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Management of european red mite populations on apple and plum trees with soybean oil

Elizabeth R. Bolles

To the Graduate Council:

I am submitting herewith a thesis written by Elizabeth R. Bolles entitled "Management of european red mite populations on apple and plum trees with soybean oil." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Entomology and Plant Pathology.

Charles D. Pless, Major Professor

We have read this thesis and recommend its acceptance:

Ernest Bernard, Dennis Deyton

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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Date 24 July 1995

MANAGEMENT OF EUROPEAN RED MITE POPULATIONS ON APPLE AND PLUM TREES WITH SOYBEAN OIL

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Elizabeth R. Bolles

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ABSTRACT

Degummed soybean oil emulsions were compared to a standard petroleum oil emulsion for efficacy against overwintering and summer populations of European red mite, (ERM), Panonychus ulmi Koch, on apple and plum trees in a commercial orchard, Russellville, TN, in 1994 and 1995. Oils were applied with a handgun sprayer to dormant and delayed-dormant bud stage trees to kill overwintering ERM eggs and suppress mite populations. Summer oil applications were tested on apple for their effect on motile ERM and predatory mites.

A dormant application of 5.0% soybean oil plus a delayed-dormant application of 2.0% soybean oil significantly reduced ERM populations in April, May, and June on apple. A summer spray of 0.5% soybean oil reduced ERM densities below densities on the control trees or the 0.25% soybean oil-treated trees. ERM densities were lower on plum trees treated with a dormant application of 5.0% soybean oil plus a delayed-dormant application of 2.0% soybean than densities on control trees in June 1994. The use of soybean oil emulsions has potential as a management practice for winter and summer ERM populations on apple and plum trees.

ERM larvae appeared on apple trees in early April. In eastern Tennessee, oil sprays should be most effective when

applied just prior to the hatching of overwintering eggs, in late March. Approximately eight generations of ERM were observed on apple in 1994.

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1. INTRODUCTION

The European red mite (ERM), _Panonychus ulmi_ (Koch), exists in orchards worldwide (Beers and Hull 1987). In an unsprayed orchard there is a balance between ERM and its predators that prevents phytophagous mite outbreaks (Huffaker et al. 1970). Commercial orchards employ a wide range of practices that affect the natural balance between ERM and its predators. A disruption in regular control practices can lead to the development of a serious mite problem (Sanford and Herbert 1970, Beers and Hull 1987). Populations of predatory mites and insects are affected by applications of nonselective insecticides, which eliminate a natural means of control for ERM (Sechser et al. 1984). Heavy infestations of ERM can develop as a result of the mite's resistance to pesticides and its high reproductive capacity, eventually causing a reduction in tree health (Chapman et al. 1952, Beers and Hull 1987, 1990).

For decades the most successful treatment for orchard crops against ERM has been applications of petroleum oils (PO) in the dormant and "delayed-dormant" bud stages of the trees (Chapman 1967). Over the years mites have developed resistance to commonly used acaricides (Georghiou and Mellon 1983, Welty et al. 1987), but the mites have not developed resistance to petroleum oils, even with continued applications (Rock and Crabtree 1987, Agnello et al. 1994).

The future use of petroleum oils, however, may be altered since they are derived from an nonrenewable resource. Also, there is only moderate potential for the use of petroleum oils against summer mite populations (Rock and Crabtree 1987).

An alternative to petroleum oils are plant-derived oils, which represent a renewable resource that can also be continually applied without mite resistance. Formulations of plant oils have potential to be as effective as petroleum oils in controlling insects and mites. Plant oils possess the additional positive qualities of being inexpensive, non-toxic, and environmentally safe (Hesler and Plapp 1986, Rock and Crabtree 1987, Butler and Henneberry 1990). Much of the research on plant-derived oils has focused on insect and mite pests of vegetable crops and stored products. Fewer studies have examined plant oils as insecticides for orchard crops. The objectives of my research were 1) to evaluate the comparative efficacy of a plant oil, soybean oil, and petroleum oil on winter and summer populations of ERM on orchard crops, 2) to determine the effect of soybean oil on populations of predatory mites, and 3) to monitor the life cycle of ERM in Hamblen County, TN, to determine proper application times for soybean oil.

2. LITERATURE REVIEW

Orchards of apple and plum are hosts to a complex of pests, including over 500 species of insects and mites (Reissig et al. 1984). In commercial orchards, management programs emphasize the use of pesticides for the prevention or control of insect, mite, or disease outbreaks (Hall 1983, Hull et al. 1983, Prokopy et al. 1980, Teete et al. 1979). General applications of pesticides against primary pests have led to the emergence of secondary pest problems (Brown and Welker 1992). In Canada, the United States, and Europe, phytophagous mites have developed into the leading indirect pests of orchard crops (Sanford and Herbert 1970). The most economically important of these mite pests is ERM (Lienk 1972).

In the early 1900's, ERM was introduced into Canada and the United States from Europe. The records of Caesar (1915) and Ewing (1912) are the first documentations of ERM in Ontario and Oregon, respectively. Newcomer and Yothers (1929) observed mite populations in the Pacific Northwest. Although the mite was observed on fruit trees in Quebec in 1930 and 1931, it was not until 1945 that significant mite damage to trees was noted there (Parent and Beaulieu 1957). ERM activity was reported in Virginia in 1946 (Cagle 1946), and within several years infestations were common in apple-growing regions of the northern and northeastern United States, as well as in North Carolina and Georgia.

The wide distribution and importance of ERM has prompted numerous studies of its life history (Cagle 1946, Herbert 1970, Parent and Beaulieu 1957, Ramsdell and Jubb 1979). Climate influences the number of generations per year, with six in southeastern Ontario (Ross and Robinson 1922), eight in apple-growing regions of New York and Michigan, and nine in Virginia (Cagle 1946). As many as ten generations per year have been observed in Georgia, the southernmost point of ERM occurrence in the northern hemisphere (Majd 1986). For all areas the general life cycle is the same. Beginning in late summer and continuing until October or November, females are induced by changes in photoperiod, temperature, and nutrition to lay overwintering eggs on branches, spur shoots, and in small cracks in the bark of trees. These eggs are dark red and possess a stalk. Eggs require exposure to temperatures of 1° to 9° C for 100 days to break diapause (Lees 1950). In spring, several weeks of temperatures above 7° C stimulate hatching, and four stages follow: larva, protonymph, deutonymph, and adult. Summer eggs, which are yellow or light red, are deposited by each generation of adults on the undersides of leaves. Larvae emerge in several days. Most mites hatch from fertilized eggs, but mites also produce offspring by parthenogenesis.

All stages of ERM feed on plant tissue, which can result in significant damage to trees. In the process of feeding, the mite stylet penetrates leaf tissue and removes the contents of cells (Tomczyk and Kropczynska 1985); chloroplasts are destroyed. The leaf surface also sustains mechanical damage, which can interfere with transpiration. Stomatal function is disrupted, causing an increase in water loss (Sances et al. 1979, DeAngelis et al. 1982). The leaves may eventually suffer from wilt. In addition to mechanically injuring cells through penetration of leaf tissue, the mites inject saliva into the tissue, which can result in a toxic effect on the plant (Andrews and LaPre 1979). The injected substances can be translocated to other parts of the plant, including roots or young shoots (Avery and Briggs 1968).

In response to the mechanical damage and the physiological changes that result from mite feeding, trees exhibit changes that are observed in the current year and in successive years (Hardman et al. 1985). Studies by Chapman et al. (1952) demonstrated that infested trees had less overall growth than noninfested trees at the end of the growing season. Lienk et al. (1956), in continuing the study by Chapman, noted a vast difference the following year in the amount of bloom on infested and noninfested trees. The feeding of mites the previous season interfered with fruit bud differentiation, causing a 75% reduction in the number of fruit buds formed. Ultimately, the productivity of the tree was affected, causing a decrease in the number of fruits. Beers and Hull (1990) reported the effects of early-, mid-, and late-season mite infestations on apple. Mean fruit weight was reduced by mite injury at mid-season, and mid- and late-season injury resulted in fruit that were less firm. They noted a reduction in return bloom the following season.

For a century, several management schemes have been practiced for the control of detrimental mite species. The use of acaricides dates back to the turn of the century and continues to the present. In the late 1800's sulfur, an inorganic acaricide, was the principal control treatment for mite outbreaks. Several mite species were effectively controlled with sulfur applications, but species of the genus Panonychus were not significantly affected. The introduction of dinitrophenol acaricides during the 1930's marked the beginning of the synthetic organic acaricides. Applications of dinitrophenol to fruit crops resulted in varying degrees of control. Overall, they proved to be ineffective for consistently controlling mite populations over the growing season. The late 1940's marked a point of increased acaricide development that continued for thirty years. Numerous chlorinated hydrocarbons (CH) were applied for the control of tetranychid mites with initial success. Repeated applications of chemicals such as Ovex, Aramite, Tetradifon, and several others resulted in mite resistance (Smith 1960). The organophosphate and carbamate acaricides followed the pattern of CH in that initial applications effectively controlled mites, but mites developed resistance to the chemicals following three or four treatments (Newcomer and Dean 1953). Over the past several years the availability of acaricides has been reduced because of mite resistance and toxicity of the chemicals to natural enemies (Marshall and Pree 1991). In New York, ERM has developed resistance to 11 acaricides (Georghiou and Mellons 1983), and the effectiveness of cyhexatin, one of the most commonly used acaricides, has decreased (Welty et al. 1987). The application of acaricides can lead to an increase in phytophagous mite populations because of resistance in the pest and suppression of natural mite enemies.

The late 1800's also marked the introduction of PO sprays for control of fruit tree pests. The first petroleum control agent, kerosene, was utilized as a treatment for mites and soft-bodied insects in 1880 (Chapman 1967). Although positive results were obtained from the initial petroleum products (kerosene and lubricating oils), trees sustained considerable damage from their application (Davidson et al. 1991). In the early 1900's oil emulsions were developed that resemble the petroleum products of today. These oils dispersed well over the leaves, thus minimizing plant injury (Chapman et al. 1962). Since 1930, dormant and semi-dormant applications of PO have remained the most successful control strategy for fruit tree mite species (Chapman 1967).

PO exhibit several characteristics that contribute to their effectiveness. They are effective against all stages of mites including eggs, since they "interfere physically" with respiration (Johnson 1980). Mites and eggs eventually suffocate. The oil may also affect physiological processes by entering the mite through the respiratory system or through the egg membrane (Hesler and Plapp 1986). Mites are effectively controlled since they not able to develop resistance to PO, even with repeated applications (Rock and Crabtree 1987, Agnello et al. 1994).

Several studies have been conducted with PO to establish the most effective application procedures for management of ERM. Chapman and Pearce (1949) performed studies to "determine the efficiency of oil treatments applied at various intervals before hatching" of ERM. Their experiments established that susceptibility of ERM eggs to oils increased when applications were made nearer the egg hatching period, in the green-tip and delayed-dormant bud stages of the trees. A 0.25% oil spray applied immediately before hatch was as effective as a 3.0% oil spray applied thirty-nine days before hatch, when trees were in the dormant bud stage. Since ERM eggs are more susceptible to applications of oils applied closer to hatch, the timing of application determines the oil rate (Rock 1969). Applications of PO against overwintering populations of ERM remain one of the most effective means of preventing outbreaks of mites later in the season. The use of PO, however, is limited to the preblossom period since the oil is potentially phytotoxic when applied to foliage (Rock and Crabtree 1987). In tests with summer applications of PO, leaf damage became more severe as oil concentration increased (Agnello et al. 1994). High temperatures and dry conditions also intensified PO-induced phytotoxicity.

Although PO remains an effective means of controlling insect and mite outbreaks in orchard crops, plant-derived oils may represent an alternative means of control for fruit crop pests. The mode of action of vegetable oils resembles that of PO; therefore, vegetable oils have potential as a management practice for insect and mite pests. Several plant-derived oils have been used successfully for managing pests of cotton and vegetables. Emulsions of soybean and cottonseed oil reduced populations of sweetpotato whitefly (SPW) larvae, pupae, and adults on cotton and lettuce by 90% or more (Butler et al. 1988, Butler and Henneberry 1989). Formulations of cottonseed and castor oils reduced SPW immatures on cotton 84-95% and reduced cotton aphids 87-95% (Butler et al. 1991). Cotton, squash, lettuce, and carrot seedlings treated with cottonseed oil were repellent to populations of SPW adults for up to 9 days (Butler et al.

1989). Formulations of household cooking oils such as corn, coconut, palm, safflower, sunflower, peanut, and soybean oils plus various detergents reduced populations of SPW, several aphid species, and several Tetranychus mite species on vegetables (Butler and Henneberry 1990, 1991). Plant-derived oils have also been useful in managing pests of stored beans. Treatment of Phaseolus vulgaris L. seed with African palm and cottonseed oils provided nearly 100% control of bruchids (Schoonhoven 1978, Hill and Schoonhoven 1981). Bruchid population increases on Phaseolus aureus Roxb. were prevented with treatments of castor, mustard, coconut, and gingelly oils (Mummigatti and Ragunathan 1977).

Even though the application of plant oils exhibits potential as a pest management practice, only a few studies have been conducted to evaluate the efficacy of plant oils on pests of orchard crops. In the late 1920's comparative studies were conducted with PO and a number of vegetable oils, including cottonseed and linseed oils (deOng et al. 1927). Cottonseed oil was effective for control of California red scale on citrus; however, applications resulted in phytotoxicity. Cottonseed oil also had an ovicidal effect on grape berry moth (Taschenberg 1952). Rock and Crabtree (1987) found that applications of cottonseed oil on apple were not as good as PO for management of ERM eggs. Also, cottonseed oil used as a 0.5% postblossom spray provided little control of ERM, and resulted in phytotoxicity. Pless et al. (1994) found that a dormant application of 5.0% soybean oil caused 98% and >95% mortality of terrapin scale on peach and San Hose scale, respectively, on apple.

The use of oils for management of ERM may have an additional benefit. Oil sprays can be a part of an integrated management program, allowing for natural regulation of the active stages of ERM by predatory mites and insects. Since predatory mites and insects are more mobile than ERM, the predators are not as "susceptible to suffocation by the oil" (Agnello et al. 1994). Also, several predators overwinter as adults in vegetation around the trees, possibly minimizing contact with dormant and delayed-dormant oil sprays.

In an orchard, populations of predatory mites and insects play an integral role in the management of phytophagous mites. Predators are able to maintain ERM below economic thresholds when selective applications of pesticides are used (Sechser et al. 1984). However, poor application methods and timing of pesticides can eliminate predators of ERM. Since ERM has developed resistance to many synthetic pesticides, their populations may not be affected; however, the majority of predatory mites and insects can be killed by applications of pesticides. The predatory mites, Typhlodromus pyri Scheuten and Amblyseius fallacis (Garman), have acquired resistance to certain organophosphate and carbamate insecticides (Dover et al. 1979, Hardman and Rogers 1991). Typhlodromus pyri displays a positive response to tetranychid mite densities, but T. pyri is not as efficient as other predatory mites in consuming prey (Sabelis 1985, Hardman and Rogers 1991). Amblyseius fallacis densities do not increase as quickly as ERM densities (Walgenbach 1993). High numbers of pesticide-resistant ERM may not be effectively maintained below economic threshold by predatory mites. Predators are most effective at lower densities of ERM (Walgenbach 1993). Since ERM has not developed resistance to oil sprays, populations can be reduced by oils to levels where predators can be more effective.

The primary predatory mites belong to the families Phytoseiidae and Stigmaeidae. Phytoseiids are usually the most prevalent predatory group in an orchard and are represented by several species effective in managing ERM. In general, phytoseiids occur on foliage, bark, and humus (Tuovinen 1993). They overwinter as adult females on the ground and feed on mites in herbaceous vegetation. After the food source in the groundcover is depleted, the predators move into the tree canopy, usually later in the season when phytophagous mite populations increase (Croft and McGroarty 1977). Predatory mites feed on all ERM stages. Prey searching usually occurs from leaf to leaf; however, some species, such as A. fallacis, may move to another tree via aerial dispersal when prey densities decrease. Oviposition of predatory mites is stimulated by food consumption, temperature, and population age (Dover et al. 1979).

In Oregon, studies with Metaseiulus occidentalis (Nesbitt) and Typhlodromus pyri demonstrated that mixed populations of predators were very effective in controlling ERM (Croft and MacRae 1992). Also, M. occidentalis development was faster when prey densities were higher. The success of T. pyri in managing ERM was also attributed to the predatory mite's ability to survive on alternative food sources, such as mildew, pollen, eriophyid mites, and Tetranychus urticae (Koch), when populations of ERM decrease (Herbert 1956, Chant 1959, AliNiazee 1979, Overmeer 1985). The predatory mite Amblyseius fallacis is another effective predator and is common in apple orchards from Michigan to North Carolina (Strickler et al. 1987).

Two other common predatory mites are the stigmaeids Zetzellia mali (Ewing) and Agistemus fleschneri Summers. The former is the most significant stigmaeid predator in sprayed orchards and the latter occurs more often in abandoned orchards (Strickler et al. 1987). Santos (1976, 1982, 1984) determined the role of Z. mali in managing populations of ERM, along with other phytophagous mites. The activity of stigmaeids differs from that of phytoseiids. Stigmaeids concentrate on the undersides of leaves along the midrib and do not exhibit much movement between leaves. In addition to being predaceous on ERM, stigmaeids may also feed on other predators or survive without prey for several days. *Zetzellia mali* feeds only on eggs and immatures. Alone, *Z. mali* is not able to prevent ERM densities from increasing beyond an economic threshold (Santos 1976), but in combination with other predators, *Z. mali* is effective in managing phytophagous mites.

Several species of insects also play a role in ERM population management. The most effective insect predators of ERM are *Stethorus* spp. (Coccinellidae). Both adults and larvae feed on ERM. Prey detection by this beetle differs from that of predatory mites. Fleschner (1950) and Putman (1955) determined that prey searching by *Stethorus* sp. was random and detection occurred with physical contact. Hull et al. (1977) suggested that a stimulus is also involved in prey location. However, ERM populations on a crop must be at a level which can sustain colonization by *Stethorus* sp. (Chazeau 1985). Also, an alternative food source must be available for the beetles after ERM populations are reduced.

Other insect predators associated with ERM belong to the families Chrysopidae, Coniopterygidae, Pentatomidae, Thripidae, and Miridae (Parent 1967). Chrysopids feed mainly on aphids, but exhibit efficient predation on ERM when the aphid population is reduced (Chazeau 1985).

Members of Conipterygidae are more noted for their general feeding habits, but one species, <u>Conwentzia</u> <u>pineticola</u> End., is an effective predator of ERM in England (Chazeau 1985). The other taxa, Pentatomidae, Thripidae, and Miridae, may only be opportunistic feeders on ERM.

3. METHODS AND MATERIALS

Apple cultivars, 'Red Rome', 'Winesap', and 'Golden Delicious', and plum cultivars, 'Redheart' and 'Starking Delicious', were evaluated on 4 October 1993 for leaf bronzing due to mite feeding, and for overwintering populations of ERM in White's Little Mountain Orchard, Russellville, TN. Randomized complete block designs were established, with 4 replications in apple and 3 replications in plum. In 1994, experiments were conducted February through September, and in 1995 experiments were carried out February through June. All experimental trees were subject to the practices of a commercial orchard, including summer applications of pesticides and general maintenance. The spray program of the grower was adapted from the program outlined in the "Commercial Fruit Spray Schedules" distributed by the University of Tennessee Agricultural Extension Service; however, the grower did not apply a dormant oil to the experimental trees (Table 1A).

On 18 February 1994, dormant apple and plum trees were sprayed to runoff with one of three treatments: 1) 5.0% degummed soybean oil (SO) (Archer-Daniels Midland, Chattanooga, TN) plus 0.6% Latron B-1956 (LB) (Rohm and Haas, Philadelphia, PA); 2) 2.5% SO plus 0.3% LB; 3) 2.5% Volck Supreme Spray (petroleum oil) (PO) (Valent U.S.A. Corporation). All treatments were applied at 60 p.s.i. with a battery powered handgun sprayer. The controls were left unsprayed. Apple and plum trees in the delayed-dormant bud stage received a second application of either 1) 2.0% SO plus 0.24% LB, 2) 0.5% SO plus 0.06% LB, or 3) 2.0% PO. Apple trees received this spray on 30 March and plum trees on 12 March. Control trees were not sprayed. Apple trees received a third treatment on 7 July 1994: 1) 0.5% SO plus 0.06% LB; 2) 0.25% SO plus 0.03% LB; or 3) 0.25% PO. The controls were not sprayed.

On 20 and 25 February 1995, apple and plum trees, respectively, received the same treatment of dormant oil sprays used in 1994. The delayed-dormant sprays were applied on 1 April and 13 March, to apple and plum, respectively, at the same rates as the previous year.

Between 15 April and 14 September 1994, and 18 April and 12 June 1995, ERM populations were evaluated at weekly intervals by collecting ten intermediate-aged leaves at mid-shoot per tree. Leaves were collected around the entire tree, alternating with the interior and exterior portion of the tree. The leaves were placed in plastic containers and taken to a laboratory where motile mites and eggs were counted with the aid of a binocular microscope. The apple rust mite, <u>Aculus schlectendali</u> (Nalepa), two-spotted spider mite, <u>Tetranychus urticae</u> Koch, and predatory mites also were counted. The number of ERM generations occurring in Hamblen County, TN, was determined by observing the development of mites in the field and assessing the mite stages on leaf samples collected from trees.

Data collected from the experiments were $\log_{10}$-transformed and analyzed with ANOVA and Duncan's Multiple Range Test ($P<0.05$) (SAS Institute 1987). A threshold of 20 mites per leaf based on injury and decision thresholds established in North Carolina (Walgenbach 1993) was used in this study.

4. RESULTS AND DISCUSSION

1994 FIELD STUDY

European red mite. ERM populations on apple were reduced by dormant, delayed-dormant, and summer applications of SO and PO. Numbers of mites on control apple trees in 1994 steadily increased through April and May, reaching levels beyond an economic threshold of 200 mites per ten leaves in June (Fig. 1). Mite numbers on oil-treated trees remained significantly lower than mite numbers on untreated trees. Oil treatments were similar in April, May, and June. The number of eggs on control and oil-treated trees in April, May, and June was similar to the density pattern of motile mites. As the mite densities increased on the control trees, the number of eggs also increased, reaching their highest numbers in June. All oil-treated trees had lower numbers of eggs in April, May, and June than the control trees (Fig. 2).

At the beginning of July 1994, mite numbers on the controls decreased due to environmental factors, but they increased again in the remainder of the month (Fig. 3). In the following months, densities steadily decreased in the controls. Hamblen County received several days of rain during the first days of July, creating what is considered to be unfavorable conditions for mite development (Ramsdell and Jubb 1979). On 5 July, mite numbers decreased on

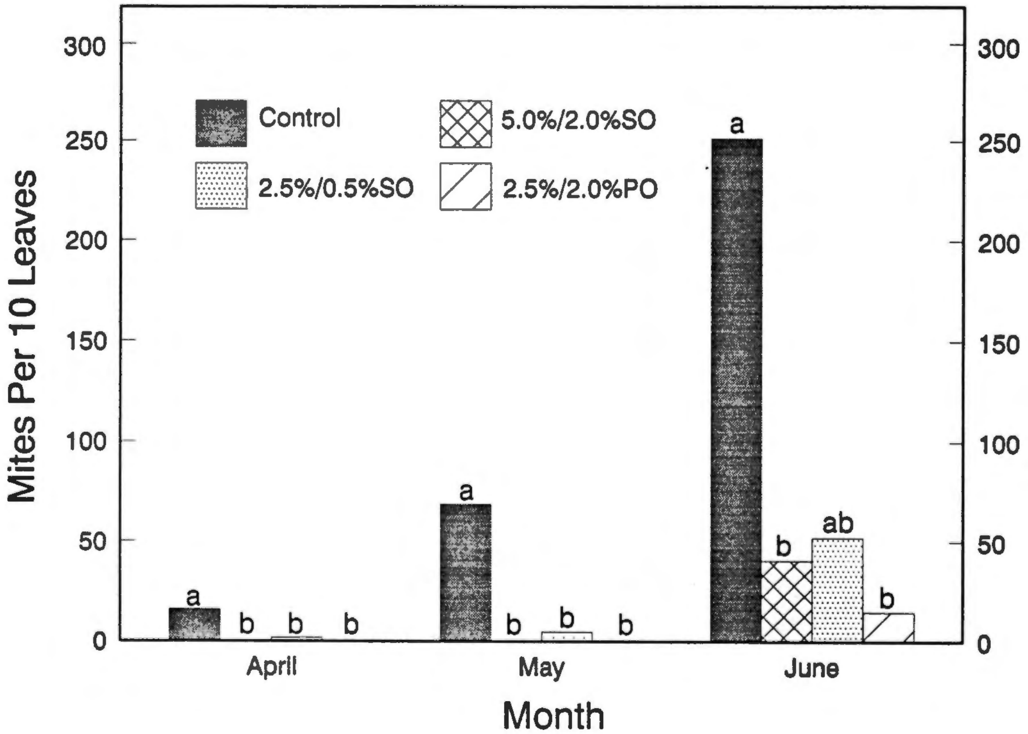

Fig. 1. Panonychus ulmi on leaves collected from apple trees sprayed in 1994 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 2.0% PO. Each column is the mean of 4 replicates. Columns with a common letter are not significantly different (P<0.05).

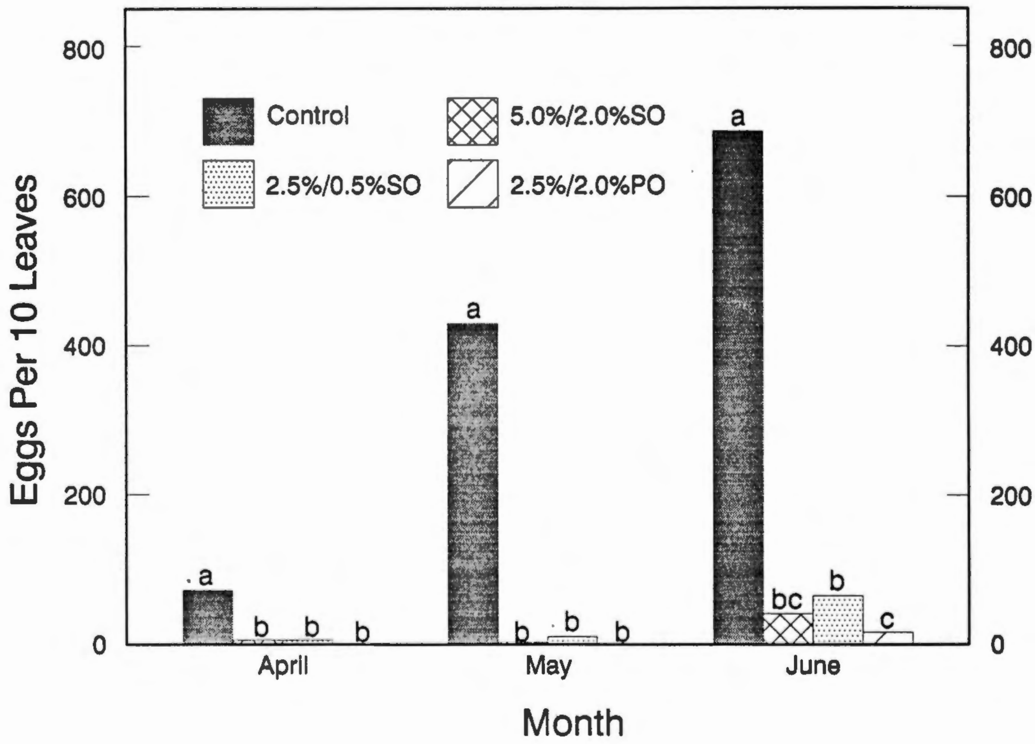

Fig. 2. <u>Panonychus</u> <u>ulmi</u> eggs on leaves collected from apple trees sprayed in 1994 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0, or 0.5% SO, or 2.0% PO. Each column is the mean of 4 replicates. Columns with a common letter are not significantly different ($P<0.05$).

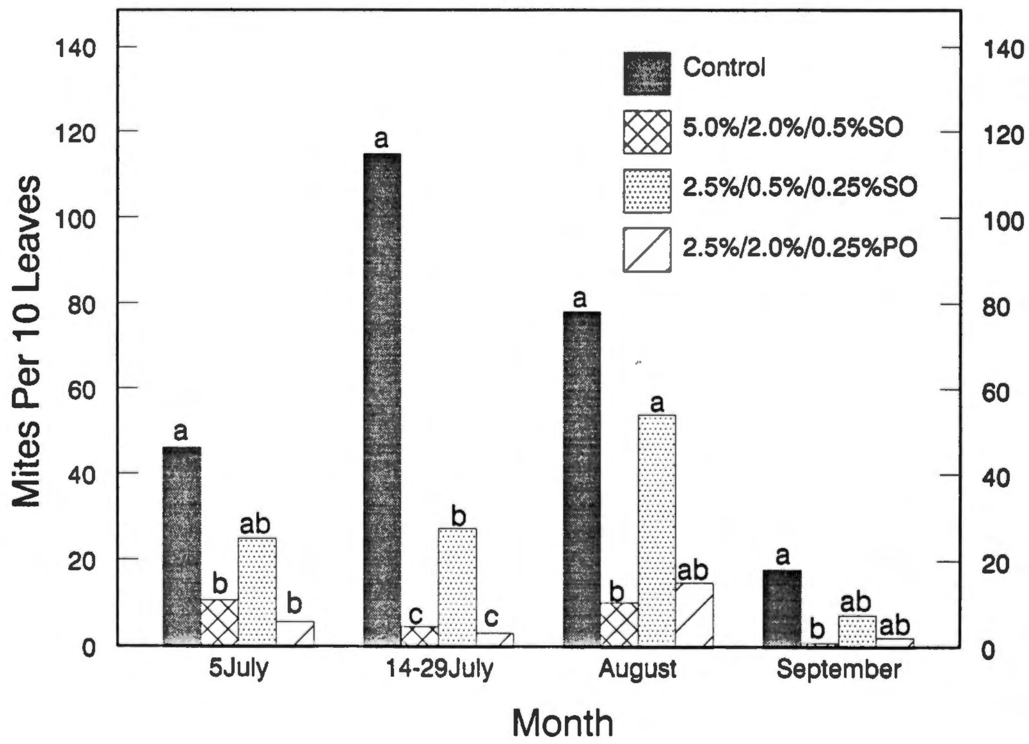

Fig. 3. Panonychus ulmi on leaves collected from apple trees sprayed in 1994 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 2.0% PO. On 7 July trees were sprayed with a summer application of 0.5 or 0.25% SO, or 0.25% PO. Each column is the mean of 4 replicates. Columns with a common letter are not significantly different ($P<0.05$).

control trees. Numbers of mites on the trees receiving the higher SO rate or PO remained lower than on the controls, even after densities were reduced in the controls on 5 July. Following the summer spray on 7 July, mite numbers increased again on control trees. The summer rates of 0.5% SO and 0.25% PO provided the greatest control of mites in July and August. The rate of 0.25% SO reduced mite numbers in July, but not enough to prevent a buildup the following month. In August, the number of mites on trees of the 0.25% SO treatment did not differ from numbers on the control. The lowest numbers of mites in August, ten mites per ten leaves, occurred on trees which had received the 0.5% SO treatment. In September, mite populations declined on all trees, probably in response to changes in photoperiod, temperature, or nutrition; however, fewer mites were on the trees which received the 0.5% SO treatment than on control trees.

In July, August, and September, the number of eggs on treatment trees corresponded to the pattern of mite numbers (Fig. 4). The decline in the mite population at the beginning of July resulted in a reduction in egg numbers. The numbers of eggs on control and oil-treated trees were not different on 5 July. After the 7 July summer spray, the lowest numbers of eggs occurred on the 0.5% SO and 0.25% PO treated trees. The numbers of eggs in these treatments were significantly different from those of the control and the

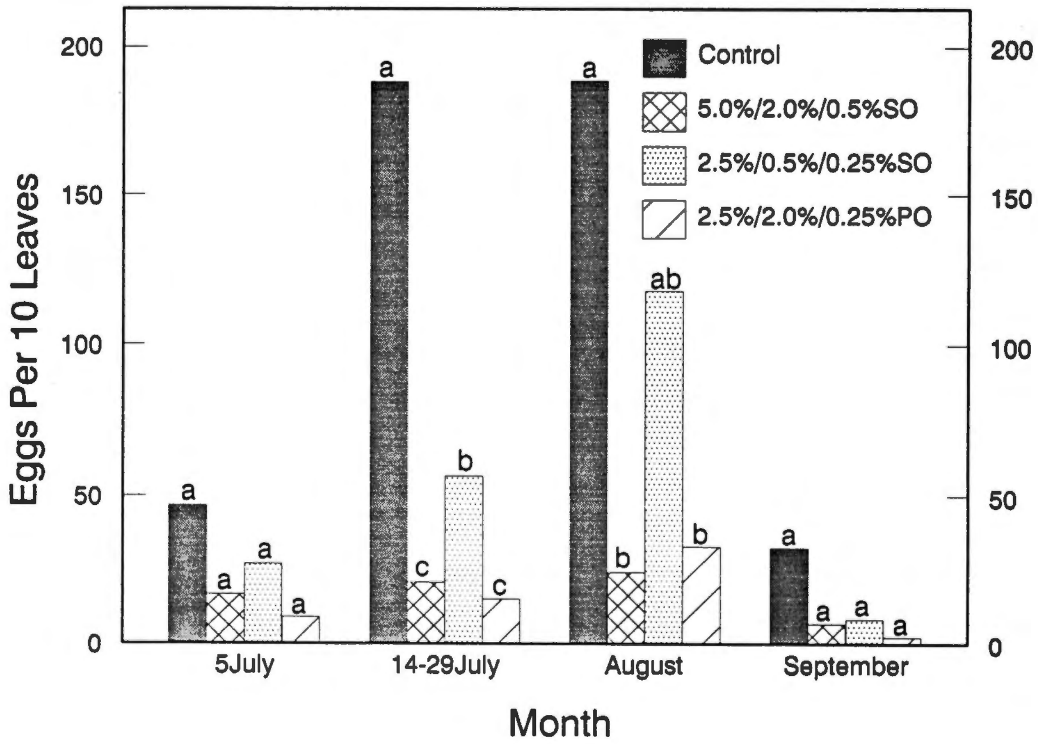

Fig. 4. Panonychus ulmi eggs on leaves collected from apple trees sprayed in 1994 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 2.0% PO. On 7 July trees were sprayed with a summer application of 0.5 or 0.25% SO, or 0.25% PO. Each column is the mean of 4 replicates. Columns with a common letter are not significantly different (P<0.05).

0.25% SO treatment. The 0.25% SO rate reduced the number of eggs in July, but the number was not significantly different from that of the control in August. The number of eggs on leaves declined on all trees in September, when females had begun to deposit overwintering eggs on other part of the trees. There was no difference in the number of eggs on the control and oil-treated trees in September.

In the 1994 season, populations of ERM were first found on plum in June. Eggs were present on leaves of two control trees on 7 June and motile mites were first collected on 14 June. The collection of eggs before mites may indicate that the sampling procedure was inadequate to detect low densities on plum early in the season. The plum trees were an average of 3.7 meters high and extremely branched. Mites may have been present prior to 14 June in the upper portions of the trees where samples were not taken.

Throughout June, July, and August the number of mites on all control and oil-treated plum trees remained significantly below a decision and economic threshold of 85 and 200 mites per ten leaves, respectively (Fig. 5). The number of mites on oil-treated trees were not different from the controls in June and July. The lack of statistical difference between mite numbers on control and oil-treated trees also may have indicated that complete coverage of the trees was not obtained with the dormant and delayed-dormant sprays, since spray effectiveness may have been reduced by

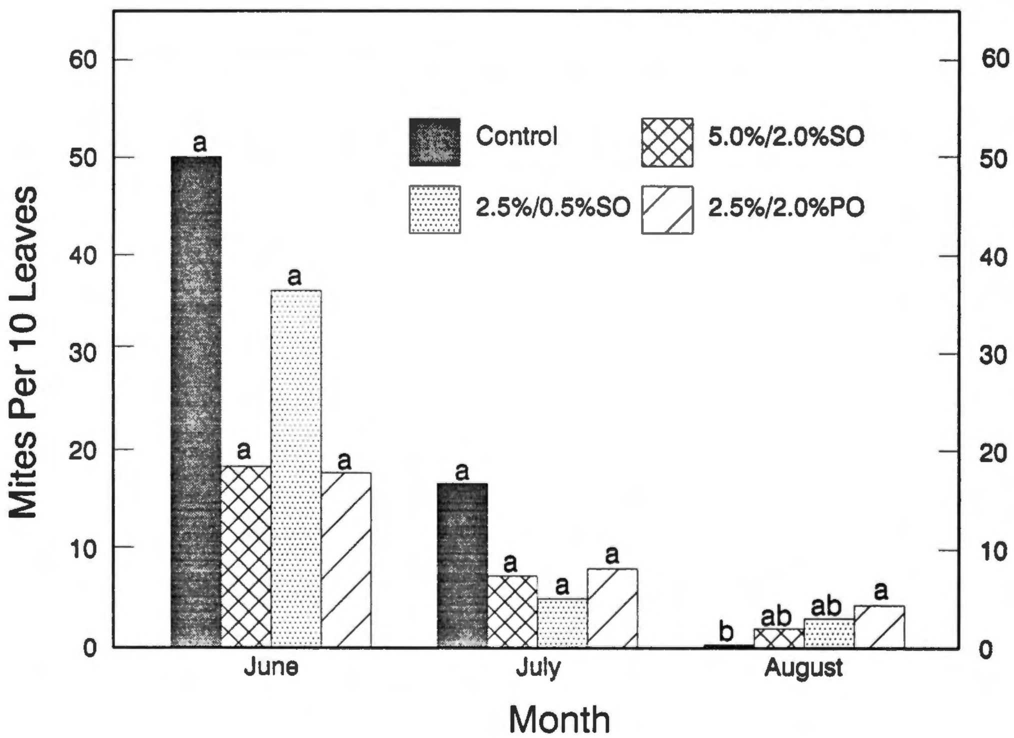

Fig. 5. Panonychus ulmi on leaves collected from plum trees sprayed in 1994 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 2.0% PO. Each column is the mean of 3 replicates. Columns with a common letter are not significantly different ($P<0.05$).

the large size of the unpruned trees. In August, the populations of mites on control and oil-treated trees averaged less than ten mites per ten leaves. The control trees possessed the lowest numbers of mites, which was statistically different from the mean number on the PO treatment. Trees of the higher and lower SO rates had mite numbers similar to those on control and the PO-treated trees. Even though a statistical difference existed among the control and treatments in August, mite numbers were very low, and the difference may have been due to the random leaf collection procedure. The statistical difference may not actually indicate a difference in effectiveness of treatments.

The number of eggs on plum in June, July, and August was similar to the density trends of motile mites during those months (Fig. 6). Trees receiving the higher SO rates or PO had the lowest numbers of eggs in June, 25 and 20 eggs per ten leaves, respectively. Egg numbers on PO-treated trees differed from those on the untreated trees, which had an average of >100 eggs per ten leaves. Number of eggs on SO-treated trees were not different from the number on control or PO-treated trees in June. In July and August there was no difference between the numbers of eggs on the control and oil-treated trees.

Apple rust mite. Beginning in June of the 1994 season, populations of the apple rust mite, Aculus schlectendali

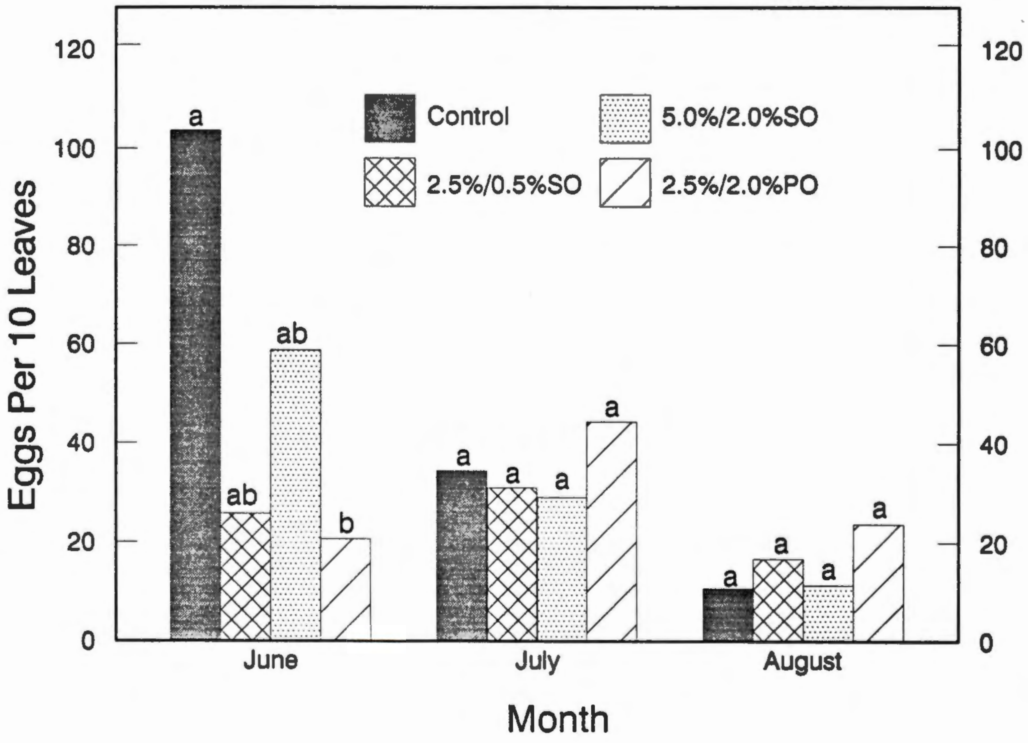

Fig. 6. Panonychus ulmi eggs on leaves collected from plum trees sprayed in 1994 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 2.0% PO. Each column is the mean of 3 replicates. Columns with a common letter are not significantly different ($P<0.05$).

(Nalepa), were found on apple trees (Fig. 7). The control leaves contained an average of 3,400 mites per ten leaves in June. Fewer mites were on trees treated with the higher SO rate or the PO standard than on the untreated trees, but mite numbers on trees with the lower SO rate did not differ from any other treatment. By 5 July, populations of apple rust mite had declined, and they remained low throughout the rest of July. There was no difference in mite populations on control and oil-treated trees in July.

Two-spotted spider mite. On apple and plum, two-spotted spider mite (TSSM) was first collected from trees on 14 June. In June, mite numbers on control apple trees averaged 100 mites per ten leaves (Fig. 8). Trees receiving the higher rate of SO, the lower SO rate, and the PO standard had 10, 45, and 3 mites per ten leaves, respectively. Densities of TSSM on PO-treated trees were different from those on the control and the lower SO rate. Mite numbers on the higher SO rate did not differ from the PO or lower SO rate. No TSSM were collected on 5 July, probably because there had been several days of rainfall previous to the collection of leaves. During the remainder of July and in August, TSSM were present but in low numbers. The controls averaged 27 mites per ten leaves on 14-29 July, and the controls in August had an average of 17 mites per ten leaves. Numbers of TSSM on control trees and PO-treated trees differed following the summer spray of 7 July. In

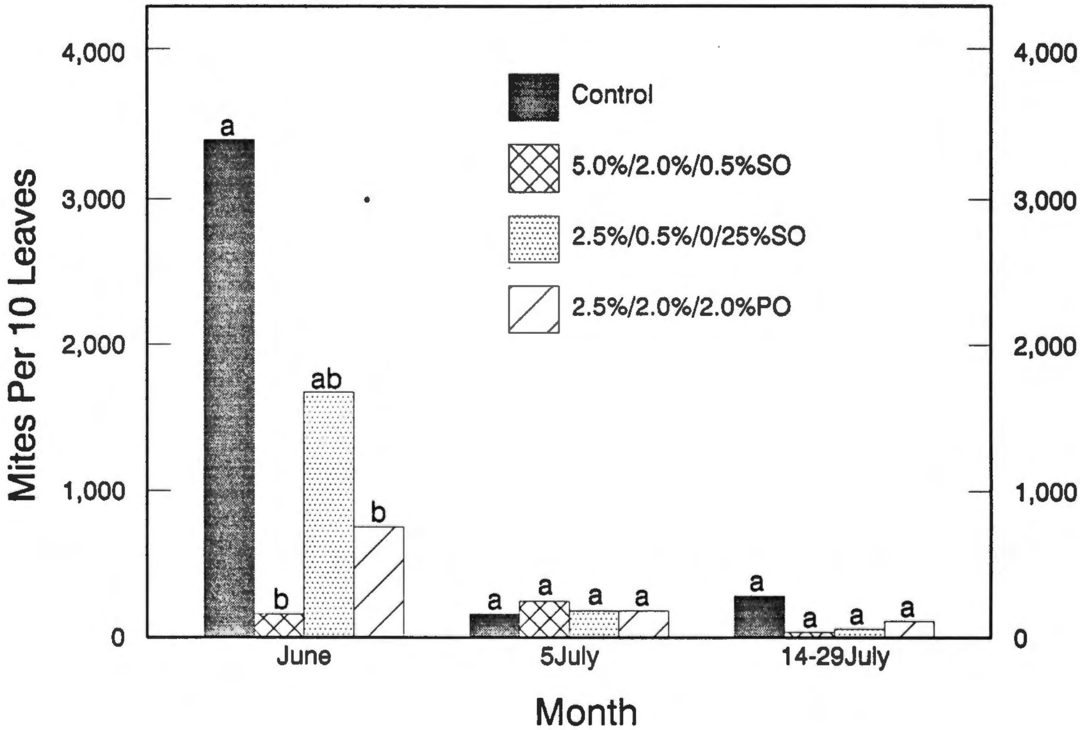

Fig. 7. Aculus schlectendali on leaves collected from apple trees sprayed in 1994 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 2.0% PO. On 7 July trees were sprayed with a summer application of 0.5 or 0.25% SO, or 0.25% PO. Each column is the mean of 4 replicates. Columns with a common letter are not significantly different ($P<0.05$).

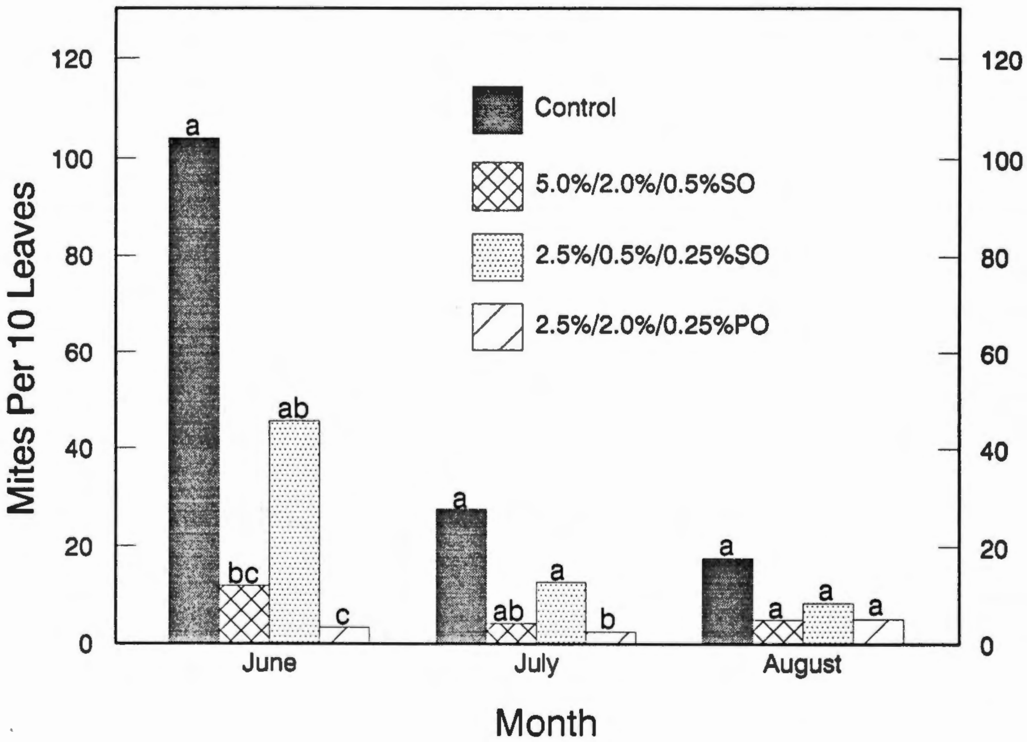

Fig. 8. Tetranychus urticae on leaves collected from apple trees sprayed in 1994 with dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 2.0% PO. On 7 July trees were sprayed with a summer application of 0.5% or 0.25% SO, or 0.25% PO. Each column is the mean of 4 replicates. Columns with a common letter are not significantly different ($P<0.05$).

August, there was no difference in mite numbers on control and oil-treated trees. The decline in August densities may have been the result of mites moving from apple trees to surrounding vegetation. No TSSM was collected from apple trees in September.

Numbers of TSSM collected from plum (Fig. 9) were lower than the number collected from apple. In June and July, control plum trees averaged 6 mites per ten leaves. Even fewer TSSM were collected from the oil-treated trees. There was no significant difference in TSSM numbers among the treatments in June and July. No mites were found on leaves during collections in August. The low numbers of TSSM may be due to either the movement of mites between trees and surrounding vegetation or the concentration of TSSM in the upper portions of trees where leaf samples were not taken.

Predatory mites. In 1994, predatory phytoseiids and stigmaeids were collected from apple trees from June through September and on plum trees in July and August. Numbers of predatory mites remained low on apple in 1994 (Fig. 10). The two predatory mites collected were the phytoseiid, *Amblyseius* sp., and the stigmaeid, *Agistemus* sp.; *Amblyseius* sp. was the more prevalent. The highest numbers of predators were found on the control trees in June, with an average of 12 mites per ten leaves. The oil-treated trees had fewer than 3 predatory mites per ten leaves. Densities of predatory mites were lower on the oil-treated trees

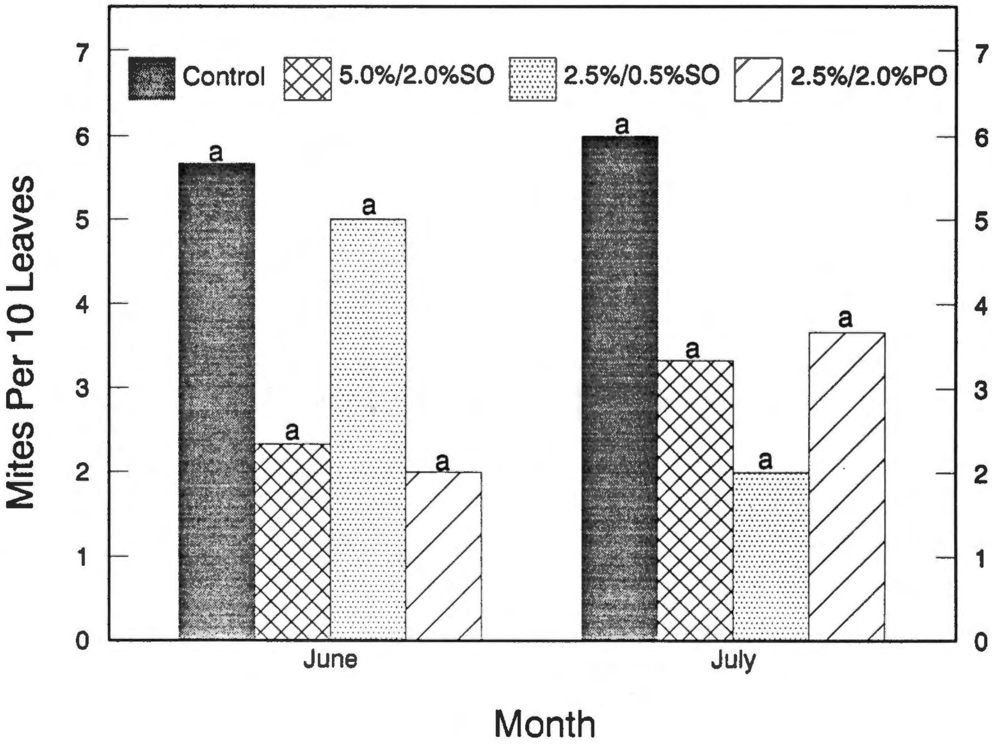

Fig. 9. Tetranychus urticae on leaves collected from plum trees sprayed in 1994 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0% or 0.5% SO, or 2.0% PO. Each column is the mean of 3 replicates. Columns with a common letter are not significantly different ($P<0.05$).

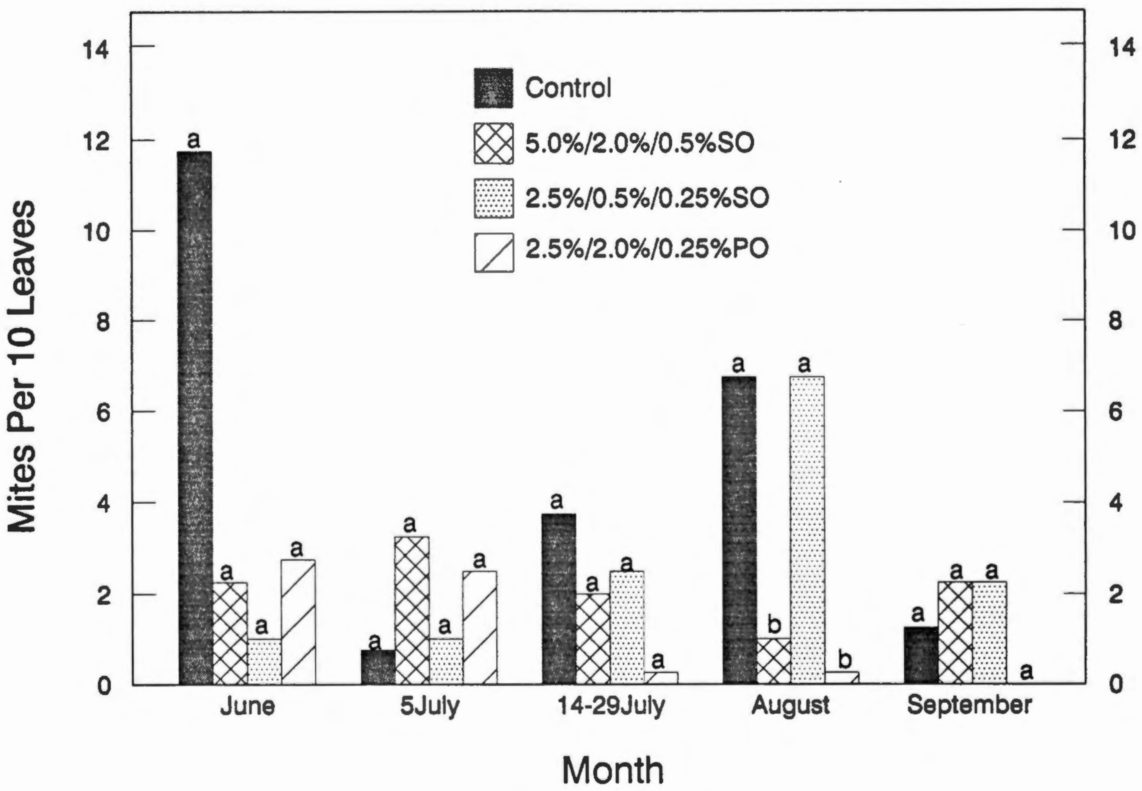

Fig. 10. Predatory mites on leaves collected from apple trees sprayed in 1994 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 2.0% PO. On 7 July trees were sprayed with a summer application of 0.5 or 0.25% SO, or 0.25% PO. Each column is the mean of 4 replicates. Columns with a common letter are not significantly different ($P<0.05$).

possibly because densities of their food sources, ERM or apple rust mite, were reduced by oil sprays. In the following month, the numbers of predatory mites on the control trees declined, possibly due to heavy rains. There was no difference between the number of mites on control trees and on oil-treated trees in June and July. In August, the number of mites on control trees and on low-SO trees increased to an average of 6.5 mites per ten leaves. The trees that were treated with PO or the higher SO rate had fewer mites than all other trees. Predaceous mites decreased in abundance in September and there were no significant differences in mite numbers among any of the treatments.

Numbers of predatory mites on plum were low in all treatments in July and August (Fig. 11). Mite densities were probably not affected by any oil residues left from dormant and delayed-dormant sprays. Differences in mite numbers among treatments may have been the result of random collecting procedures.

Tarsonemidae. In August, Tarsonemus sp. (Tarsonemidae), was collected from both apple and plum trees. Members of this genus feed on fungi (McDaniel 1979) and possibly are an alternative food source for predatory mites. This mite was present in low numbers on all trees (Fig. 12).

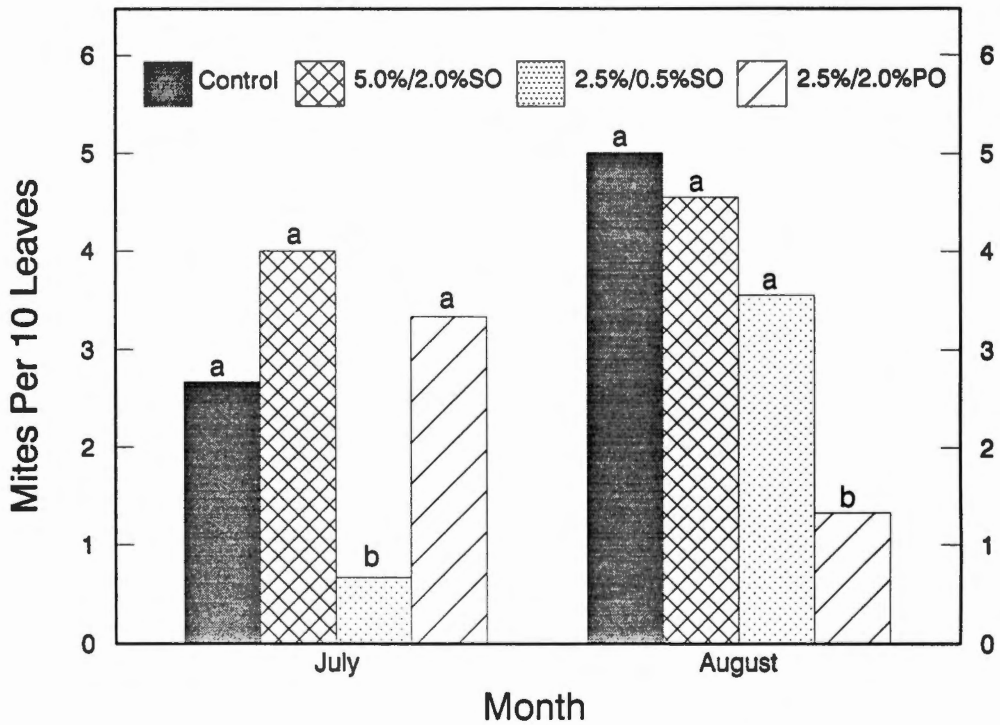

Fig. 11. Predatory mites on leaves collected from plum trees sprayed in 1994 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 2.0% PO. Each column is the mean of 3 replicates. Columns with a common letter are not significantly different ($P<0.05$).

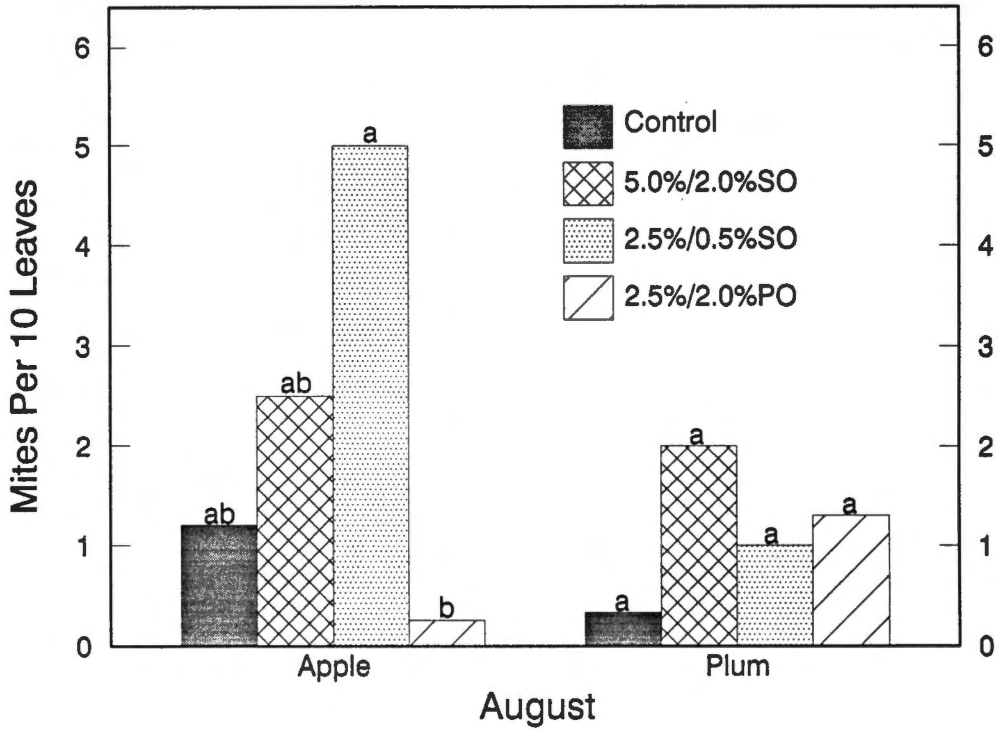

Fig. 12. Tarsonemus sp. on leaves collected from apple and plum trees sprayed in 1994 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 2.0% PO. Apple trees received an additional spray on 7 July with a high rate of 0.5% SO, or a low rate of 0.25% SO, or a standard PO rate of 0.25%. Columns with a common letter are not significantly different ($P<0.05$).

ERM Seasonality. During the 1994 season, eight generations of ERM were observed on apple. Winter-laid eggs began hatching in early April and continued into early May. Larvae were first observed on 8 April and summer eggs of ERM were first seen on leaves on 23 April, indicating the first generation. The developmental time from egg to adult averaged 16 days throughout the season. Winter eggs were observed on limbs on 7 September.

1995 FIELD STUDY

European red mite. ERM was first collected from apple on 10 April. Populations of ERM were affected by dormant and delayed-dormant oil treatments (Fig. 13). Throughout April, mite numbers on apple remained low in all treatments. ERM increased on control trees in May to an average of 98 mites per ten leaves. Mite numbers on trees receiving the higher SO rates or PO were different than those on control trees. Mite numbers on trees sprayed with the lower SO rates were not significantly different from mite numbers in the other treatments. In June, ERM densities increased on all trees but did not exceed the economic threshold; however, the highest populations were collected from trees sprayed with the lower SO rate, which had an average of 179 mites per ten leaves. The number of eggs on control and oil-treated trees in April and May (Fig. 14) corresponded with the populations of mites during those months. Egg

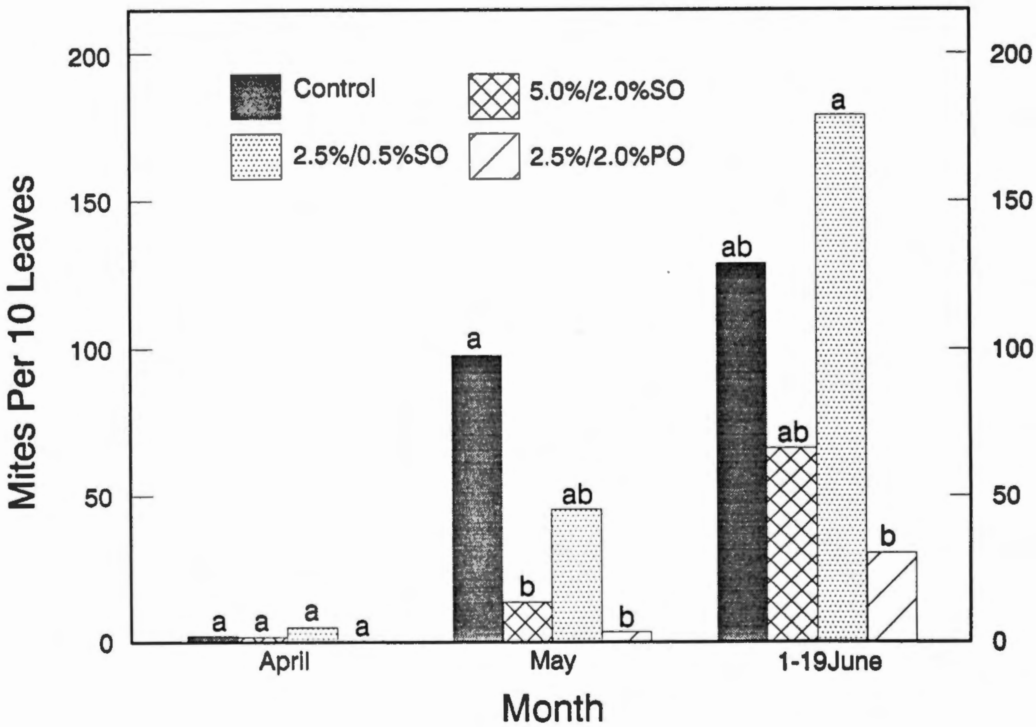

Fig. 13. Panonychus ulmi on leaves collected from apple trees sprayed in 1995 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 2.0% PO. Each column is the mean of 4 replicates. Columns with a common letter are not significantly different (P<0.05).

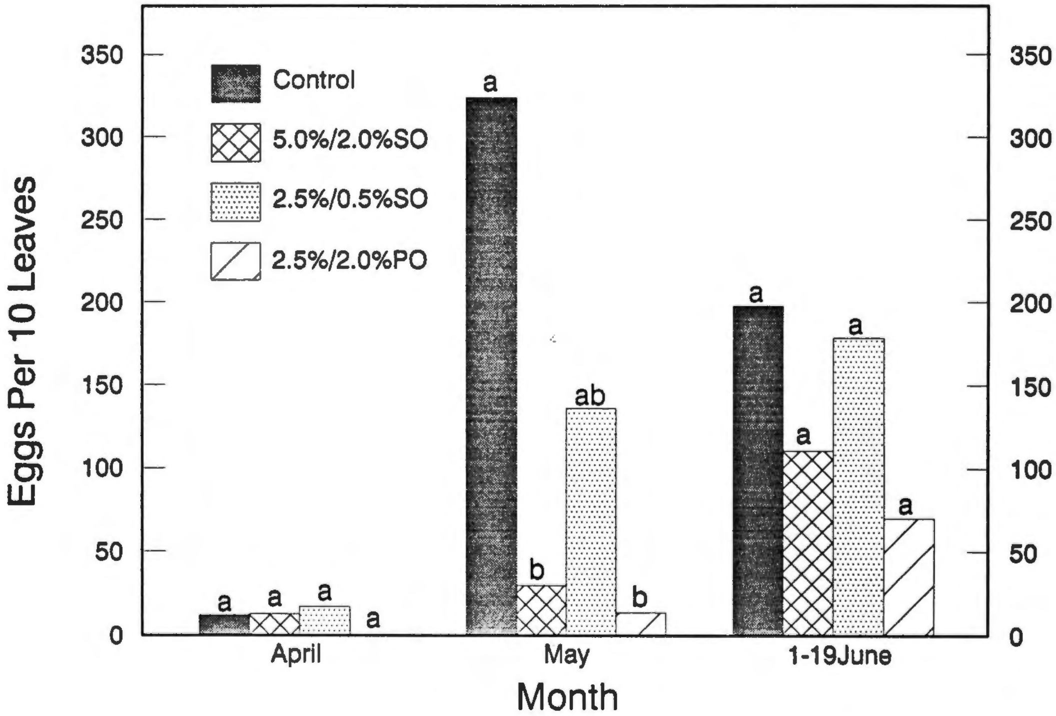

Fig. 14. Panonychus ulmi eggs on leaves collected from apple trees sprayed in 1995 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 2.0% PO. Each column is the mean of 4 replicates. Columns with a common letter are not significantly different ($P<0.05$).

numbers were low in April on all trees, when mite populations were low. The increase in mite numbers in May on control trees resulted in an increase in the numbers of eggs, averaging 323 eggs per ten leaves. The lowest numbers of eggs in May were collected from trees treated with the higher SO rates or the PO standard, with 30 and 13 eggs per ten leaves, respectively. In June, the mean number of eggs on control trees decreased, even though higher numbers of mites were present on leaves; however, the egg numbers remained greater than motile mite numbers in June. There was no difference between the mean number of eggs on control and oil-treated trees in June.

In 1995, ERM populations were collected from plum trees on 19 April, much earlier than in the previous year. From April through June, mite densities remained low, and there was no difference in mite numbers among the treatments in April and May (Fig. 15). Fewer mites were found on control trees in June than in May, probably since leaves were collected only for the first part of the month. Trees receiving the lower SO rates had the highest numbers of mites and the numbers differed from the PO-treated trees, which had the lowest ERM numbers. Numbers of ERM eggs remained low among all treatments in April, May, and June (Fig. 16). There was no difference in egg numbers among the treatments in April and May. In June, PO-treated trees had

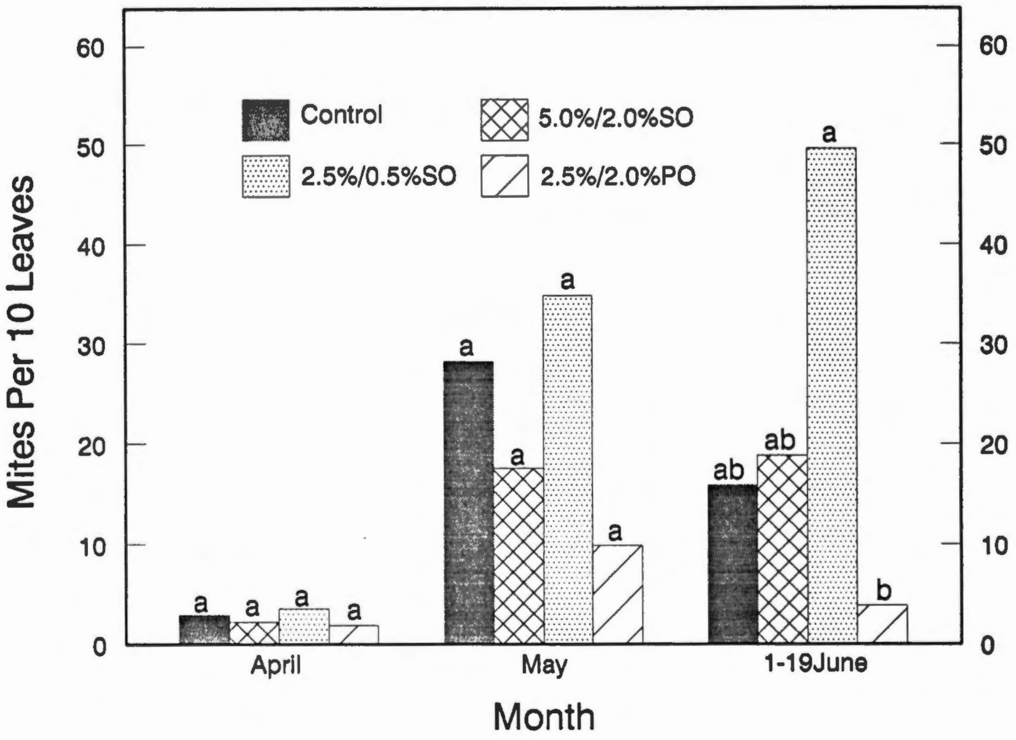

Fig. 15. Panonychus ulmi on leaves collected from plum trees sprayed in 1995 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 2.0% PO. Each column is the mean of 3 replicates. Columns with a common letter are not significantly different (P<0.05).

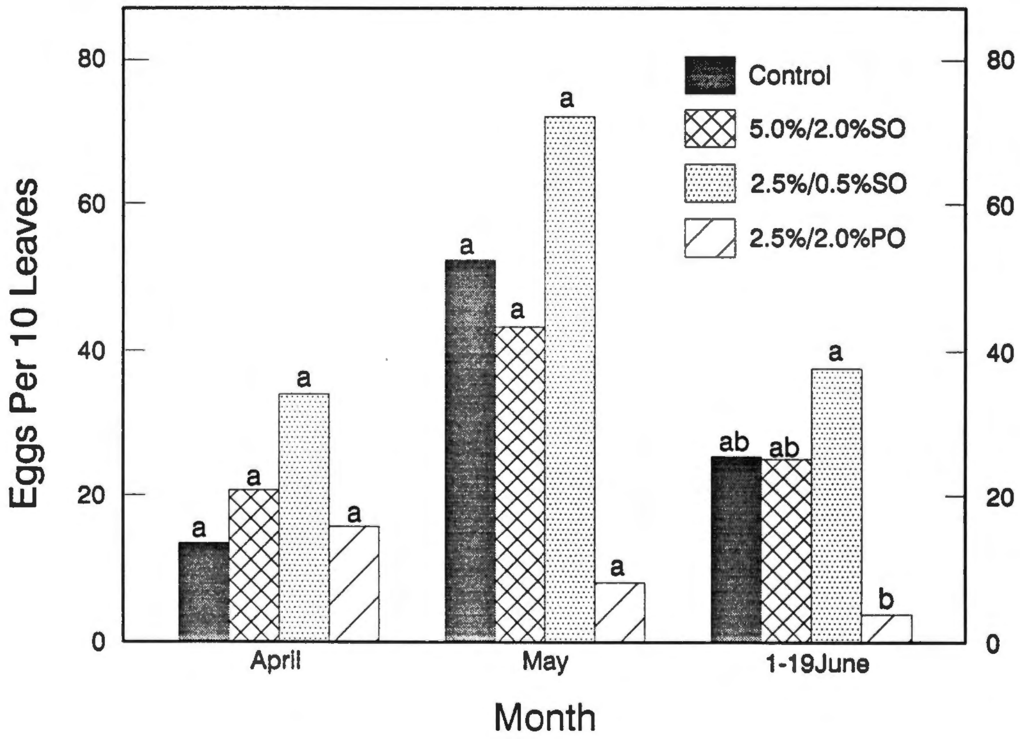

Fig. 16. Panonychus ulmi eggs on leaves collected from plum trees sprayed in 1995 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 0.5% PO. Each column is the mean of 3 replicates. Columns with a common letter are not significantly different ($P<0.05$).

the fewest eggs and egg numbers were different from those on the lower SO rate of SO-treated trees.

Two-spotted spider mite. TSSM was collected from both apple and plum trees much earlier in 1995 than in 1994. TSSM was first collected from apple on 19 April and from plum on 3 May. Numbers of mites in all treatments were low (Figs. 17-18). In April, May, and, June there was no difference in mite numbers among the treatments. The largest numbers of TSSM, 25 mites per 10 leaves, were collected from trees sprayed with the lower-SO rate. On plum trees, there was no difference in numbers of mites among the treatments. The low densities of TSSM collected from both apple and plum trees probably were due to the slow movement of the mites into trees early in the season while a food source still remained in surrounding vegetation.

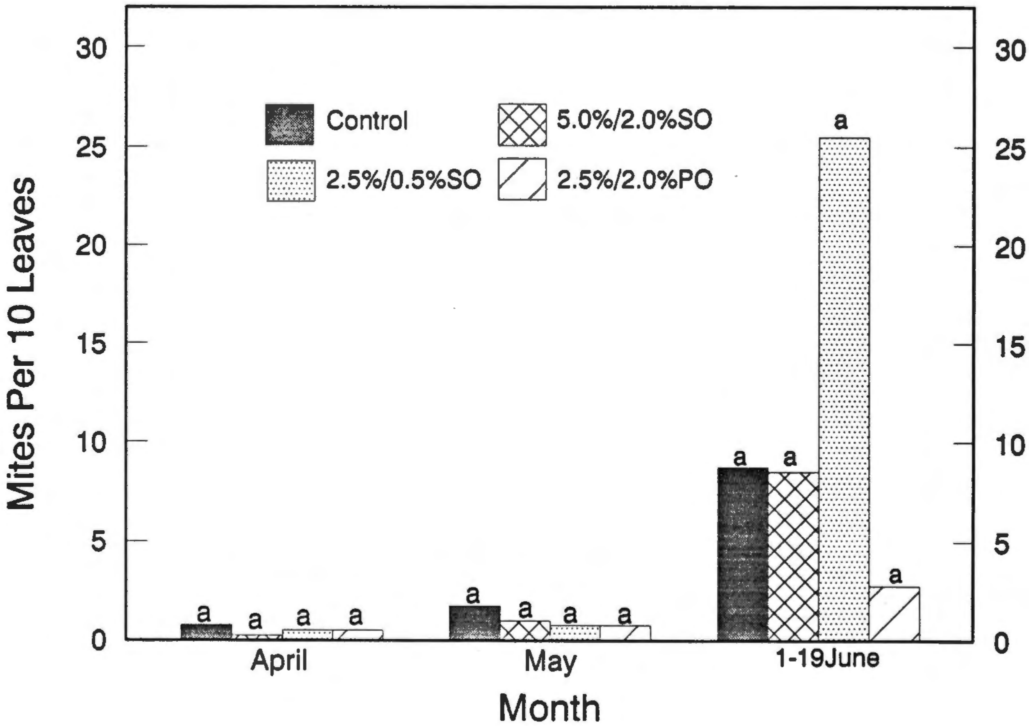

Fig. 17. Tetranychus urticae on leaves collected from apple trees sprayed in 1995 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 0.5% PO. Each column is the mean of 4 replicates. Columns with a common letter are not significantly different (P<0.05).

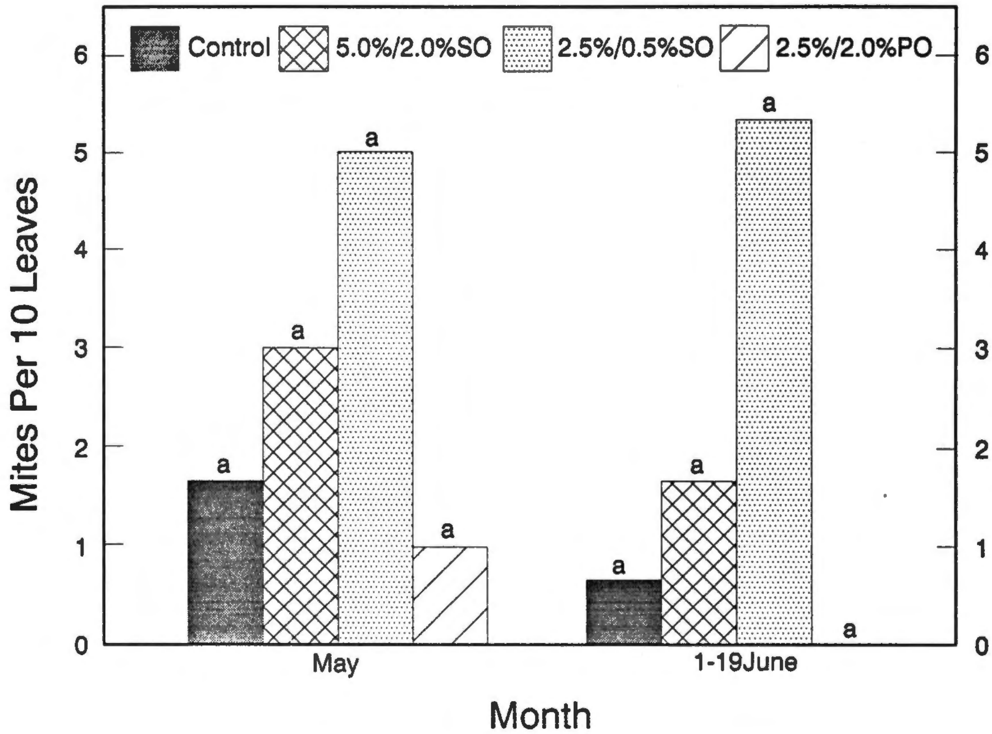

Fig. 18. Tetranychus urticae on leaves collected from plum trees sprayed in 1995 with a dormant application of 5.0 or 2.5% degummed soybean oil (SO), or 2.5% petroleum oil (PO), and a delayed-dormant application of 2.0 or 0.5% SO, or 0.5% PO. Each column is the mean of 3 replicates. Columns with a common letter are not significantly different (P<0.05).

5. SUMMARY AND CONCLUSION

Experiments with emulsions of SO to control overwintering and summer populations of ERM indicated that SO has potential for management of ERM and other mite pests on apple and plum trees. Applications of SO reduced populations of ERM on apple and plum trees in 1994 and 1995; however, more effective control of ERM occurred in the 1994 season. The reduction of ERM populations in 1994 caused female mites to produce a higher number of overwintering eggs, leading to increased populations of mites in the 1995 season.

Dormant applications of 5.0% SO followed by a delayed-dormant application of 2.0% SO provided the most effective control of motile mites and eggs later in the season. Densities of the apple rust mite and two-spotted spider mite were also reduced by this treatment. An additional summer spray of 0.5% SO maintained ERM populations at a low level throughout the remainder of the season. Although a summer spray of 0.25% SO reduced mite numbers initially, the rate did not prevent a buildup in the following month. Predatory mite numbers remained low throughout the summer, so differences in numbers between oil treatments could not be clearly observed; however, since the lowest numbers of predators occurred on PO-treated trees following the summer sprays, predators may be more susceptible to PO than to SO.

Field observations indicated that winter eggs of ERM began hatching in early April of 1994 and 1995. Since oil sprays are most effective when applied closer to the date of ERM emergence (Chapman and Pearce 1949), the optimum time for application of delayed-dormant oil sprays in eastern Tennessee probably would be late March.

SO has potential to be as effective as PO in managing several pests of orchard crops. In the future, PO may not be available for use in pest management and SO may be a suitable alternative. Integrated pest programs that focus on environmental quality can include the relatively non-toxic and safe SO. Also, common pesticides presently used in pest management may eventually become obsolete since pests may develop resistance to them. Pests are not likely to develop resistance to SO. The future of pest management could include vegetable oils and SO may be one of the most promising management materials for many destructive pests.

REFERENCES CITED

Agnello, A.M., W.H. Reissig, and T. Harris. 1994. Management of summer populations of European red mite (Acari: Tetranychidae) on apple with horticultural oil. J. Econ. Entomol. 87: 148-161.

AliNiazee, M.T. 1979. Mite populations on apple foliage in western Oregon. pp. 71-75. In J.G. Rodriguez [Ed.], Recent advances in acarology, vol. I. Academic Press. Inc. Publishers., New York.

Andrews, K.L. and L.F. LaPre. 1979. Effects of Pacific spider mite on physiological processes of almond foliage. J. Econ. Entomol. 72: 651-654.

Avery, D.J. and J.B. Briggs. 1968. Damage to leaves caused by fruit tree red spider mite, Panonychus ulmi (Koch). J. Hortic. Sci., 43: 463-473.

Beers, E.H. and L.A. Hull. 1987. Effect of European red mite (Acari: Tetranychidae) injury on vegetative growth and flowering of four cultivars of apples. Environ. Entomol. 16: 570-574.

Beers, E.H. and L.A. Hull. 1990. Timing of mite injury affects the bloom and fruit development of apple. J. Econ. Entomol. 83: 547-551.

Brown, M.W. and W.V. Welker. 1992. Development of the phytophagous arthropod community on apple as affected by orchard management. Environ. Entomol. 21: 486-492.

Butler, G.D. Jr., D.L. Coudriet, and T.J. Henneberry. 1988. Toxicity and repellency of soybean and cottonseed oils to the sweetpotato whitefly and the cotton aphid on cotton in greenhouse studies. Southwest. Entomol. 13: 81-86.

Butler, G.D. Jr. and T.J. Henneberry. 1989. Sweetpotato whitefly migration, population increase, and control on lettuce with cottonseed oil sprays. Southwest. Entomol. 14 287-293.

Butler, G.D. Jr, D.L. Coudriet, and T.J. Henneberry. 1989. Sweetpotato whitefly: Host plant preference and repellent effect of plant-derived oils on cotton, squash, lettuce and cantaloupe. Southwest. Entomol. 14: 9-16.

Butler, G.D. Jr. and T.J. Henneberry. 1990. Pest control on vegetables and cotton with household cooking oils and liquid detergents. Southwest. Entomol. 15: 123-131.

Butler, G.D. Jr. and T.J. Henneberry. 1991. Sweetpotato whitefly control: Effect of tomato cultures and plant derived oils. Southwest. Entomol. 16: 37-43.

Butler, G.D. Jr., S.N. Puri, and T.J. Henneberry. 1991. Plant-derived oil and detergent solutions as control agents for Bemisia tabaci and Aphis gossypii on cotton. Southwest. Entomol. 16: 331-337.

Caesar, L. 1915. An imported red spider attacking fruit trees. Can. Entomol. 47: 57-68.

Cagle, L.R. 1946. Life-history of the European red mite. Virginia Agr. Expt. Sta. Tech. Bull. 98.

Chant, D.A. 1959. Phytoseiid mites (Acarina: Phytoseiidae). Part I. Bionomics of seven species in southeastern England. Can. Entomol. 91 Suppl., 12: 1-44.

Chapman, P.J. 1967. Petroleum oils for the control of orchard pests. N.Y. State Agric. Exp. Stn. Bu. 814. 22 pp.

Chapman, P.J. and G.W. Pearce. 1949. Susceptibility of winter eggs of the European red mite to petroleum oils and dinitro compounds. J. Econ. Entomol. 42: 44-47.

Chapman, P.J., S.E. Lienk, and O.F. Curtis Jr. 1952. Responses of apple trees to mite infestations: I. J. Econ. Entomol. 45: 816-821.

Chapman, P.J., S.E. Lienk, A.W. Avens, and R.W. White. 1962. Selection of a plant spray oil combining full pesticidal efficiency with minimum plant injury hazards. J. Econ. Entomol. 55: 737-744.

Chazeau, J. 1985. Predaceous insects. pp. 211-246. In W. Helle & M.W. Sabelis [Eds.], Spider mites. Their biology, natural enemies, and control, vol. 1B. Elsevier Science Publishers, Amsterdam.

Croft, B.A. and D.L. McGroarty. 1977. The role of Amblyseius fallacis (Acarina: Phytoseiidae) in Michigan apple orchards. Mich. State Univ. Agric. Exp. Stn. Res. Rep. 333. 22 pp.

Croft, B.A. and I.V. MacRae. 1992. Biological control of apple mites by mixed populations of Metaseiulus occidentalis (Nesbitt) and Typhlodromus pyri Scheuten (Acari: Phytoseiidae). Environ. Entomol. 21: 202-209.

Davidson, N.A., J.E. Dibble, M.L. Flint, P.J. Marer, and A. Guye. 1991. Managing insects and mites with spray oils. Univ. Calif., Agric. Nat. Resources, Oakland. Publ. 3347.

DeAngelis, J.D., K.C., Larson, R.E. Berry, and G.S. Krantz. 1982. Effects of spider mite injury on transpiration and leaf water status in peppermint. Environ. Entomol. 11: 975-978.

deOng, E.R., H. Knight, and J.C. Chamberlain. 1927. A preliminary study of petroleum oil as an insecticide for citrus trees. Hilgardia 2: 351-384.

Dover, M.J., B.A. Croft, S.M. Welch, and R.L. Tummala. 1979. Biological control of Panonychus ulmi (Acarina: Tetranychidae) by Amblyseius fallacis (Acarina: Phytoseiidae) on apple: A prey-predator model. Environ. Entomol. 8: 282-292.

Ewing, H.E. 1912. The occurrence of the citrus red spider mite, Tetranychus mytilaspidis Riley, on stone and pomaceous fruit in Oregon. J. Econ. Entomol. 5: 414-415.

Fleschner, C.A. 1950. Studies on searching capacity of the larvae of three predators of the citrus red mite. Hilgardia. 20: 233-265.

Georghiou, G.P. and R.B. Mellon. 1983. Pesticide resistance in time and space. pp. 1-46. In G.P. Georghiou & T. Saito [Eds.], Pest resistance to pesticides. Plenum Press Publishers, New York.

Hall, F.R. 1983. Pesticide usage patterns for Ohio apple orchards. J. Econ. Entomol. 76: 584-589.

Hardman, J.M., H.J. Herbert, and K.H. Sanford. 1985. Effect of populations of the European red mite, Panonychus ulmi, on the apple variety Red Delicious in Nova Scotia. Can. Entomol. 117: 1257-1265.

Hardman, M.H. and M.L. Rogers. 1991. Effects of temperature and prey density on survival, development, and feeding rates of immature Typhlodromus pyri (Acari: Phytoseiidae). Environ. Entomol. 20: 1089-1096.

Herbert, H.J. 1956. Laboratory studies on some factors in the life history of the predaceous mite Typhlodromus tiliae Oudms. (Acarina: Phytoseiidae). Can. Entomol. 88: 701-704.

Herbert, H.J. 1970. Limits of each stage in populations of the European red mite, Panonychus ulmi. Can. Entomol. 102: 64-65.

Hesler, L.S. and F.W. Plapp, Jr. 1986. Uses of oils in insect control. Southwest. Entomol. Suppl. 11: 1-8.

Hill, J. and A.V. Schoonhoven. 1981. Effectiveness of vegetable oil fractions in controlling the Mexican bean weevil on stored beans. J. Econ. Entomol. 74: 478-479.

Huffaker, C.B., M. van de Vrie, and J.A. McMurtry. 1970. Ecology of tetranychid mites and their natural enemies: A review. II. Tetranychid populations and their possible control by predators: An evaluation. Hilgardia 40: 391-458.

Hull, L.A., D. Asquith, and P.D. Mowery. 1977. The mite searching ability of Stethorus punctum within an apple orchard. Environ. Entomol. 6: 684-688.

Hull, L.A., K.D. Hickey, and W.W. Kanour. 1983. Pesticide usage patterns and associated pest damage in commercial apple orchards of Pennsylvania. J. Econ. Entomol. 76: 577-583.

Johnson, W.T. 1980. Spray oils as insecticides. J. Arboriculture. 6: 169-174.

Lees, A.D. 1950. Diapause and photoperiodism in the fruit tree red spider mite. Nature 166: 874-875.

Lienk, S.E., P.J. Chapman, and O.F. Curtis. 1956. Responses of apple trees to mite infestations: II. 49: 350-353.

Lienk, S.E. 1972. European red mite control on apple with early-season sprays. J. Econ. Entomol. 65: 1684-1686.

Majd, J.A. 1986. Population and biology of the European red mite, Panonychus ulmi (Koch) (Tetranychidae: Acarina), on apples in Georgia. Ph.D. dissertation, University of Georgia.

Marshall, D.B. and D.J. Pree. 1991. Effects of miticides on the life stages of the European red mite, Panonoychus ulmi (Koch) (Acari: Tetranychidae). Can. Entomol. 123: 77-87.

McDaniel, B. 1979. How to know the mites and ticks. Wm. C. Brown Company Publishers, Dubuque, Iowa, pp. 1-335.

Mummigatti, S.G. and A.N. Ragunathatn. 1977. Inhibition of the multiplication of Callosobruchus chinensis by vegetable oils. J. Food Sci. Technol. 14: 184-185.

Newcomer, E.J. and F.P. Dean. 1953. Control of orchard mites resistant to parathion. J. Econ. Entomol. 46: 894-896.

Newcomer, E.J. and F.P. Yothers. 1929. Biology of the European red mite in Pacific northwest. U.S. Dept. Agr. Tech. Bull. 89.

Overmeer, W.P.J. 1985. Alternative prey and other food resources, pp. 131-140. In W. Helle & M.W. Sabelis [Eds.], Spider mites. Their biology, natural enemies, and control, vol. 1B. Elsevier Science Publishers, Amsterdam.

Parent, B. 1967. Population studies of phytophagous mites and predators on apple in Southern Quebec. Can. Entomol. 99: 771-778.

Parent, B. and A.A. Beaulieu. 1957. Life-history of the European red mite. Can. Entomol. 89: 328-333.

Pless, C.D, D.E. Deyton, and C.E. Sams. 1995. Control of San Hose scale, terrapin scale, and European red mite on dormant fruit trees with soybean oil. Hortscience 30: 94-97.

Prokopy, R.J., W.M. Coli, R.G. Hislop, and K.J. Hauschild. 1980. Integrated management of insect and mite pests in commercial apple orchards in Massachusetts. J. Econ. Entomol. 73: 529-535.

Putman, W.L. 1955. The bionomics of Stethorus punctillum Weise (Coleoptera: Coccinellidae) in Ontario. Can. Entomol. 87: 9-33.

Ramsdell, D.R. & G.L. Jubb, Jr. 1979. Seasonal life history of European red mite on Concord grapes in Erie county, Pennsylvania. Environ. Entomol. 8: 1018-1020.

Reissig, W.H., R.W. Weires, G.C. Forshey, W.L. Roelops, R.C. Lamb, and H.S. Aldwinckle. 1984. Insect management in disease-resistant dwarf and semi-dwarf apple trees. J. Econ. Entomol. 13: 1201-1207.

Rock, G.C. 1969. European red mite control in North Carolina apple orchards with early-season applications of acaricides. J. Econ. Entomol. 62: 1119-1122.

Rock, G.C. and K.W. Crabtree. 1987. Biological activity of petroleum and cottonseed oils against two tetranychid mite species and two tortricid insect species found on apple. J. Agric. Entomol. 4: 247-253.

Ross, W.A. and W. Robinson. 1922. Notes on the plum spider mite or European red mite. 52nd Ann. Rept. Ent. Soc. Ontario, 1921, pp. 33-42.

Sabelis, M.W. 1985. Predation on spider mites. pp. 103-129. In W. Helle & M.W. Sabelis [Eds.], Spider mites. Their biology, natural enemies, and control, vol.1B. Elsevier Science Publishers, Amsterdam.

Sances, F.V., J.A. Wyman, and J.P. Ting. 1979. Morphological responses of strawberry leaves to infestations of the two-spotted spider mite. J. Econ. Entomol. 72: 710-713.

Sanford, K.H. and H.J. Herbert. 1970. The influence of spray programs on the fauna of apple orchards in Nova Scotia. Can. Entomol. 102: 592-601.

Santos, M.A. 1976. Evaluation of Zetzellia mali as a predator of Panonychus ulmi and Aculus schlechtendali. Environ. Entomol. 5: 187-191.

Santos, M.A. 1982. Effects of low prey densities on the predation and oviposition of Zetzellia mali (Acarina: Stigmaeidae). Environ. Entomol. 11: 972-974.

Santos, M.A. 1984. Effects of host plant on the predator-prey cycle of Zetzellia mali (Acari: Stigmaeidae) and its prey. Environ. Entomol. 13: 65-69.

SAS Institute. 1987. SAS user's guide: statistics, version 5 ed. SAS Institute, Cary, N.C.

Schoonhoven, A. van. 1978. Use of vegetable oils to protect stored beans from bruchid attack. J. Econ. Entomol. 71: 254-256.

Sechser, B., P. Thueler, and A. Bachmann. 1984. Observations on populations levels of the European red mite (Acarina: Tetranychidae)and associated arthropod predator complexes in different spray programs over a 5-year period. Environ. Entomol. 13: 1577-1582.

Smith, F.F. 1960. Resistance of greenhouse spider mites to acaricides. Misc. pub. Entomol. Soc. Am. 2(1): 5-11.

Smith, E.H. and G.W. Pearce. 1948. The mode of action of petroleum oils as ovicides. J. Econ. Entomol. 41: 173-180.

Strickler, K., N. Cushing, M. Whalon, and B.A. Croft. 1987. Mite (Acari) species composition in Michigan apple orchards. Environ. Entomol. 16: 30-36.

Taschenberg, E.F. 1952. Evaluation of petroleum and vegetable oils on grape berry moth eggs. J. Econ. Entomol. 46: 85-91.

Teete, J.P., E.H. Glass, D. Bruno, and D. Way. 1979. New York tree-fruit pest management project 1973-1978. N.Y. Food Life Sci. Bull. 81: 1-10.

Tomczyk, A. and D. Kropczynska. 1985. Effects on the host plant. pp. 317-327. In: W. Helle and M.W. Sabelis [Eds.], Spider mites their biology, natural enemies and control, volume 1A. Elsevier Science Publishers, Amsterdam.

Tuovinen, T. 1993. Identification and occurrence of phytoseiid mites (Gamasina: Phytoseiidae) in Finnish apple plantations and their surroundings. Entomological Fennica. 31: 95-114.

Walgenbach, J.F. 1993. Biological control of mites on apples in North Carolina. Ag. NC Agric. Ext. Serv. 483. 6 pp.

Welty, C., W.H. Reissig, T.J. Dennehy, and R.W. Weires. 1987. Cyhexatin resistance in New York populations of European red mite (Acari: Tetranychidae). J. Econ. Entomol. 80: 230-236.

APPENDIX

Table 1A. 1994 grower spray program for apple in White's Little Mountain Orchard, Russellville, TN.

Tree Growth Stage	Date	Material Rate/220 Gal Water
Half-inch Green	7 April	Imidan 50 WP 3.5 lb Nova 40 WP 5 oz
Bloom 5% Open	19 April	Streptomycin sulfate 21 WP 1 lb 2 oz
Petal Fall	21 April	Imidan 50 WP 3.5 lb Nova 40 WP 5 oz Captan 50 WP 4.5 lb
First Cover	5 May	Same as Petal Fall
Second Cover	17 May	Same as Petal Fall
Third Cover	30 May	Same as Petal Fall
Fourth Cover	30 June	Imidan 50 WP 3.5 lb Benlate 50 W 1 lb 2 oz Captan 50 WP 4.5 lb

Table 2A. 1994 grower spray program for plum in White's Little Mountain Orchard, Russellville, TN.

Tree Growth Stage	Material Rate/220 Gal Water
Pink Tip	Pounce 3.2 EC 8 fl oz
Pre-bloom	Benlate 50 W 1 lb 2 oz Captan 50 WP 4.5 lb
Bloom before Peak	Benlate 50 W 1 lb 2 oz Captan 50 WP 4.5 lb
Petal Fall	Pounce 3.2 EC 8 fl oz Benlate 50 W 1 lb 2 oz Captan 50 WP 4.5 lb
Shuck-split	Imidan 50 WP 3.5 lb Captan 50 WP 4.5 lb
Shuck-fall	Same as Shuck-split
First Cover	Imidan 50 WP 3.5 lb Belate 50 W 1 lb 2 oz Captan 50 WP 4.5 lb
Second Cover	Same as Shuck-split
Third Cover	Same as Shuck-split
Fourth Cover	Imidan 50 WP 3.5 lb Benlate 50 W 1 lb 2 oz Captan 50 WP 4.5 lb
Preharvest	Captan 50 WP 4.5 lb

Table 3A. 1995 grower spray program for apple in White's Little Mountain Orchard, Russellville, TN.

Tree Growth Stage	Date	Material Rate/220 Gal Water
Half-inch Green	23 March	Imidan 50 WP 3.5 lb Nova 40 WP 5 oz
Pink Blossom	31 March	Pounce 3.2 EC 3.5 fl oz Nova 40 WP 5 oz
Bloom-Full	14 April	Streptomycin sulfate 21 WP 1 lb 2 oz
Petal Fall	19 April	Imidan 50 WP 3.5 lb Nova 40 WP 5 oz Captan 50 WP 4.5 lb
First Cover	6 May	Imidan 70 WP 2 lb 3.5 oz Nova 40 WP 5 oz Captan 50 WP 4.5 lb
Second Cover	20 May	Same as First Cover

Table 4A. 1995 grower spray program for plum in White's Little Mountain Orchard, Russellville, TN.

Tree Growth Stage	Date	Material Rate/220 Gal Water
Pink Tip, Pre-bloom	23 March	Pounce 3.2 EC 8 fl oz Benlate 50 W 1 lb 2 oz Captan 50 WP 4.5 lb
Bloom before Peak	31 March	Benlate 50 W 1 lb 2 oz Captan 50 WP 4.5 lb
Petal Fall	10 April	Pounce 3.2 EC 8 fl oz Benlate 50 W 1 lb 2 oz Captan 50 WP 4.5 lb
Shuck-split	19 April	Imidan 50 WP 3.5 lb Captan 50 WP 4.5 lb
Shuck-fall	7 May	Imidan 70 WP 2 lb 3.5 oz Captan 50 WP 4.5 lb
First Cover	20 May	Imidan 50 WP 3.5 lb Captan 50 WP 4.5 lb Benlate 50 W 1 lb 2 oz

VITA

Elizabeth Ruth Bolles was born in Nashville, TN on August 8, 1971. She graduated from Hillwood Comprehensive High School in 1989. She entered The University of Tennessee, Knoxville and received a Bachelors of Science in Ornamental Horticulture and Landscape Design in May, 1993. She continued with her education at The University of Tennessee in the Department of Entomology and Plant Pathology as a Graduate Research Assistant in August 1993. She obtained a Master of Science degree in Entomology and Plant Pathology in August 1995. Ms. Bolles is a member of the Entomological Society of America and the Georgia Entomological Society. She plans to move to California where she will continue to work in the field of entomology.