results were used to form specifications adopted by California in 1932 for registration and labeling of spray oils.

Some problems of effects on the fruit remained, however. Investigations led to the development in 1965 of the narrow-range (N-R) 415-type oil, a spray oil that could be used on oranges (particularly navels) in September against citrus red mite and California red scale without adverse effects on the fruit. Also, its narrow range meant that the oil could be used in low-volume application against citrus red mite. However, for such use in hotter months such as August, the N-R 440-type oil, with larger molecules, was developed. Both of the N-R oils are useful in IPM programs for citrus. Two other developments important in the safer use of oil spray are (1) adding 2,4-D to oil spray to prevent leaf and fruit drop and (2) application of gibberellin to prevent water spot of navel oranges.

In the late 1930s, work on mites of citrus and walnuts developed the first successful organochemical acaricide, a dinitrophenol compound that was the forerunner of the organochemical pesticides burgeoning in the 1950s. In 1956, as a means of giving this new information to growers, a publication of recommended treatments against insects and mites on citrus was begun, now entitled *Treatment Guide for California Citrus Crops* (published by the Division of Agricultural Sciences, University of California, Berkeley). Among materials developed and recommended against 29 pests are parathion for California red scale and citricola scale, trichlorfon for several orangeworms, oxythioquinox for citrus red mite, chlorobenzilate for citrus bud mite, and dimethoate for citrus thrips. Resistance in some pests has been a recurring problem, requiring testing and development of new materials. Research will continue to update the guide.

With the development of organic chemicals came increased interest in residues of these materials in commodities. Studies were begun to determine residues of insecticides and acaricides on treated crops, their degradation, and other aspects. Residue data became an integral part of investigations before recommendation of a material. The U.C. residue group played an important role worldwide in developing safety standards

A. Oscillating boom applying dilute spray.

B. Adult female California red scale.

C. *Aphytis melinus* parasite laying eggs in California red scale.

D. *Cales noacki* parasite of woolly whitefly.

E. Parasitization of a heavy infestation of woolly whitefly on a leaf by *Amitus spiniferus*, as shown by the exit holes of the parasite.

F. Female citrus red mite.

concerning pesticides in foods. With rising concern for workers, research by the group developed basic and practical information on hazards of residues, on the posttreatment interval necessary for reentry by workers having contact with treated foliage, and on conditions and amounts of exposure during application work.

The shortage of workers in the 1940s sparked development of machines with spray application booms. By 1951 a new pump provided the volume and force needed for a boom; mechanical oscillation moved the spray guns in a circular pattern. Related studies at Riverside provided information on operation and calibration. An experimental procedure was devised to quantitatively measure the coverage of citrus trees; later modifications enabled measurement of coverage by low-volume sprayers.

Studies of low-volume sprayers culminated in models with two sets of spray discharge heads—lower and upper—joined by a vertical air tower, which gave satisfactory coverage of citrus trees. The low-volume sprayer is important, because savings in application costs are substantial and the physical aspects of the spray do not affect natural enemies.

Continuing research on fumigation included studies of commodity treatments of citrus and avocados, which now provide the information basic to export shipment under quarantine restrictions.

Use of a granular formulation to control ants was developed with chlordane; its ban has been offset by the development at Riverside of two replacement chemicals, diazinon and chlorpyrifos. The ban of calcium arsenate removed an effective, low-cost bait for control of the brown garden snail, but research has replaced it with the metaldehyde and methiocarb bait.

Biological control

Biological control research in the University of California began in 1923 at the Citrus Experiment Station, when H.S. Smith and the biological control unit of the State Commission of Horticulture were transferred to Riverside. The more scientific bio-ecological approach delineated important characteristics of effective natural enemies and their role in pest population regulation. This approach shifted emphasis from natural enemies that feed on a variety of hosts to more specific ones highly adapted to a particular host (pest) and having the high searching ability required to keep the host at low population densities.

The importance of taxonomy in distinguishing between closely related natural enemy species or even races was recognized early. This has made possible the discovery and importation into California of a considerable number of reliable parasites of citrus pests that, otherwise, would have remained unknown. Intricate biologies of various parasites of citrus scales and mealybugs were first worked out at Riverside; the result was laboratory culture and subsequent colonization in the field, for the first time anywhere, of those species whose females develop normally as primary parasites but whose males develop as hyperparasites—that is, upon other parasites.

Perhaps the most important ecological principle in applied biological control is importation of as many natural enemy species as possible, as opposed to singling out the one most effective natural enemy. This principle was first proposed, tested, and demonstrated at Riverside. Competition may eliminate some, but the best individual or complex survives to effect the maximum biological control possible from the total natural enemy complex originally colonized in the field. Most workers now follow this precept.

Experimental methods of evaluating the effectiveness of natural enemies were first emphasized at Riverside. All of this basic research has led to more successes in biological control of citrus pests in California than has been achieved with any other crop in any other country. Many of these results have been used in other regions.

Foreign exploration for new natural enemies has been vigorously pursued, once basic research has given the explorer key information on where to go and how to search. Techniques of bringing back the natural enemies have been developed and greatly refined.

In the early 1920s the citrophilus mealybug spread rapidly, becoming a catastrophic pest of citrus in southern California. By 1927, 100,000 acres were heavily infested, and chemical treatments, periodic mass release of the ladybeetle (*Cryptolaemus montrouzieri* Mulsant) and even expensive, high-pressure water-washing were ineffective. The Citrus Experiment Station sent H. Compere to Australia in the summer of 1927 to search for the mealybug and possible natural enemies. England and South Africa were known to have been invaded by the mealybug, and it was assumed that the pest had originated in a subtropical climate linked by steamer to those two countries and southern California. Australia was considered to be the most likely country, even though the citrophilus mealybug had not been recorded there.

This detective work paid off. In Sydney, early in 1928, Compere found a heavily infested mulberry tree, which produced an abundance of parasites. He immediately decided to return with this material to California by steamer; the three-week trip necessitated culturing the mealybug and parasites on potatoes in a vacant hospital room en route. At Riverside, the insects were cultured in large numbers during March to May 1928 and released in the field throughout southern California.

The two parasite species involved, *Coccophagus* *gurneyi* Compere and *Arhopoideus* (= *Tetracnemus*) *pretiosus* (Timberlake), increased and spread rapidly, effecting complete control by 1930. Since then, this mealybug has been seen only rarely. Over the years, this effort has saved the California citrus industry a prodigious amount for the mere cost of $1,700 expenses plus Compere's salary of $50 per month.

Black scale was the most important citrus pest up to about 1940. In 1937, *Metaphycus helvolus* Compere was imported from South Africa, cultured, and released in numbers. It built up and spread rapidly, especially in coastal areas. Since 1940-41 black scale has continued to decrease everywhere, so that today it is, at most, an occasional minor pest.

The California red scale assumed primary pest status following the reduction of black scale. It had been the object of biological control research since 1890, with no significant results, although a natural enemy, *Comperiella bifasciata* Howard, from China became well established. Just after World War II, ecological field studies demonstrated that *Aphytis chrysomphali* Mercet, a naturally established parasite, was effective in some groves in strictly coastal areas. This led to a search for new and better species of *Aphytis*.

Aphytis lingnanensis Compere, imported in 1947 from southern China, became generally established and was quite effective in **untreated** groves in coastal and intermediate areas. *Aphytis melinus* DeBach, imported from India and Pakistan in 1956-57, generally supplanted *A. lingnanensis* in intermediate and interior areas, where its effectiveness in untreated groves ranges from moderate to complete depending on local severity of climate. *Comperiella bifasciata* (Chinese race) and *Encarsia* (= *Prospaltella*) *perniciosi* (Tower) complement the *Aphytis* spp. Thus, biological control of red scale is substantial, ranging from essentially complete in some areas (Ventura County) to inconsequential (desert areas and the San Joaquin Valley). The search for better adapted parasites continues.

The yellow scale was once a major pest of citrus, and thousands of acres were treated annually. After colonization of *Comperiella bifasciata* Howard (Japanese race) from Japan in 1931, yellow scale populations were rapidly reduced in southern California and later in the San Joaquin Valley. Today this scale is virtually never seen.

The purple scale declined considerably following the introduction of *Aphytis lepidosaphes* Compere from south China in 1948. Today it generally is controlled by this parasite.

Many other insects are also held in check principally by imported natural enemies, including the dictyospermum, chaff and oleander scales, the longtail and citrus mealybugs and the citrus whitefly. Other citrus pests are controlled completely or at certain times and places by naturally occurring natural enemies. These include the brown soft scale, brown citrus aphid, Baker's mealybug, greedy scale, and the citrus red mite. U.C., Riverside, research has demonstrated that effectiveness of the natural enemies can be partially or completely eliminated by the use of nonselective pesticides or by honeydew-seeking ants.

Lately, the woolly whitefly has been brought under complete biological control wherever it has spread. The parasites *Cales noacki* Howard, imported from Chile in 1970, and *Amitus spiniferus* (Brethes), from Mexico and other countries during 1967-70, are responsible for this most recent great success.

Also, during the last decade, the invading and potentially serious Comstock mealybug has been brought under complete biological control in the San Joaquin Valley, principally by the imported Japanese parasites *Allotropa burrelli* Muesebeck and *Pseudaphycus malinus* Gahan.

Since 1978 the bayberry whitefly has invaded southern California and spread on citrus. Already, two apparently new species of parasites—*Eretmocerus* sp. and *Encarsia* sp.—have been established from collections made in Japan between 1979 and 1981. Other exotic parasite species are known and will be imported. Some study groves have already shown complete control by the parasites in 1982, but the ultimate degree of success remains to be seen.

For control of another pest, the brown garden snail, Riverside researchers have found and introduced the predatory snail *Ruminia decollata*.

Research on biological control of citrus pests will continue to emphasize discovery and importation of new natural enemies and investigation of new research approaches.

Integrated pest management

During the last few years, research on integrated pest management (IPM) has resulted in a practical program for citrus in southern California coastal to inland zones. Studies at the U.S. Department of Agriculture Boyden Laboratory have developed pheromone techniques for use in trapping male California red scale and mealybugs to detect and monitor infestations. An important result shows that the number of red scale males trapped is a sensitive indicator of the threshold above which economic damage to the crop is likely to occur.

Future research will focus on quantitative biological data for each species in the pest complex and for the natural enemies, and on determinations of economic thresholds. It is envisioned that, through multidisciplinary approaches and teamwork, we will move toward the long-range goal of integrating knowledge of citrus pests into a computer-assisted model for use in choosing optimal field procedures.