Cleopatra mandarin, and Ichang lemon were among the ten best. One of the five lemons on King mandarin had gummosis. When the volumes of foliage canopies were measured in July, 1964, 73 of the 100 Lisbon lemon check trees on Bessie sweet orange rootstocks had contracted *Phytophthora* gummosis on the stock, and the number of infected stock checks had increased to 84 by October, 1964. The number of Valencia orange check trees on Bessie sweet orange rootstocks that were visibly infected with gummosis on the stock remained at 47 of the 100 during that period. Past research has shown the influence of the two species of tops on susceptibility of the sweet orange rootstock to *Phytophthora* gummosis.

Table 4 shows results for the trees on the triangular plots with only four replicates. Three trifoliate varieties, Nasnaran and Ichang lemon showed no gummosis infection. Under the lemon scion, one of the four trees on Rangpur lime had gummosis; this stock under the Valencia orange showed no disease symptoms. Here again, the lemon top made the sweet orange rootstock more susceptible to *Phytophthora* gummosis than did the sweet orange top (12 of the former and four of the latter were infected).

TABLE 4. RESISTANCE OF CITRUS ROOTSTOCKS TO PHYTOPHTHORA AS MEASURED BY TRUNK CIRCUMFERENCES IN THE TRIANGULAR PLOTS (Oct. 1963 to Oct. 1964)

Number	Name	Number of trees	Number with gummosis	Average increase in circumference: rootstock 2″ below bud union	Average increase in circumference: scion 6″ above bud union	Order of rate of scion growth (1 — greatest)*
Valencia orange scions on the following rootstocks:						
				Millimeters		
0	Bessie swt. orange	24	4	36.0	30.6	
21	Nasnaran†	4	0	46.5	43.0	3
22	Rangpur lime	4	0	35.0	35.2	5
23	Ichang lemon #1	4	0	45.8	38.0	4
24	New Mexican trifoliate	4	0	59.5	44.8	1
25	English trifoliate	4	0	53.8	44.0	2
26	Argentine trifoliate	4	0	60.0	44.8	1
Lisbon lemon scions on the following rootstocks:						
0	Bessie swt. orange	24	12	49.9	46.9	
21	Nasnaran†	4	0	60.8	61.5	3
22	Rangpur lime	4	1	41.0	39.8	
23	Ichang lemon #1	4	0	70.5	60.2	5
24	New Mexican trifoliate	4	0	77.7	61.0	4
25	English trifoliate	4	0	79.0	63.0	2
26	Argentine trifoliate	4	0	78.8	64.2	1

* Those varieties having gummosis of trunk were not included in the rating.
† Nasnaran is Citrus amblicarpa.

L. J. Klotz is Plant Pathologist and Professor of Plant Pathology Emeritus; W. P. Bitters is Professor and Horticulturist; and T. A. DeWolfe is Specialist, University of California Citrus Research Center and Agricultural Experiment Station, Riverside. Layout of plantings was by M. J. Garber. Po-Ping Wong assisted by budding the rootstocks.

Biological Control of Olive Scale

C. E. KENNETT · C. B. HUFFAKER · K. W. OPITZ

For nearly thirty years, olive scale, Parlatoria oleae (Colvée), has been the most important insect pest of olives in California. Prior to the introduction of the Persian wasp, Aphytis maculicornis (Masi), in 1952, olive scale was also a most serious pest on deciduous fruits and many species of ornamentals in the Central Valley area. Since then, establishment of the Persian wasp, as well as one other parasite, Coccophagoides sp., has drastically reduced the severity and frequency of scale infestations in California, as reported in this study.

OLIVE SCALE has two generations during the year in California. Young scales of the spring generation are produced by overwintered females of the fall generation. The eggs hatch, and the young crawlers settle on the twigs and leaves during May. The male scales develop and emerge as adults during July, when they fertilize the female scales. The females become fully mature in late July, and eggs are produced during August and September.

The crawlers of the fall generation hatch and settle on the twigs, leaves, and fruits of olive trees during August and September, causing areas of discoloration (premature ripening) and sometimes distortion. These scale-marked fruits are culled by the olive processor. The male scales develop and emerge as adults during October and November, at which time they fertilize the immature female scales. The females of this generation overwinter in the immature third instar and mature in late April.

During the period of colonization and widespread establishment of the Persian *Aphytis*, many studies were conducted in olive groves to determine the effect of this parasitic wasp on densities of olive scale. Because most of the commercial acreage of olives in California is annually treated with parathion to control olive scale, the studies were often limited to small untreated blocks of not more than one to four acres. However, a few growers initiated biological control throughout entire groves with *Aphytis*.

The success of *Aphytis* in maintaining adequately low and commercially acceptable levels of olive scale was excellent in certain groves each year. In other groves, the level of scale-marked fruits was often too high. (A commercially acceptable level of fruit marking is 2 to 5%.)

The *Aphytis* wasp is an external parasite of olive scale. The female wasp deposits its eggs, one per scale host, on the scale body beneath the scale covering or "armor." Upon hatching from the egg the *Aphytis* larva feeds externally on the scale body, and the entire contents are consumed.

Peak reproduction by *Aphytis* in these tests occurred on the overwintered female scales during April and May. When the hot, dry weather of late spring and early summer becomes a daily occurrence, the adult wasps produced during the peak activity earlier, may be nearly annihilated. Absence of suitable scale stages for deposition of *Aphytis* eggs also contributes to the marked reduction in numbers of wasps. As the extreme conditions (95° to 115° F. daily maxima) become less frequent in late summer and the humidity increases (August and September), the parasite survives and reproduces more successfully. Increases in parasitized scales occur during the fall months, with levels sometimes reaching 20 to 25%. During midwinter there is little or no adult *Aphytis* activity. As warmer spring weather approaches, adults resume emergence, and reproduction peaks again by late April.

If unusually hot, dry conditions prevail in a given year, the decimation of the wasps during the summer may be severe enough to prevent their resurgence in adequate numbers by the following spring. Without an adequate parasite resurgence, scale densities are not reduced to the level necessary to assure a high degree of clean fruits in the fall. Conversely, a relatively mild summer allows the wasp to survive in relatively high numbers (2 to 5% parasitization on spring generation female scales in July and August), and 90 to 98% parasitization may be attained by the following spring (late April). Except in groves with very high scale densities, this degree of parasitization was usually sufficient to assure a very high percentage of clean fruits in the subsequent fall.

While *Aphytis* was found capable of maintaining olive scale at satisfactorily low levels in most olive groves during favorable years, its inconsistent performance in some groves, during certain years, made its adoption unlikely as a control for olive scale on an industry-wide basis. Additional natural enemies had to be introduced before biological control of olive scale could become a widely accepted practicable method of control.

New parasites

With this in mind, two additional species of parasitic wasps were obtained from Pakistan in 1957. These parasites, *Coccophagoides* sp. and *Anthemus* sp. were initially reared and colonized in California in 1957 and 1958. By early 1961, *Coccophagoides* sp. was well established at two of the six colonization sites. After early indications of establishment in 1958 and 1959, *Anthemus* sp. had disappeared by 1961.

In the two groves where *Coccophagoides* became well established, the degree of control by this species and *Aphytis*, acting together, has been excellent each year since 1960 (see table 1). The average level of fruit marking has been 1% or less since 1960 for both groves.

TABLE 1. PERCENTAGE OF SCALE-MARKED (CULL) OLIVES IN BIOLOGICAL CONTROL GROVES IN WHICH COCCOPHAGOIDES SP. WERE COLONIZED IN 1957 AND 1958

Grove	Year Coccophagoides colonized	Aphytis alone fully established				Intermediate status	Both Aphytus and Coccophagoides fully established				
		1955	1956	1957	1958	1959	1960	1961	1962	1963	1964
		Per cent									
Herndon (Duncan)	1957	3.8	5.4	4.4	27.4	7.4	0.4	0.5	0.0	0.0	0.0
Madera (Oberti)	1958	..	..	22.2	60.2	4.4	1.0	0.5	0.6	0.4	0.3

Coccophagoides, an internal parasite of olive scale, is well synchronized in its development with that of the scale. The female wasp deposits one egg per host within the body of the scale. Upon hatching, the young parasite larva feeds on the body fluids of the scale. *Coccophagoides* has one generation on each of the two scale generations each year. This wasp, unlike *Aphytis*, successfully attacks scales of both generations, although it never approaches the level of parasitization which *Aphytis* is capable of reaching during the spring. *Coccophagoides* is not as vulnerable to hot summer weather because of its close developmental synchronization with the life cycle of the scale itself.

During the summer period, the bulk of the *Coccophagoides* population occurs as immature stages within the host scales, and the population does not emerge as susceptible adult wasps until late summer when the weather extremes have lessened. Parasitization by *Coccophagoides* usually reaches 30 to 40% (occasionally 50 to 60%) on the female scales of each generation. When this degree of kill is added to that accomplished by *Aphytis* during the fall and early spring and by other miscellaneous natural agencies, the effect on scale densities is most dramatic within one or two years after *Coccophagoides* has become established in a grove.

Insectary production of *Cocophagoides* was resumed in 1961 on a much larger basis than was attempted in 1957 and 1958. During 1962 and 1963 over four million adult wasps were colonized in 24 counties. Since the colonization and establishment of this species during the past two years, the total olive acreage utilizing biological control under the close technical advice of the Division of Biological Control has increased from less than 200 acres to nearly 1,000 acres. The level of marked fruits observed in these groves in 1964 averaged less than 1.5% with only three groves having levels higher than 3.0% (see table 2). These three groves had 8.0%, 6.0%, and 5.0% marked fruits. *Coccophagoides* was first colonized in the two highest density groves in 1963; it is expected that in the following year, the level of control will improve.

TABLE 2. PERCENTAGE OF SCALE-MARKED OLIVE FRUITS (CULLS) IN OLIVE GROVES UNDER BIOLOGICAL CONTROL IN 1964

Grove	Date of sampling	Per cent scale-marked fruits	Years under biological control	Year Coccophagoides first colonized
Clovis	Oct. 5, 1964	2.1	7	1962
Hills Valley	"	6.0	8	1963
Greer	Oct. 6, 1964	0.0	6	1962
Lucca	"	0.5	3	1962
Kirkpatrick	"	0.25	7	1961
Holworthy	"	0.5	3	1962
Sunland	"	0.8	3	1962
Kennedy	"	0.25	3	1962
Yebisu	"	5.0	3	1962
Hatakeda	"	1.0	3	1962
Fox	Oct. 7, 1964	0.0	2	1963
Shimaji	"	1.5	3	1962
Paregien	"	2.5	3	1962
Owensby	"	2.0	3	1962
Oberti	"	0.3	7	1958
Snelling	Oct. 14, 1964	1.0	3	1962
Martinelli	"	0.0	3	1962
Sheeler	"	0.75	3	1962
Daggett	"	0.0	3	1962
Oberti-River	"	1.6	3	1962
Duncan	Oct. 15, 1964	0.0	11	1957
Murdick	Oct. 16, 1964	2.0	3	1962
Brun	"	1.0	2	1963
Blacet	"	8.0	2	1963

While the prospects for continued success of biological control are excellent in groves which have both species of wasps well established, the expansion of this program to include new growers is limited by the availability of the large numbers of *Coccophagoides* required to colonize large acreages.

Field-tree "insectaries"

An alternative to insectary production of parasites, which, in the case of *Coccophagoides*, has severe limitations, is the production of parasites in the field.

Earlier field tests (1957 to 1960) employing DDT treatments as a means of excluding *Aphytis* from olive trees (to show the effect of their presence in adjacent untreated trees) resulted in densities of 400 to 500 scales per twig within two to three years. When treatments were discontinued *Aphytis* returned to these trees from surrounding untreated trees and increased to very high levels within one year. During this period, *Coccophagoides* had also been colonized coincidentally in two groves having the DDT-test trees. Upon discontinuation of treatments in the spring of 1960, *Coccophagoides* in these two groves also moved into these trees and were parasitizing very large numbers of scales by mid-1961. Rough estimates indicated that each of these two trees produced *Aphytis* and *Coccophagoides* in excess of one million, and possibly as many as two million. This number is equal to the total insectary production of *Coccophagoides* for each of the years 1962 and 1963. Trees treated with DDT in later years have also produced high scale and subsequent parasite densities. Parasites produced by this technique were "harvested" by pruning twigs and small branches with scales and parasites attached at the proper time of year and transferring them into several hundred acres of olive trees—as a supplement to the insectary-produced wasps.

A program for field production of *Coccophagoides* should be initiated in early March with a treatment of four lbs of 50% wettable DDT per 100 gallons of water, applied at a rate of 20 to 25 gallons per average-sized tree. The trees to be treated should be limited to the number required to produce *Coccophagoides*. This treatment prevents the spring build-up of *Aphytis*. A second treatment, to be made in mid-April, also prevents further activity by *Aphytis* and prevents parasitization of the scales of the spring generation by *Coccophagoides* during May and June. While *Aphytis* is very likely to be present in *any* olive grove having an olive scale infestation that has not been treated with parathion, Sevin, or other material of similar effect for one or more years, *Coccophagoides* has not yet become sufficiently established to get into most groves on its own. The exclusion of parasites to allow scale build-up is thus aimed principally at *Aphytis*. A third treatment in late August or early September, while not mandatory, is recommended to eliminate any *Aphytis* that may have attacked the scales in the interval since the April treatment. This prevents further *Aphytis* activity and allows a maximum increase in scales of the fall generation.

TABLE 3. INCREASE IN SCALE DENSITIES ACHIEVED BY THE PARASITE-EXCLUSION TECHNIQUE EMPLOYING TREATMENTS WITH DDT FOR A TWO-YEAR PERIOD

Sample and treatment schedule	Number of mature female scales per twig	
	Herndon	Madera
Sample date ... 1–10–62	0.56	0.75
Treatment date 3–12–62	....	....
" " 4–17–62	....	....
" " 8–10–62	....	....
Sample date ... 2–7–63	2.8	5.2
Treatment date 3–6–63	....	....
" " 6–18–63	....	....
Sample date ... 8–1–63	9.1	15.0
No treatments	....	....
Sample date ... 2–14–64	116.9	121.2

Second year

At the beginning of the second year, the March and April treatments should be repeated. This completes the treatment schedule. The exclusion of parasites during this period should allow a considerable increase in scale densities, even if starting at very low initial levels. Higher initial scale densities will, of course, result in much higher final densities (and later the production of more *Coccophagoides*).

By late summer, the DDT of the spring treatments has weathered off and *Aphytis* can then re-enter the trees. However, it is not necessary to treat during the summer of the second year to insure further scale increase, since *Aphytis* cannot return to the trees and build up rapidly enough to prevent egg deposition by the female scales during the late summer. Thus, the fall generation of scales increases still further with almost no interference by *Aphytis*.

In recent tests at Herndon, Fresno County, and Madera, Madera County, scale densities increased 16- to 20-fold after three parasite-free generations. The next scale generation (fall) then increased to 160- to 200-fold over the initial densities as shown by the samples of February, 1964 (table 3).

While *Aphytis* will return to the DDT-treated trees after the insecticide disappears, absence of *Coccophagoides* in the grove necessitates obtaining a stock of this parasite from another source. This can be accomplished by moving prunings from a grove having ex-DDT-treated trees with high scale densities, well parasitized by *Coccophagoides*, or by obtaining insectary-produced material, if available.

Aphytis may build up to considerable numbers by the following spring, but *Coccophagoides* will require at least two generations (one year) to increase to large numbers. Thus, if heavily infested trees are stocked with *Coccophagoides* in late summer after the DDT of the spring treatment has weathered off, it will be necessary to wait until the same time the following year before the *Coccophagoides* can be harvested. Since the time required to build up scale densities before the parasites are allowed to resume activity is approximately 18 months, the total minimum time involved in field production of *Coccophagoides* is roughly 30 months. This period may be extended to 38 months should *Coccophagoides* be retarded in its build-up. The cheapness of the method and the great promise of general success without the need for insecticides fully warrant the planning and waiting period required.

Harvesting and transfer of *Coccophagoides*

Parasites on prunings may be transferred to new groves during two short periods of the year—at each time when they are in the pupal stage within the host scales. During the spring the transfer must be made in May, and during late summer, the transfers must be made in late August or early September. If the transfer is made during other periods, most, if not all, of the immature *Coccophagoides* will die within the scales on the transferred prunings.

Depending on the scale and parasite densities, the harvest from one tree will supply adequate prunings to stock 20 to 40 acres of olive trees. Prunings should be placed in the crotches of the trees at the rate of 2 to 6 ft of prunings per tree.

Transition to biological control

Although excellent control of olive scale may be achieved once both *Aphytis* and *Coccophagoides* are well established,

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certain problems may arise before and during the period of transition from chemical to biological control.

An adequate density of olive scales should be present in the grove at the time the parasites are stocked, as this will enhance the probability of early parasite establishment. While scale densities may be adequate in untreated groves where *Aphytis* is being relied on for olive scale control, this is usually not the case in groves which have been receiving chemical treatments annually. Thus, groves previously under chemical control that are to be converted to biological control by stocking parasites in late summer should not receive any chemical treatments during that year. This provides for an increase in scale densities, which in turn improves the chances for good parasite establishment.

If the stocking of parasites is to be done in May, olive groves under a program of chemical control may be treated at the usual time (July) during the year prior to stocking. While this treatment will prevent an increase in scale densities prior to the stocking of parasites, if it is omitted, the period between the last treatment and stocking of parasites would then be almost two years. This would, in most cases, allow entirely too much increase in scale densities prior to stocking of parasites.

Some growers may wish to convert only a part of their acreage to biological control at the beginning. In this case, a block of trees or individual trees scattered throughout the grove, should be left untreated during the year in which parasites are stocked. If results with these trees are favorable at the end of the first year, the grower may then expand biological control throughout the grove with additional parasites.

Two years

The period of transition from chemical to biological control will require at least one and possibly two years. During this time, qualified technical personnel should make periodic observations to evaluate the progress of the parasites and the scale.

If both *Coccophagoides* and *Aphytis* become well established early, the prospects are good for a successful transition to biological control during the first year. Should observations show a lesser degree of establishment, and there are indications of increasing scale densities, it may be necessary to employ chemical control measures. If only occasional trees in the grove exhibit increased scale densities, the grower may check the increase by spot treatments with oil—which will not interfere with a majority of the parasites in the grove. If the entire grove requires treatment, a light medium summer oil applied in late August will reduce but not eliminate scale densities. This technique has been used successfully in several groves during the transition period. Although an oil treatment will delay temporarily the achievement of adequate parasite densities, it may be necessary in order to insure a commercially clean crop in the fall.

If scale densities have increased during the first year after stocking with parasites, but the grove will not be harvested that year, and parasites are not well established, the grower may forego treatment to allow the parasites another year to increase to adequate densities. If at the end of the second year the parasites have not reduced the scale to a satisfactory level, then other controls can still be employed. At this time either spot treatments to reduce scale densities in certain trees or treatment of the entire grove may be employed.

Should scale densities remain low during the first year after stocking the grove with parasites, with poor parasite establishment, additional stocking (if parasites are available) may be made in late summer.

Other insect pests

The next most important pest species is the black scale, *Saissetia oleae* Bern. Although the olive tree withstands rather high black scale infestations, the honeydew excreted by the developing scales and the resultant sooty mold, may, in the case of very high densities, so cover the foliage and fruits as to reduce or prevent harvesting of the crop.

In most years, black scale is of little consequence in the great majority of olive groves, particularly those in the lower San Joaquin Valley. The crawlers hatch during mid and late summer, and although each female scale produces several thousand eggs, the survival rate is usually extremely low. However, if summer temperatures are well below normal, or if humidities are higher, the survival rate may increase considerably, causing a scale problem the following year. Black scale densities are extremely low during most years because of climatic adversity. Parasites and predators, in the Central Valley, therefore, appear quite erratic in occurrence. Thus, short-term relatively rapid fluctuations in black scale densities are affected very little by natural enemies.

In 1962 and 1963, summer temperatures were below the mean maxima which usually prevail in the Central Valley. These conditions contributed to good survival of the immature stages and extended the reproductive period of the female scales well into the fall months. This resulted in an increase in black scale densities in several biological control groves.

A medium summer oil applied in August against the young newly settled stages is effective in most cases and does not interfere drastically with the olive scale parasites, *Aphytis* and *Coccophagoides*. Tests showed that a combination of DDT and kerosene applied in early December also had little effect on parasite densities. Later applications (late December or January) may persist long enough to curtail adult *Aphytis* survival when it becomes active in late winter, while *Coccophagoides* is not affected since it does not emerge from the host scales until May.

Use of proper cultural practices such as regular pruning and opening up of the centers and tops of the trees may also materially aid in controlling black scale. This technique is often all that is required.

Interference

Interference with parasite activity due to drift from chemicals applied on adjacent crops often results in an increase in olive scale to damaging levels. Evidence of this nature has been observed many times in olive groves before the introduction of *Coccophagoides*. However, several groves in which both *Aphytis* and *Coccophagoides* are well established have shown continuing excellent control, even though cotton, grapes, and citrus were grown adjacent to the olives. It appears that the addition of *Coccophagoides* which is inherently less vulnerable to chemical interference may alleviate this problem.

Fruit damage due to thrips feeding and ivy scale may occur, but these problems are of a minor nature, since they are seldom encountered in the major production areas. The program for 1965 includes further colonization of *Coccophagoides* and the initiation of field "insectaries" by cooperating growers.

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