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MANAGEMENT OF SAN JOSE SCALE (SJS) (HOMOPTERA: DIASPIDIDAE) ON APPLE TREES WITH SOYBEAN OIL DORMANT SPRAYS AND OCCURRENCE OF SJS PARASITOIDS IN EASTERN TENNESSEE

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Degree

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ABSTRACT

Petroleum dormant spray oils have been used to manage San Jose scale (SJS), *Quadraspidiotus perniciosus* (Comstock), on apple trees since the introduction of SJS into the United States in the 1870's. Although studies have shown that cottonseed or soybean oil could be used to control several aphid, whitefly, and mite species on vegetables and cotton, few studies have examined the use of soybean oil as dormant sprays on fruit trees.

The objectives of this study were to determine: 1) the efficacy of soybean oil dormant sprays for management of SJS on apple, and 2) life cycles of SJS and its predominant parasitoid, *Aphytis* sp. (Hymenoptera: Aphelinidae), in Tennessee. In 1993, an *Aphytis* sp. was determined in a preliminary survey to be the most abundant SJS parasitoid.

Dormant oils were applied to 'Bounty' apple trees in a commercial orchard on 14 Feb 1994, and 20 Feb 1995. The treatment units were single trees with five replications (completely randomized design). The following treatments were applied to run-off with a hand-gun at 60 psi: 1) 6% (v/v) degummed soybean oil with 0.6% (v/v) Latron B-1956 sticker spreader (Rohm & Haas, Philadelphia, Pennsylvania) as an emulsifier, 2) 3.0% degummed soybean oil with 0.6% Latron B-1956 sticker spreader as an emulsifier, 3) 3% 6E Volck Supreme Oil (VC1023 Valent Corporation) prepackaged with an emulsifier (X-77), and 4) an untreated control.

SJS crawlers on bark were counted for three min per tree weekly during the growing season with a 16x hand lens. Adult *Aphytis* were also counted for three min

per tree weekly with a 16x hand lens. Three pheromone traps were used to monitor male scale emergence in the orchard weekly (8 Mar-10 Nov 1994, and 1 Mar-1 Jun 1995). Separation of means was determined by Tukey's HSD ($P=0.05$) on first, second, and third generation crawler data in 1994 and first generation crawler data in 1995. Twenty apple fruit from each tree were evaluated for first generation SJS infestation on 13 Jun 1995.

The male SJS flight periods occurred during 15 Apr-17 May, 14 Jun-29 Jul, and 1 Aug-26 Sept 1994. Crawler SJS emergence periods occurred during 17 May-28 Jun, 7 Jul-30 Aug, and 7 Sept-24 Oct 1994. Numbers of adult *Aphytis* peaked between 24 Aug and 26 Sept 1994.

Both 3% petroleum oil and 6% soybean oil sprays reduced first and second SJS crawler generations by > 93% in 1994; first generation was reduced by 98% in 1995. The 3% soybean oil reduced first and second generations by 60% in 1994 and 83% in 1995. In 1995, apple fruit infestation by first generation SJS on the 3% soybean, 6% soybean, and 3% petroleum oil treated-trees did not differ. Averages ($\pm$ SD) of first generation SJS per fruit ($n=100$) on treated trees were: 3% soybean oil, 3.1 ± 3.7; 6% soybean oil, 1.2 ± 0.8; 3% petroleum oil, 0.9 ± 0.9; and untreated controls, 139.3 ± 80.2.

This study demonstrated that degummed crude soybean oil dormant sprays were effective for management of SJS on apple trees. Data from this study suggest that SJS had three generations in 1994. The abundance of *Aphytis*, compared to other parasitoids, suggests that this wasp was the major parasitoid of SJS in this study.

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INTRODUCTION

Armored scale insects (Homoptera: Diaspididae) can seriously damage fruit and nut trees and woody ornamentals (Miller & Kosztarab 1979). About 50 species of armored scale are known to feed on apple, *Malus domestica* Borkh., and pear, *Pyrus* spp., trees (Madsen & Morgan 1970). San Jose scale (SJS), *Quadraspidiotus pernicious* (Comstock), a diaspidid, is both a direct and an indirect pest of apple trees. SJS can damage fruit directly; it also reduces tree vigor by removing sap, often resulting in death of the tree. Worldwide, SJS is considered the most troublesome scale insect on apple (Madsen & Morgan 1970).

SJS was introduced into the U.S. from China in about 1870. It was first identified near San Jose, California, on peach, *Prunus persica* (L.) Batsch (Marlatt 1902). In 1880, Comstock described SJS specimens collected from apple; pear; almond, *Prunus amygdalus* L.; plum, *Prunus americanum* Marsh; and peach (Marlatt 1906, 1953). By 1900, SJS had spread throughout North America. Approximately 1,000 acres of mature apple trees were killed by SJS in southern Illinois during 1922 (Howitt 1993). This scale insect continues to be a major pest in apple-growing regions of North America (Rice & Jones 1988, Reissig et al. 1985, McClain et al. 1990, Jorgensen et al. 1981, Pfeiffer 1985a, b, Rice et al. 1979). Rice and Jones (1988) considered it to be a key pest of *Prunus* spp. in California. At least 700 species of plants in 34 families are used as hosts by SJS (Gentile & Summers 1958, Madsen & Morgan 1970). SJS is an international pest, as well; it is found on deciduous fruit trees in Africa, Asia, Australia, Canada, Europe, the Mediterranean region, North America, and South America (Gentile & Summers 1958, Chumakova 1969, Downing and Logan 1977, Kozar 1976, Madsen & Morgan 1970, Richards 1961, Yashnosh 1972).

SJS was first reported in Tennessee in 1886 (Chambliss 1897). W.W. Stanley wrote to Rice (1937) regarding the status of SJS and its parasitoids in Tennessee:

> "Small infestations of the scale have been observed in many orchards which have not been sprayed for years, but the pest has not been exceedingly harmful to these trees. Parasitism has been observed, but none of the species have been recorded."

This was the only reference found in the literature regarding SJS parasitoids in Tennessee.

SJS infestations were found in a commercial orchard, White's Little Mountain Orchard, in Hamblen County, Tennessee, during the fall of 1992. Scales encrusted apples and branches on numerous trees; many of the trees were weakened and several had died as a result of infestations. Apple fruit affected by the SJS were marked with red spots characteristic of SJS damage (Fig. 1). SJS infestations were examined in a private apple orchard in Hawkins County, Tennessee, and at the University of Tennessee Plant Sciences Farm in southern Knox County in May, 1994.

SJS and several other insect pests sometimes are managed by petroleum oil summer sprays and dormant sprays. Little work has been done with soybean oil on apple or any other orchard crop, even though soybean oil has several advantages: it is a renewable agricultural product; it is not toxic to humans; and it is environmentally compatible. It also may prove to be less expensive than petroleum oil, especially if it can be used in the crude state. Additionally, insect and mite pest

Fig. 1. Apple fruit infested by San Jose scale with characteristic red spots.

species have not been reported to develop resistance to vegetable or petroleum oils (Chapman 1967, Johnson 1980, Hesler & Plapp 1986, Davidson et al. 1991). Pless et al. (1995) reported that 2.5% and 5.0% soybean oil dormant sprays killed 85% and 98% of terrapin scale, *Mesolecanium nigrofasciatum* (Pergande) (Homoptera: Coccidae) in field tests on peach trees; a similar level of management of SJS was obtained in field tests. Almost 100% control of terrapin scale and SJS when a second soybean oil spray was applied (Pless et al. 1995).

Management of SJS in Tennessee currently is maintained by dormant and/or delayed-dormant petroleum oil sprays. The objectives of this study were to: 1) determine the efficacy of dormant soybean oil sprays to manage SJS on apple; 2) study the life cycle of SJS in eastern Tennessee; and 3) search for the major SJS parasitoid(s) in eastern Tennessee.

LITERATURE REVIEW

SJS Biology

SJS may have up to six generations per year, depending on the climate. SJS has been reported to have three generations per year in Maryland (Stoetzel 1975) and Virginia (Pfeiffer 1985a), two in western New York state (Mague & Reissig 1983a, b), and four in North Carolina (Rock & McClain 1990).

Gentile and Summers (1958) described the SJS life cycle. The first instar of SJS consists of the crawler, white cap and black cap stages. The bright yellow crawler is the only motile stage for SJS females. Crawlers may disperse at a rate of approximately 1 m/h for a distance of up to 3 m before settling. After settling, the white cap stage inserts mouth parts into the plant, and legs and antennae are lost during molting. The white cap stage also begins secreting the test (scale covering), a process usually requiring less than 24 h. Second-instar males have oblong tests; females have circular tests. Second-instar nymphs develop into adult females or prepupal males. Prepupal males develop legs, antennae and one pair of wings. Males leave their tests and fly in search of females. SJS females are ovoviviparous, and produce as many as 10 crawlers per day for nearly six weeks. Birth usually occurs from 30 to 40 days after mating. The males are weak fliers and often rely on walking. Females produce a pheromone to attract males (Rice 1974, Rice & Jones 1977, Miller & Kosztarab 1979, Rice et al. 1979, Rice & Hoyt 1980).

Because SJS can move only short distances by crawling, dispersal of SJS was thought to be primarily on infested nursery stock (Gentile & Summers 1958).

However, Mague and Reissig (1983a) demonstrated that airborne dispersal of SJS crawlers occurred between trees within an orchard; thus, dispersal to nearby orchards by winds may be possible.

Morgan and Angle (1969) described the distribution of SJS on apple trees. SJS distribution was reported to be variable throughout the tree but more uniform on older limbs. The majority of SJS collected from leaves was reported to be males. The few females found on leaves seldom reproduced. Older twigs and limbs provided the most reliable samples for biological surveys or determining the effects of insecticides (Morgan & Angle 1969).

Parasitoids

For effective integrated pest management (IPM), the biology of the most important natural enemies in the community should be considered. Riley (1873) and Howard (1894) noted early the importance of parasitoids in the genus *Aphytis* Howard (Hymenoptera: Aphelinidae), formerly in the genus *Aphelinus* Dalman, for natural control of scale insects. Approximately 90 *Aphytis* spp. have been described, and all are parasitoids of armored scale insects (Rosen & DeBach 1979). In the U.S., seven *Aphytis* spp. are known to be SJS ectoparasitoids (Gulmahamad & DeBach 1978a, b, Rosen & DeBach 1979, Rice & Jones 1982, Titayavan 1983, Viggiani 1984). *Encarsia perniciosi* (Tower) (Hymenoptera: Aphelinidae) is an endoparasitoid reported to be effective in the biological control of SJS (Tower 1914, Rice 1937, Gulmahamad & DeBach 1978a). *Encarsia perniciosi* parasitizes all stages of SJS except the crawler stage. *Coccidoencyrtus ensifer* (Howard), *Aspiditiphagus citrinus*

(Crawford), and *Coccophagoides kuwanae* (Silv.) (Hymenoptera: Chalcidoidea) are SJS endoparasitoids in North America (Cox 1942, Flanders 1960, Titayavan 1983). There are other rare species of SJS parasitoids in the Chalcidoidea (Rice 1937).

Aphytis spp. generally out compete *Encarsia* spp. and other endoparasitoids in parasitizing armored scale insects (DeBach & Sundby 1963, Gulmahamad & DeBach 1978a, b, Yu et al. 1990). For example, *E. perniciosi* can parasitize first-, second-, or third-instar SJS, but developing *Aphytis* spp. can destroy developing endoparasitoids in third-instar SJS. However, *E. perniciosi* usually is not entirely displaced, and may actually compliment *Aphytis* spp. in certain situations. *Aphytis aonidae* (Mercet) (Gulmahamad & DeBach 1978b), *A. diaspidis* (Howard), *A. vandenboschi* DeBach (Titayavan 1983) and *A. proclia* (Walker), appear to be very effective SJS parasitoids (Rosen & DeBach 1979). Rosen and DeBach (1979) considered *Aphytis* spp. to be the most effective natural enemies of armored scale insects.

Most *Aphytis* spp. are multivoltine, and may have up to three generations per generation of their host (DeBach 1964). Most *Aphytis* spp. with known sexuality are biparental (males and females occur); approximately one fourth of the species are believed to be uniparental (only females occur) (Rosen & DeBach 1979). In biparental species, unfertilized eggs produce males (arrhenotoky), and fertilized eggs produce females. Females make up 60-70% of the population in most biparental species. Thelytokous parthenogenesis (parthenogenesis that produces only females) is common in uniparental species; males may be produced in these species at a rate of 1-

5% of the population. Arrhenotokous parthenogenesis (parthenogenesis that produces only males) occurs in uniparental species, but is rare. All species in Aphelinidae have three larval instars with development from egg to emergence requiring about 19 d (Rosen & Eliraz 1978, Vigianni 1984).

The life span for *A. proclia* females ranges from 13 to 50 days. Its mean fecundity is 31.6 eggs, with a maximum of 73 eggs (Sumaroka 1967). Mean fecundity of *A. aonidae* is 81.5 eggs with a minimum of 35 eggs and a maximum of 102 eggs; the life span is 35.4 $\pm$ 6.9 days (Gulmahamad & DeBach 1978b). *Aphytis proclia* and *A. aonidae* both parasitize adult SJS females and prepupal males.

Adult *Aphytis* spp. obtain carbohydrate nutrition from nectar and honeydew (Avidov et al. 1970). Newly emerged wasps usually die within 24 h if carbohydrates are not available. Adult female *Aphytis* adults require protein meals for egg production (Howard 1910, Imms 1916, Quayle 1910). To obtain protein, the female drills a hole in the scale test with her ovipositor creating a feeding tube from waxy secretions from accessory glands when the ovipositor is slowly removed. The female then feeds on the host body fluids (Fisher 1952). Males were observed by Fisher (1952) to feed at vacated feeding tubes. Parasitization rates up to 25% may occur in populations at equilibrium. *Aphytis* spp. kill as many or more scale insects by host feeding as by parasitization (DeBach et al. 1948, DeBach & White 1960, DeBach & Sundby 1963). SJS mortality caused by wasp feeding may be underestimated resulting in lower field counts of scale insects killed by that means (Rosen & DeBach 1979, Vigianni 1984).

Petroleum Oils

Petroleum spray oils are refined oils that are safe for use on trees and shrubs for the management of scale insects, aphids, phytophagous mites, mealybugs, and psyllids. For simplicity in this text, dormant oil refers to spray oil applied in winter or early spring, when tree metabolism is low. Summer oil refers to spray oil applied during the growing season. Davidson et al. (1991), Miller (1983), Johnson (1980), and Chapman (1967) provide historical perspectives on the use of horticultural oils and give a thorough account of past and current terminology.

Petroleum oils were used as insecticides as early as 1787. Kerosene emulsions were in common use by the late 1870's (Pearce et al. 1941, Miller 1983, Lawson & Weires 1991). Because of their phytotoxicity, these early dormant sprays were far from ideal, often causing plant injury. One common formulation consisted of dissolving 186.5 g of whale-oil soap in 4 liters of boiling water, which was added to 8 liters of kerosene and agitated violently for 5 min; this emulsion was diluted and used as needed (Howard 1894). Another emulsion used in areas with hard water consisted of 8 liters of kerosene with 4 liters of soured milk for immediate use (Howard 1894).

Around 1900, lime-sulfur replaced kerosene emulsions as the main insecticide for management of SJS (Quaintance 1906). In 1914, SJS became the first insect reported to have developed resistance to an insecticide, lime sulfur (Howitt 1993). Ackerman (1923) demonstrated that 2% light petroleum lubricating oils could be used as dormant sprays for management of SJS. Petroleum dormant spray oils subsequently have been used to manage SJS (deOng 1927, Chapman 1967, Davidson et al. 1991).

Current petroleum spray oils consist of saturated, long straight-chain lubricating oils (Chapman 1967, Johnson 1980, Lawson & Weires 1991). As chain length increases, oil viscosity increases. Spray oil viscosity ranges from 60 to 200 seconds. Petroleum spray oils tend to be light and are very pesticidal throughout their distillation range. Aromatic oils and shorter chain unsaturated hydrocarbons typically are phytotoxic. Insecticidal properties of spray oils are not fully understood; they are thought to physically impede or suffocate insects and mites (Johnson 1980).

Johnson (1980) considered petroleum oil sprays to be some of the best, safest, and least expensive insecticides, and stated that this material is under used in IPM. He stated that there were no known cases of insect or mite resistance to oils. Dormant oils are used to control scale insects, mites, aphid eggs, and some species of hibernating lepidopterans. Summer oils are used to control aphids, aphid eggs, mites, mealybugs, whiteflies, scale insects, and thrips.

Baxendale and Johnson (1988a) applied 2%, 4%, 6%, and 8% concentrations (v/v) of horticultural oil (Sunspray 6E) to dormant saplings of six species of woody ornamentals. No phytotoxicity was observed even at 8%, an application rate four times greater than the recommended rate. Baxendale and Johnson (1988b, 1990) reported that 2% and 3% summer oils (v/v Sunspray 6E) could be used to manage a wide range of arthropod pests on 53 species of woody plant and 7 species of herbaceous ornamentals. These studies also evaluated toxicity of the oils to several deciduous and evergreen ornamentals, and found that current petroleum-based horticultural oils could be used safely on many ornamentals previously thought to be oil-sensitive. Silver maple, *Acer saccharinum* L., considered sensitive to spray oil, was not damaged. The blue color was removed from Colorado blue spruce, *Picea pungens* Englemann, and juniper, *Juniperus communis* Pursh, but structural damage was not observed. Sunspray 6E caused severe foliar stippling, chlorosis, necrosis, and abscission to three species of walnut, *Juglans* spp. Sunspray 6E was rarely phytotoxic and provided acceptable control of eight species of scales, plus several species of aphids, mites, lepidopterans, sawflies, adelgids, psyllids, and whiteflies (Baxendale & Johnson 1988a, b, 1990).

Vegetable Oils

Relatively little work has been performed to assess efficacy of vegetable oils for control of insect pests. Riley (1873) reported that adequate control of the armored scale insect, *Aspidiotus conchiformis* (Gmelin), on apple trees could be achieved with linseed oil, with no obvious phytotoxicity. In the mid-1920's, deong (1927) evaluated the usefulness of linseed oil, cottonseed oil, caster oil, and rosin oil as dormant sprays. All of these oils were considered toxic to insects due to their fatty acid content (deOng et al. 1927). DeOng et al. considered the future for vegetable oils great even though use of these oils did result in some defoliation.

Taschenberg (1952) determined that cottonseed, peanut, and linseed oils were effective in managing the grape berry moth, *Polychrosis viteana*. Rock and Crabtree (1987) reported cottonseed oil to be less effective than petroleum oil against mites and insects, and cottonseed oil was toxic to apple. Cottonseed oil and soybean oil can be used to control species of aphids, mites, and whiteflies on vegetables and cotton (Butler, Coudriet & Henneberry 1988, 1989, Butler & Henneberry 1990, 1991, Butler, Puri & Henneberry 1991, Butler et al. 1993).

MATERIALS AND METHODS

This study was conducted at White's Little Mountain Orchard near Morristown, Tennessee. The orchard contained approximately 3,000 trees, including 53 cultivars of apples and assorted cultivars of cherries, peaches, and plums. Several apple trees in the orchard had been killed by SJS in recent years, and fruit damage was substantial. Heavily infested 'Bounty' apple trees were used in this study. The grower did not apply dormant sprays to the trees used in this study in 1994 or 1995. Sprays applied by the grower to the study trees in 1995 followed recommended practices (Table 1).

Preliminary Survey of Parasitoids

A preliminary survey of the SJS parasitoid complex on apple trees was conducted during August-December, 1993. In this study, parasitoids were captured in field emergence traps made from black 35-mm film canisters and screw-cap glass vials, as described by Nalepa (1987). These traps were placed over regions on limbs heavily infested by SJS (Fig. 2A). Most SJS parasitoids are positively phototaxic, and thus move to light entering the clear collection vials. Vials were collected and replaced with new vials weekly. The traps were relocated every 21 d.

On apple trees in the orchard, *Aphytis* sp. observed searching SJS to determine host or feeding suitability were counted with a 16x hand lens for a 3-min period per tree between 10:30 a.m and 2:00 p.m.; this procedure is similar to the technique reported by Smith and Maelzer (1986). Afterwards, voucher specimens were also collected and taken to the laboratory for identification.

Table 1. Sprays applied to test trees in 1995 by grower.

Application name[1]	Date	Pests targeted	Material per 100 gallons of water
Pink	31 March	catfacing insects	3.5 oz Pounce 3.2EC
		scab, rust, mildew	5 oz Nova 40WP
Bloom	14 April	fireblight	1 lb 2 oz Streptomycin
Petal Fall	19 April	codling moth, plum curculio, leafroller	3.5 lb Imidan 50WP
		scab, rust, mildew	5 oz Nova 40WP
		summer rots	4.5 lb Captan
1st Cover	6 May	codling moth, plum curculio, leafroller	2.25 lb Imidan 70WP
		scab, rust, mildew	5 oz Nova 40WP
		summer rots	4.5 lb Captan
2nd Cover	20 May	same as 1st Cover	same as 1st Cover
3rd Cover	9 June	same as 1st Cover	same as 1st Cover

Application[1] names are based on 1995 Tennessee Agricultural Extension Service Commercial Fruit Spray Schedule.

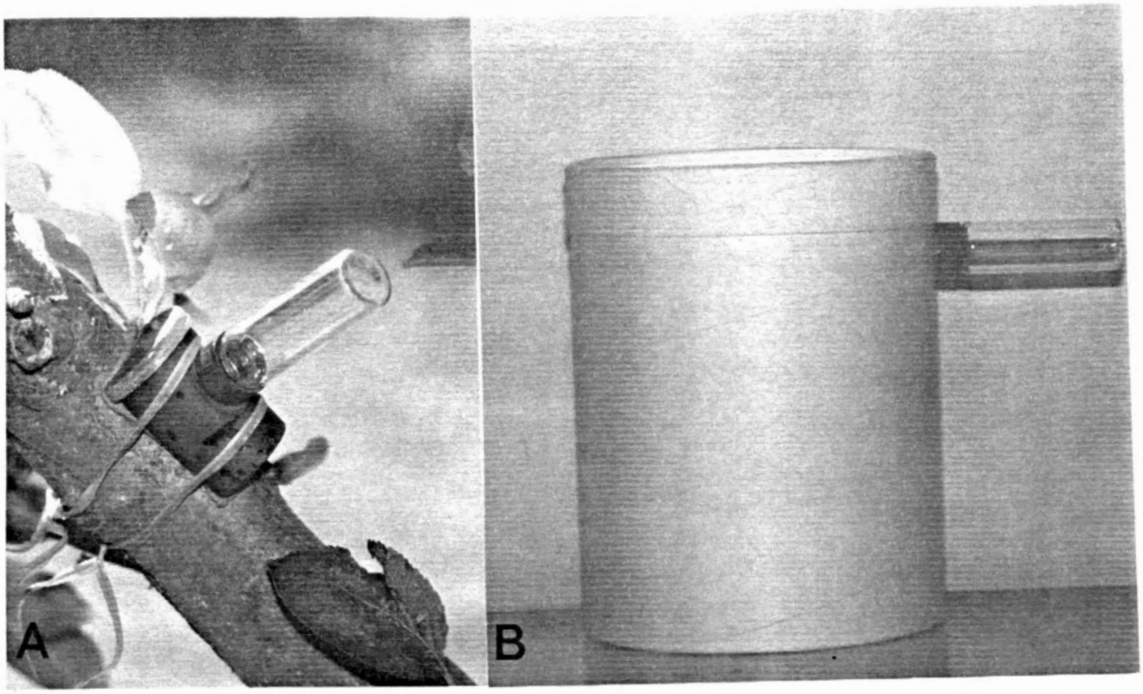

Fig. 2. 35-mm film canister field emergence trap (A) and 2-liter ice cream container rearing cage (B).

In addition, parasitoids were reared from all stages of SJS infesting apple stems and fruit in emergence cages in the laboratory. Infested plant material was replaced every 21 d. These traps were made from 2-liter ice cream containers with 0.5-cm holes to which glass vials were attached to attract the parasitoids by phototaxis (Rice 1937, Cox 1942) (Fig. 2B). Parasitoids were identified by Dr. Mike Rose at the Biological Control Facility, Department of Entomology, Texas A&M University.

Degree-Day Calculations

The degree-day (DD) is a unit of physiological development used by entomologists to describe the rate of growth of insects (Baskerville & Minin 1969, Howitt 1993). Since SJS physiological development occurs above 10°C (51°F), this temperature is used as the base temperature for DD calculations for SJS (Howitt 1993). The formula used for DD calculations for a single date was: DD=(maximum °F + minimum °F)/2-51°F (Howitt 1993). Seasonal DD accumulation was started on 1 March 1994 and 1995. Degree-day accumulations for individual months were also calculated. Data for high and low temperatures for Morristown, TN were obtained from the National Oceanic and Atmospheric Administration (1994). Weather data for 1995 was obtained from the National Oceanic and Atmospheric Administration.

Male SJS Monitoring

Pheromone traps were used to monitor male scale emergence from 18 February to 1 November 1994. These traps were placed in the orchard at three locations, approximately 2 m above the ground on 18 February 1994. Trap liners were changed weekly through 1 November. Traps were placed in the orchard again at three locations, approximately 2 m above the ground, on 24 February 1995. The liners for these traps were replaced weekly through 1 July. Pheromone obtained from Trece (Salinas, CA) was added to the traps every three weeks. All male SJS on the trap liners were counted.

Dormant Oil Experiments

In the fall of 1993, apple trees were rated subjectively for SJS infestation using a 1 to 5 rating scale, with 1 indicating no infestation and 5 indicating severe infestation. All trees used in these experiments received ratings of four or five. A completely randomized design consisting of four treatments with five replications was used for the oil application experiments (Fig. 3). Individual trees served as treatment units. Dormant oils were applied to trees on 14 February 1994 and 20 February 1995. The treatments were: 1) 6% (v/v) degummed soybean oil with 0.6% (v/v) Latron B-1956 sticker spreader (Rohm & Haas, Philadelphia, PA) as emulsifier; 2) 3.0% degummed soybean oil with 0.6% Latron B-1956 sticker spreader as emulsifier; 3) 3% 6E Volck Supreme Oil (VC1023 Valent Corporation) prepackaged with emulsifier (X-77); and 4) unsprayed control trees referred to hereafter as controls.

On the 1994 application date, the minimum temperature was 38°F, and the maximum temperature was 47°F. On the 1995 application date, the minimum temperature was 45°F, and the maximum temperature was 57°F. On both dates, there was low wind and no precipitation.

Sprays were applied to run-off at 60 psi using a cart-mounted sprayer equipped with a handgun. The sprayer's major parts were two 12-volt diaphragm pumps, a 53-

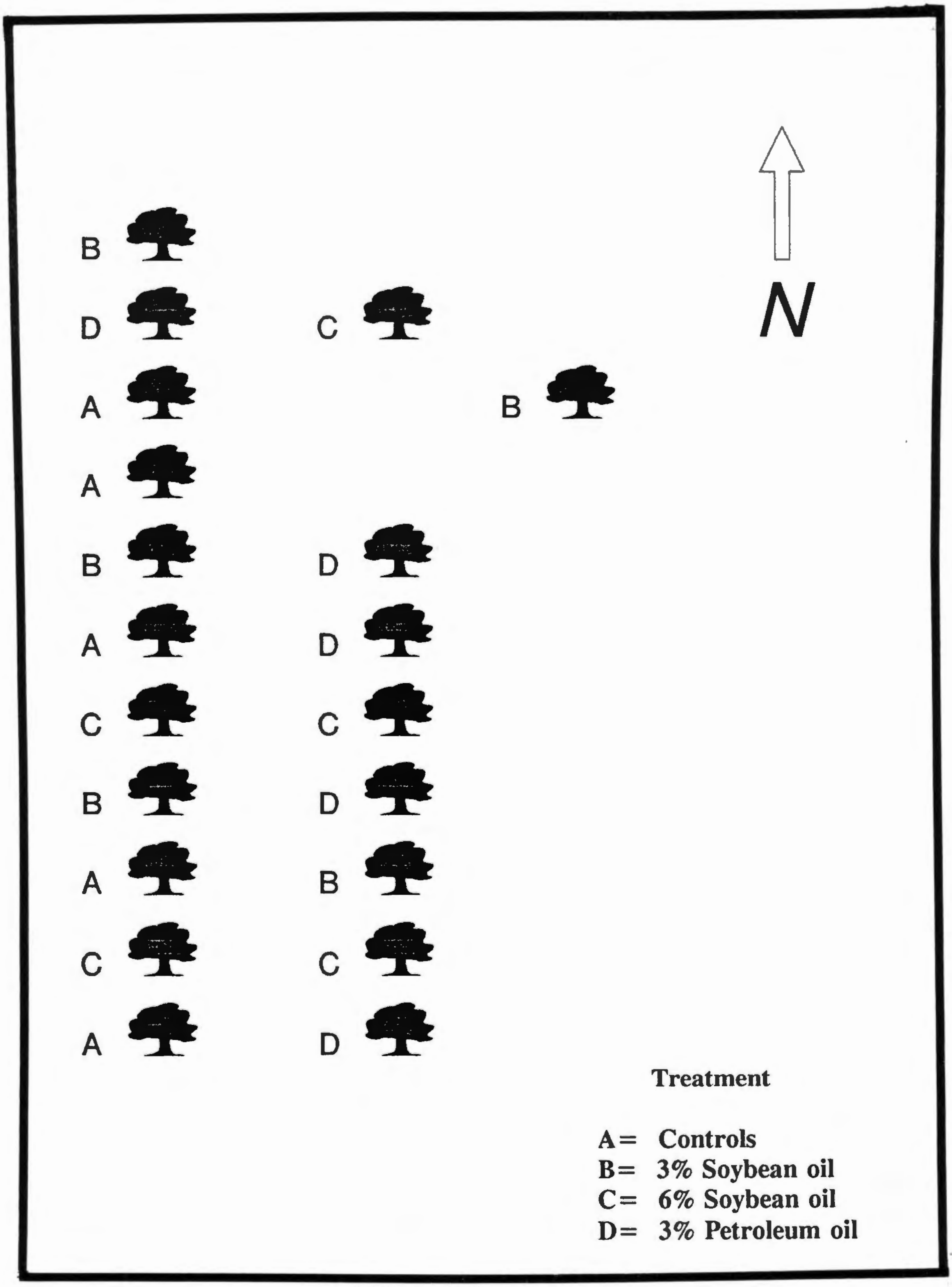

Fig. 3. Map of 'Bounty' apple trees used in dormant oil tests.

liter tank, and 12-volt marine battery (Fig. 4). One pump provided spray pressure to the handgun, and the other provided agitation.

Each tree was examined weekly for SJS crawler activity. Counts were initiated in the area of the tree with the highest activity, based on cursory observations. Crawlers on bark were counted weekly for 3 min per tree with a 16x hand lens (Mague and Reissig 1983b).

Analysis of Variance (ANOVA) was used to evaluate data for first-, second-, and third-generation crawlers in 1994, and data for first generation crawlers in 1995. Separation of means was determined with Tukey's Honest Significant Difference test ($P=.05$) (SAS Institute 1987).

Because of poor fruit set, only 11 apples per treatment were used to evaluate SJS fruit damage in 1994. Apples were harvested and inspected for infestation on 1 July 1994 (Fig. 5). In 1995, fruit was more plentiful on the test trees, so 20 apples per tree were evaluated for SJS infestation by first-generation SJS on 13 June 1995. ANOVA was used to evaluate the first-generation SJS fruit infestation data for 1995, with separation of means being determined with Tukey's Honest Significant Difference test ($P=.05$) (SAS Institute 1987).

Parasitoids

The predominant SJS parasitoid, an *Aphytis* sp. in the *A. proclia* species group (Fig. 6) observed searching SJS for host suitability, was counted for a 3-min period per tree. Voucher specimens were aspirated afterwards. Wasps were mounted on slides for identification as described by Rosen and DeBach (1979). Permanent

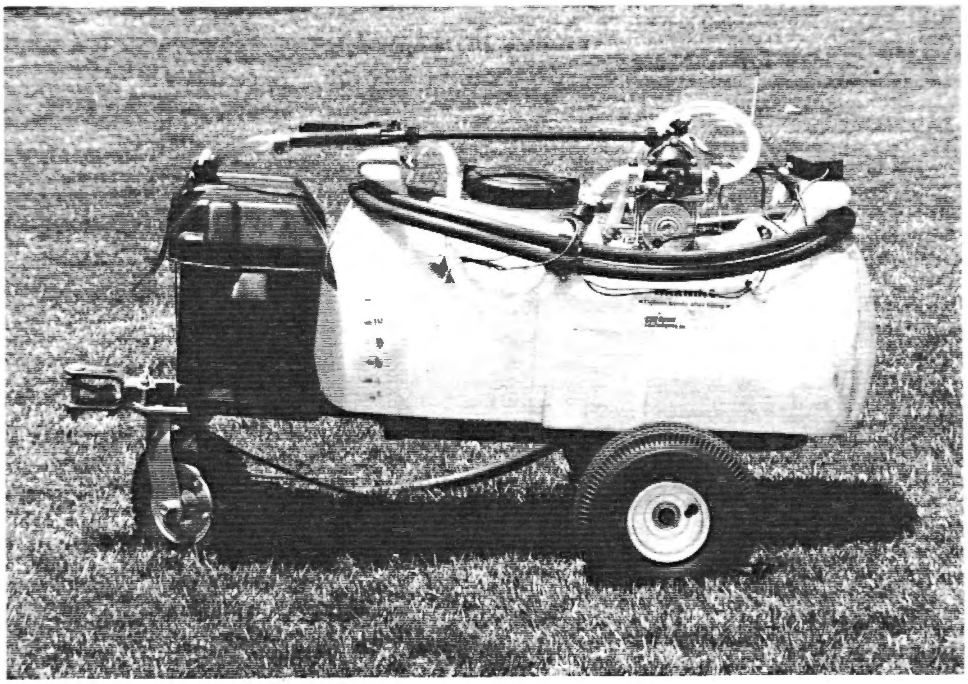

Fig. 4. Sprayer equipped with handgun, 12-volt agitation pump, and 12-volt application pump.

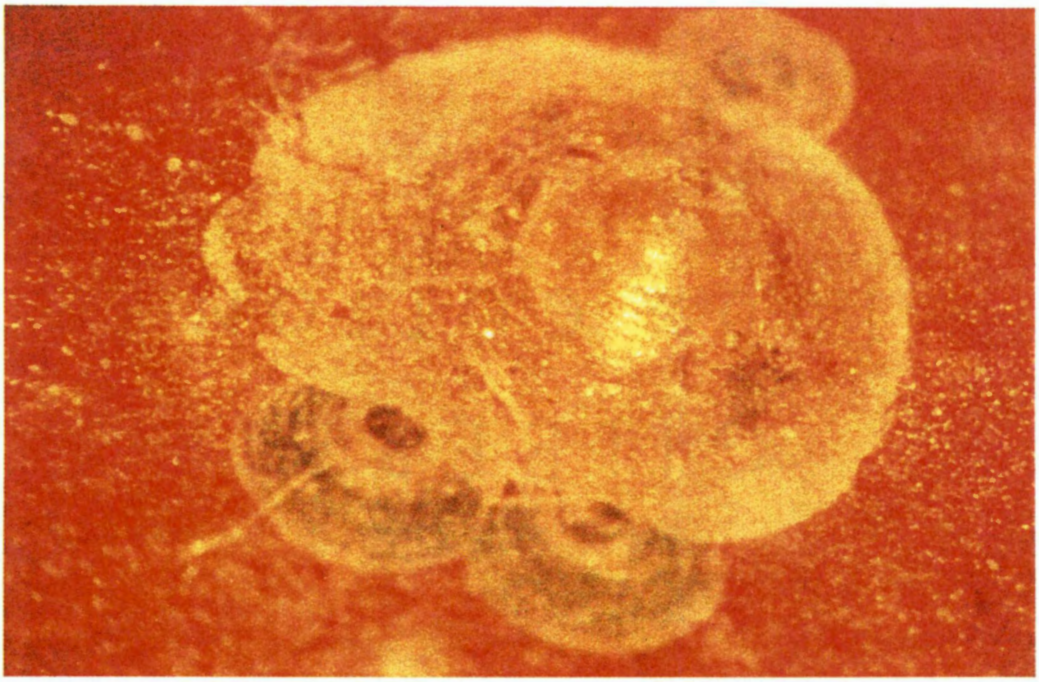

Fig. 5. Adult female San Jose scale (center) and black cap San Jose scales (lower left). Diameter of adult female is approximately 1.4 mm.

Fig 6. Female *Aphytis* sp. Length is approximately 1 mm. (Photo by E. C. Bernard)

voucher specimens were mounted in CMC-10 mounting medium (Master's Chemical Company, Elk Grove, IL) and placed in the University of Tennessee Insect Museum.

Overwintering SJS

Stems were collected from unsprayed trees for evaluation on 14 February, 18 February, and 20 February 1994 to determine the overwintering stage and mortality rate for SJS. Scales were removed from stems to determine their stage of development and to assess viability. SJS on apple stems were evaluated again on 12 February and on 20 February 1995.

RESULTS

Preliminary Survey of Parasitoids

Five species of parasitoids in the families Aphelinidae and Encyrtidae were recovered. A total of 560 parasitoid specimens was collected by trapping, aspiration, and laboratory rearing. Approximately 237 *Aphytis* sp. were collected with the 35-mm film canister traps in the preliminary study, 203 *Aphytis* sp. were collected in the preliminary study by aspiration, and an additional 100 *Aphytis* sp. were collected in emergence cages in the laboratory. In addition, two specimens of *Aphidiotiphagus* sp. and four specimens of *Encarsia perniciosi* were collected. Two encyrtid species were collected by all methods: seven individuals of *Coccidoencyrtus ensifer* and seven individuals of an unidentified species in the tribe Habrolepidini. The *Aphytis* sp. was the predominant parasitoid in the preliminary survey.

Degree-Day Calculations

Degree-day calculations, by month, are shown in Table 2. In 1994, the first SJS male flight date began about 152 DD; the second, 1,005 DD; and the third, 2,370 DD. The first-generation SJS crawler emergence began around 529 DD; the second, 1,350 DD; and the third, 2,971 DD (Fig. 7). In 1995, the first-generation crawler emergence began around 515 DD.

Male SJS Monitoring

Male SJS had three emergence periods between 15 April and 24 October (Fig. 7). The male SJS flight periods occurred from 15 April-17 May, 14 June-29 July, and 1

Table 2. Degree-day accumulations for 1994, by month.

Month	Degree-Day Accumulation
March	50
April	302
May	327
June	709
July	748
August	704
September	491
October	235
November	41
December	21

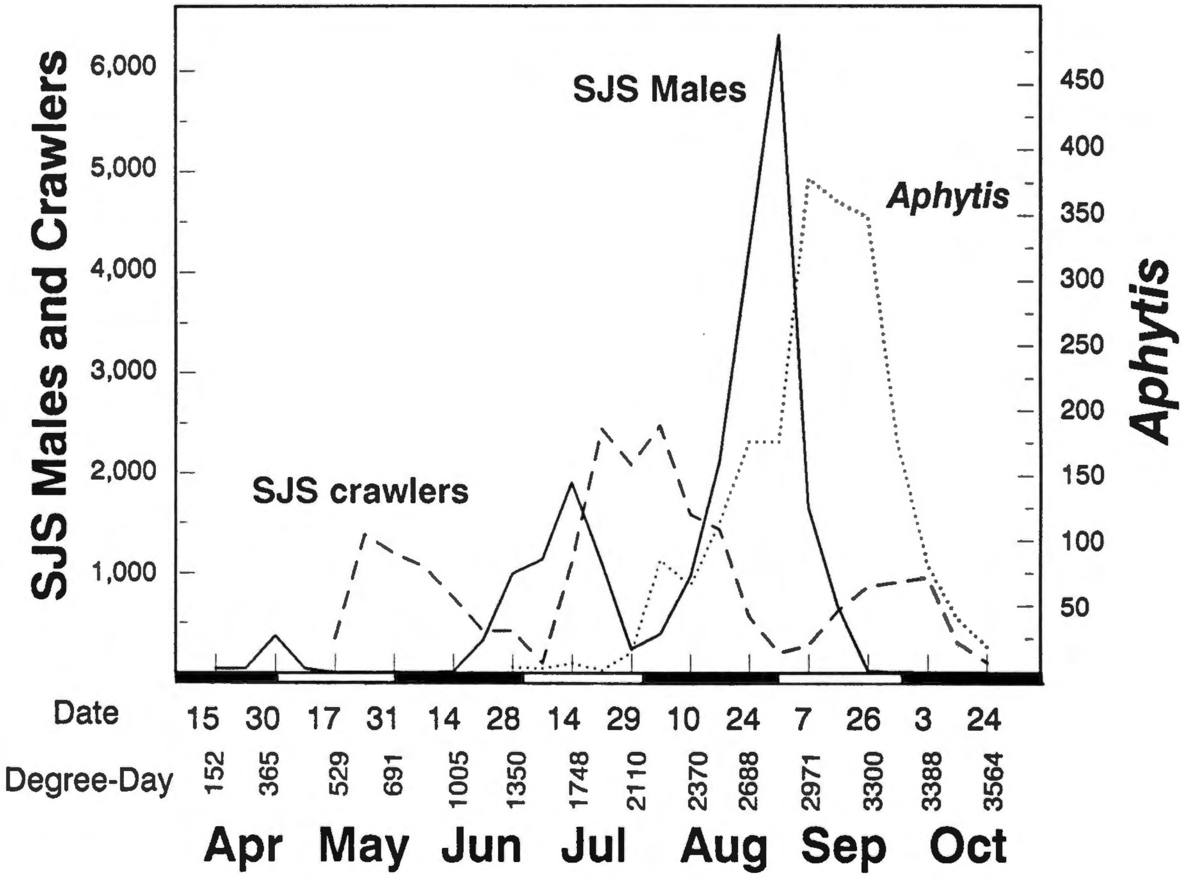

Fig. 7. Mean number of male San Jose scales per pheromone trap (n=3), and mean number of SJS crawlers and *Aphytis* sp. per 3-min count on control trees (n=5) in 1994.

August-26 September. The pheromone traps were ineffective in 1995. The pheromone was kept in cold storage as recommended by the manufacturer, but may have become inactive.

Dormant Oil Experiments

In 1994, Crawler SJS emergence periods occurred from 17 April-1 June, 7 June - 30 August, and 7 September-24 October (Fig. 7). In 1995, the first-generation crawler emergence period occurred from 8 May-20 June.

In 1994, treatment with 3% petroleum oil or 6% soybean oil resulted in > 93% reduction in first and second generation SJS crawler populations. Treatment with 3% soybean oil resulted in > 60% reduction in first and second generation SJS crawler populations.

No significant differences were found in the effects of 3% petroleum oil and the effects of 6% soybean oil sprays on numbers of the first-, second-, or third-generation SJS crawlers in 1994 (Figs. 8-10). The 3% petroleum oil or the 6% soybean oil sprays provided better control of SJS than 3% soybean oil spray during 1994. Crawler populations on the 3% soybean oil treated-trees were also significantly lower than crawler populations on the controls (Figs. 8-10). In 1995, no differences were found in the effects of the 3% soybean, 6% soybean, or 3% petroleum oil treatments on first-generation crawler populations; the effects of all the oil treatments differed significantly from the controls (Fig. 11). The percentage of first-generation SJS reduction on the oil treatments in 1995 was: 3% soybean oil, 83%; 6% soybean oil, 98%; and 3% petroleum oil, 98%.

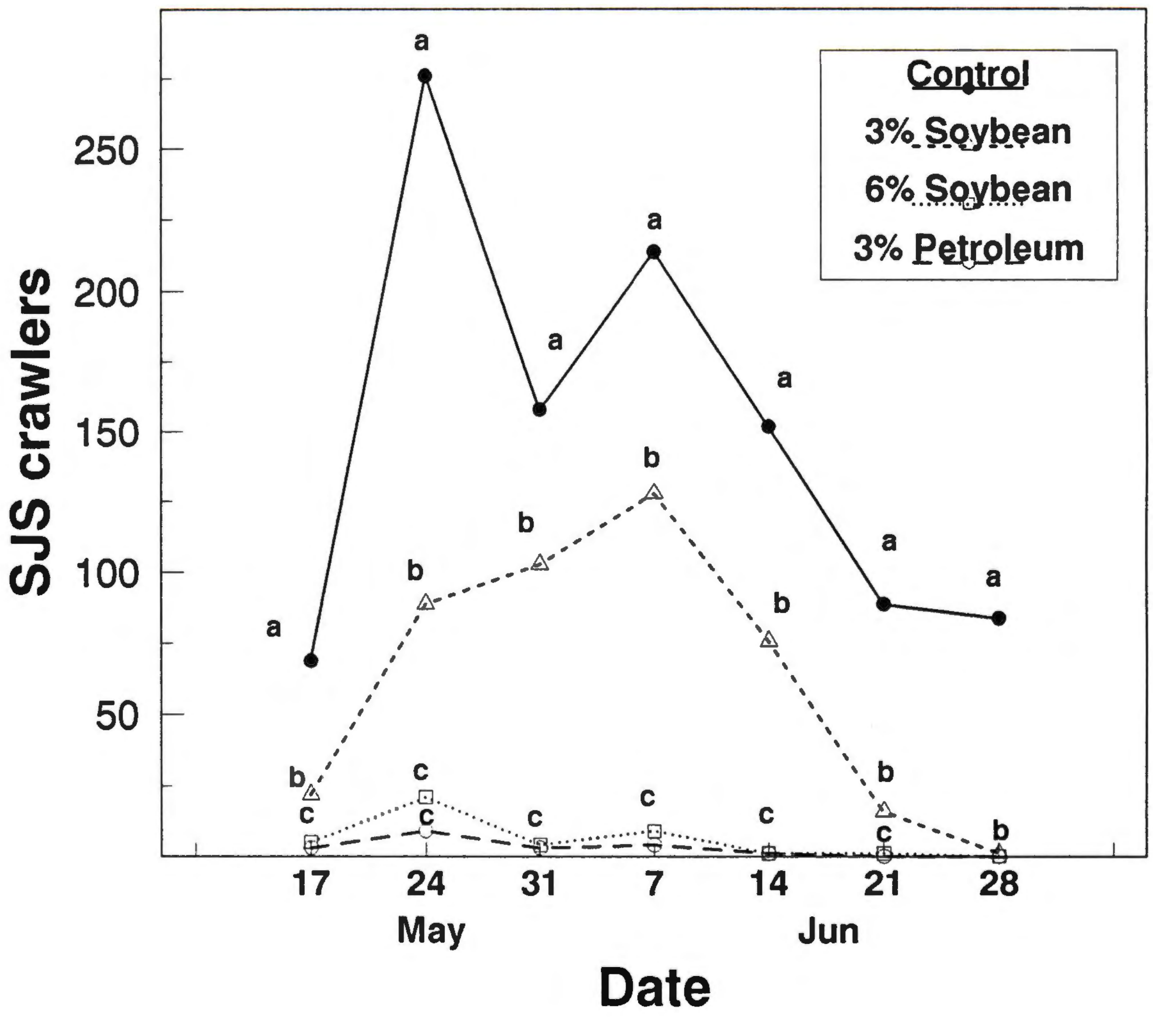

Fig. 8. Mean number of first-generation SJS crawlers per 3-min count (n=5) in 1994. Points on a date with a common letter do not differ significantly. Separation of means was determined with Tukey's HSD (P>0.05).

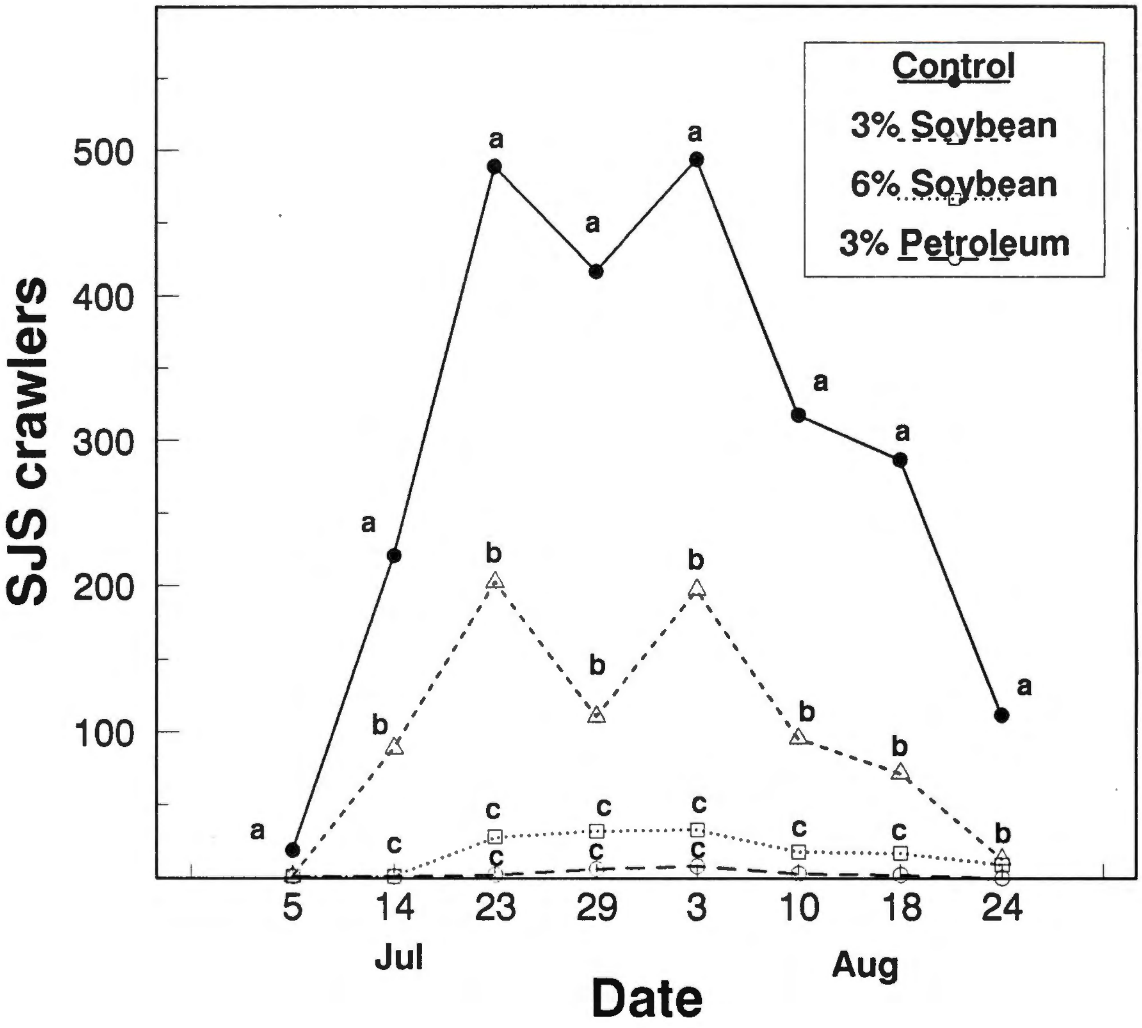

Fig. 9. Mean number of second-generation SJS crawlers per 3-min count (n=5) in 1994. Points on a date with a common letter do not differ significantly. Separation of means was determined with Tukey's HSD (P>0.05).

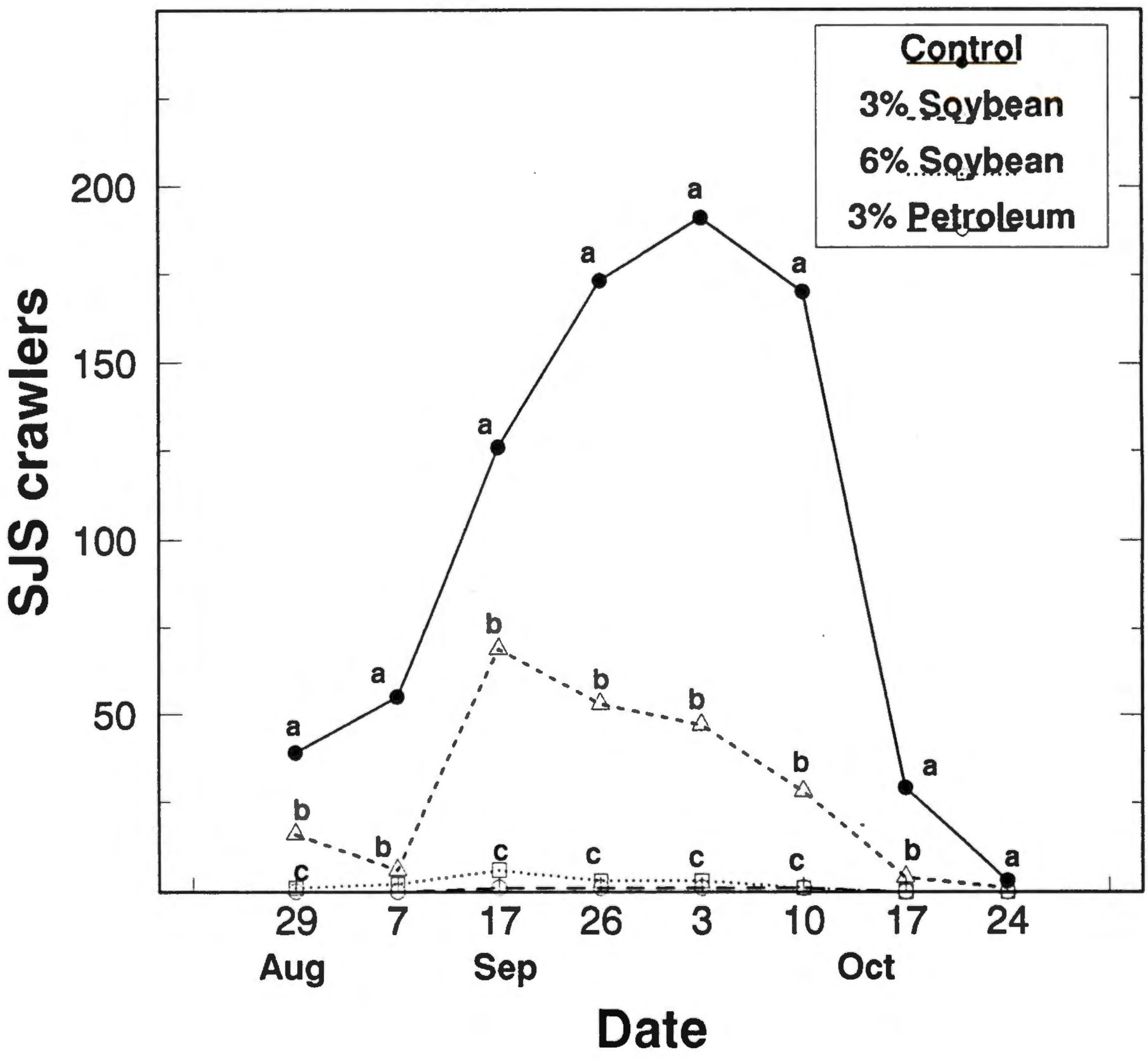

Fig. 10. Mean number of third-generation SJS crawlers per 3-min count (n=5) in 1994. Points on a date with a common letter do not differ significantly. Separation of means was determined with Tukey's HSD (P>0.05).

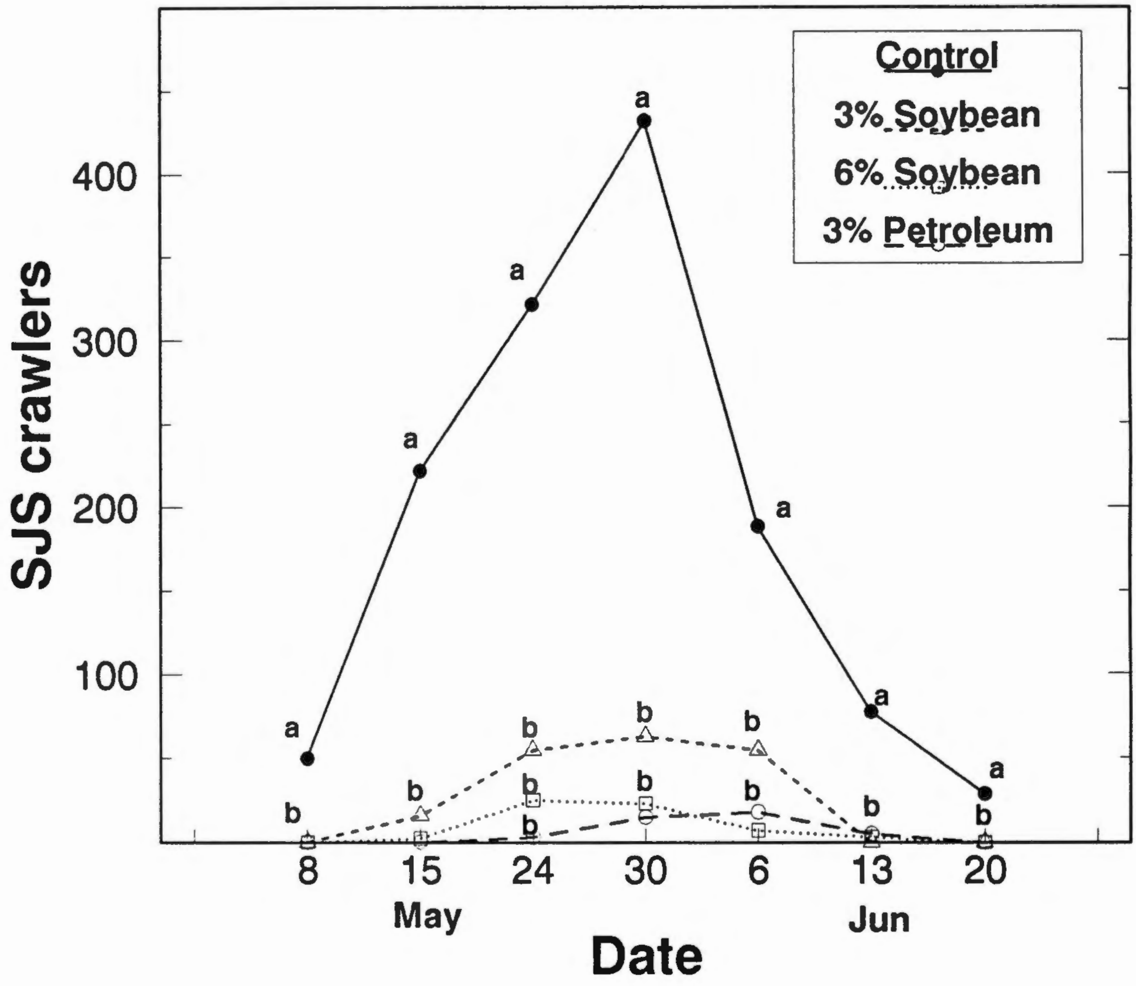

Fig. 11. Mean number of first-generation SJS crawlers per 3-min count (n=5) in 1995. Points on a date with a common letter do not differ significantly. Separation of means was determined with Tukey's HSD (P>0.05).

The mean ($\pm$SD) number of SJS infesting 11 apples evaluated for each of the treatments in 1994 was: controls, 282.6 $\pm$ 61.31; 3% soybean oil, 5.6 $\pm$ 1.86; 6% soybean oil, 0.9 $\pm$ 0.83; and 3% petroleum oil, 0.6 $\pm$ 0.82. In 1995, infestations on the fruit of the 3% soybean, 6% soybean, and 3% petroleum oil did not differ significantly; infestations on the three oil treatments differed significantly from the controls (Fig. 12). Control trees averaged 139.3 $\pm$ 80.2 first-generation SJS per fruit ($n=100$). Averages ($\pm$ SD) of first-generation SJS per fruit ($n=100$) on treated trees are: 3% soybean oil, 3.1 $\pm$ 3.7; 6% soybean oil, 1.2 $\pm$ 0.8; and 3% petroleum oil, 0.9 $\pm$ 0.9.

Parasitoids

The *Aphytis* emergence period in 1994 occurred between 21 June-24 August (Figs. 7 & 13). Wasps were more abundant on the controls than on any of the oil-treated trees. The trees treated with 3% soybean oil had more wasps than the trees treated with 6% soybean oil or the trees treated with 3% petroleum oil (Fig. 13).

Overwintering SJS

Of 1,030 SJS evaluated for viability in 1994, approximately 837 (81%) were alive in the black cap stage, 163 (16%) were dead, and 30 (3%) were third-instar females. About 733 SJS were evaluated in 1995; about 603 (82%) of these were alive in the black cap stage, 83 (11%) were dead, and 47 (6%) were adult females.

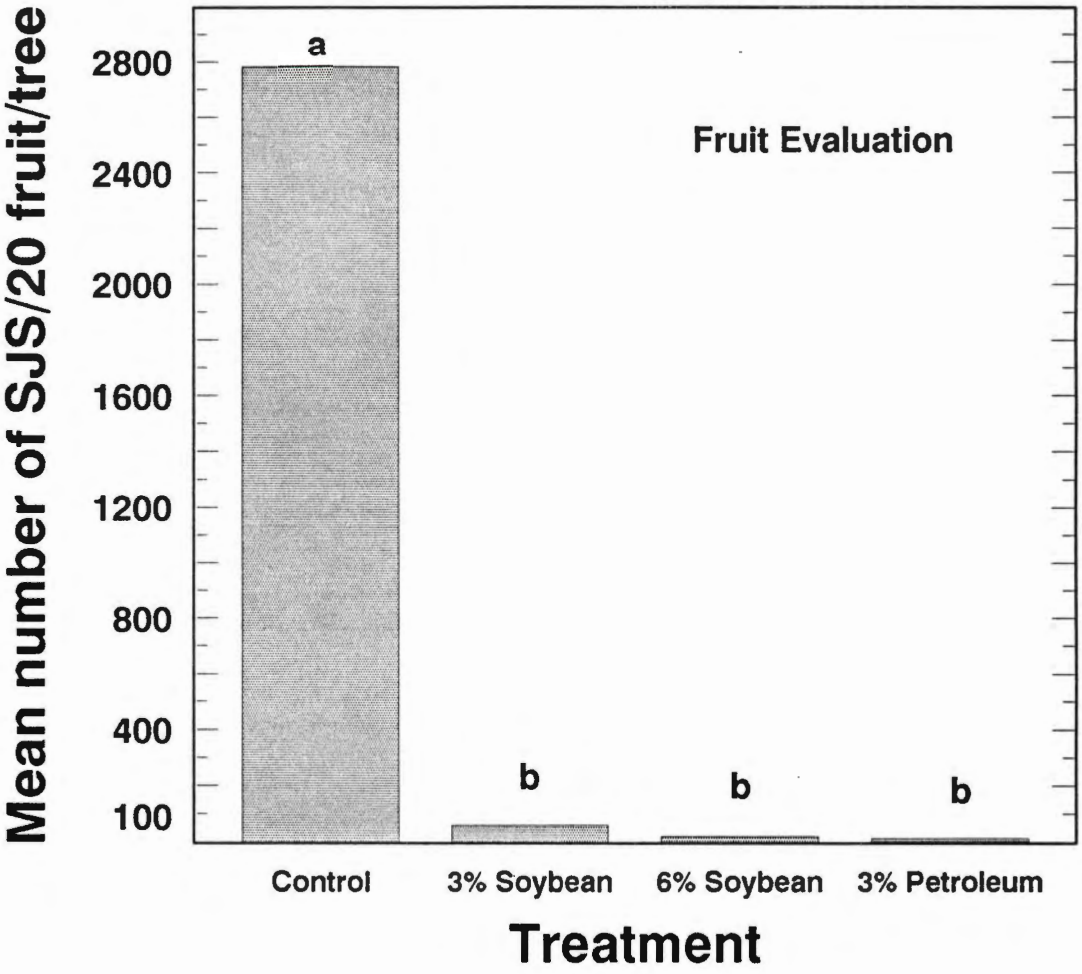

Fig. 12. Apple fruit infestation by first generation San Jose scale in 1995. One hundred apples per treatment were evaluated. Bars with same letter do not differ significantly. Separation of means was determined with Tukey's HSD ($P>0.05$).

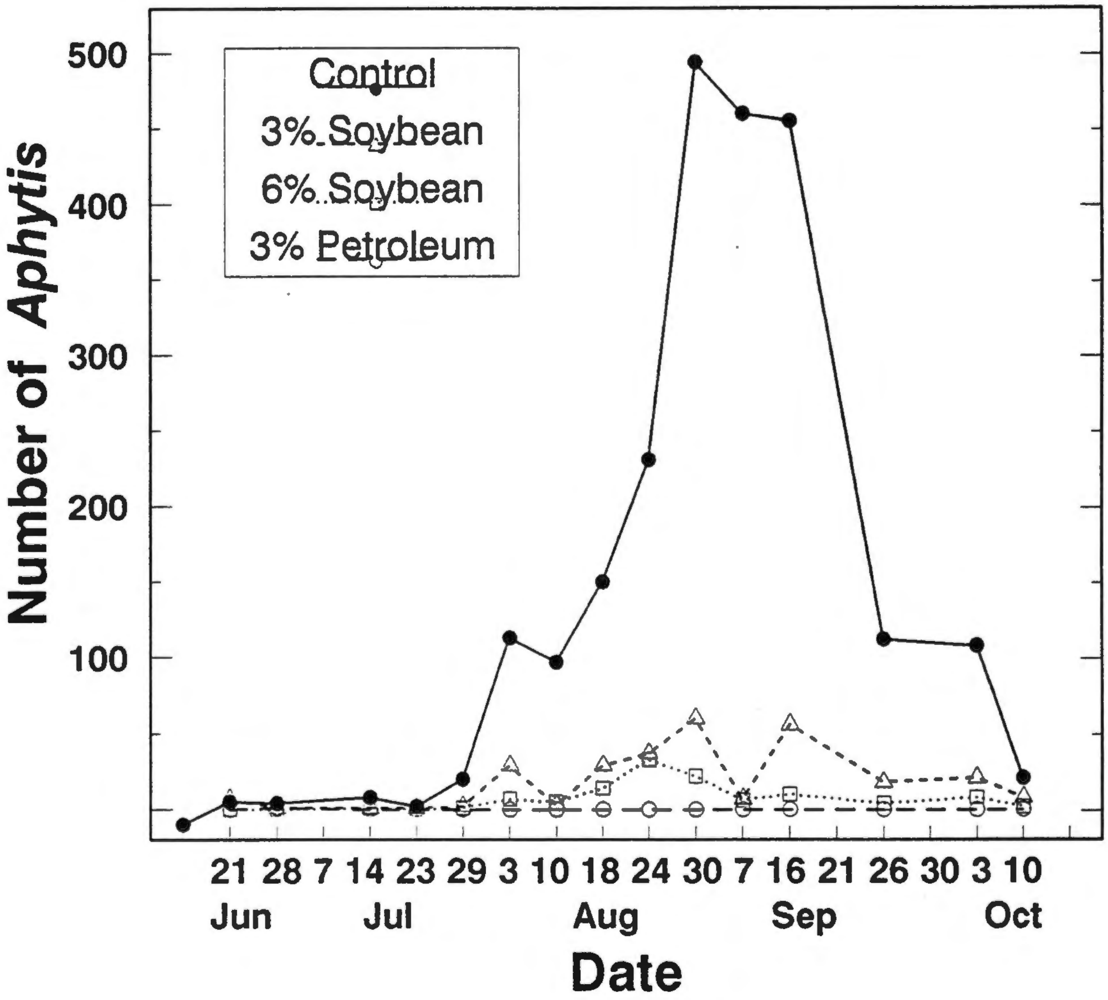

Fig. 13. *Aphytis* sp. emergence period in 1994 for all treatments used in this study.

DISCUSSION AND SUMMARY

The test trees produced few fruit in 1994: only seven of the trees had 20 or more apples, and each of the remaining trees produced 0-2 apples. Lack of fruit set appeared to be random, except for the 3% petroleum oil treatment: the five trees in this treatment produced only 11 apples. Lack of sufficient numbers of fruit prevented evaluations after the first-generation crawler emergence and precluded a more thorough evaluation in August 1994. A more plentiful fruit set occurred in 1995. Compared to the controls, all oil treatments kept fruit infestation low in 1995.

The data from this study indicate that SJS has three generations per year in Tennessee. In 1994 and 1995, SJS overwintered predominantly in the black cap stage. Approximately 11%-16% of overwintering SJS apparently died from unknown causes. The second-generation crawler emergence period was complete by 24 August. Therefore, most fruit damage would be caused by the first and second generations of SJS, because fruit growth and harvest was complete by 30 August. Third-generation SJS would occur too late in the year to damage fruit, with the exception of some late-maturing cultivars.

Prior to this study, the test trees had been severely infested by SJS. After this two-year study, SJS abundance on the test trees had been reduced dramatically by all dormant oil sprays compared to the controls. The effects of 3% soybean oil and 6% soybean oil sprays on SJS crawler populations differed in 1994, but not in 1995. This finding suggests that the soybean oil is the major insecticidal component of the formulation, because both application rates contained the same amount of B-1956 spreader-sticker used as the emulsifier.

Natural enemies and substantially lower DD accumulation for September and October may account for low third-generation crawler numbers in 1994 (Fig. 10), allowing better management of first-generation crawlers on the 3% soybean oil-treated trees in 1995 (Figs. 11). Most *Aphytis* activity was in August and September (Fig. 7); parasitoids in this genus can increase populations rapidly in a short period. Small numbers of lady beetle larvae and adults (Coleoptera: Coccinellidae) and lacewing larvae (Neuroptera: Chrysopidae) were observed feeding on SJS during the 1994 growing season. Lady beetle and lacewing larvae are voracious predators, and could reduce SJS populations substantially. In addition, DD accumulations were down from August to September by 30%, to October by 67%, and to November by 94% (Table 2).

Modern petroleum oil sprays work well for insect and mite management and can be applied as dormant sprays or summer sprays. Pest species of insects and mites apparently do not develop resistance to vegetable or petroleum oils, unlike with other pesticides (carbamates, organophosphates, etc.) (Chapman 1967, Johnson 1980, Hesler & Plapp 1986, Davidson et al. 1991). However, petroleum oil sprays have been developed continuously for over 100 years, while soybean oil sprays have been developed only recently.

Degummed crude soybean oil dormant sprays can be as effective as a petroleum oil dormant spray for the management of SJS on apple trees. Oleic and linoleic acid are known to be toxic to insects and may contribute to the insecticidal properties of soybean oil sprays. Future studies could evaluate the effect of oleic acid in soybean oil on insects, and possible methods to enhance the effectiveness of soybean oil as and insecticidal spray by increasing the oleic acid content. Other areas of study could concentrated on a developing a vegetable-based emulsifier for soybean oil. Soybean oil is likely to be effective for management of many species of aphids, scale insects and mites on various deciduous fruit trees and woody ornamentals.

The USDA (Bagby 1992) made a commitment to seek alternative uses for domestic agricultural products and issued a challenge to researchers to pursue possible alternative uses. Soybean oil dormant sprays appear to meet this challenge and can be added to the list of alternative uses of soybeans. Soybean oil is also a potential diesel fuel substitute or additive (Abelson 1995). Workers at the University of Illinois and Illinois Natural History Survey are currently working on a soybean oil larval mosquito insecticide, which would provide an alternative to diesel oil in mosquito control programs (National Soybean Research Laboratory 1995). Collectively, these new uses for soybean oil could expand the market for soybean growers. Soybean oil shows promise as a dormant spray for management of several scale insect species and mites.

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