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PAUL DeBACH[2] and JOHN LANDI[3]

INTRODUCTION

THE PURPLE SCALE, *Lepidosaphes beckii* (Newman), has long been recognized as one of the most serious pests of citrus on a world-wide basis. It exists and thrives over an extended geographical range in areas having similar mild, humid climatic conditions. It is common on citrus in the Far East, its presumed native home, and has been considered one of the most destructive citrus insects in parts of Australia, South America, Central America, various Mediterranean countries, South Africa, Mexico, Florida, the Gulf states, and California (Ebeling, 1959).[4]

The early records indicate that the purple scale was first found in Florida on lemons imported from Bermuda in 1857, and it is believed to have been introduced into California from Florida in 1889 in two carloads of orange trees which were subsequently planted in Los Angeles and Orange counties (Quayle, 1912).

By 1909, it occurred in all counties in which it is now known (Essig, 1909), and its early seriousness was attested by C. C. Chapman (1909) as follows: "If the associated growers at Fullerton had bought outright all those orchards which were first infected [*sic*], and had destroyed them utterly by fire—root and branch—it would not have cost them nearly as much as the purple scale is now actually costing them, each year. . . . The purple scale is the most unpleasant and the most difficult to handle of all citrus pests. It completely covers the tree—trunk, branches, and leaves—and hopelessly fouls the fruit. It defies all ordinary methods of fumigation, and can only

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[4] See "Literature Cited" for citations, referred to in the text by author and date.

be touched by the very maximum dosages." Also, Essig (1909) states: "The purple scale is considered the most serious of all our scale pests, as it is the most difficult to exterminate.... As yet, no natural parasite or predaceous insect has been found which will begin to cope with it."

Lepidosaphes beckii is recorded as infesting a variety of plants in many of the locales where it occurs; however, it is rarely found on plants other than citrus in California. Purple scale thrives in areas having moderate temperatures combined with relatively high humidities, and has only been a problem in the more coastal citrus areas in southern California. The area of greatest economic importance is Orange County.

The distribution of purple scale in Orange, Los Angeles, Santa Barbara, San Diego, and Ventura counties of California, as given by Quayle (1912), remains essentially the same today, except that eradication measures have kept it virtually nonexistent in Ventura County. Inasmuch as it existed near Pomona, in eastern Los Angeles County, at least fifty years ago, it seems quite likely that spread would have occurred long ago through contiguous citrus plantings into the interior areas of San Bernardino and Riverside counties if the scale were capable of existing in these latter climatic areas. It has also failed to spread from the Santa Ana Canyon citrus plantings into the near-by interior citrus district of Corona. Based on this, similar field observations elsewhere, and on biological information from the laboratory, it appears that due to climatic limitations the purple scale has reached the maximum distribution it can attain outdoors in southern California.

Biology, description of stages, and other information relating to the purple scale are well covered by Quayle (1912, 1938) and Ebeling (1959).

Past experience indicated that an incipient infestation of purple scale under favorable California coastal conditions was usually first apparent on the inside or center of the tree, attacking the leaves, branches, and fruit, but that eventual spreading over the entire tree might occur, resulting in severe infestation and extensive killing, even of large limbs, unless insecticides were regularly applied. In established tree infestations, in addition to the usually heavily infested center portion, the majority of the scale was generally found on the leaves, branches, and fruit on the north or northeast quadrants of the trees, apparently not surviving as well on the south and west portions of the trees most exposed to the sun. In addition, trees shaded by windbreaks would frequently be found to be more heavily infested than those receiving more sun.

According to DeBach (1953), "...purple scale appears to be the key problem standing in the way of progress toward general biological control of orange-tree pests in coastal areas of southern California." Previous studies by the authors of several years' duration in untreated groves indicated that satisfactory biological control of most orange-tree pests other than purple scale might be obtained in coastal areas, where a complex of natural enemies capable of controlling them generally occurs unless upset by unusually adverse climatic or cultural conditions. Although purple scale had been attacked in California for many years by several native or accidentally introduced natural enemies, none of these gave evidence during our earlier studies of being capable of restricting the scale to satisfactorily low population levels. Prior to the introduction of *Aphytis lepidosaphes* Compere from China, which is discussed in the following section, *Aspidiotiphagus citrinus* (Crawford) was the most common parasite of purple scale in California. However, it was never abundant enough to effect a noticeable degree of control. Several predators were also common, including *Lindorus lophanthae* (Blaisdell), *Chilocorus* spp., *Orcus chalybeus* (Boisduval), and, on occasion, *Cybocephalus* spp. The parasitic mite, *Hemisarcoptes malus* Banks, attacks the purple scale but is generally associated with heavy scale infestations, inasmuch as its searching ability is extremely limited due to its poor means of locomotion. The "traveling form" of this mite attaches itself to the legs or elytra of *Chilocorus* spp. (so-called heavy-density feeders) and drops off upon reaching suitable scale infestations.

Two approaches to the solution of this problem appeared feasible. We needed either (1) a new effective parasite or predator of the purple scale, or (2) a method of controlling the scale chemically which would not upset the natural enemies of the other potential pests.

THE PARASITE *APHYTIS LEPIDOSAPHES* COMPERE

Importation

The successful conclusion of the integration of the chemical with the biological control program on oranges in Orange County, California, may stem from the introduction of the purple scale parasite *Aphytis lepidosaphes* from China and Taiwan (Formosa) in 1948–49. Although this parasite is not completely effective under California conditions, it has so greatly retarded the rate of increase of the purple scale that the reduced spray program by means of strip-treatment, which will be discussed later, appears feasible.

The Department of Biological Control of the Citrus Experiment Station at Riverside received the initial breeding stock of eighty-six specimens of *Aphytis lepidosaphes* from J. L. Gressitt and Y. W. Djou. This material was reared from purple scale that had been collected on oranges at Lo-Kong-Tung, near Canton, China, and shipped to the quarantine insectary at Riverside on November 28, 1948. Several other shipments of purple scale containing over a thousand individuals of this species were received at Riverside during subsequent months.

It may be interesting to note that the Italian entomologist, Filippo Silvestri, then in the employ of the University of California, recorded observing a purple scale parasite on lemons in Macao, China, during his exploration of south China and Japan in 1924–25, which in all probability was this same species. It is also possible that this parasite may have been included in shipments from the Orient by George Compere over a decade earlier; however, the identification and subsequent disposition of this material are uncertain (Flanders, 1950).

Culture, Colonization, and Establishment

Prior to the introduction of *Aphytis lepidosaphes,* R. J. Bumgardner, of the Orange County Department of Agriculture, had demonstrated that the citron melon, *Citrullus* sp., was a satisfactory medium for the culture of purple scale in the laboratory, and it was on this plant that the first cultures of parasites were propagated in the Citrus Experiment Station insectary at Riverside. Rojas (1954) gives an account of culture methods used following the importation of *A. lepidosaphes* into Chile from California.

The purple scale culture methods employed by the Department of Biological Control insectary at Riverside are as follows:

Of the suitable host plants readily available, mature green lemons and seed potatoes (White Rose, number 1 grade) are generally preferred, primarily because of the ease of handling in the type of parasite-rearing units used. Other equally satisfactory insectary host plants commonly used are citron melon and pink banana squash.

At regular intervals (dependent upon the desired quantity of parasite production), wire trays containing ten to twelve potatoes or freshly picked lemons are transferred from cold storage to the scale-development storage rooms, which are maintained at 78° ± 2° F. and 65 ± 2 per cent relative humidity. Here the trays are placed in racks for the scale-infestation procedure,

TABLE 1
DURATION (IN DAYS) OF THE PURPLE SCALE LIFE CYCLE ON TWO HOST PLANTS

Host plant	First stages	Second stages	Third stages (including egg-production period)	Total life cycle
Lemon	21.9	18.5	21.9	62.3
Potato	26.2	24.5	21.0	71.7

which may utilize either of two techniques: (1) trays of crawler-producing mother-scale-infested lemons or potatoes may be placed on top of the new material, which is thus infested by the direct contact of the two units; or (2) egg-producing mother scale may be scraped from the old host plants and placed directly on the new ones.

The time required for the purple scale to complete its life cycle is dependent upon the temperature and humidity of the rearing chamber and to an extent on the host plant utilized. The data in table 1 depict the time in days required for the complete development of the purple scale from egg to egg-producing adult on two different host plants (lemon and potato) at 78° ± 2° F. and 65 ± 2 per cent relative humidity. It is seen that about two months are required for a generation on lemons in the insectary—about six generations per year. In the coastal areas of southern California, the purple scale produces from approximately two and one-half to four field generations per year, dependent upon yearly climatic variations.

According to Ebeling (1959), approximately forty to eighty eggs per female are deposited over a three-week period in the field during summer months; however, under the more stabilized insectary conditions, the deposition of eggs is nearly completed in ten days.

When the purple scale in the scale-development room has reached the third-instar stage, the trays of infested fruit or potatoes are transferred to sleevecage rearing units in the parasite culture rooms. The new trays, bearing third-instar scales (the stage preferred for oviposition by the parasites), are placed on the top racks in the rearing units and the trays previously placed in the units are moved down one level; the bottom trays of fruit, having now produced their complement of parasites, are discarded.

Honey is streaked on the top glass portion of the rearing units daily, to insure an adequate supply of the carbohydrates so necessary to newly emerged parasites. Parasites for field release are aspirated periodically from the upper glass surface of the cage and placed in half-pint ice-cream-type waxed cardboard cartons containing a small strip of honey-coated wax paper. If the field colonizations are to be delayed for any appreciable time, the cartons containing the parasites are held under refrigeration at 60° to 65° F.

During 1949, several small colonies of *Aphytis lepidosaphes* were released in test plots in Orange, Santa Barbara, and San Diego counties. However, these initial colonizations were drastically reduced by the extremely cold winter of 1949–50, and by early 1950, apparently few parasites remained.

Additional colonizations were made in 1950, 1951, and 1952 in the original plots and in other sites by the Department of Biological Control at Riverside and the Orange County Department of Agriculture, which began insectary propagation of *Aphytis lepidosaphes* in 1950 under the direction of the then commissioner, Dixon W. Tubbs. By the spring of 1953, the Orange County insectary had thoroughly distributed over 580,000 of the parasites throughout the entire district.

By the fall of 1950, it became apparent that initial establishment of this parasite had occurred in most of that year's colonization sites. As time passed, this establishment proved to be permanent (DeBach, 1953). Colonizations during 1951–53 were generally for the purpose of increasing the dispersal of the parasite.

Distribution

The senior author explored various countries in the Orient during 1956–57, primarily in a search for parasites of the California red scale, but made limited observations on the purple scale as well. Purple scale was noted in Hawaii, Japan, Taiwan (Formosa), south China (Hong Kong), Thailand, Burma, and India. Field observations revealed *Physcus* sp.[5] as an internal parasite in northern Taiwan only, whereas *Aphytis* sp. or spp. (the cast pupal skins and live pupae seen were indicative of *Aphytis lepidosaphes*) were commonly seen attacking purple scale in Hawaii, Taiwan, Hong Kong, Thailand, Burma, and India. *Aphytis* thus seems to range pretty well over the presumed native home area of this scale, and appears to be primarily responsible for the generally low numerical status of purple scale on citrus

[5] Following the introduction of *Aphytis lepidosaphes*, a second new parasite, *Physcus* sp. (*P. fulvus*, according to Compere and Annecke [1960], and formerly *Physcus* "B" [Flanders, 1952]), was introduced into California in 1950, but became established in only one locality in San Diego County. Possibly because of its unusual hyperparasitic-male developmental habit, it failed to become established in most of the release sites and at present may be recovered in limited numbers only at Carlsbad. Although *Physcus* has produced a fair degree of parasitization at times, rather heavy purple scale infestations continue at this site. It has not appeared nearly as encouraging as *A. lepidosaphes*.

in the Orient. Its presence in Hawaii is presumably due to an accidental introduction. It is interesting to note that we probably could have obtained this parasite originally from Hawaii much more easily than from China. Live parasite material that appeared in the field to be *A. lepidosaphes* was shipped to Riverside from Hawaii and Burma during this trip. Laboratory cultures were started, and these were found to cross readily with the original strain of *A. lepidosaphes,* hence positively confirming the identity of the species on purple scale in Hawaii and Burma. Subsequent observations in 1957 on purple scale in Italy, Sicily, and Spain revealed no evidence of *Aphytis* or *Physcus* attacking purple scale. Again in 1960, the senior author surveyed citrus areas for natural enemies in other Mediterranean and some Caribbean areas. Purple scale was found commonly in Turkey (southeast coastal area only), Iran (Caspian area), Israel, Cyprus, Morocco, Trinidad, and Puerto Rico. Of these areas, *A. lepidosaphes* was found in Turkey, Israel, and Puerto Rico, thus demonstrating that this parasite has been gradually moving accidentally around the world. However, it is evident that the purple scale has not yet invaded some countries which should be suitable to it and that the parasite has not yet generally followed the purple scale in its travels.

Rather a curious thing happened in relation to our making shipments of *Aphytis lepidosaphes* to Florida. In May 1958, D. W. Clancy, U. S. Department of Agriculture entomologist stationed at the University of Florida Citrus Experiment Station, Lake Alfred, requested shipments of *A. lepidosaphes* from Riverside for colonization in Florida. We prepared a culture and shipped these early in July 1958. The following excerpt from Clancy's letter of July 11, 1958, to DeBach is self-explanatory: "Your first shipment of 600 *Aphytis lepidosaphes* arrived the morning of July 9. . . . A very puzzling situation has just arisen with regard to *Aphytis* on purple scale in Florida. A yellow species is emerging from several collections of adult female scales, which Compere has just identified as *lepidosaphes*. Dr. Muma has not reared it previously in over six years of careful study and we have no idea where it came from or why it has suddenly appeared in several widely separated groves." How *A. lepidosaphes* got to Florida may never be known, but unknown to anyone at that time, it already occurred in New Orleans, Louisiana, and the citrus section a few miles south. We learned of this after B. R. Bartlett, of the Department of Biological Control at Riverside, reported emergence holes in purple scales at New Orleans early in 1958, and C. A. Fleschner followed up with shipments of purple scale material to Riverside in July 1958, which yielded *A. lepidosaphes.* How this species got to Louisiana also will probably never be known. The senior author is quite certain from personal observation in the field that it did not occur in Texas or Florida before 1950 and that it was not present in Mexico by 1954. Inasmuch as shipments were made from California to Texas in 1952, and the species became thoroughly established there, it is possible that it moved or was accidentally transported along the Gulf coast from Texas to Louisiana and Florida. However, since we now know that *A. lepidosaphes* occurs in Puerto Rico, it could have come accidentally from there. Perhaps it also occurs in Cuba. If so, the move to Florida would have been even less difficult.

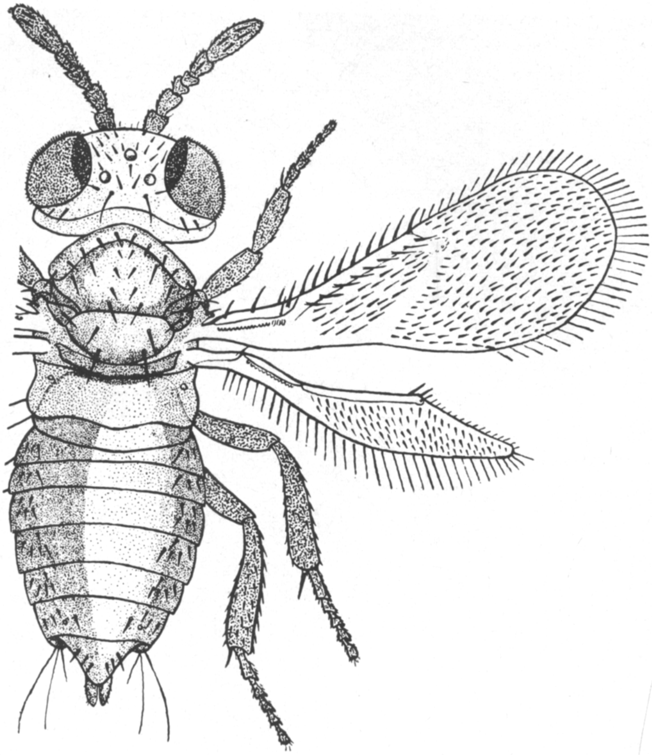

Fig. 1. Adult *Aphytis lepidosaphes* female.

Shipments to Other Countries

Shipments of *Aphytis lepidosaphes* were made by the senior author from Riverside to other countries or states, as follows: Chile, 1952, 1954; Texas, 1952; Mexico, 1954, 1956; Peru, 1958; and Italy, 1960. No progress reports have been received from Peru or Italy; however, H. D. Smith, U. S. Department of Agriculture entomologist in Mexico, informed DeBach by letter in January 1956 that *A. lepidosaphes* (then known as *Aphytis* "X") was well established in Texas and had cleaned up the scale at the original release points in the Rio Grande Valley, had spread about seventy miles, and had even controlled the purple scale in groves to which it had spread naturally; in Mexico, good control had been obtained around the release points near Córdoba, Veracruz, and Colima. In February 1959, H. A. Dean, of the Texas Agricultural Experiment Station at Weslaco, wrote DeBach that ". . . they [*A. lepidosaphes*] are doing a good job on purple scale," and again in February 1961, "Purple scale was ranked . . . as fourth most important pest of citrus in this area in 1950. Purple scale must now be placed down the list of minor insect pests, principally as a result of activity of this parasite." Rojas (1954) records the establishment of *A. lepidosaphes* in Chile.

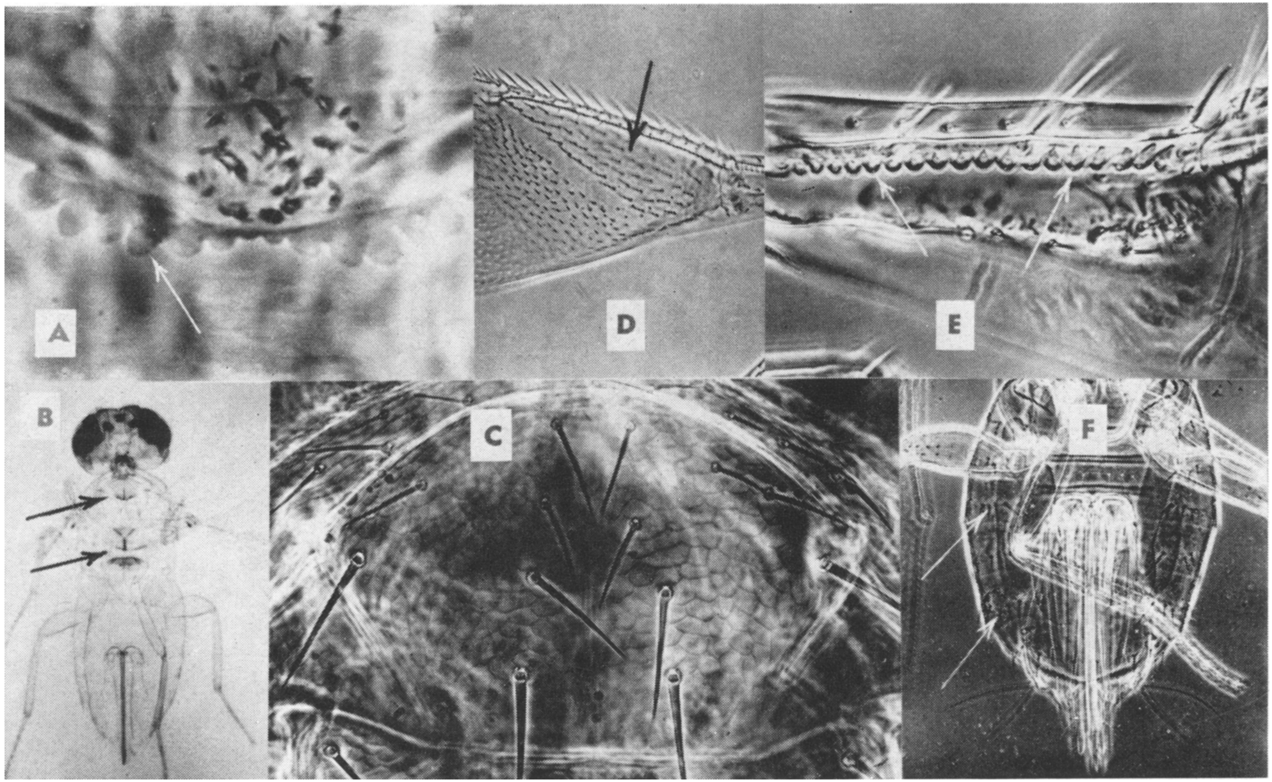

Fig. 2. Some key morphological characteristics of the female *Aphytis lepidosaphes* (highly magnified). *A*, crenulae on the posterior margin of the propodeum; *B*, thoracic sterna with dusky areas; *C*, setae on mesoscutum; *D*, wing setae basad of the speculum; *E*, nodules on submarginal vein; and *F*, lateral setae on abdomen.

Biology

Aphytis lepidosaphes females, in life and under low magnification, resemble other golden-yellow species of the genus, including *A. chrysomphali* (Mercet), *A. lingnanensis* Compere, *A. citrinus* Compere, *A. melinus* DeBach, *A. fisheri* DeBach, *A. holoxanthus* DeBach, *A. coheni* DeBach, and others. General characteristics of the adult female are shown in figure 1. Prepared and cleared microscope mounts are necessary for accurate determination of species. Even so, it may be difficult to distinguish *A. lepidosaphes* females from those of *A. lingnanensis, A. coheni,* or *A. chrysomphali.* Keys for separation of these species are given by Compere (1955) and DeBach (1960). The best rule-of-thumb characters for recognition of cleared, slide-mounted specimens of *A. lepidosaphes* are shown in figure 2, and include

TABLE 2

BIOLOGICAL DATA INCLUDING THE LIFE CYCLE, LONGEVITY, TOTAL OVIPOSITION, AND PER CENT OF FEMALE PROGENY OF *APHYTIS LEPIDOSAPHES*

Trial No.	Life cycle, egg to adult, days*		Longevity, days*		Oviposition during lifetime*		Per cent of female progeny	
	Range	Average	Range	Average	Range	Average	Laboratory	Field
1	16–19	17.5	7–29	12.0	16–33	29.7	34.0	....
2	16–17	16.5	1–22	9.4	28–37	33.9	65.0	82.9 (9/16/59)
3	16–18	17.0	4–31	11.7	25–34	32.7	59.8	78.6 (3/18/60)
Over-all averages:		17.0		11.0		32.1	52.9	80.8

* At 80° ± 2° F. and 50 per cent relative humidity with honey as food.

(1) nonoverlapping, small crenulae on the posterior margin of the propodeum (*A*); (2) thoracic sterna with plainly dusky areas (*B*); (3) mesoscutum with twelve or more setae (*C*); (4) front wings basad of the speculum usually with forty to forty-five setae (*D*); (5) about eighteen nodules along submarginal vein (*E*); and (6) lateral setae on abdomen clearly evident at × 120 magnification (*F*). In addition, the pupa (see fig. 6, *D*) is generally yellowish, except that it has dusky thoracic sternal markings like those of the adult shown in figure 2, *B*.

The aphelinid parasite *Aphytis lepidosaphes* is a small (1 mm. average length), biparental ectoparasite of the purple scale, *Lepidosaphes beckii.* Its life history is broadly similar to other species of the genus, and a brief account has been given by Rojas (1954) and by Clancy and Muma (1959). It attacks second- and third-stage female scales (including the egg-producing adults) and second-stage prepupal male scales. Third-stage female scales are distinctly preferred.

Reproduction is arrhenotokous in this species. Unfertilized eggs, either from virgin or mated females, give rise to males only; fertilized eggs give females. Mated females may lay either fertilized or unfertilized eggs, thus

Fig. 3. A purple scale with five pupae and meconia of *Aphytis lepidosaphes.*

producing both females and males. Unmated females produce male progeny. Normally, mating occurs within a few minutes after emergence of the virgin female. One mating appears to be sufficient for the lifetime of the female; in fact, preliminary evidence indicates that subsequent attempts at copulation by males may be refused by the female.

Apparently, *Aphytis lepidosaphes* is highly host-specific. It is not known to occur on scales other than the purple scale in the field. We have not been able to rear it on various other diaspine scales tested in the laboratory, including *Aonidiella aurantii* (Maskell) and *Aspidiotus hederae* (Vallot). Freshly laid eggs and early larval stages of *A. lepidosaphes* failed to complete development when transferred to *A. hederae* and *A. aurantii;* however, the egg transfers to *A. hederae* developed through the late larval stages, and it is conceivable that in further more extensive trials, transferred eggs might succeed in developing to adults.

From table 2 it can be seen that under insectary conditions of 80° ± 2° F. and 50 per cent relative humidity, the average life cycle of *Aphytis lepido-*

saphes is 17 days, and the average longevity of nonproducing adult females with access to fresh food (honey) and in the absence of hosts is 11 days. Without honey or other suitable carbohydrate food, adults die rapidly. The average total oviposition of *A. lepidosaphes* with food and under the above-noted physical conditions was 32.1 eggs per female. The progeny of *A. lepidosaphes* reared under laboratory conditions averaged 52.9 per cent females, whereas under field conditions the progeny averaged 80.8 per cent females. In Florida, it was found (Clancy and Muma, 1959) that in the field, about 59 per cent of the individuals reared were females.

Aphytis lepidosaphes larvae, under both laboratory and field conditions, are generally gregarious. The emergence of two adults per scale is usual under field conditions in California, although in Florida, Clancy and Muma (1959) found 52.2 per cent of the scales with only one parasite, 43.3 per cent

TABLE 3

NUMBER OF *APHYTIS LEPIDOSAPHES* PUPAE PER PURPLE SCALE

Number of scales	Number of pupae per scale	Pupae: per cent of total
53	1	16.5
199	2	61.8
30	3	9.3
33	4	10.2
7	5–6	2.2
322		100.0

with two parasites, and 4.5 per cent with three to five parasites. In the laboratory, we have observed as many as eight healthy pupae on one scale and have reared as many as six adults from an individual scale. The size of the emerged adults shows an inverse relationship to the number which develop on one scale. Figure 3 shows a purple scale with five pupae and meconia.

A check of 322 scales parasitized in the laboratory under normal culture conditions revealed the distribution of mature healthy parasite pupae shown in table 3.

It is evident from these figures that *Aphytis lepidosaphes* has a strong tendency toward gregariousness. Nearly 84 per cent of the scales had two or more pupae present. This is certainly more marked than is the case with various other *Aphytis* species studied in the laboratory.

Adult female parasites feed extensively on the hemolymph (body juices) of the host, causing considerable scale mortality. This is necessary for continued, sustained egg production during the life of the female. According to Rojas (1954), if gravid females do not find suitable hosts within seven days, there is temporary inability to oviposit. However, it is not necessary for the newly emerged females to host-feed prior to oviposition. Host-feeding is accomplished by drilling through the scale cover and into the scale body with the ovipositor. A waxy material which hardens into a tube is secreted along the ovipositor, and the ovipositor is withdrawn. The mouthparts are then applied to the tube orifice and the body juices of the scale are sucked up. Within a period of two or three days after host-feeding has occurred, the scale body is shriveled and dead. Such parasite-caused mortality is an appreciable factor in the field, but it may be overlooked unless this habit of the parasite is recognized.

Inasmuch as the eggs of *Aphytis lepidosaphes* are generally deposited on the midventral portion of the purple scale body, which is normally nearly completely encased within the scale shell, it was necessary to devise a means whereby this area of the scale body could be exposed *in vivo* to examination

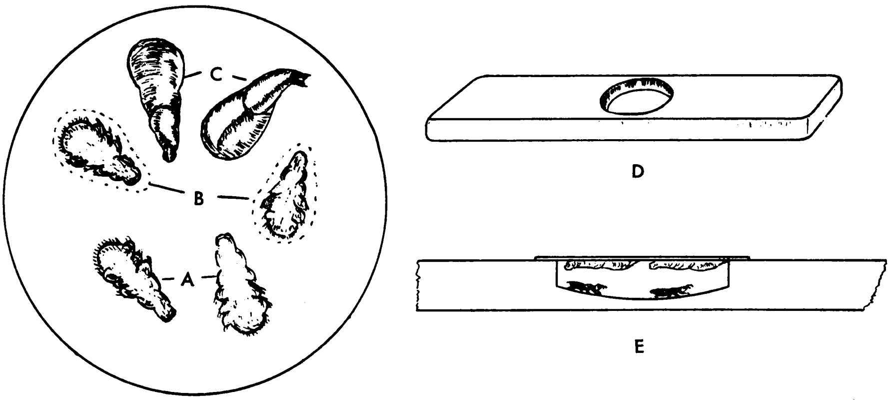

Fig. 4. Technique for study of oviposition and host-feeding habits of *Aphytis lepidosaphes*. Progressive steps in mounting purple scale on microcover glass. *A*, Scale bodies removed from protective covering and placed ventral side down on cover glass. *B*, Fine adhesive band of honey encompassing scale body to conform with general contour of scale covering. *C*, Scale covering positioned and firmly anchored in adhesive. *D*, Standard microculture slide with straight-wall depression. *E*, Cover glass with previously mounted scale specimens inverted and held in position over culture slide depression with adhesive (honey) applied to rim of cover glass. Two parasites are shown inside.

under a binocular microscope for extended periods of time in such a manner that ovipositional as well as host-feeding phenomena could be observed.

To accomplish this, several (usually five to seven) mature scales were carefully removed from the host plant. Employing two extremely fine needle probes and taking care not to puncture the scale bodies, the ventral portions of the scale coverings (armor) were removed by incising the waxy tissue along the perimeter of the exposed surfaces. The scale bodies were then carefully "teased" out of their respective covers and placed at intervals, ventral side down, on a number 1, seven-eighths-inch microcover glass, allowing approximately a one-eighth-inch margin on the perimeter of the cover glass (fig. 4, *A*). Using a single horsehair or fine needle, a narrow band of adhesive (honey) was applied to the cover glass, closely encircling each scale body and conforming as nearly as possible with the contour of the scale covering (*B*), which was then replaced in "normal" position and firmly anchored in the sticky honey (*C*). Extreme care must be taken in the latter operation, not only to avoid the use of excessive honey but to place it so that little or none will extrude beyond the edge of the scale covering.

For these studies, three to four newly emerged and mated female parasites were anesthetized with ether and placed in a microculture slide measuring 75 by 25 mm. with a straight-wall depression 3 mm. deep by 14 mm. in diameter (fig. 4, *D* and *E*). The cover glass containing the previously mounted scale specimens was then inverted and placed over the depression in the microculture slide, being held securely in place by honey applied to the rim around the depression on the culture slide (*E*).

Cells so prepared enable the worker to observe clearly under a binocular microscope the entire sequence of ovipositional and host-feeding events from an attitude comparable to being directly beneath the parasite.

A typical sequence of the parasite's action prior to and including oviposition on purple scale on lemons in the laboratory is as follows: The adult female parasite moves rapidly over the surface of the fruit, palpating scales with its antennae, perhaps hesitating momentarily over several different scales or stopping abruptly between scales, to remain motionless for several seconds or even minutes before continuing its search. Upon selecting a particular scale for more thorough investigation, the parasite makes several exploratory antennal examinations over and around the perimeter of the scale, consuming from one to four minutes. Satisfied that the scale is suitable for oviposition, a site is chosen for the penetration or "drilling" of the hard dorsal surface of the scale covering, generally about midway longitudinally near the lateral edge of the scale covering. On occasion, the ovipositor may be thrust under the edge of the scale covering between it and the surface of the fruit.

The tenacity with which the parasite seems to grip the scale surface with its tarsi and pull downward gives one the impression that the operation requires a very strenuous effort. The drilling procedure consists of rapid thrusts of the twisting, turning ovipositor at an angle of contact with the scale surface of approximately 45 degrees. The rapid "up-and-down" movements of the stylets are accompanied by a slower rotary movement in both a clockwise and counter-clockwise direction, approaching 180 degrees in each direction. The actual time required for penetrating the scale covering varies from slightly over thirty seconds to nearly four minutes, and it is not uncommon for a parasite to cease drilling altogether for perhaps a minute or two, and on occasion leave the scale momentarily, then return and resume drilling.

Just prior to complete penetration of the scale covering, the drilling tempo slows considerably. The actual penetration of the shell is followed by rather slow, deliberate thrusts of the stylets into the scale body and the probing interiorly of the greater part of the posterior ventral portion of the soft scale body. It seems logical that this probing action may be concerned with the dispersion of a paralytic agent rather than a mutilation of the scale body, as some have hypothesized, inasmuch as this process results in the paralysis and preservation of the host instead of its rapid death, as occurs following host-feeding activities. As many as fifteen probing motions within a single scale body have been observed prior to deposition of the egg.

Shortly before actual oviposition occurs, the ovipositor makes several thrusts, penetrating the ventral surface of the scale body, usually anterior to

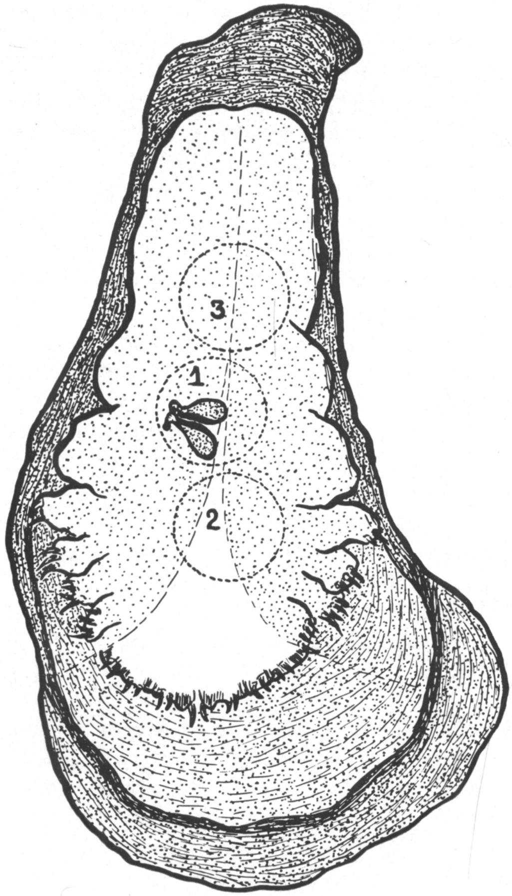

Fig. 5. Ventral surface of an adult female purple scale exposed, indicating area *1* where majority of eggs of *Aphytis lepidosaphes* are attached, although areas *2* and *3* are not uncommon.

the apex (fig. 5) formed by the ventral portions of the waxy, white, protective scale covering which lies next to the plant surface. Just seconds before the egg is laid, rapid pulsation of the stylets ceases, the ovipositor is withdrawn from the body, the tip contacts the body wall, and an ovoid, somewhat tear-shaped, nearly translucent egg is deposited on the ventral surface of the scale body from a lateral orifice anterior to the tips of the stylets. Apparently, the egg adheres instantly at the point of deposition, for no further manipulation of the egg has been observed. Figure 5 shows the ventral surface of an adult female purple scale exposed to indicate the areas where the majority of *Aphytis lepidosaphes* eggs are attached.

The deposition of the first egg may be followed by a brief respite, during which time the ovipositor may be partially or completely withdrawn from the scale covering. A second probing action is soon started, however, utilizing the same puncture in the scale covering that was used to lay the first egg.

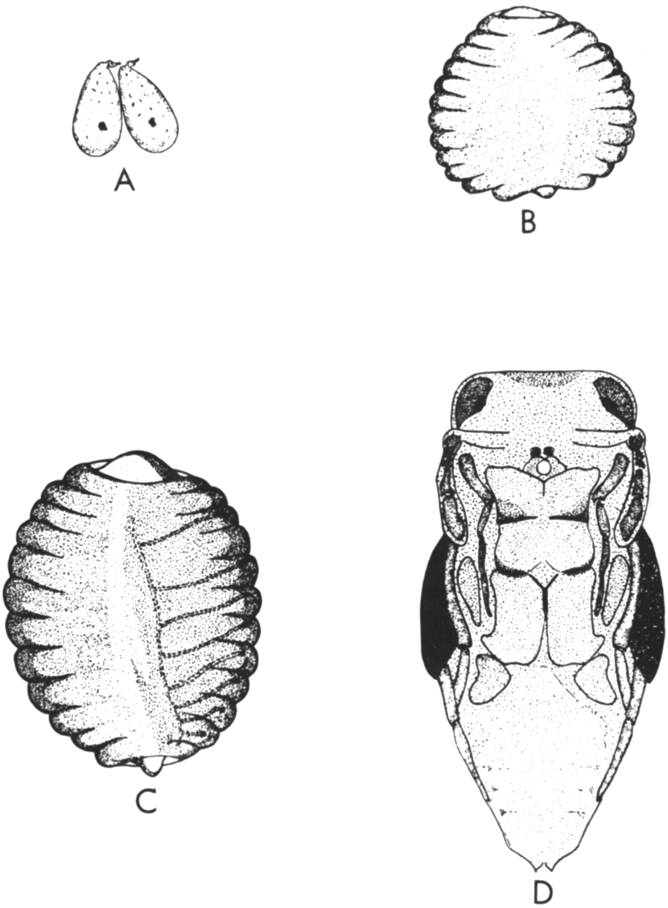

Fig. 6. Eggs, larvae, and pupa of *Aphytis lepidosaphes*. *A*, typical appearance and arrangement of newly deposited eggs; *B*, characteristic shape of seven-day-old larva; *C*, ten-day-old mature larva, showing spiracles; and *D*, late pupal stage, showing distinctive Y-shaped mark on mesosternum.

Again the ovipositor explores the scale body rather slowly with the tips of the stylets, sometimes actually touching the surface of the first egg but never puncturing it. The remarkable phenomenon of the sharply pointed stylets "knifing" extremely close to, and even touching, the newly laid egg without damaging it clearly indicates the extreme sensitivity of this organ. The second egg is deposited adjacent to and usually touching the first one, with the tapered end attached closely to the corresponding portion of the first egg (fig. 5).

The newly laid egg is slightly less than 0.1 mm. in length and 0.05 mm. in width at the widest point, with the crook-shaped neck or pedicel extending another 0.02 mm. (fig. 6, *A*). A fine, hairlike appendage has been observed protruding from the micropyle or tip of the pedicel on a few of the many eggs observed.

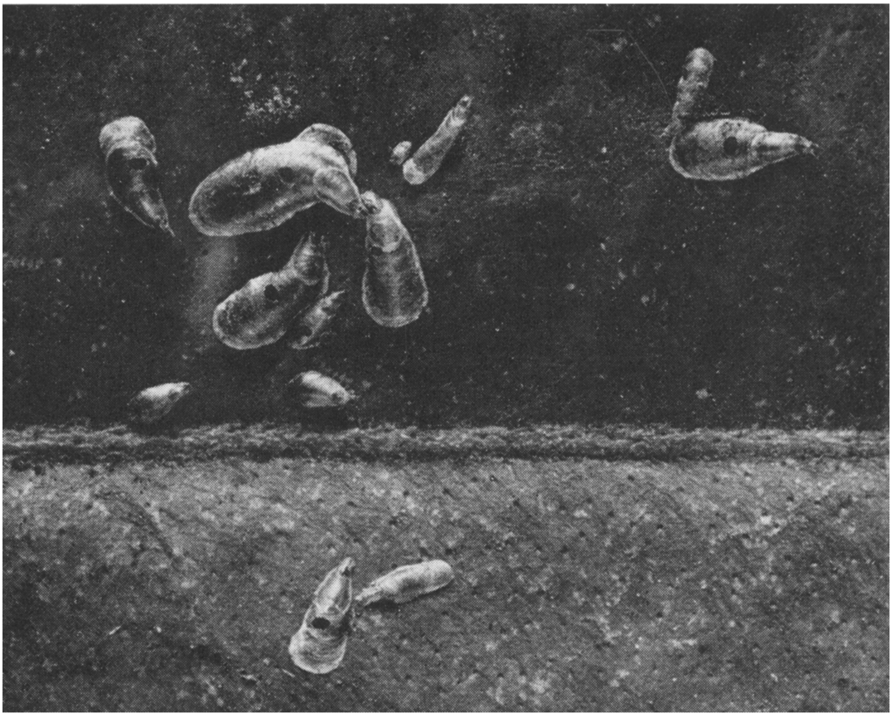

Fig. 7. Emergence holes of *Aphytis lepidosaphes* in purple scale on a citrus leaf.

After three days at 80° F. and 50 per cent relative humidity, the egg hatches and enters the larval stage. On the fourth day, the larva measures approximately 0.2 mm. in length and 0.08 mm. in width at its widest point. By the seventh day, the larva has reached slightly over 0.3 mm. in length, with a width of 0.25 mm., and has changed from an elongate to a prolate spheroid form comprising thirteen segments, with slight, cone-shaped protrusions on either end (fig. 6, *B*). The larva develops very rapidly now, and by the tenth day measures approximately 0.6 mm. in length by 0.4 mm. in width (*C*). At this time, the larva enters the prepupal stage, with this and the pupal stage (*D*) consuming approximately five to seven days.

The newly developed pupa is nearly translucent, appearing milky white with a slight yellowish tinge. As development progresses, the body assumes a definite yellow cast, and the eyes become brilliant red. The late pupal stage is characterized by a general body color of light golden yellow, with pale-green eyes and blood-red ocelli, indicative of the body and eye colors of the adult parasite.

Emergence of the adult parasite is generally accomplished by the chewing of an exit hole in the scale covering approximately midway longitudinally and very near the median line of the dorsal surface transversely (fig. 7). When more than one parasite completes development on a single scale, all adults usually emerge through the exit hole chewed by the first individual, although two exit holes are seen occasionally.

Field Ecology

Untreated Test Plot Studies. The progress of *Aphytis lepidosaphes* against purple scale has been followed in detail for nearly ten years (1949–59) in two large, untreated plots and in several chemical-biological control strip-treatment plots in Orange County.

One of the oldest case histories is that of the Hugh Walker grove, located on Trabuco Canyon Road, a short distance from the town of El Toro. Here, in 1949, in an isolated, ten-acre, completely untreated block of Valencia orange trees previously free of purple scale, a limited number of parasites was colonized on two trees heavily but newly infested with purple scale. At this time, other scattered trees were found to be infested. The extremely cold winter of 1949–50 apparently eliminated the progeny of these initial parasite releases, for as late as August 1950, no evidence of *Aphytis lepidosaphes* was to be found on the original colonization trees.

In the spring of 1950, approximately 4,000 insectary-reared *Aphytis lepidosaphes* were colonized on a new tree in the Walker grove. Evidence of their establishment was not apparent until July. However, by September 1950, the parasites were abundant on this tree, and by December they had dispersed six tree rows from the spring colonization tree. During February and March 1951, all stages of *A. lepidosaphes* were observed on the 1950 colonization tree and on adjacent trees, showing that they had passed through the winter months successfully.

In August 1950, shortly after the parasites became initially established, purple scale populations on the 1950 colonization tree contained 84 per cent live scale individuals, excluding the first stages. This represents a good general average of the rather high proportion of purple scales alive at any given time prior to this date (i.e., prior to the establishment of *Aphytis lepidosaphes*). By midwinter of 1950, only 10 per cent of the scales remained alive. After that time, through 1959, the average per cent of the purple scale population alive at any given time ranged from 9 to 60, with a mean of 20.2 per cent alive, based on monthly laboratory counts of the most heavily infested leaves available (fig. 8).

The observed trends in purple scale population densities on the 1950 colonization tree (which has been an accurate index to grove trends) for the period August 1950 through July 1959 were briefly as follows: An initial heavy scale infestation in and prior to August 1950 had caused extensive damage resulting in the defoliation or "burning out" of large areas of the tree. Scale-encrusted areas on the fruit, leaves, and wood were general, and several portions of the tree exhibited dieback of the terminal growth and medium-sized inner branches.

Considerable parasite-caused mortality occurred late in 1950, and by January 1951, the purple scale population was visibly reduced. In the spring of 1951, new flush growth appeared for the first time since 1949, and by August 1951, this tree had outgrown most of the previous damage. By December 1951, it was estimated that the purple scale population was only 1 per cent of the original infestation. From 1952 through July 1959, this tree, as well as others in the plot, was never so heavily infested as formerly,

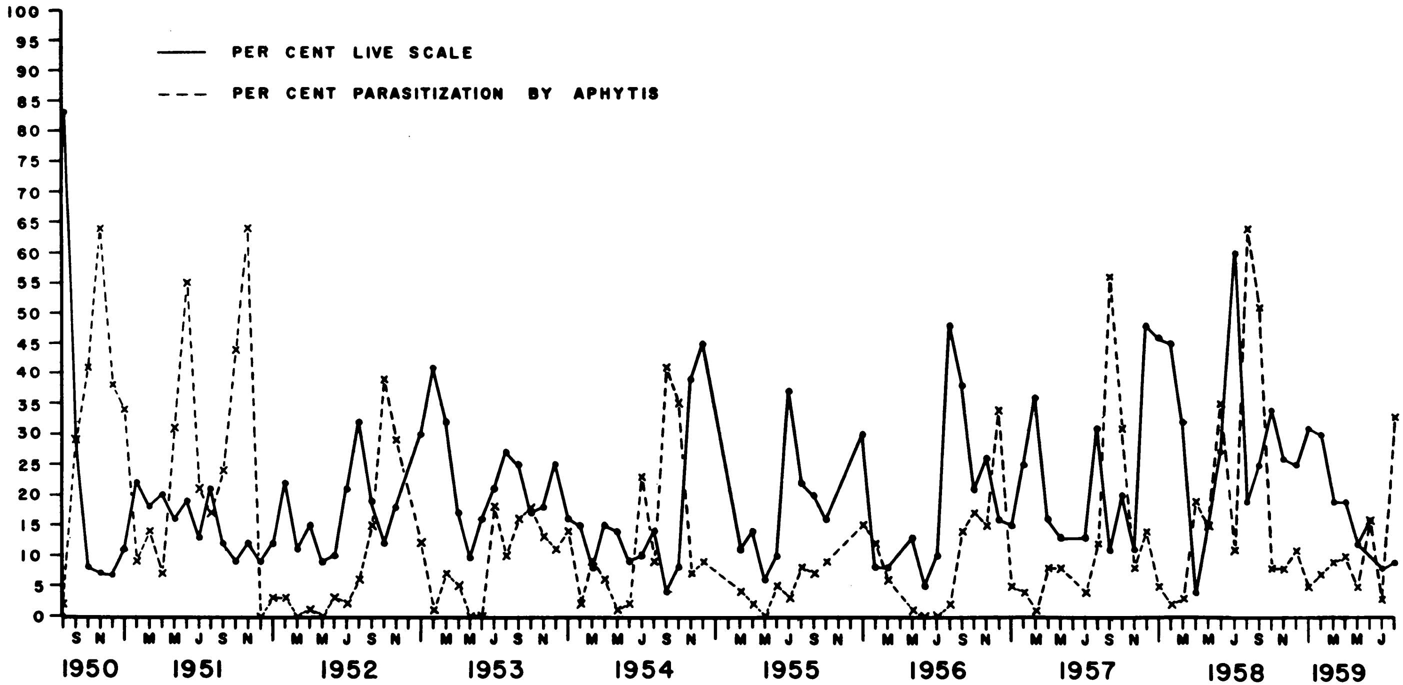

Fig. 8. Trends in the per cent of live purple scale and the per cent of parasitization by *Aphytis lepidosaphes* on the untreated colonization tree for the period August 1950 through July 1959. (Walker Grove, El Toro, California.)

but nevertheless developed light to medium infestations of purple scale annually, and fluctuations in the scale population periodically approached or reached the level of economic damage following climatic and/or biological conditions adverse to the parasites' ecological requirements.

In addition to the Walker grove study just discussed, a second untreated test plot was established in 1950 at the Irvine Ranch near Tustin in Orange County and continued until 1959. This orange grove is in open, flat country and is about ten miles from the Walker grove, which is located in a foothill canyon. Whereas the Walker plot involved a grove with no previous spray treatments and an incipient infestation of purple scale at first, the Irvine plot had a previous history of regular, major insecticidal treatments for purple scale, the equivalent of one and one-half applications per year, typical of citrus groves in this area. No treatment was applied during the period of our studies (1950–59).

Aphytis lepidosaphes was first colonized on one tree in this plot in September 1950 and on several more trees early in 1951. Many trees heavily infested with purple scale were present in this grove when the initial colonizations were made, even though they were sprayed the year before (1949). By late 1951, parasites were common on the colonization and adjacent trees and had dispersed throughout much of the plot. By the end of 1952, *A. lepidosaphes* had become abundant throughout the entire plot, causing considerable scale mortality. However, despite increased parasite activity, the scale population remained of sufficient density to cause a continued build-up during 1952, resulting in 97 per cent of the trees suffering economic damage.

From 1952 through 1955, parasite-induced mortality accounted for a slow but gradual reduction in scale density, and by May 1956, this grove was judged commercially clean of purple scale. At this time, for instance, virtually no fruit was infested, as compared with nearly 100 per cent in 1952. In October 1956, estimates based on field and laboratory counts indicated that approximately 95 per cent of the existing purple scale was dead.

The plot remained commercially clean of scale from May 1956 through early 1958; however, there were indications in the latter part of 1957 that the purple scale population was increasing, and by mid-1958, many of the trees were again suffering some economic damage, although to a lesser extent than originally.

Figure 9 shows the per cent of parasitization of purple scale by *Aphytis lepidosaphes* in relation to the per cent of live scale for the period September 1952 through August 1959. It should be noted that on only four monthly counts during this period was there more than 50 per cent of the scale alive. Before the advent of *A. lepidosaphes,* an average of at least 80 per cent live scale would be expected.

There are both similarities to and differences from the Walker plot. The different parasite-host fluctuation patterns exhibited in these two plots (figs. 8 and 9) may be accounted for in part by (1) the history of treatment prior to the establishment of plots, (2) the microclimatic variations between the plot locations, (3) the differences in the immediate environments of the groves, and (4) the differences in tree spacing and cultural practices within the groves.

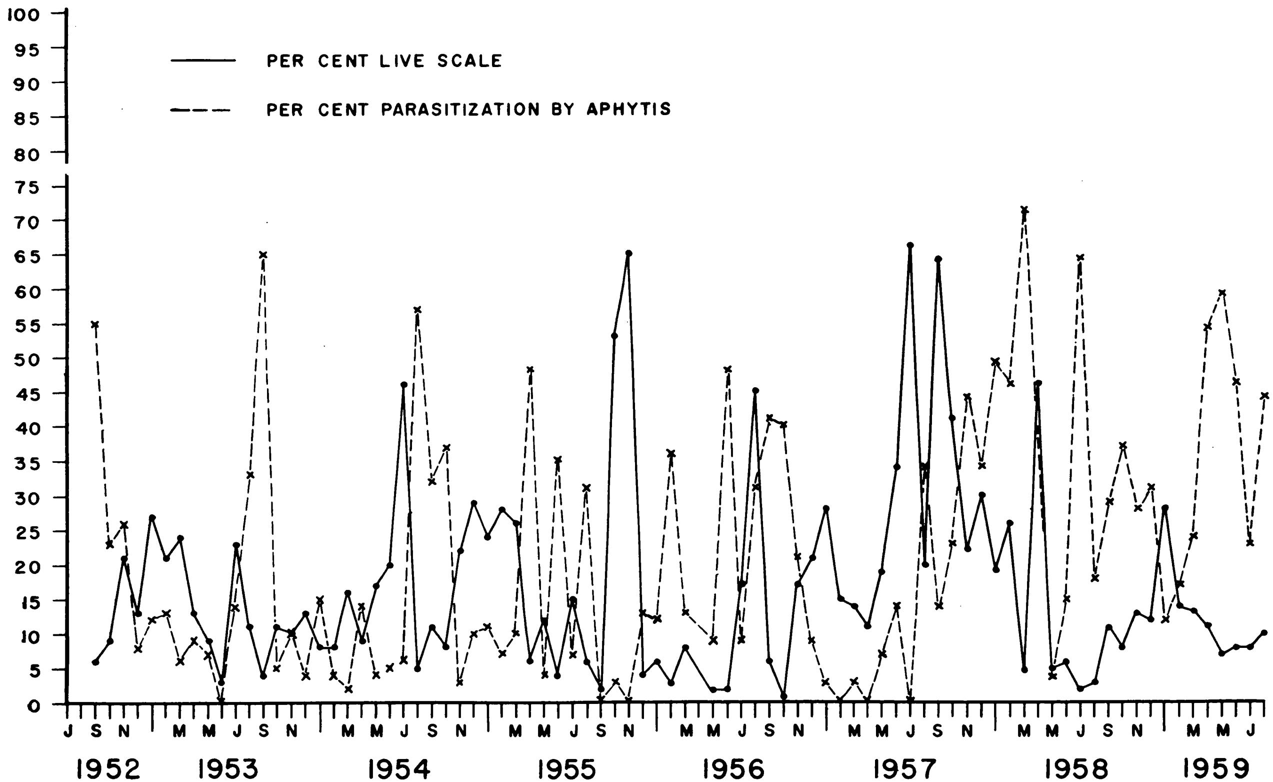

Fig. 9. Trends in the per cent of live purple scale and the per cent of parasitization by *Aphytis lepidosaphes* on the untreated trees for the period September 1952 through August 1959. (Irvine Ranch, Tustin, California.)

In general, the per cent of parasitization in the two plots showed fairly similar trends in tending to be low during the winter and spring and high during the late summer and fall. Also, the per cent of live scale tended to be low during spring and fall and to peak in midwinter and midsummer. However, distinct differences between the two groves showed that the immediate environmental conditions of the grove sometimes were more important than the general weather conditions. For instance, in the Irvine plot during October and November 1955, the per cent of live scale was high (above 50 per cent), and parasitization was very low, whereas in the Walker plot, the per cent of live scale was low (about 20 per cent), and parasitization was about average. Also, in the Irvine plot, the per cent of parasitization remained very high over the 1957–58 winter (November–March) whereas in the Walker plot, it declined sharply during this period. This was probably a response to the marked increase in scale population density which was observed during this period in the Irvine plot, while the population density in the Walker plot remained more or less static. Many other differences in detail can be seen by comparing the trends in figures 8 and 9. In general, increases in parasitization can be seen to follow, by a month or two, increases in the per cent of live scale, the tendency for parasitization being highest during the warmer months of the year.

Several factors may help to account for the differences between plots:

The Irvine plot consists of large, old trees, widely spaced and subject to frequent cultivation. It lies adjacent and open to extensive bean fields on the southwest border, which are cultivated frequently. Dust from within the grove or carried from the adjoining fields by the prevailing winds deposits heavy residues on the foliage throughout the plot, which can seriously inhibit parasite activity. During periods of high summer temperatures, coupled with relatively low humidities, parasite dispersal between trees may also be impaired because of the wide tree spacing with large areas of bare ground subject to greater heat radiation.

By contrast, the Walker grove consists of somewhat younger and smaller trees, closely planted and surrounded on three sides by extensive citrus and avocado acreage, with a eucalyptus windbreak on the remaining border. These factors tend to insure higher humidity and lower temperature readings during the hot summer months. With less exposed ground, heat radiation is reduced, and with less frequent cultivation, dust deposits on the tree foliage are less.

It would appear that the combined factors of locale (immediate environment), climate, and cultural practices more nearly approach the optimum for *Aphytis lepidosaphes* in the Walker grove, as indicated by the initial slow, gradual increase in purple scale followed by the maintenance of a medium infestation over an extended period of time without appreciable fluctuation, as compared with the more noticeable fluctuations in the Irvine plot. However, the evidence from both these untreated plots, as well as many other observations in Orange County, indicates that although the parasite causes considerable mortality and greatly retards the rate of increase of purple scale populations, it does not effect completely satisfactory biological control.

Some reasons why *Aphytis lepidosaphes* has not been completely successful in controlling purple scale in California are suggested by an analysis of combined count data collected monthly in the two test plots from 1950–51 through 1959 regarding the per cent of parasitization, per cent of live and dead scale according to stages of development, per cent of live scale suitable for oviposition, and ratio of dead to live immature parasites, (eggs, larvae, and pupae). Cases of hyperparasitism or predation of immature parasite stages were so rare as to be inconsequential.

Each monthly count was made by picking ten average-sized, mature citrus leaves, containing the heaviest purple scale infestations that could be found in the plot in not more than one-half hour's search. These were brought into the laboratory for examination under a binocular microscope. Individual scales were dissected, and the following information was noted and tabulated on three banks of laboratory counters: (1) the stage of development and condition (live, dead, or parasitized) of the scale body; and (2) the stage of development and condition (live or dead) of the immature parasites, if present. The laboratory count of each leaf (or unit) was terminated when either fifty live scales (excluding the first-instar and first-molt stages) or one hundred dead scales (due to all causes, including parasitization) was reached. Upon completing ten leaf counts in a similar manner, the count was terminated, the data were tabulated, and the results were recorded on a monthly count sheet.

To a great extent, the degree of effectiveness of *Aphytis lepidosaphes* in controlling purple scale is dependent directly or indirectly upon favorable weather, as will be shown later in detail. In order to permit analysis of seasonal differences in the per cent of live scale, parasitization, and so forth, data for both plots for each of the twelve months were combined and averaged for the entire period 1950–51 through 1959. Thus, the monthly count data denoting the per cent of live purple scale, the proportion of scales suitable for oviposition by *A. lepidosaphes,* parasitization by *A. lepidosaphes,* and ratio of dead to live immature parasites, are shown as an average per cent for each identical month for the period 1950–51 through 1959 in tables 4, 5, 6, and 7, respectively. In order to condense and simplify the presentation, the data shown in these tables are depicted as four graphs in figure 10.

Scales suitable for oviposition (i.e., "susceptible scale") are here considered to include only third-instar and early adult female scales, inasmuch as these stages are greatly preferred by the parasite, even though second-stage females and male scales are sometimes attacked (about 5 per cent of total).

First-off, we shall try to explain some reasons for the observed fluctuations in the average monthly per cent of live purple scale shown in figure 10, *A.* It is evident from this figure that although there is considerable fluctuation in the per cent of live purple scale during the year, rarely does it exceed 25 per cent. The highest per cent of live scale occurs during two periods—midwinter and midsummer—and the lowest per cent of live scale occurs during the late spring and early summer months and again in the fall.

The winter increase in the average per cent of live purple scale from November through February correlates well with the winter decline in per cent of scale parasitized by *Aphytis lepidosaphes,* as shown in figure 10, *C;*

(Text continues on page 484.)

TABLE 4*

AVERAGE PER CENT OF LIVE PURPLE SCALE PER MONTH FOR THE YEARS 1950–59 IN TWO UNTREATED ORANGE COUNTY CITRUS GROVES

Month	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	Average 1950–59
Jan.	..	11	12	30	16	33	30	15	46	31	24.9
Feb.	..	22	22	41	15	23	8	25	45	30	25.7
Mar.	..	18	11	32	8	11	8	36	32	19	19.4
Apr.	..	20	15	17	15	14	..	16	4	19	15.0
May	..	16	9	10	14	6	13	13	15	12	12.0
June	..	19	10	16	9	10	5	..	27	16	14.0
July	..	13	21	21	10	37	10	13	60	8	21.5
Aug.	..	21	32	27	14	22	48	31	19	9	24.8
Sept.	29	12	19	25	4	20	38	11	25	8	19.1
Oct.	8	9	12	17	8	16	21	20	34	24	16.9
Nov.	7	12	18	18	39	..	26	11	26	17	19.3
Dec.	7	9	..†	25	44	18	16	47	25	20	23.5

* See figure 10, *A*, for a graph that depicts these data.
† No data.

TABLE 5*

AVERAGE PER CENT OF LIVE PURPLE SCALE PER MONTH SUITABLE FOR OVIPOSITION† BY *APHYTIS LEPIDOSAPHES* FOR THE YEARS 1951–59 IN TWO UNTREATED ORANGE COUNTY CITRUS GROVES

Month	1951	1952	1953	1954	1955	1956	1957	1958	1959	Average 1951–59
Jan.	..	15	9	22	17	29	50	3	77	27.8
Feb.	..	3	48	52	25	76	39	10	88	42.6
Mar.	..	32	14	65	30	16	39	26	97	39.9
Apr.	37	29	37	85	54	..	63	55	94	56.9
May	86	88	91	99	94	24	93	64	20	73.2
June	76	66	100	88	79	96	..	35	10	68.9
July	33	41	23	3	7	63	11	3	74	28.7
Aug.	56	14	22	27	13	3	31	64	48	30.9
Sept.	74	58	55	82	45	44	97	9	25	54.4
Oct.	22	47	71	10	92	72	15	9	25	40.3
Nov.	29	18	35	7	..	53	3	42	67	31.8
Dec.	35	..‡	8	12	46	78	6	63	80	41.0

* See figure 10, *B*, for a graph that depicts these data.
† Determined as third-instar and early adult female scales.
‡ No data.

TABLE 6*

AVERAGE PER CENT OF PARASITIZATION PER MONTH OF PURPLE SCALE BY *APHYTIS LEPIDOSAPHES* FOR THE YEARS 1950–59 IN TWO UNTREATED ORANGE COUNTY CITRUS GROVES

Month	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	Average 1950–59
Jan.	..	37	3	12	14	6	15	5	7	5	11.6
Feb.	..	9	3	2	2	4	12	4	2	7	5.0
Mar.	..	14	0	7	9	4	6	1	3	9	5.9
Apr.	..	7	1	5	6	2	..	8	19	10	7.3
May	..	31	0	0	1	0	1	8	15	5	6.8
June	..	55	3	0	2	5	0	..	35	16	14.5
July	..	21	2	18	23	3	0	4	11	6	9.8
Aug.	..	17	6	10	9	8	2	12	64	33	17.9
Sept.	29	24	15	16	41	7	14	56	51	11	26.4
Oct.	41	44	39	18	35	9	17	31	8	7	24.9
Nov.	64	63	29	13	7	..	15	8	8	37	27.1
Dec.	38	5	..†	11	9	13	34	14	11	16	16.8

* See figure 10, *C*, for a graph that depicts these data.
† No data.

TABLE 7*

MONTHLY COUNTS SHOWING RATIO OF DEAD TO LIVE IMMATURE *APHYTIS LEPIDOSAPHES* FOR THE YEARS 1950–59 IN TWO UNTREATED ORANGE COUNTY CITRUS GROVES

Month	Ratio of dead to live immature parasites										Average per cent of dead immature parasites (1950–59)
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	
Jan.	....	4:29	1:3	0:46	0:23	2:26	6:23	9:19	0:12	12:47	14.9
Feb.	....	1:9	1:5	5:29	2:9	7:31	8:21	6:13	4:148	20:58	16.7
Mar.	....	0:9	3:3	6:34	1:7	5:25	11:20	11:15	14:87	10:48	24.6
Apr.	....	6:16	4:5	2:16	3:17	4:32	....†	12:20	14:55	16:109	22.6
May	....	7:50	2:2	1:5	0:5	3:6	26:28	10:26	2:15	37:95	37.9
June	....	9:114	2:3	1:1	1:7	1:11	9:19	9:46	11:60	25:81	19.9
July	....	0:21	0:2	2:46	1:21	10:20	4:14	6:9	6:61	21:37	21.6
Aug.	1:75	2:30	1:14	0:57	1:45	1:27	1:5	4:87	31:254	25:89	9.8
Sept.	22:261	1:22	5:80	0:57	0:44	8:18	2:55	6:126	14:132	10:15	8.4
Oct.	2:340	1:15	0:40	1:22	3:37	14:39	2:29	10:106	20:67	4:16	8.0
Nov.	1:58	1:5	0:81	4:25	0:20	0:0	2:50	14:138	25:59	1:64	9.4
Dec.	0:18	4:4	0:7	1:23	4:49	10:21	10:58	3:153	16:63	5:29	12.5

* See figure 10, *D*, for a graph that depicts these data.
† No data.

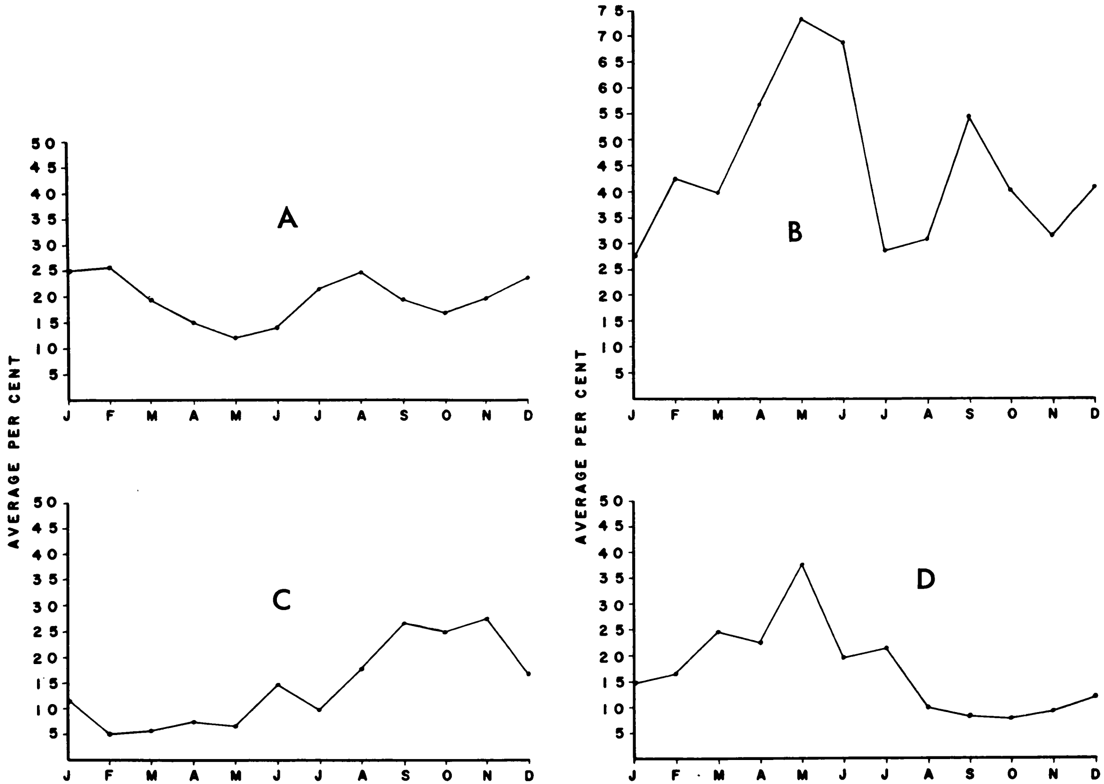

Fig. 10. Average per cent of: *A*, live purple scale; *B*, purple scale suitable for oviposition by *Aphytis lepidosaphes; C*, parasitization of purple scale by *A. lepidosaphes;* and *D*, dead immature parasites. The periods cover each month in the year during 1950 or 1951 through 1959 in two untreated Orange County citrus groves.

this is in turn a result of an initial decline of suitable host material (fig. 10, *B*) in September, October, and November, followed by adverse winter conditions.

The decline in the average per cent of live scale from the end of February through May (fig. 10, *A*) is believed to be due, directly or indirectly, to overwintering scale mortality brought about by unfavorable weather conditions. Certainly, the influence of the parasite is at a minimum during this period.

The decline in the average per cent of live scale from the end of August through October was due to the fact that a good proportion of the scales was parasitized (fig. 10, *C*), owing in part to seasonal favorableness of weather to the parasites and in part to a fair proportion of scales being in a stage of development susceptible to parasitization.

The scarcity or abundance of susceptible stages of scale (i.e., preferred stages), coincident with a satisfactory parasite population and favorable weather conditions, obviously constitutes a group of critical factors influencing future parasite and host densities, particularly in an area where the scale is predominantly even-brooded. Monthly variation in the proportion of live susceptible scales is shown in figure 10, *B*.

It may be seen from this figure that the average per cent of live purple scale suitable for oviposition by *Aphytis lepidosaphes* is subject to considerable fluctuation throughout the year, with a range of from 28 to 73 per cent of susceptible scale out of the total live scale population. However, it must be kept in mind that this graph cannot be interpreted correctly without reference to figures 10, *A* (average per cent of live scale) and 10, *C* (per cent of parasitization). For example, the average per cent of susceptible scale reached a high of 73 per cent in May, brought about by the maturation of the spring brood of scale; however, the average per cent of live scale (fig. 10, *A*) was comparatively low at this time (12 per cent), and the per cent of parasitization (fig. 10, *C*) was low.

The increase in the average per cent of susceptible scale from January through May is thus correlated with the development of the spring brood of scale in combination with poor parasitization. The latter is correlated with the increased immature parasite mortality for this period (fig. 10, *D*), which results in a decreasing parasite population. The abrupt decrease in susceptible scale from June to July and August is due to the fact that most scales are in the nonpreferred first and second stages following the late spring hatch. The peaks of susceptible scale in September, and to a lesser extent again in December, represent the maturation of a second and partial third scale generation.

The decline in the per cent of susceptible scale beginning in September and continuing through November probably was due to the higher parasitization by *Aphytis* (fig. 10, *C*) coincident with the more favorable months of the year. With the advent of winter temperatures and subsequent reduced parasite activity, combined with some hatch, the average per cent of susceptible scale increases through December.

Figure 10, *C*, shows the average monthly per cent of parasitization of purple scale by *Aphytis lepidosaphes* for the entire test period. It may be seen in this graph that the per cent of parasitization reaches a high in September through November and then drops consistently to a February–March low. The low average per cent of parasitization by *A. lepidosaphes* from January through May may be attributed both to direct and cryptic effects of unfavorable winter and early spring weather conditions. Occasional extreme low temperatures, as well as prolonged periods of cool weather, operate against both adults and immature stages of the overwintering parasite population (DeBach, Fisher, and Landi, 1955). The adverse effects on immature stages which contribute to the greatly reduced spring and early summer parasite population and preclude a satisfactory per cent of parasitization may be seen in figure 10, *D*, which shows the mortality curve of immature *Aphytis* for this period.

The increase in the per cent of parasitization of purple scale by *Aphytis lepidosaphes* in June is correlated with an abundance of susceptible host material (fig. 10, *B*)—the spring brood of scale largely having reached the preferred third stage of development—accompanied by a sharp decline in immature parasite mortality because of favorable weather. The decline in the per cent of parasitization in July occurred in seven years of the ten-year study. It appears to be correlated with the perceptible drop in the per cent of susceptible host material which follows the late spring hatch (fig. 10, *B*, June–July).

The increase in the average per cent of parasitization in August through September and November coincided with the August–September increase of susceptible host material (fig. 10, *B*), coupled with a low parasite mortality factor (fig. 10, *D*) because of favorable weather.

Figure 10, *D*, depicts the average yearly trend in per cent of dead immature *Aphytis lepidosaphes,* as condensed from the ratios in table 7. This figure strongly helps to explain figure 10, *C* (per cent of parasitization). It is evident from figure 10, *D*, that the average per cent of mortality of immature *Aphytis* increases from a low during August to October to a peak in May. The October through February increase in the per cent of dead parasites may be attributed to adverse winter temperatures, particularly during December, January, and February, inasmuch as these are the most severe winter months in southern California.

The peak mortalities occurring in March, April, and May are believed to be due to the cumulative effects of previous unfavorable climatic conditions. Such effects are discussed by DeBach, Fisher, and Landi (1955). They show that *Aphytis lingnanensis* eggs subjected to sublethal low temperatures, then moved to optimum temperatures, may hatch and develop to the pupal stage, only to succumb before emergence. Thus, sublethal adverse temperatures acting against *Aphytis* eggs in January and February, and against the surviving *Aphytis* larvae in February or March, could very well produce cumulative effects resulting in peak pupal mortalities during March, April, and perhaps May.

An additional explanation seems necessary in order to account for peak yearly immature parasite mortalities occurring during the rather mild weather of May. This involves some principles of population genetics. It is known that some insect populations annually tend to become adapted to seasonal changes by natural selection (Dobzhansky, 1951). Thus, overwintering *Drosophila* populations show progressive increases in the proportion of genes favoring tolerance to cold. This is a process of natural selection, which, of course, must be accompanied by the death of considerable numbers of nonadapted individuals. If we apply this to *Aphytis*, the net result can be that by late winter or early spring (February–March), the surviving population will have become adapted to cold weather. Rather suddenly, then, warm to hot spells of weather come along in April and May. Temperatures may reach 95° or even 100° F. The cold-adapted parasites are suddenly subjected to new conditions. This can result in the high mortality of immature parasites observed in May.

Current Distribution, Relative Abundance, and Progress in California. As stated earlier, *Aphytis lepidosaphes* was initially colonized in small numbers in Orange, Santa Barbara, and San Diego counties by the Department of Biological Control at Riverside. In addition, under the direction of R. J. Bumgardner, of the Orange County Department of Agriculture, a local insectary program for the propagation of *A. lepidosaphes* was inaugurated, and additional colonizations of large numbers of parasites (over 580,000) were made throughout the county's citrus-growing districts from 1950 to 1953. By 1953–54, *A. lepidosaphes* had become common and generally established in all of Orange County. It is also established in the Whittier area of Los Angeles County, where purple scale once was of economic importance but now little citrus is left.

Although highly susceptible to many of the more toxic insecticides, *Aphytis lepidosaphes* has been able to maintain itself throughout Orange County in groves receiving annual oil-spray applications (the material generally employed in this area), and may become abundant between treatment dates. There is no question that the parasite has made insecticidal control efforts easier and that it adds to the efficacy of control measures. According to Bumgardner (1958): "Where there is no oil-spray program in operation, it is problematical if this parasite alone can sustain commercial control of purple scale. There are several groves throughout the county where the parasite has kept the scale commercially clean for three or more years. Although the inside of the trees might be quite heavily infested with purple scale, fruit has remained relatively clean.... It is evident that the parasite has helped oil sprays control purple scale. During 1956 and 1957, purple scale has decreased until it is of the least importance for the entire period of the past thirty years."

Aphytis lepidosaphes is also successfully established in San Diego and Santa Barbara counties, but detailed studies of its degree of effectiveness have not been made in these areas because the purple scale has not been a major pest in them. Studies were concentrated in Orange County because this is the only large citrus-growing area in southern California where purple scale is a major pest. It is of interest to note that *A. lepidosaphes* was initially colonized in only two locations in San Diego County—in Chula Vista, approximately seven miles north of the Mexican border, and in centrally located Escondido. It may now be recovered throughout the county in all areas where purple scale exists, representing a dispersal of over twenty miles from each of the two original colonization sites. Field observations indicate that it is at least as effective here as in Orange County.

A METHOD OF INTEGRATING CHEMICAL WITH BIOLOGICAL CONTROL

Introduction

We have concluded from the over-all analysis of data obtained from purple scale studies in Orange County and elsewhere that the Oriental parasite *Aphytis lepidosaphes* is very effective in substantially retarding the potential rate of increase of purple scale and, on occasion, achieving temporary biological control at a satisfactory economic level under favorable meteorological and environmental conditions. However, low winter temperatures which inhibit parasite activity and may cause considerable mortality of the immature stages, occasional severe summer temperatures coupled with low humidity, and the characteristic of periodic, more or less even-brooded scale developmental stages, are critical factors adverse to maximum parasite efficacy. Cultural practices in and immediately adjacent to the grove are additional factors affecting the obtainable degree of biological control. Thus, consistent and reliable control appears unlikely without the judicious integration of the chemical with the biological method.

The collection, interpretation, evaluation, and subsequent application of basic ecological data are pertinent, perhaps indispensable, to the successful integration of chemical with biological control. Knowledge of the interrelationships or interaction of single- or multiple-species populations of beneficial insects, both parasitic and predaceous, in association with single or mixed populations of pest species, on various host plants under varied climatic and cultural conditions and in the presence or absence of chemical sprays, is proving invaluable in bringing about better over-all pest-control measures.

Much of the basic ecological information concerning the pests and beneficial insects associated with citrus has been gleaned in recent years, inasmuch as earlier investigators were hampered by the necessity for combating immediate pest problems and by the lack of sufficient skilled personnel and adequate equipment. Only a few decades ago, present-day methods of pest control were in their infancy, and comparatively little was known of the basic concepts of the regulation of pest populations.

Earlier, both biological and chemical control techniques were aimed at achieving complete control of the pest populations, and they enjoyed a considerable degree of success, amounting to incalculable savings in the field of agriculture. However, whether biological or chemical control procedures directed against a given pest achieved complete or partial success, or failed, few attempts were made to study the effects of treatment on the over-all faunal complex or to analyze failures.

Whereas the outcome of any particular biological control project, regardless of the results obtained, is not likely to spawn future detrimental repercussions, the same may not always hold true for chemical control practices. Early and, to a degree, present-day chemical control procedures involve the utilization of chemicals designed to insure the maximum kill of particular pest populations, often with little concern for effects on the associated faunal complex. With the development and improvement of methods and equipment for insecticidal applications, set patterns of periodic or "by-the-clock" (seasonal) treatments emerged, utilizing single- or multipurpose chemical sprays designed to give all-inclusive pest control on an annual or semiannual schedule and, unfortunately, often used on an insurance basis rather than being regulated by the degree of infestation.

The deleterious results of the indiscriminate use of insecticides on citrus may have been slow in their manifestations; however, with the advent and widespread usage of DDT and other extremely toxic chemicals, there was no longer a question as to the impact of such materials on beneficial populations of parasites and predators. A classic example of such an occurrence was the effect of DDT in reducing the vedalia beetle (*Rodolia cardinalis* [Mulsant]) population to a level of inefficiency in the central valley of California shortly after World War II, when it had previously demonstrated its dramatic ability to control the cottony-cushion scale, *Icerya purchasi* Maskell, following its introduction from Australia.

During the past two decades, much information has been published citing numerous cases of adverse effects of pest-control applications upon the natural enemies of agricultural pests. DeBach and Bartlett (1951) listed over a dozen incidences of obvious upsets in the natural balance in relation to the use of a particular insecticide, and many others now are well known.

From the foregoing account, it would seem logical to question the established chemical control procedures in many instances and to determine whether the most judicious use of insecticides is being employed. Because of the continuous use of numerous insecticides over a span of many years in most crops, which obscures the effectiveness of various natural enemies to a greater or lesser degree, it would be difficult, if not impossible, to predict the degree of severity of any particular pest or the potential effectiveness of its natural enemies in the absence of treatment. The senior author concluded, about 1947, that in order to measure the effectiveness of the entire complex of natural enemies in relation to the various pest populations, and to determine if certain pests actually possessed inherently effective natural enemies, it was necessary to conduct long-range studies in completely untreated test plots. The knowledge gained from these studies could, it was hoped, eventually be applied to techniques designed to conserve reservoirs of natural enemies, to improve the effectiveness of established beneficial insects, and to indicate the need for new importations, as well as to insure the judicious use of pesticides, i.e., to integrate chemical with biological control.

Ecological Studies in Untreated Groves

Studies begun in 1948 in long-term untreated citrus groves in Orange County and other counties indicated, after a period of years, that various pests, previously thought to be serious in regularly treated groves, subsided or remained of minor importance in untreated groves. The control of ants, particularly the Argentine ant, *Iridomyrmex humilis* (Mayr), and the avoidance or minimization of excessive dust deposits on the trees, which are factors adverse to biological control, were found to be prerequisites for studies on the maximum efficiency of natural enemies in untreated plots (DeBach, 1951).

Results of experimental and quantitative field studies in untreated orange groves have been summarized by DeBach (1951, 1958). It was shown that in citrus groves in Orange County which had received no insecticidal applications for from three to ten or more years, satisfactory natural control of most pests usually resulted. This included biological control of the citrus red mite, *Panonychus citri* (McGregor), by predators, and of the California red scale, *Aonidiella aurantii* (Maskell), by the aphelinid parasites *Aphytis chrysomphali* and *A. lingnanensis*. These two pests previously were usually considered to lack effective natural enemies. Other pests showing good control by natural enemies in these studies included the long-tailed mealybug, *Pseudococcus adonidum* (Linnaeus); the citrophilus mealybug, *P. gahani* Green; the citrus mealybug, *Planococcus citri* (Risso); the black scale, *Saissetia oleae* (Bernard); the cottony-cushion scale, *Icerya purchasi* Maskell; and the brown soft scale, *Coccus hesperidum* Linnaeus. The aphids *Toxoptera aurantii* (Fonscolombe) and *Aphis spiraecola* Patch, and the orangeworms *Pyroderces rileyi* (Walsingham), *Holcocera iceryaeella* (Riley), and *Argyrotaenia citrana* (Fernald), which are minor pests occasionally requiring treatment in Orange County, were not problems in the untreated groves. The purple scale, *Lepidosaphes beckii* (Newman), appeared to be the only major pest of citrus without satisfactory effective natural enemies in the coastal areas of Orange County capable of causing extensive damage if left untreated. At the time of initiation of these tests, it was not known what effect the newly established *Aphytis lepidosaphes* would have. Barring an occasional environmentally induced upset of other species, it appeared that if the purple scale could be controlled by the use of an insecticide in a manner that did not appreciably upset the general natural enemy complex, then over-all pest control might be improved and costs might be reduced appreciably.

Alternative Possibilities for Integration of Chemical with Biological Control

Regular periodic insecticidal treatments applied against one or more pests in the drastic manner normally employed would usually disallow the development of an effective integrated chemical-biological control program. In an integrated program, one or more major pests, which lack effective natural enemies, would have to be controlled chemically without upsetting the balance of the potential pests controlled biologically. A broad discussion of the integrated control concept may be found in Stern *et al.* (1959). Our studies in untreated groves had shown by comparison that the complete-coverage, large-area oil sprays and other material normally used in Orange County for pest control were causing upsets and could not be used without modification in an integrated program. It was imperative, then, that other means of treatment be found in order to integrate chemical control of purple scale with biological control in general. Various possibilities for modified treatment were considered, *all with the basic concept of leaving areas of the grove or portions of the trees untreated as preserves for the natural enemy complex.* This appeared necessary because no insecticide was known for purple scale control which, if applied to solid blocks, would not be likely to decimate natural enemy populations. Several approaches were considered, of which the following appeared to be the most feasible: (1) the treatment of the north one-half of each tree, leaving the south one-half untreated as a reservoir for natural enemies, inasmuch as previous studies in Orange County had shown that the vast majority of purple scale occurs on the north side of the tree; also, a variation of this half-tree treatment was considered wherein the heavier-density inside portions of the trees were treated, leaving the lighter-infested outside branches untreated; (2) the periodic spot-treatment of heavily infested trees throughout the grove, or of specified areas within the grove, leaving lightly infested trees untreated; and (3) periodic strip-treatment which would follow a predetermined schedule of spraying or skipping alternate tree rows or pairs of rows, leaving untreated rows as reservoirs for natural enemies. The use of selective insecticides was considered, but none appeared feasible.

All these possibilities, with the exception of the strip-treatment plan, were discarded for various reasons, based primarily on the analysis of previous findings, preliminary tests, and on the feasibility of their being commercially acceptable. It should be mentioned, however, that selective miticides have been tested successfully in a different citrus faunal complex in the Carpinteria area of Santa Barbara County to control citrus bud mite, *Aceria sheldoni* (Ewing), and citrus red mite, *Panonychus citri* (McGregor), on lemon trees, while retaining biological control of the California red scale and other citrus pests (DeBach, Landi, and Jeppson, 1959).

Prerequisites for the Establishment of a Strip-Treatment Program

Several preliminary requirements were essential to the successful establishment of an alternate or strip-treatment program. It was imperative that following the chemical treatment of predesignated rows, sufficient time must elapse before the next treatment to enable the beneficial insects to recolonize the treated areas effectively. Other factors to be considered were: (1) the timing and application of spray treatments should be applicable to current cultural practices; (2) the schedules and patterns of treatments should be simplified, to enable commercial spray crews to operate efficiently and to minimize the necessity of keeping elaborate records and timetables on the part of the management; (3) the cost of the materials and their application should be less than present figures for an equivalent degree of control; and (4) the materials used must afford effective control of the pest over a sufficiently lengthy period of time to permit the alternation of pairs of rows to be treated. In this regard, it should be re-emphasized that the establishment of *Aphytis lepidosaphes*, the parasite of purple scale imported from China in 1948, was very likely the supplement needed to extend the period between treatments in the strip-treatment test plots, although its potential effectiveness had not been determined at the time these studies were initiated. We have already shown that this parasite is well established throughout the citrus-producing areas of Orange County and, although usually it does not effect complete biological control of the purple scale, it causes considerable mortality of the scale and greatly retards its rate of increase.

The primary purpose of an integrated chemical-biological control program is to utilize *necessary* insecticides in such a manner that they will be most compatible with biological control. The chemicals selected and their use must be of a nature that will conserve beneficial insect populations by minimizing any detrimental effects on parasites and predators while still producing adequate control of the pests lacking satisfactory natural enemies. Oil spray was chosen for testing in this program because it leaves no long-term toxic residues, its drift effect on natural enemies is not great, and it has proved satisfactory in controlling purple scale in the area studied. The application of the oil spray in these test plots was a manual operation.

Results of Strip-Treatment Tests

First Trials, 1951–55. Based primarily on the preceding requisites and the initial assumption that an oil spray would give satisfactory control of purple scale for eighteen months but no longer,[6] two trial plots of approximately ten acres each were established in the Newman and the Mabury Valencia orange groves in Orange County on a six-month alternate strip-treatment plan which involved retreatment of any given strip each eighteen months. Each of these ten-acre blocks was divided systematically on a map into six-row areas, each containing three alternate pairs of rows. The first pair of rows in each six-row area would be treated, then six months later, the second pair would be treated, and six months later, the third pair. Treatment would then revert to the original rows after eighteen months, and so on. Spring and fall treatment times, six months apart, were chosen for cultural and pest-control reasons. This program would always leave an untreated row next to a treated row so that natural enemies could rapidly reinoculate the treated rows.

To evaluate the degree of purple scale control obtained from this strip-treatment pattern of spraying, purple scale population density surveys were made each spring and fall prior to treatment. The surveys were based on a careful examination and subsequent rating of each tree in the two test plots by trained personnel, and are highly reproducible. In addition to surveys, monthly observations and ratings were recorded, denoting the effects, if any, of the alternate-row treatments on the purple scale–parasite relationship, and on the other pests in the groves, to determine whether or not those pests which have effective natural enemies were upset by this program. The blocks under study were also visually compared periodically with adjacent blocks receiving more or less standard over-all spray treatments, and in many instances these observations were compared with those of the owner or manager and with those of personnel of the Orange County Agricultural Department.

In both the Newman and the Mabury groves, purple scale and citrus red mite were the most serious pests during the years before these studies commenced. Other pests present in these groves, which were, or had been, serious problems on citrus in some districts and are potential pests in this area, were

[6] This was generally the case before the establishment of *Aphytis lepidosaphes*.

the California red scale, black scale, brown soft scale, cottony-cushion scale, citrus aphids, orangeworms, and mealybugs. During the 1951–55 study period, these insects were usually held in check by natural enemies, although the citrus red mite and the mealybugs (particularly Baker's mealybug, *Pseudococcus maritimus* [Ehrhorn]) became fairly common on occasion but then were reduced by parasites and predators. When these tests were commenced, heavier purple scale and mealybug infestations, as well as other pest problems, were evident in the Mabury test block along a west border windbreak of eucalyptus trees as compared with the central and eastern portions of the grove, and this tendency continued, although to a lesser and inconsequential extent, during the strip-treatment period. It is thought that the afternoon shade, which resulted in lower temperatures and higher humidities close to the windbreak, favored pest increase over that of natural enemies.

By the fall of 1955, it was evident that these strip-treatment trials were successful. Purple scale had remained under good commercial control for the five-year test period, and populations of various potential pests showed no significant increases or differences that could be correlated with the use of strip-treatment as compared with a normal complete treatment program. Citrus red mite populations were generally lower than in adjacent regularly treated areas, and mealybugs were less evident throughout the groves than pretest surveys had indicated. The natural enemies of the black and California red scale were common throughout both plots and were effective in maintaining a satisfactory degree of biological control.

Second Trials, 1956–59. The above results and other new information that accumulated during 1951–55 led to the conclusion that an improved modification of this program would be highly desirable and could probably be accomplished. This has been termed the twelve-month alternate strip-treatment program.

The desirability of modification hinged on the following factors: (1) Riehl, Wedding, and Rodriguez (1956, 1957) found that spring oil-spray treatments on Valencias in Orange County may be detrimental to fruit quality and production; spring treatment was necessary under the six-month alternate strip-treatment program. (2) The program of treating alternate pairs of rows at six-month intervals would be difficult for management and pest-control operators to keep track of and coordinate. (3) Financial savings to the grower could be improved, because even though, under the six-month program, one-third less spray material was applied per year, the pest-control operator had to go through the grove twice a year, which tends to increase costs.

The reasons that improved modification seemed possible were: (1) It was now known that purple scale could go untreated for a full eighteen months under a strip-treatment program. (2) The new purple scale parasite, *Aphytis lepidosaphes*, had spread and increased during the 1951–55 test period and was successfully slowing down the rate of purple scale increase in Orange County. (3) This indicated that a twenty-four-month period between treatments might be feasible under strip-treatment. (4) This would mean a simple program involving treatment of every other pair of rows only once a year (i.e., only one-half the grove) in the fall, with resultant reductions of at least

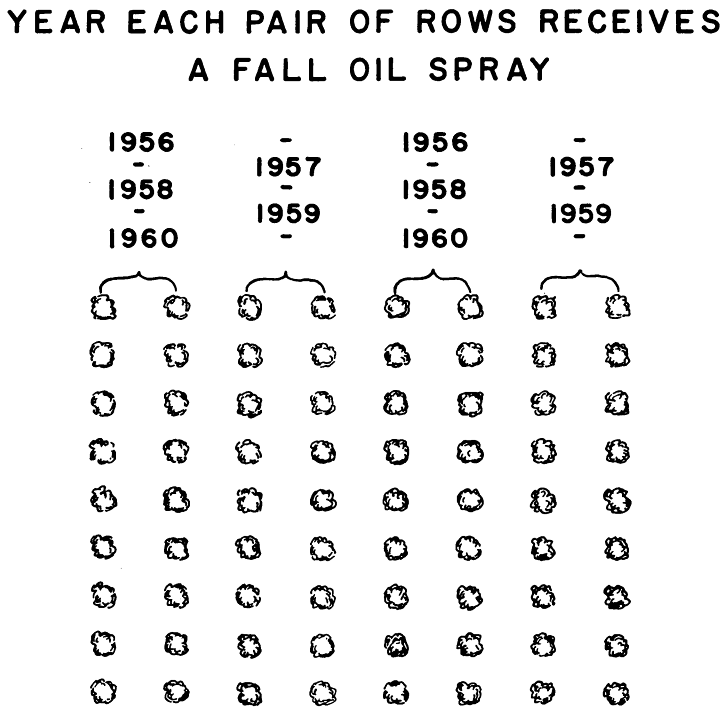

Fig. 11. Diagram showing the basic plan for a twelve-month alternate strip-treatment program.

50 per cent in pest-control costs if successful, and the elimination of the need for spring oil sprays.

Figure 11 shows the basic plan for a twelve-month alternate strip-treatment program for the typical period 1956–60.

Consequently, early in 1956 the Newman and Mabury plots were modified to omit the usual spring oil treatment application and thenceforth to receive treatment each fall on every other pair of rows. Each successive year, the rows untreated the year before would be treated. A third ten-acre plot on the Irvine Ranch in Orange County was established under this new program early in 1956.

In the process of converting the original Mabury and Newman strip-treatment plots from a six-month to a twelve-month alternate strip-treatment program, it happened that certain rows had to go untreated for a longer period of time than would have occurred if the original schedule had been followed, and in the Mabury plot, in particular, a considerable citrus red mite attack occurred in these particular rows the first season. Barring this incident, these two alternate strip-treatment plots continued, until terminated in April 1959, under satisfactory commercial control of all pests under the twelve-month alternate strip-treatment program.

The new plot established in 1956 on the Irvine Ranch, which previously had received regular annual treatments, had a heavy infestation of black scale to start with; it showed evidence of previous citrus red mite damage and had all the insect species present that were mentioned earlier as occurring in the other plots. Under the twelve-month alternate strip-treatment program, the black scale infestation decreased satisfactorily within one year, and all other pests remained under good commercial control for the duration of the tests, which were terminated formally in April 1959 but have been continued satisfactorily by the grower until the time of writing (1961).

It is again emphasized that the introduced purple scale parasite *Aphytis lepidosaphes* accounted for considerable mortality through parasitization and host-feeding of scale in the untreated rows as well as of scale that may have survived in the treated rows, and was thus instrumental in insuring the success of this program. Other potential pests in the groves studied were held in check by effective natural control factors, primarily parasites and predators.

Discussion and Conclusions

In past years, it was generally assumed and practiced that about one and one-half major applications per year of insecticides were necessary for pest control in Orange County. The major pests were considered to be the purple scale, the California red scale, and the citrus red mite. Because most potential orange-tree pests in Orange County have been shown by studies in untreated test plots to have generally effective natural enemies, and because the seriousness of the purple scale has been greatly alleviated by the 1948–49 importation of an Oriental parasite, *Aphytis lepidosaphes,* integration of chemical with biological control appears desirable and feasible.

Based on the results of the nine-year study on the integration of chemical with biological control, it would appear that a twelve-month alternate strip-treatment program utilizing oil spray should be feasible throughout Orange County areas where purple scale is the primary pest on oranges. This program gives good control of the purple scale and at the same time always retains untreated reservoirs to conserve natural enemy populations, thus usually permitting biological control of all other potential pests to occur. However, more acreage under this plan needs to be observed over a longer period of time before sweeping conclusions can be drawn. On an experimental basis, it would appear that interested growers in this area could adopt a similar program in a portion of their groves, involving possibly five to ten acres, without assuming undue risks. Under the direction of the University of California Extension Service and with the cooperation of the Orange County Department of Agriculture, the original plots, plus a few additional new ones, continue to show good results in 1961.

Savings in pest-control costs will be considerable if the suggested twelve-month strip-treatment program proves generally reliable. Only one-half the actual acreage would be treated each year, and since the total acreage in Orange County has averaged at least one and one-half major treatment applications per year, the strip-treatment costs would be only about one-third of current pest-control costs.

As previously mentioned, the decision to divide the test plots into pairs of rows was more or less arbitrary and was based on the premise that the natural enemies in the untreated pairs of rows could recolonize the adjacent treated pairs of rows in a relatively short period of time following treatment, and on the ease of operation for the manual application of oil spray. It seems likely that the choice of the number of rows in each strip to be treated might be somewhat flexible and could extend to four or possibly six or more rows per strip. This might be particularly desirable in cases where the grower preferred the use of a "boom sprayer" over that of manual operation, inasmuch as a certain amount of oil spray penetrates the rows on either side adjacent to the two rows being treated by the "boom sprayer." (See Ebeling [1959], pp. 87–89, for descriptions and pictures of boom sprayers.) This would thus reduce the area of the reservoir of natural enemies on either side if the division of the grove were in pairs of rows, whereas if the division of the grove were in strips of four rows each, the center two rows would be unaffected.

There is no reason why a strip-treatment method for integration of chemical with biological control would not apply to other areas or other crops, but each case will have to be worked out on its own merits in relation to the indications drawn from basic ecological studies. For instance, it appears impractical at the present time to consider such a program in interior citrus areas of southern California. This is because different pest–natural enemy complexes necessitate different chemical controls; at present, the ones required in the interior are too drastic.

Any grower starting a trial program of strip-treatment should begin with a comparatively "clean" grove, having no more than a light infestation of purple scale, as well as of other potential citrus pests, and a good population of the purple scale parasite *Aphytis lepidosaphes* should be present. This parasite is generally established in Orange County, but should the grove be isolated from other citrus and have a history of regular chemical treatment, it might be necessary to colonize it initially. Some arrangement for the spot-treatment of scale-infested trees outside the strips scheduled for treatment might be considered as a possibility in the early, first-cycle phases of the program.

Although citrus red mite populations were generally under satisfactory biological control in the test plots during this nine-year study period, it is conceivable that under extremely favorable conditions they might reach damaging populations on occasion. Should it be necessary to treat for citrus red mite, the following materials have been found to be relatively nontoxic to natural enemies: Ovotran, Chlorobenzilate, Tedion, and Kelthane.

The initial and sustained control of ants cannot be too strongly emphasized in this scheme. As in the case of a strict biological control program, the effectiveness of natural enemies is seriously inhibited by even moderate ant populations.

SUMMARY

Importation, culture, colonization, and progress of the purple scale parasite, *Aphytis lepidosaphes* Compere, in southern California, particularly in Orange County, are discussed. Phases of the parasite's biology and distribution are covered in detail. The parasite has produced partial biological con-

trol of the purple scale, *Lepidosaphes beckii* (Newman), to the extent that considerable yearly scale mortality occurs and the rate of scale population increase is appreciably reduced. Ecological studies in untreated groves, before the establishment of *A. lepidosaphes,* indicated that in the absence of treatment, purple scale generally would be the only pest achieving serious pest status in Orange County. Certain others, such as the California red scale and the citrus red mite, previously had been assumed to lack effective enemies on the basis of observations made in regularly treated groves and/or in groves infested with ants, which upset the natural balance.

To assure adequate control of the purple scale while permitting maximum natural enemy activity to operate against the other potential citrus pests, several methods of integrating chemical with biological control were considered. Field plot tests showed a twelve-month alternate strip-treatment program, utilizing oil spray, to be feasible. This involves spraying alternate pairs of rows across a grove in a given year, leaving the other pairs untreated, and then the next year spraying the rows left untreated the previous year. Pest control under this system was as good as or better than that usually obtained in regularly commercially sprayed groves, and cost is indicated to be less than half that experienced under the usual treatment.

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