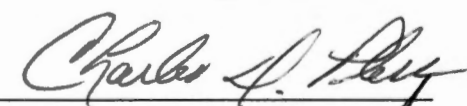
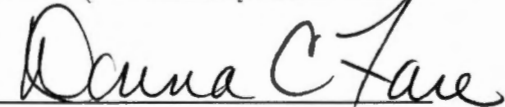


To the Graduate Council:

I am submitting herewith a thesis written by Aaron L. Lancaster entitled "Management of Insects and Mites on Ornamentals using Soybean Oil." I have examined the final 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 Plant and Soil Sciences.


Dennis E. Deyton, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:


Associate Vice Chancellor and
Dean of The Graduate School

**MANAGEMENT OF INSECTS AND MITES
ON ORNAMENTALS USING SOYBEAN OIL**

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Aaron L. Lancaster

May, 2000

AG-VET-MED.

Thesis
2000
L35

DEDICATION

This thesis is dedicated in honor of my family...

My Father, Major Robert M. Lancaster

His instruction in Mathematics provided me a sufficient background to pursue science.

My Mother, Cynthia S. Lancaster

Her instruction in Composition enabled me to compose this thesis.

My Sisters, Shannon S. Schrum and Jessica L. Lancaster

Their devoted support and encouragement empowered me to complete my degree.

...And in Memory of...

My Undergraduate Advisor, Dr. Lois P. Lord

Her vast knowledge and bold persona elevated my analytic capacities and self assurance.

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“Be grateful for what we've shared together and be glad...” Bob Dylan (1978)

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Introduction

Pest management strategies within the ornamental industry differ greatly from those of other agricultural crops. Farmers of most agronomic and horticultural crops control pests to minimize economic crop loss (Doutt, 1983). However, ornamentals are widely used in both urban and rural landscape settings. Since ornamentals fulfill aesthetic purposes, instead of nutritional needs, responses to pest presence are often chemical sprays, regardless of their appropriateness (Sadof *et al.*, 1993; Freeman *et al.*, 1997). Plant retail customers and homeowners have low tolerance of pests in their gardens and yards (Owens, 1986), and constitute 27% of all pesticide users in the U.S. (Freeman *et al.*, 1997). Coffelt and Schultz (1990) reported that a mere 5% defoliation of woody ornamentals by the orange striped oakworm (*Anisota senatoria* J.E. Smith) increased homeowners' requests for pest control by >50% in Norfolk, VA. Sadof and Alexander (1993) concurred with the interrelationship between leaf discoloration and aesthetic value, stating that 50% of 134 nursery customers surveyed believed burning bush (*Euonymus alatus* Thunberg Siebold 'Compacta') plants with $\geq 5\%$ leaf discoloration from spider mite infestations were damaged and unsalable.

Urban pest management poses potential problems for environmental pollution, health hazards, and ecosystem disruption (Bradley, 1991; Owens, 1986). The UCLA Center for Environment Risk Reduction indicates that on a per hectare basis, urban pesticide use often exceeded that of agricultural applications (Freeman *et al.*, 1997). The majority of pesticide applicators are untrained homeowners and landscape gardeners, who rarely heed attention to the chemical's appropriateness or safety precautions (Bennett *et al.*,

1983). Modern gardeners and nursery growers use synthetic pesticides due to their speed and efficacy of pest control (Smith, 1991). Problems from over-spraying exist in urban environments as well, and are similar to historical agricultural situations, including soil and water contamination, pest resistance and resurgence, and acute / chronic human health problems (Freeman *et al.*, 1997). Modern agricultural ecosystems possess relatively low diversity in comparison to that found in landscapes, parks, vacant lots, gardens, and other urban communities (Owens, 1986). It is critical that alternative pest management strategies be developed and implemented, so as to better manage ornamental pests without environmental toxicity and ecosystem disruption, particularly of beneficial arthropods.

Oil sprays were first used agriculturally in the 1780s to control overwintering insects in orchards (Chapman, 1967). Oils differ from synthetic pesticides in that they are non-toxic to mammals, possess little to no residual pesticidal activity, control pests with a physical mode of action (suffocation), and are usually less expensive than their competitive pesticide counterparts (Hesler *et al.*, 1986; Johnson, 1985). Advanced refinement procedures have created lighter petroleum oils (known as superior or horticultural oils) that control arthropod pests year-round on many plant species with minimal phytotoxicity (Baxendale *et al.*, 1988a, 1988b; Mizell, 1991; Nielsen, 1990). Modern nursery growers use horticultural oils, such as Sunspray Ultra-fine Spray Oil® or Success Naturalyte Insect Control®, at label-suggested rates to control common horticulture and nursery insects and mites (Miller, 1997; Bisabri *et al.*, 1997). Early research on citrus indicated that natural plant oils possess insect and mite controlling properties similar to petroleum spray oils (deOng *et al.*, 1927). Many scientists have investigated insect and disease controlling properties of plant oils in efforts to find effective and safe alternatives to synthetic pesticides (Allen *et al.*, 1993;

Butler *et al.*, 1988, 1989a, 1989b, 1990, 1991a, 1991b, 1991c; Chen *et al.*, 1996; Flint *et al.*, 1995; Hesler *et al.*, 1986; Hill *et al.*, 1981; Northover *et al.*, 1996; Obeng-Ofori, 1995; Webb *et al.*, 1994).

This thesis explores the potential usage of soy oil (*Glycine max* L. Merrill) as an insecticide and acaricide on ornamentals. Petroleum oils and soy oils were compared for their efficacy against soft-bodied haustellate (sap sucking) insects such as cotton aphids (*Aphis gossypii* Glover), sweet potato whiteflies (*Bemisia tabaci* Gennadius), and azalea lace bugs (*Stephanitis pyrioides* Scott) , and two-spotted spider mites (*Tetranychus urticae* Koch) on nursery stock. Soy oil was evaluated for effects on phytotoxicity, net photosynthesis, stomatal conductance, transpiration, and beneficial mites on various herbaceous and woody ornamental species.

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PART I

LITERATURE REVIEW

PERSISTENT PROBLEMS WITH PESTICIDES

Pesticides are an integral part of nursery and landscape pest management programs (Neel and Reinert, 1975). Synthetic pesticides, including DDT, were introduced during World War II, but were not the panacea researchers hoped them to be (Davidson *et al.*, 1991). Reports of targeted insects quickly developing resistance to synthetic sprays in orchards, nurseries, and urban landscapes soon accumulated (Campos *et al.*, 1995; Davidson and Cornell, 1988; Welty *et al.*, 1987). Pesticides are often misused by applicators, and sprayed regardless of need and label warnings (Freeman and Sundu, 1998). Toxicity problems are amplified in urban dwellings (Raupp *et al.*, 1992). Concerns regarding the non-selective nature of pesticides against beneficial and pest insects and mites (Nielsen, 1989), air and water pollution (Shoemaker, 1989), and pesticide-related mammalian sensitivities, allergies, and chronic illness like cancer (Freeman and Sundu, 1998) must be considered.

DEVELOPMENTS OF ALTERNATIVE (NON-SYNTHETIC) PESTICIDES

Urban pesticide use accounts for an estimated 27% of all pesticide applications in the United States, with rates often exceeding those found in agricultural production (pounds / acre) (Freeman and Sundu, 1998). However, few urban pest management programs exist despite the increasing awareness of environmental problems and mammalian toxicity (Raupp *et al.*, 1992). The availability of pesticides labeled for ornamentals changes often and becomes increasingly limited each year (Cashion *et al.*, 1994). Public environmental and sociological demands have encouraged the development of non-synthetic pesticide

alternatives (Mizell, 1991). Horticultural oils and soaps present unique advantages, in that they possess no mammalian toxicity, have an expansive array of pest control, and are easily implemented into integrated pest management (IPM) programs (Miller, 1997). Pesticides used in IPM programs must be lethal to contacted pests, yet break down quickly and contain no residual activity, so as not to disrupt beneficial and predatory insects and mites (Davidson *et al.*, 1991). Due to their physical mode of action, oils are the only class of insecticides to which no insect resistance has developed (Pless *et al.*, 1995).

OILS: PAST AND PRESENT USE IN AGRICULTURAL AND URBAN ENVIRONMENTS

Oil sprays are fatal to mites and soft-bodied insects; however, the lethal mechanism of the oils is uncertain (Davidson *et al.*, 1991). Oils may be toxic to contacted insects and mites, or interfere with the spiracles, causing death by asphyxiation (Miller, 1989). Some oils also contain antifeedant properties, resulting in insect death via starvation (Chen *et al.*, 1996). Studies conducted on the effects of oil on mite eggs suggest that oils weaken the external membrane, causing the egg to abort or dessicate (Baxendale and Johnson, 1990). Oils may also be a mechanical interference with the gas exchange of insect and mite eggs (Hesler and Plapp, 1986). Lower egg survivorship decreases the population of future adult mites. Reports of oil-resistance by pine needle scale (*Chionaspis pinifoliae* Fitch) and oystershell scale (*Lepidosaphes ulmi* L.) insects have surfaced in the literature (Johnson, 1985). However, it is believed that the dense wax or armor-plates rendered the insect impenetrable. Oil contact with the targeted insects is essential for effective control, regardless of the mode of action (Davidson *et al.*, 1991).

Petroleum oil sprays have been used as insecticides on fruit and shade trees since the late 1800s (Miller, 1989). Early formulations consisted of 10-25% kerosene-soap emulsions, and were applied to control overwintering aphids and scale insects (Chapman, 1967). The kerosene-soap emulsions efficaciously controlled insects and mites, but also injured the bark and limbs of trees (Davidson *et al.*, 1991). Sulfuric acid, added as an emulsifier, minimized plant damage, but was costly due to the high volume of the emulsion necessary for efficacious control (deOng *et al.*, 1927). The development of fast-breaking oil-and-water emulsions in the mid-1920s improved surface coverage and increased overall control (Davidson *et al.*, 1991). Paraffinic spray oils were first recommended as a dormant oil in 1942 (Chapman *et al.*, 1942). Oils declined in popularity during World War II, due to their lack of fumigant properties (Davidson and Cornell, 1988). In 1959, the “60-second superior oil” was developed, which allowed pests to be controlled year-round with minimal phytotoxicity (Chapman, 1959). Three events secured horticultural oils as a cornerstone in biorational pesticides: 1) improved refining procedures were developed between 1945 and 1970 and allowed the removal of unsaturated hydrocarbons and aromatics, which are attributed to plant damage (Miller, 1989); 2) Rachel Carson’s novel *The Silent Spring* (1962) stimulated a frenzied public interest in environmentally-safe alternatives to residual synthetic pesticides (Davidson and Cornell, 1988); and 3) the Sun Refining and Marketing Company developed a new, EPA-approved, and user-friendly label for their petroleum oil product Sunspray 6E in 1983 (Johnson, 1983).

With increasing aversion to synthetic pesticides, the use of plant oils as insecticides was a logical alternative. However, limited research with vegetable oils exists, leaving critics to discourage their use (Jones, 1996). DeOng and associates (1927) reported that

cottonseed (*Gossypium* sp.), linseed (*Linum usitatissimum* L.), castor (*Ricinus communis* L.), and tall (rosin) (*Pinus* sp.) oils efficaciously controlled insects similar to petroleum oil, but had greater phytotoxic qualities than petroleum oil due to the higher amounts of fatty acids. Wickizer and Meisch (1977) noticed a 68% reduction in two-spotted spider mites (*Tetranychus urticae* Harvey) on greenhouse-raised dahlias on the fourth day after spraying with a 0.1% anise oil-detergent mixture. Rock and Crabtree (1987) reported that a 0.5% cottonseed oil spray reduced densities of European red mite (*Panonychus ulmi* Koch) populations in orchard trials, but caused foliage burn. Vegetable oils have been demonstrated effective at controlling Mexican bean weevils (*Zabrotes subfasciatus* Boheman), the flat grain borer (*Cryptolestes pusillus* Shonherr), and the lesser grain borer (*Rhyzopertha dominica* Fabr.) on stored beans (*Phaseolus vulgaris* L.), maize (*Zea mays* L.), and sorghum (*Sorghum vulgare* Pers.), respectively (Hill and Schoonhoven, 1981; Obeng-Ofori, 1995).

Several factors favorably distinguish plant oils from petroleum oils. Plant oils are derived from renewable resources, whereas petroleum oils are produced from non-renewable fossil fuels. Plant oils are normally less expensive than synthetic pesticides. A number of plant-derived oils were deemed “least toxic”, environmentally friendly, and therefore exempted from standard EPA registration; these pesticides included soybean (*Glycine max* L.), corn (*Zea mays* L.), garlic (*Allium sativum* L.), rosemary (*Rosmarinus officinalis* L.), citronella (*Collinsonia canadensis* L.), clove (*Eugenia caryophyllata* Thumb.), cinnamon (*Cinnamomum zeylanicum* Garc.), lemongrass (*Cymbopogon* sp.), peppermint (*Mentha piperita* L.), and thyme (*Thymus vulgaris* L.) oils (Quarles, 1996). Many plant oils contain aromatics which repel insects and control diseases, thereby increasing their practicality and appeal (Prakash and Rao, 1997).

Exploration of soy oil as a petroleum oil replacement has been initiated. Soy oil is the most abundant plant oil in the United States (Harrison and Wax, 1984). Novak and fellow researchers (1995) reported trials of mosquito-controlling soy-based insecticides that degraded within 12 to 24 hours. Synthetic pesticides are highly regulated in aquatic environments. Soy oil's swift decomposition may make it safe for spraying in protected settings (Glancey *et al.*, 2000).

Limited research exists in disease-controlling characteristics of oils. Oils are believed to aid in disease prevention (prophylactic control) and cure (therapeutic control). Oils may prevent disease formation by coating the plant surface and impeding or suffocating fungal spores (Becker, 1994). Northover and Schneider (1996) reported that three horticultural petroleum oils (Stylet Oil, Sunspray Ultra-fine Oil, and Safe-T-Side) provided moderate prophylactic protection and excellent therapeutic control, both pre- and post-lesion formation, from powdery mildew (*Oidium tuckeri* Berk.) infection on potted grapevines (*Vitis vinifera* L. cv. Chardonnay) within a greenhouse. Clement and partners (1994) indicated that a 2% petroleum oil spray controlled powdery mildew on lilac (*Syringa vulgaris* L.) as well as the fungicide Bayleton®. Oils may filter viruses from the stylets of insect vectors, preventing infection (Adams, 1991). Horticultural oil reduced tomato spotted wilt virus development and Western flower thrips (*Frankliniella occidentalis* Pergande) feeding on petunia (*Petunia × hybrida*) by 57% and 4%, respectively (Allen *et al.*, 1993). A 1% application of Virol® spray oil reduced the incidence of virus infection in peppers (*Capsicum annuum* L.) by 40% (Marco, 1993).

INTEGRATED PEST MANAGEMENT (IPM)

Integrated pest management (IPM) was described by Nielsen (1990) as a plant-health management program “whereby practitioners monitor landscapes, use pesticides only where they are needed, and actually improve pest control while dramatically reducing the amount of pesticides used.” Large quantities of pesticides are used annually to control landscape pests in urban and nursery habitats (Raupp *et al.*, 1992). Urban IPM programs have been in development since 1976, whereas researchers discovered similarities in IPM components for urban landscape and agrarian ecosystems (Davidson and Cornell, 1988).

INSECTS AND MITES

Haustellate (sap-feeding) arthropods are the most frequent pests of landscape ornamentals. Sap-feeding arthropods insert needle-like mouthparts (stylets) into the mesophyll cells within leaves, and remove the cell contents (Barrett, 1996). Included in the category of phytophagous arthropod pests are mealybugs, scales, psyllids, leafhoppers, thrips, plant bugs, lace bugs, aphids, whiteflies, and mites (Gilkeson, 1991; Miller, 1997). Most piercing-sucking pests are small and soft-bodied, making them vulnerable to oil treatments. However, some of these pests are covered with nearly-impenetrable armor-like plates, wax, or wool (Johnson and Lyon, 1991).

Damage incurred on plants by sap-feeding arthropods initiates as distortion (curling or galling) and yellowing/mottling of affected plant tissues (Gilkeson, 1991). Severe damage may induce significant leaf drop (Bennett, 1996). Insect pests of ornamentals cause cosmetic damage to their hosts as well. White cast skins (former insect casings) litter the plants' foliage (Dreistadt *et al.*, 1994). Some sap-sucking insects exude a carbohydrate-water

complex (honeydew) during feeding. Although sticky and unsightly, honeydew is harmless to plants, but provides growth medium for the sooty mold fungi (Pierce *et al.*, 1998). The hyphae of sooty mold fungi rarely penetrate the tissues of host plants (Campana, 1983). However, proliferous sooty molds exclude light penetrating the foliage and restrict gas exchange within the respiring tissues of the foliage (Dreistadt *et al.*, 1994). Net photosynthesis is adversely affected, resulting in starved affected tissues, and possibly death (Campana, 1983).

Aphids

Aphids (Family Aphididae) are soft-bodied arthropods that may infest over 200 species of agricultural and landscape plants (Dreistadt *et al.*, 1994). Their feeding behavior is determined mostly by the host plant and feeding site preference, which includes roots, bark, twigs, leaves (primarily the protected undersides), flowers, and fruit (Johnson and Lyon, 1991). Aphids have tiny, pear-shaped bodies ranging in length from 0.08 cm to 0.32 cm and in colors of green, yellow, black, red, brown, or powdery grey, depending upon species and host plant (Gilkeson, 1991). Wingless aphids are most prevalent, but environmental stresses such as overpopulation, lack of food, pesticide applications, seasonal changes may stimulate the development of wings, which are positioned roof-like over the body (Barrett, 1996).

Most aphids overwinter as eggs that hatch in the early spring, but certain species survive the winter months as immature or adult females (Barrett, 1996). Nymphs mature within one to two weeks (Gilkeson, 1991). The aphid family has the highest reproductive potential of all insects as female nymphs parthenogenetically bear live young (Johnson and Lyon, 1991). Several generations of wingless forms are produced in the spring, followed by

a winged generation which travel to uninhabited plants and produce several more wingless generations. The cool, shorter autumn days stimulate the production of another winged generation, which return to host plants (Barrett, 1996). Male aphids, which are produced only in the fall by certain aphid species, mate with the females to produce the overwintering eggs (Gilkeson, 1991).

Cotton / melon aphids (*Aphis gossypii* Glover) frequently infest numerous garden and landscape plants, including apple (*Malus domestica* Borkh.), camellia (*Camellia japonica*), crape myrtle (*Lagerstroemia indica* L.), *Euonymus japonica*, *Prunus* sp., *Malva* sp., *Platanus* sp., *Salix* sp., and *Eucalyptus* sp. Mature females range from yellowish to dark, mottled green during their wingless stage (Johnson and Lyon, 1991). Winged generations are typically dark green to black (Dreistadt *et al.*, 1994). Cotton aphids overwinter as eggs on rose of sharon (*Hibiscus syriacus* L.) and *Catalpa* sp. in the Northeast (Johnson and Lyon, 1991); adult cotton aphids survive and reproduce year-round in California and other areas with mild winters (Dreistadt *et al.*, 1994). Cotton aphids are ubiquitous, and readily controlled by parasitic wasps where aphids are abundant (Johnson and Lyon, 1991). Cotton aphids are considered secondary pests because they feed on the lower surfaces of plants and terminal buds. However, cool springs may slow the reproduction and accumulation of predators to counteract the pests, thereby creating an aphid infestation (Carter *et al.*, 1981).

Whiteflies

Sweetpotato whiteflies (SPW) (*Bemisia tabaci* Gennadius) attack both indoor and outdoor plants, although they are severe within greenhouses (Hale *et al.*, 1995). These insects are very serious pests of cotton in the Southwest (Butler *et al.*, 1991). Adults are 0.8

mm long, moth-like, snowy-white, and have a wax coating on their wings and body. Whiteflies position their wings in an A-line form over their bodies while feeding for protection (Johnson and Lyon, 1991). In warm conditions, the SPW has a life cycle of 2 to 3 weeks. This high reproductive rate combined with SPW's elusive tendencies to inhabit leaf undersides make controlling these arthropods extremely difficult (Butler and Henneberry, 1989). Endosulfan is a harsh synthetic chemical commonly used to control whiteflies (Seal *et al.*, 1994). Frequent pyrethroid insecticide usage has been blamed for the resurgence of this pest in India (Butler *et al.*, 1991). Lack of innovative spray technology that distributes pesticides to the entire plant surface and the increasing reports of resistance have prevented growers and homeowners from obtaining effective control (Butler and Henneberry, 1991).

Lace bugs

Azalea lace bugs (ALB) (*Stephanitis pyrioides* Scott) are the most serious pest of cultivated azaleas (Neal and Douglass, 1988). Eggs of the ALB are inserted along leaf midribs in the late fall, and hatch the following early spring (Braman *et al.*, 1992). Azalea lace bugs pass through four nymphal instars before molting into adults (Casey and Raupp, 1999). Planting location of the azaleas is highly correlated to ALB's presence. Azaleas can perform well in sunny locations as well as their preferred shady ones. Azalea lace bugs prefer to feed and oviposit on shade-grown azaleas (Trumbule and Denno, 1995). Traditional methods of controlling lace bugs have been limited to cultural control methods, such as pruning out insect-infested branches and planting lace bug-resistant varieties (Braman *et al.*, 1992). The few pesticides currently existing are limited to the

growing season, when lace bugs are active (Neal and Douglass, 1988).

Mites

Two-spotted spider mites (*Tetranychus urticae* Koch) are one of the most ubiquitous pests of landscapes, gardens, and nurseries (Flint, 1995). After overwintering in a protective location, spider mites emerge in late spring and lay about 100 eggs within 30 days (Jones, 1996). Mites also have a high reproductive rate, and are notorious for swiftly developing resistance to the currently available miticides (Campos *et al.*, 1995). Spider mites may spin extensive and dense webs over foliage and branches, thereby interfering with gas exchange and light penetration (Hale *et al.*, 1996). Currently, researchers are investigating new, non-synthetic mechanisms to control spider mites, including releasing predatory mites (Zhang and Sanderson, 1995).

ALTERNATIVE CONTROL METHODS

Recommended cultural control methods for sap-extracting arthropods include applying forceful water sprays to dislodge insects and remove recent honeydew deposits, and pruning out infested new growth (Barrett, 1996). Limited use of non-selective pesticides may encourage the colonization of natural predators, including green lacewings (larvae), parasitic wasps, syrphid flies (larvae), and predatory mites. Lady beetle larvae effectively control aphids within greenhouses. Labeled insecticide alternatives for controlling aphids on trees and shrubs include insecticidal soap and pyrethrins (Gilkeson, 1991).

GAS EXCHANGE

The effects of arthropods on net photosynthesis (Pn), stomatal conductance (Gs), and transpiration (E) are often monitored since these metabolic plant processes are critical determinants of plant growth, yield, and health (Peterson *et al.*, 1996). Phloem-feeding (haustellate) insects interfere directly with plant metabolism by removing photosynthate from the phloem (Casey and Raupp, 1999). Secondary inhibition by pests involves physical restriction of sunlight and gas exchange by sooty mold, honeydew, castskins, frass, and mummies (Pierce *et al.*, 1998). Feeding injury on peppermint (*Mentha piperita* L.) by TSSM increased E rates and thus water loss, causing mass stomatal closure. As a result, CO₂ exchange was impaired, net photosynthesis reduced, and crop yield lowered on mite damaged leaves (DeAngelis *et al.*, 1983). Peterson and colleagues (1996) stated that gross leaf tissue removal of apple (*Pyrus malus* L. 'Jonathan') and crabapple (*Pyrus coronaria* L. 'Liset' and 'Spring Snow') by cecropia moth larvae (*Hyalophora cecropia* L.) did not affect the Pn rates of the remaining leaf tissue. Similar findings on alfalfa (*Medicago sativa* L.) following defoliation by the alfalfa weevil (*Hypera postica* Gyllenhal) were previously noted (Peterson *et al.*, 1992). Diseases may also reduce levels of Pn, Gs, and E. Gould and associates (1996) reported that Pn, Gs, and E rates of pecan foliage (*Carya illinoensis* (Wang.) Koch 'Choctaw' and 'Cape Fear') declined linearly and curvilinearly with the increased incidence of pecan scab (*Cladosporium caryigenum* (Ellis & Langl.) Gottwald).

Reduction of Pn, Gs, and E rates by pesticides is well documented (Ayers and Barden, 1975; Ferree and Hall, 1975; Wood *et al.*, 1997). Oils may also physically inhibit plant gas exchange. In 1923, Burroughs stated that the oil film remaining on the plant surface may interfere with plant gas exchange and reduce E rates, possibly causing

abscission. Hesler and Plapp (1986) reported that mineral and crop oils counteracted volatilization, photodegradation, and biodegradation of synthetic pesticides when both chemicals were mixed and applied together. Northover and Schneider (1996) indicated that oils coat plant surfaces like a raincoat, thereby creating a prophylactic and possibly gas-restrictive barrier.

PHYTOTOXICITY AND DISCOLORATION

Phytotoxicity is a chronic problem with pesticides, including oils. A survey of the nursery industry reported by Johnson and Caldwell (1987) indicated that even though only 10% of the respondents reported moderate to severe phytotoxicity from oil sprays, many were hesitant to use oil after a single negative experience. Oils cause damage by penetrating plant cuticles and membranes and killing cells or by saturating and darkening the bark, which increases heat absorption (Davidson *et al.*, 1991; Johnson, 1985). Phytotoxicity may consist of foliage yellowing, which then darkens and decays, leaf scorch, or burn (Sorensen, 2000). Petroleum oils can permanently change the waxy blue tint on evergreen ornamentals to emerald green (Baxendale and Johnson, 1989b; Miller, 1997). Although phytotoxic damage is permanent, new foliage growth often quickly obscures these areas (Baxendale and Johnson, 1989b; Sorensen, 2000).

Phytotoxicity can develop despite proper use. Petroleum oils contain unsulfonated residues or unsaturated hydrocarbons; phytotoxic damage is related to the percentage of impurities in an oil (Johnson, 1991). Oils that are fully saturated (i.e. contain no unsaturated hydrocarbons or aromatics) are generally viewed as safe for dormant and summer application, without fear of phytotoxicity (when applied under label precautions) (Miller,

1989). Plant oils can contain high amounts of fatty acids, which also may cause damage (DeOng *et al.*, 1927). Oil sprays should be avoided when the temperature exceeds 100° F (56°C) and plummets below 40°F (22°C) (Miller, 1989). Moisture is another factor: oils should not be sprayed on foliage when plant tissues are wet, if rain is likely within 2-4 hours, or if the humidity will remain above 90% for 36-48 hours (Johnson, 1980). Finally, oil sprays should be delayed while buds are first opening and rapid shoot elongation is occurring (Davidson *et al.*, 1991).

Historical reports of phytotoxicity are expansive and inconsistent. In the late 1800s, crude petroleum oil or kerosene emulsions applied to dormant fruit trees at rates from 20% to 50% caused inconsistent damage (Burroughs, 1923). Oils were mostly limited to dormant applications until the mid-1960s, when narrow-range (60-second) oils were produced (Davidson *et al.*, 1991). Tippins (1974) indicated that multiple applications of 2% oil sprays at 2-week intervals for a year did not cause any phytotoxicity on azalea (*Rhododendron* sp.), boxwood (*Buxus* sp.), camellia (*Camellia* sp.), and holly (*Ilex* sp.). A summer application of 4-6% horticultural oil was sprayed during the summer on a wide range of woody ornamentals without phytotoxic damage (Johnson, 1985). Baxendale and Johnson (1988b) indicated that a summer application of 3% dormant oil damaged certain deciduous nut tree species (6 out of 51 tested). Phytotoxicity trials repeated by these researchers with 2% Sunspray 6E resulted in no damage (1989). Davidson and associates (1990) applied multiple sprays of 2% Sunspray 6E Plus to 52 species of woody nursery plant under drought stress. Only arborvitae (*Thuja occidentalis* L.) was burned by four oil sprays; *Acer rubrum* L. 'October Glory' and *Acer saccharum* Marshall 'Green Mountain' showed moderate yellowing but no burn after four applications. Butler and Henneberry reported phytotoxicity on vegetables

sprayed with 5-10% raw cottonseed oil (1990b, 1991a). Squash (*Cucurbita* sp.), cauliflower (*Brassica oleracea* L), and red cabbage (*Brassica oleracea* L.) were damaged by homemade cooking oil-detergent emulsions (Butler and Henneberry, 1990a). Mizell (1991) sprayed 5 applications of 2% Sunspray Ultra-fine Spray Oil® to 30 species of ornamental trees and shrubs during the late summer without any damage. Pesticides used in aphid-management programs have caused phytotoxicity on Sitka spruce [*Picea sitchensis* (Bong.) Carr] (Straw *et al.*, 1996).

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PART II

SOYBEAN OIL CONTROLS TWO-SPOTTED
SPIDER MITES ON BURNING BUSH

ABSTRACT

Research evaluating miticidal, phytotoxic, and gas exchange properties of soybean and petroleum oil on burning bush, *Euonymus alatus* Thunb. Sieb. 'Compactus', was conducted from 1996 to 1998. In expt. 1, efficacy of soy oil versus Sunspray Ultra-fine Spray Oil® (petroleum oil) for mite control was evaluated. Sprays of 1% to 3% oil formulations controlled mites $\geq 87\%$ than the water control both 7 and 14 days after spraying (DAS). Net photosynthetic rates were reduced on oil-treated plants 1 DAS, but was equivalent to unsprayed plants by 11 DAS. In expt. 2, summer applications of soybean and petroleum oil temporarily reduced net photosynthetic (P_n), stomatal conductance (G_s), and transpiration (E) rates on burning bush shrubs for seven days. Rates of P_n on oil-treated plants were equal to those on the unsprayed and water-treated plants by 24 DAS. Only plants sprayed with 3% soy oil had G_s and E levels different from the water-treated plants at the end of the experiment (24 DAS). No phytotoxicity developed on any of the plants. In expt. 3, burning bush plants were sprayed with multiple applications of 0% (water control), 0.25%, 0.5%, 0.75%, 1%, 1.5% soy oil or 1.0%, 1.5% Sunspray Ultra-fine Spray Oil® on 12, 17, and 22 June. Daily maximum temperatures within the greenhouse sometimes exceeded 32°C (90°F) after treatment. All of the oils reduced populations of two-spotted mites. Water-sprayed plants had 27.7 ± 2.6 mites per leaf five days after spraying, whereas soy oil-treated plants averaged 2 ± 2.6 mites per leaf. All oil-treated plants exhibited minor phytotoxicity, and a temporary reduction in P_n , G_s , and E . Plants sprayed with Sunspray Ultra-fine Spray Oil® were severely defoliated by the end of June and had lower gas exchange on remaining leaves than water or soy-treated plants. In Expt. 4, burning bush (plants grown outdoors and inside a greenhouse) were sprayed three times, six

days apart. Phytotoxicity and defoliation only occurred on more stressed plants.

INTRODUCTION

Two-spotted spider mites (*Tetranychus urticae* Koch) (TSSM) infest many ornamental plants commercially grown for flowers and foliage, including winged Euonymus (*Euonymus alatus* Thunb. Sieb. 'Compactus'). Thus, TSSM are serious pests in the nursery industry, and prime targets in nursery integrated pest management (IPM) programs (Goodwin, 1983; Holmes *et al.*, 1984). Johnson and Lyon (1991) reported that the two-spotted spider mite was one of the two most ubiquitous and destructive spider mites in the Tetranychidae family. Found primarily on low-growing plants from early spring to late fall, TSSM flourish in hot weather. The life cycle (egg hatch to adult) of a two-spotted mite at 24°C (75°F) is completed in five days, although higher temperatures hasten the generation time (Goodwin, 1983). Mites feed on the cell contents of leaf tissues, thereby removing photosynthate from the plant. As mite infestations increase, leaves appear bronze (due to chlorophyll removal) and may abscise (Barrett, 1996). Smithley and colleagues (1991) reported that TSSM feeding damage on burning bush increased transpiration (E) rates and water loss, and reduced net photosynthetic (Pn) rates. Populations of TSSM are difficult to maintain at aesthetically acceptable levels (Wickizer *et al.*, 1977). A survey of retail nursery customers conducted by Sadof and Alexander (1993) reported that 50% of the respondents viewed TSSM-infested burning bush leaves with >5% discoloration as “damaged” and unsalable. Powerful, prolonged applications of water (rain or sprays) and predators can deter mite infestations (Jepson *et al.*, 1975). Severe epidemics necessitate alternative management methods, such as introducing natural enemies or spraying insecticidal soaps or narrow-range oils (Dreistadt *et*

al., 1994).

The *Euonymus* genus contains over 170 species of deciduous and evergreen woody ornamentals (Hudak, 1984). Burning bush shrubs are popular due to their spectacular autumn foliage and unique corky stems, and were praised by Dirr (1998) as “one of the finest landscape plants for American gardens”. *Euonymus alatus* Thunb. Sieb. ‘Compactus’ is an outstanding hardy cultivar, and popular in Southern gardens (Dirr, 1998; Hudak, 1994).

Increasing concerns of pesticide misuse permeate the nursery industry (Davidson and Cornell, 1988). Nielsen (1990) reported an aversion among homeowners and horticulturists to pest-preventative chemical sprays. Superior petroleum-based horticultural oils exist in a line of biorational (i.e. environmentally safe) pesticides, and are widely used in the nursery industry (Raupp *et al.*, 1992). Oils have provided effective insecticidal and miticidal control for years in the horticulture industry, without increasing the incidence of insect and mite resistance (Rock *et al.*, 1987). Synthetic insecticides and miticides, such as carbaryl, organophosphates, and pyrethroids, may actually create favorable conditions for TSSM by destroying natural enemies, stimulating mite reproduction, and increasing nitrogen levels in the leaves (Ohlendorf *et al.*, 1995). Dramatic mite outbreaks were reported within a few days of spraying insecticides for summer insect control (Dreistadt *et al.*, 1994). Oils interfere physically with respiration of contacted insects, and therefore provide the best available control for soft bodied insects and mites (Johnson, 1991). Baxendale and Johnson (1988b) achieved 100% control of spider mites (adults and nymphs) on deciduous ornamentals within 24 hours of treatment with 3% Sunspray 6E® (Sun Refining Corp., Philadelphia, PA) petroleum oil in autumn. Microscopic observation revealed the mite eggs had become darkened and distorted. Later inspections indicated that none of the eggs

hatched.

Researchers have investigated the insecticidal and miticidal properties of plant oils since the early 1900s (deOng *et al.*, 1927). Wickizer *et al.* (1977) reported that a 0.1% mixture of anise oil, a seed oil from the annual herb anise (*Pimpinella anisum* Linn.), reduced TSSM numbers on greenhouse dahlias (*Dahlia* sp.) by 68% and 50% compared to water (control) 4 and 11 days after spraying (DAS), respectively. The following spray treatments controlled TSSM (in order of decreasing efficacy): Plictran® (0.5 g of 50% wp), anise oil (1.25 ml anise oil + 0.5 ml detergent), buttermilk and flour (18 ml : 113.5 g), garlic-onion-red pepper solution [1/4 bulb garlic (*Allium sativum* L.): 1 large onion (*Allium cepa* L) + 236 ml water : 22.5 g ground red pepper (*Capsicum annuum* L.)], cedar chip tea [440.5 g cedar chips (*Cedrus* sp.)+ 1420 ml water], and water control. Butler and Henneberry (1990) showed that soybean (*Glycine max* (L.) Merrill), corn (*Zea mays* L.), sunflower (*Helianthus annuus* L.), safflower (*Carthamus tinctorius* L.), peanut (*Arachis hypogaea* L.), and cottonseed (*Gossypium hirsutum* L.) oils provided between 97 and 99% control of TSSM on bush beans (*Phaseolus vulgaris* L.), peppers, and squash (*Cucurbita* sp.). The Rodale Press recommended weekly sprays of 1-3% citrus oil or 0.06% neem (*Azadirachta indica* A. Juss.) oil for severe mite infestations (Gilkeson, 1991). Neem is an essential oil extracted from seed kernels of neem trees, which are native to tropical and arid zones (Prakash and Rao, 1997).

Phytotoxicity caused by horticultural oil sprays is a major concern with nurserymen. A survey of the arbor and nursery industries by Johnson and Caldwell (1987) indicated a variable amount of oil usage by arborists and nurserymen. Water stress may influence the development of phytotoxicity. Johnson (1983) previously stated that moisture stress from low relative humidity, high temperature, or wind is the “key to potential phytotoxicity

during the growing season”. Drought stress has been shown to increase oil-induced leaf abscission, especially when combined with additional stresses, such as insect infestation or disease infection (Smithley *et al.*, 1991). Davidson and associates (1991) advised horticulturists to avoid applying spray oils when plants were subjected to water, temperature, or pest-related stress. However, other researchers have indicated that the role of temperature in plant injury development on oil-treated plants is minimal. Tippins (1974) reported that oil-treated ornamentals withstood temperature extremes of -20°C and 34°C and displayed no phytotoxicity at the experiment completion.

Reports of oil-related injury are as diverse as the ornamentals they affect. Miller (1997) reported no phytotoxicity occurred to any of the 32 species/cultivars of shade trees, evergreens, and woody ornamentals sprayed with 2% Sunspray Ultra-fine Spray Oil® during the growing season. Davidson (1990) sprayed 4 to 6% petroleum spray oil on a wide array of woody ornamentals during a summer drought without phytotoxicity. Tippins (1974) reported that repeat applications of 2% petroleum oil during the summer did not damage azalea, boxwood, camellia, or holly. Winter applications of 0, 2, 4, 6, or 8% Sunspray 6E® petroleum spray oil damaged neither bark nor bud scales of six species of deciduous and evergreen woody ornamentals (Baxendale and Johnson 1988a).

The objectives of these experiments were 1) to evaluate the effects of summer applications of petroleum and soy oil on net photosynthesis, stomatal conductance, transpiration, and phytotoxicity of burning bush; and 2) to compare efficacy of soybean and petroleum oils to control TSSM.

MATERIALS AND METHODS

Experiment 1: Research was conducted in early autumn of 1996, to evaluate the immediate and delayed effects of degummed soy oil (Central Soya, Fort Wayne, IN) on 1) mite control efficacy; and 2) Pn rates of winged *Euonymus*. Thirty burning bush plants that were two-years old and in 2.81 liter (#1) containers were obtained from a commercial nursery and placed inside a greenhouse at the University of Tennessee, Knoxville. The plants were arranged in a randomized complete block design (RCB) with five replications. Preliminary mite counts determined that the shrubs were heavily infested with TSSM prior to spraying. Plants were sprayed until runoff with 0%, 1%, 2%, or 3% soy oil (v/v) in water, or 1% Sunspray Ultra-fine Spray Oil® petroleum oil (Sun Refining Co., Philadelphia, PA) (v/v) in water. Soy oil treatments were pre-mixed with Latron B-1956 Spreader-Sticker® (Rohm & Haas, Philadelphia, PA) at 10% of the respective oil concentration prior to mixing with water. Each treatment was sprayed until runoff using a Stihl® SR-400 backpack mist blower (Stihl Inc., Virginia Beach, VA) on 20 Sept. Twenty leaves were randomly selected per plant, removed at the petiole, and immediately brushed with a mite brushing machine (Leedom Enterprises, Mi Wuk Village, CA) on the seventh and fourteenth day after treatment. Mites were preserved in 70% ethanol and quantified using a compound light microscope.

Experiment 2: Research was conducted in the summer of 1997 to determine if soy oil 1) influenced Pn, Gs, or E rates or 2) caused phytotoxicity on burning bush. Thirty-six plants of three years-old 'Compactus' burning bush grown in 12.4 liter (# 5) pots were placed in a 30% shaded enclosure at the University of Tennessee Agricultural Experiment Station, Knoxville. Containers were arranged in an RCB design containing six replications. An

overhead irrigation system was installed on 23 May 1997. All plants were irrigated twenty minutes in the morning and thirty minutes in the late afternoon.

Plants were sprayed on 29 July 1997 with 1%, 2%, or 3% soy oil (mixed with Latron B-1956® at 10% of oil concentration); or 1% Sunspray Ultra-fine Spray Oil®. Treatments of unsprayed control plants and water sprayed plants were included in the experiment. Treatments were sprayed until runoff with a Stihl SR-400® backpack mist sprayer on 29 July 1997.

Rates of Pn, Gs, and E were measured with an ADC-3 model portable infrared gas analyzer (ADC Inc., Hoddenson, UK) on one leaf per plant (between the first and third fully expanded leaf from the apical meristem) on 28, 30 Jul., and 1, 5, 22 Aug. Gas exchange data were analyzed as an RCB design consisting of six treatments, six replications, and thirty-six experimental units. Data were analyzed with the General Linear Models (GLM) procedure and Duncan's multiple range test (SAS 6.12, 1996).

Foliage phytotoxicity ratings were made periodically throughout the experiment with the following five-point rating scale (Davidson *et al.*, 1990): 1 = no visible damage, 2 = slight yellowing on some leaves, 3 = moderate yellowing on most leaves, 4 = burn without dieback, and 5 = burn with dieback. Daily overhead irrigation deterred two-spotted spider mite colonization, thus no mites were found in the collection taken 11 Aug.

Experiment 3: On 6 May 1998, 40 'Compactus' burning bush plants that were two-years old and approximately 0.8 meter (2.5 feet) tall were obtained from a commercial nursery and repotted into 7.4 liter (# 3) containers. Pots were randomized in an RCB design with five replications in a greenhouse at the University of Tennessee, Knoxville. To ensure an even mite infestation, a TSSM-infested raspberry leaflet was placed in the foliage of each burning

bush shrub on 28 May. Infestation of TSSM was evident on all burning bush plants by 11 June.

Plants were treated as described in experiment one with repeated sprays of water (control), 0.25%, 0.5%, 0.75%, 1.0%, or 1.5% soy oil (v/v) on 12, 17, and 22 June. The oil was pre-mixed with Latron B-1956® at 10% of respective oil concentration before mixing in 7.6 liters of water. The objectives of this experiment were to determine if repeated oil sprays had a cumulative effect on suppressing mite populations, influencing gas exchange, and causing foliar phytotoxicity.

Twenty leaves per experimental unit (plant) were removed at the base of the petiole with tweezers and placed in paper containers with lids on the fourth day after each spray (16, 21, and 26 June). After each sample collection, containers were stored at 6°C (42° F) in a controlled storage chamber to slow mite movement. Mites on leaves were removed the day following sample collection with a mite brushing machine. Mites from each plant were preserved in 70% ethanol and later counted using a compound light microscope. Numbers of two-spotted spider mites and predatory mites per sample were ascertained. Predatory mite identification (currently presumed to be *Phytoseiulus persimilis*) will be verified eventually by the USDA Pest Identification Laboratory in Beltsville, MD.

Phytotoxicity ratings were made on 16 June using the same rating scale used in expt. 1. Due to the premature defoliation that was initially observed on 13 June, a modified five-point scale was used to rate defoliation: 1 = no defoliation, 2 = slight defoliation ($\leq 30\%$), 3 = moderate defoliation (31% to 60%), 4 = severe defoliation, but no twig dieback ($\geq 61\%$), and 5 = defoliation with twig dieback to entire plant death.

Rates of Pn, Gs, and E on a newly expanded leaf and on a tagged mature leaf were

measured on 12, 13, 16, 18, 20, 22 June, and 23 July with an ADC-3 portable infrared gas analyzer.

The experiment used an RCB design with five replications and eight treatments. Data were analyzed with the General Linear Models (GLM) procedure, linear regression, and contrasts to determine differences between soybean and petroleum oils (SAS 6.12, 1996). Since plants were sprayed multiple times, only mite levels within each collection day were compared statistically.

Experiment 4: Sixty 'Compactus' burning bush plants that were approximately two-years old and in 2.8 liter (# 1) containers were obtained from a commercial nursery. Thirty plants were randomly selected and placed outdoors. The remaining 30 plants were randomized in an RCB design and placed inside the greenhouse. Plants were sprayed as described in expt. 1 with either water (control), 1.0% or 1.5% soy oil (mixed with 0.1% or 0.15% Latron B-1956[®], respectively), 1.0% or 1.5% Sunspray Ultra-fine Spray Oil[®] petroleum oil, or 0.15% Latron B-1956[®]. Plants were sprayed three times: 13, 18, and 24 Aug. 1998. Rates of Pn, Gs, and E were measured on one newly expanded leaf per plant on 13, 17, 19, 23, 25, 31 Aug., and 4, 7 Sept. Phytotoxicity ratings were taken on 24 and 26 Aug. with the five point rating scale used in expt. 1.

RESULTS

Experiment 1: Both soybean and petroleum oil treatments reduced populations of TSSM by the seventh and fourteenth days after spraying (Fig. 1). Mite populations were reduced by 97-99% by 1-3% soy oil and 1% Sunspray Ultra-fine-treated plants compared to

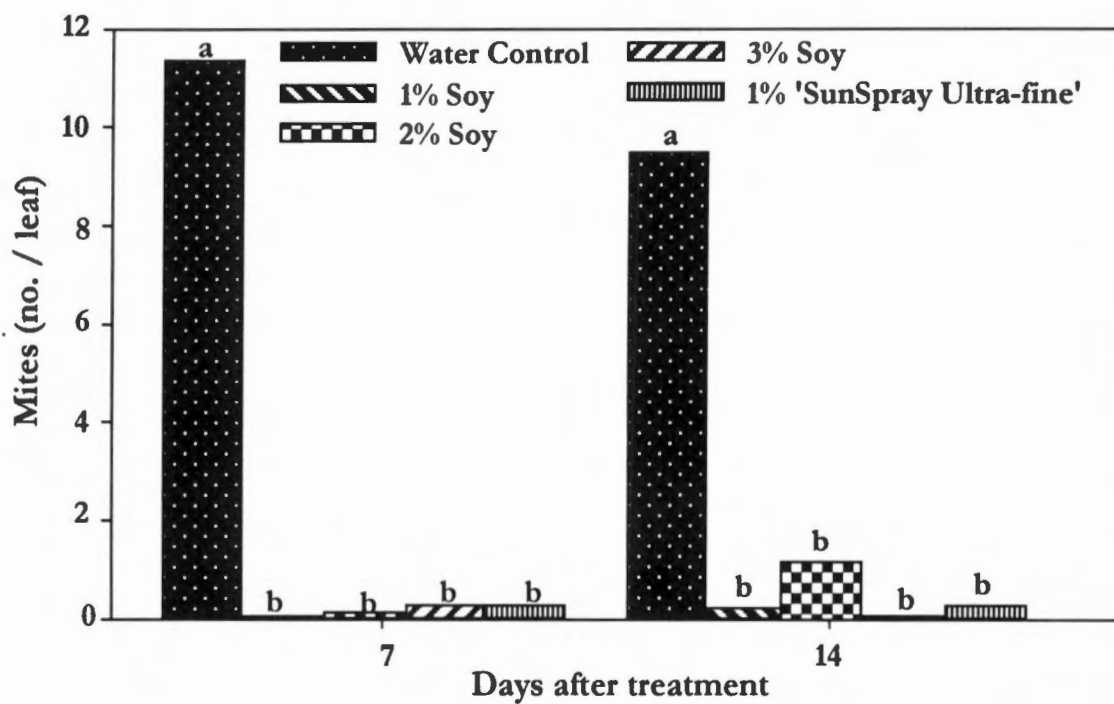


Fig. 1. Effect of soybean and petroleum oil on two-spotted spider mites 7 & 14 days after spraying on *Euonymus alatus* 'Compactus'. Letters represent mean separation with Duncan's multiple range test ($P \leq 0.05$). Sprays were applied 20 Sept. 1996.

the water-treated plants by 7 DAS. Although all of the oil treatments reduced mite populations, no differences existed among the oil treatments. Sprays of 1% to 3% soy oil continued to reduce TSSM populations by 87% to 98% compared to the water control at 14 DAS.

Net photosynthetic rates on 1 DAS were negatively correlated with soy oil concentration (Fig. 2). Plants treated with 1% Sunspray Ultra-fine Spray Oil® had statistically lower Pn rates 1 DAS than plants sprayed with water or 1-3% soy oil (Fig. 3). The Pn rates of plants sprayed with 1-3% soy oil or 1% Sunspray Ultra-fine Spray Oil® returned to those statistically equivalent with water-sprayed plants by 11 DAS. No phytotoxicity was observed throughout the study. This research indicated that soy oil controlled TSSM as well as the petroleum oil with only short-term reduction of Pn and no visual phytotoxicity to burning bush plants.

Experiment 2: Net photosynthesis, stomatal conductance, and transpiration rates of plants to be treated were statistically equal on 28 July 1998 (1 day before spraying) (Fig. 4, Tables 1, 2, 3). Spraying 1, 2, or 3% soy oil or 1% Sunspray Ultra-fine Spray Oil® significantly reduced Pn and E rates compared to the dry control. Leaves on oil-treated plants had significantly lower Gs rates than leaves on untreated or water-treated plants 1 DAS. At 3 and 7 DAS, plants sprayed with 1% Sunspray Ultra-fine Spray Oil® or 1, 2, or 3% soy oil had lower Pn, Gs, and E rates than the dry control. Plants treated with 3% soy oil tended to have the lowest Pn, Gs, and E rates, with the Gs and E rates being statistically lower than those of plants treated with petroleum oil. By the final rating (24 DAS), Pn rates were statistically equivocal for all treatments. No phytotoxicity occurred to any of the burning bush shrubs for the duration of the experiment.

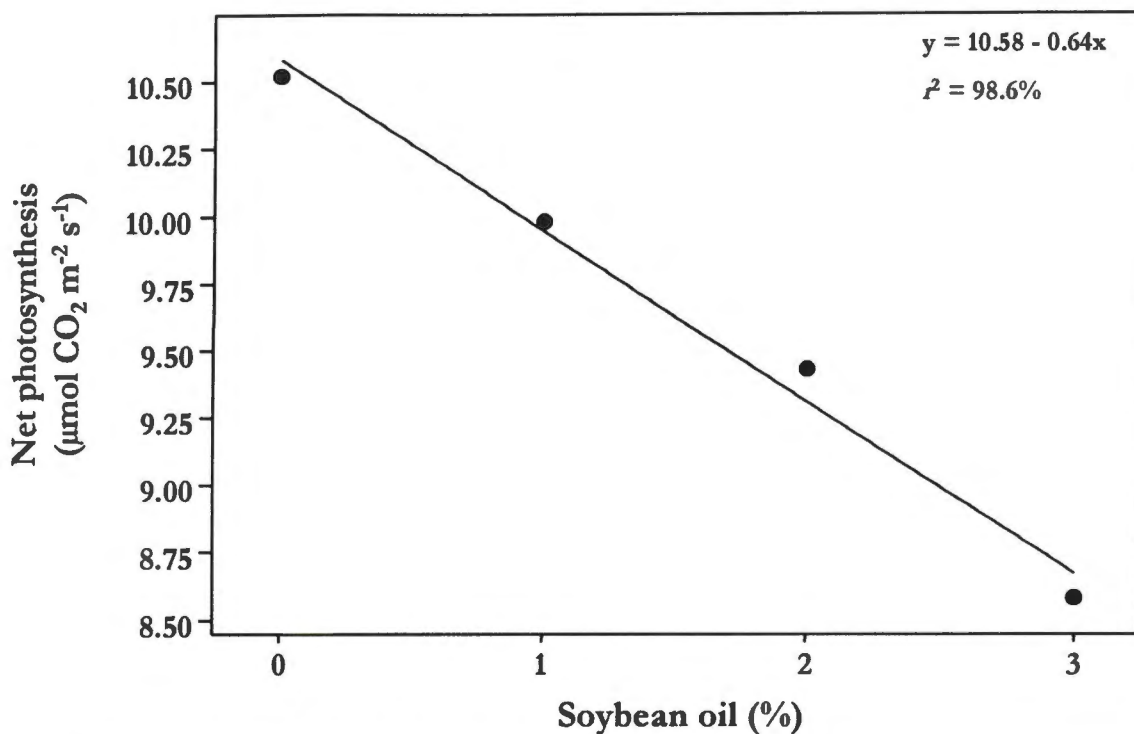


Fig. 2. Effect of soybean oil concentrations on the net photosynthetic rate on *Euonymus alatus* 'Compactus' one day after spraying oil (21 Sept. 1996).

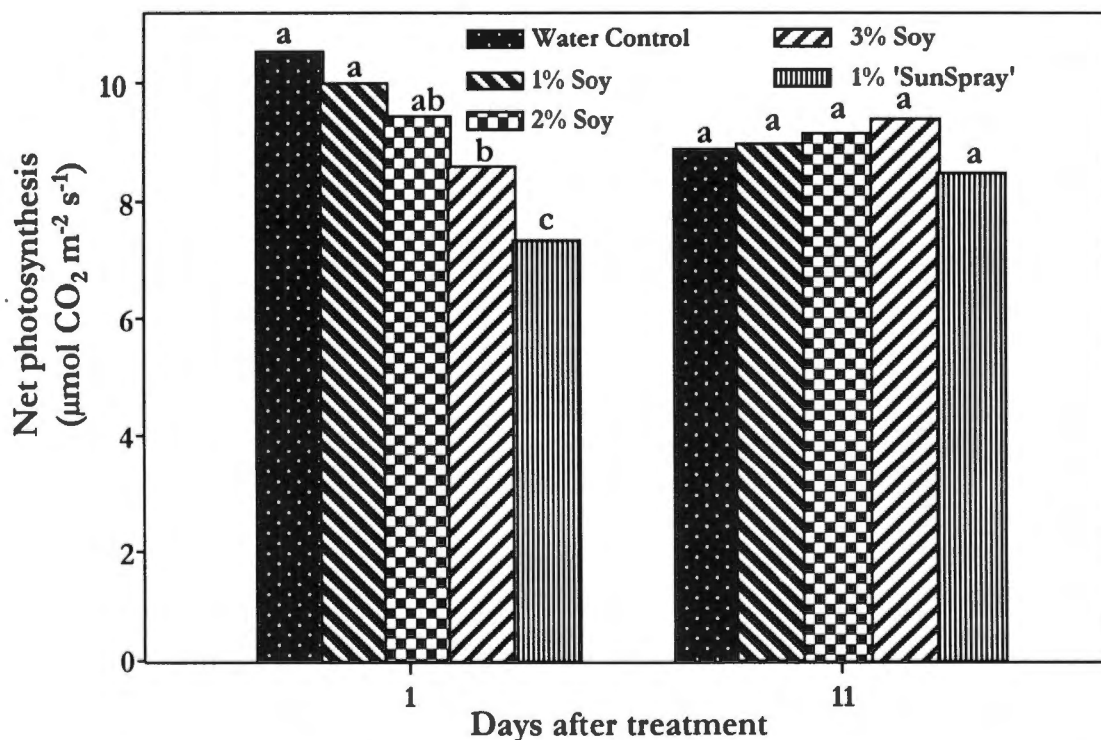


Fig. 3. Effect of soybean and petroleum oil on *Euonymus alatus* 'Compactus' net photosynthesis on 21 Sept. and 2 Oct. 1996. Letters within dates represent mean separation by Duncan's multiple range test ($P \leq 0.05$).

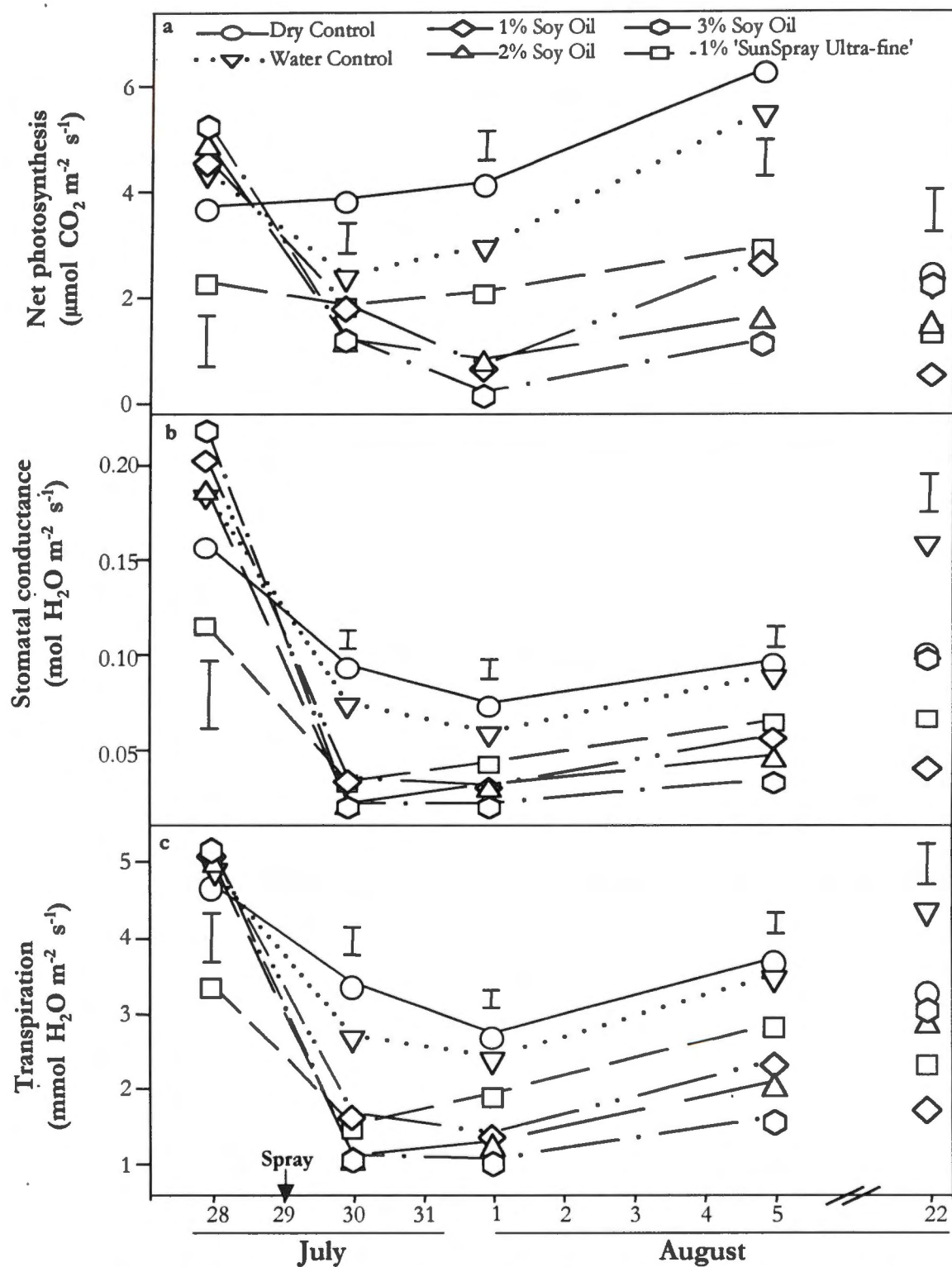


Fig. 4. Effect of soybean and petroleum oils on net photosynthesis (a), stomatal conductance (b), and transpiration (c) of 'Compactus' burning bush. Sprays were applied 29 July 1997. Vertical bars represent one SE.

Table 1. Comparison of soybean and petroleum oil sprays on net photosynthesis ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) of *Euonymus alatus* 'Compactus' grown under 30% shade

Treatments ^z	28 Jul	30 Jul	1 Aug	5 Aug	22 Aug
1% Soy Oil ^y	4.62 a ^x	1.88 b	0.74 cd	2.72 b	0.60 a
2% Soy Oil ^y	4.93 a	1.23 b	0.85 cd	1.65 b	1.58 a
3% Soy Oil ^y	5.30 a	1.27 b	0.23 d	1.20 b	2.30 a
1% Sunspray ^w	2.30 a	1.89 b	2.12 bc	2.96 b	1.35 a
Water Control	4.38 a	2.42 ab	2.98 ab	5.50 a	2.27 a
Contrasts					
1% Soy vs. 1% Sunspray Ultra-fine	NS	NS	NS	NS	NS

^z Treatments applied 29 July 1997.

^y Soy oil treatments emulsified with Latron B-1956® Spreader-Sticker at 10% of the oil.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

^{NS} Nonsignificant at $P \leq 0.05$.

Table 2. Comparison of soybean and petroleum oil sprays on stomatal conductance ($\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) of *Euonymus alatus* 'Compactus' grown under 30% shade

Treatments ^z	28 Jul	30 Jul	1 Aug	5 Aug	22 Aug
1% Soy Oil ^y	0.20 a ^x	0.04 b	0.03 c	0.06 bc	0.04 b
2% Soy Oil ^y	0.19 a	0.02 b	0.03 c	0.05 bc	0.10 ab
3% Soy Oil ^y	0.22 a	0.02 b	0.02 c	0.04 c	0.10 ab
1% Sunspray ^w	0.12 a	0.03 b	0.04 bc	0.07 b	0.07 ab
Water Control	0.19 a	0.08 a	0.06 ab	0.09 a	0.16 a
Contrasts					
Soy vs. Sunspray Ultra-fine	NS	NS	NS	NS	NS

^z Treatments applied 29 July 1997.

^y Soy oil treatments emulsified with Latron B-1956® Spreader-Sticker at 10% of the oil.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

^{NS} Nonsignificant at $P \leq 0.05$.

Table 3. Comparison of soybean and petroleum oil sprays on transpiration ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) of *Euonymus alatus* 'Compactus' grown under 30% shade

Treatments ^z	28 Jul	30 Jul	1 Aug	5 Aug	22 Aug
1% Soy Oil ^y	5.16 a ^x	1.68 bc	1.42 cd	2.38 cd	1.80 b
2% Soy Oil ^y	5.05 a	1.13 c	1.30 cd	2.10 de	2.95 ab
3% Soy Oil ^y	5.23 a	1.13 c	1.08 d	1.63 e	3.13 ab
1% Sunspray ^w	3.40 a	1.52 c	1.94 bc	2.88 bc	2.37 ab
Water Control	4.93 a	2.73 ab	2.43 ab	3.53 ab	4.40 a
Contrasts					
Soy vs. Sunspray Ultra-fine	*	NS	NS	NS	NS

^zTreatments applied 29 July 1997

^y Soy oil treatments emulsified with Latron B-1956® Spreader-Sticker at 10% of the oil.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

NS,* Nonsignificant or significant at $P \leq 0.05$, respectively.

Experiment 3: Sprays of 0.25% to 1.5% soy oil significantly reduced TSSM populations in an decreasing asymptotic relationship with soy oil concentration (Fig. 5). Populations of TSSM on oil-treated plants were reduced to nearly zero after the second soy oil spray (21 June 1998). Numbers of TSSM on water-sprayed plants descended from 9 to 1 mites per leaf between the 21 and 26 June (Fig. 6). Statistical analysis using contrast statements of PROC GLM indicated that 1.0 and 1.5% soy oil sprays had consistently fewer mites per leaf than did the same rates of Sunspray Ultra-fine Spray Oil® at each sampling ($P \leq 0.01$) (SAS 6.12, 1996).

Predatory mite populations were more variable than the populations of TSSM (Fig. 7). On 16 June (3 DAS) there were scattered distributions of the predatory mites (currently presumed to be *Phytoseiulus persimilis*; submitted to the USDA Pest Diagnostic Lab for

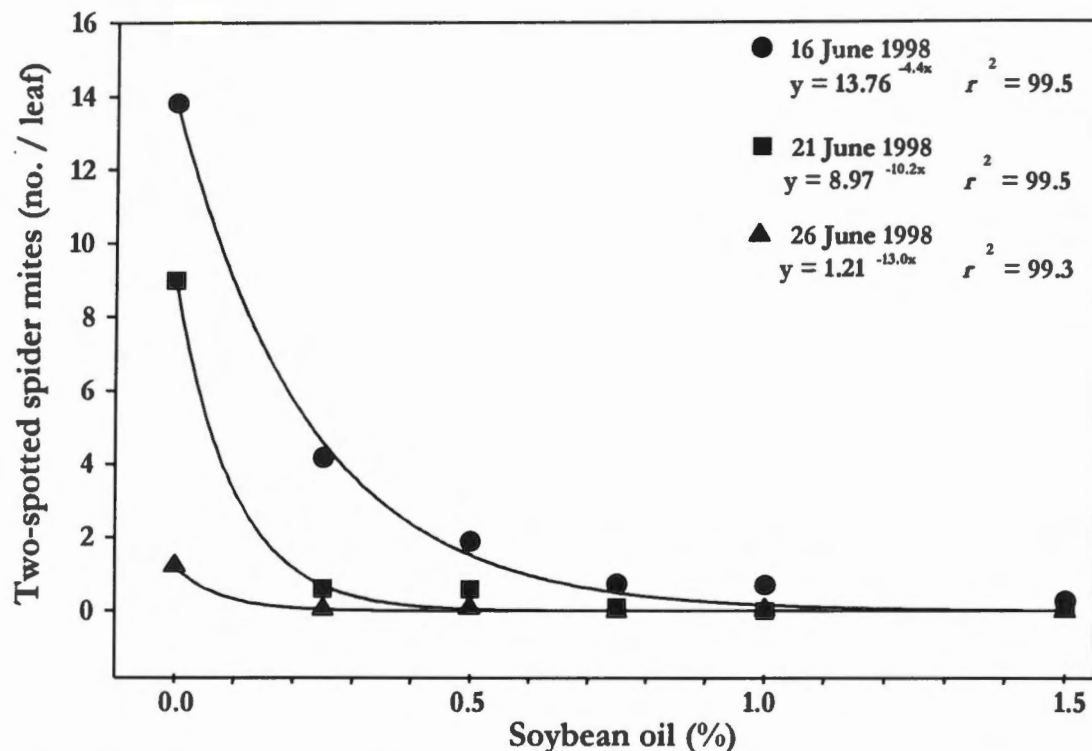


Fig. 5. Effect of repeated applications soybean oil on two-spotted spider mites on burning bush. Sprays applied on 12, 17, and 22 June 1998.

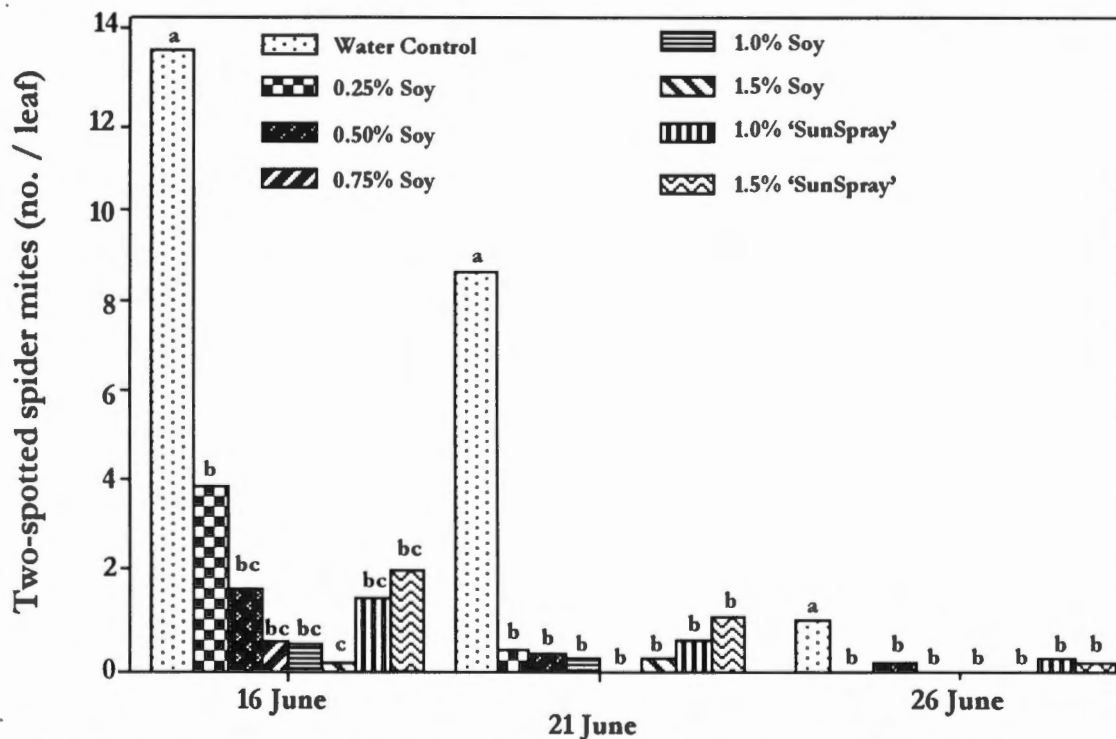


Fig. 6. Effect of soybean and petroleum oils sprays on 12, 17, and 22 June 1998 on two-spotted spider mites on burning bush. Letters represent mean separation within each date with Duncan's multiple range test ($P \leq 0.05$).

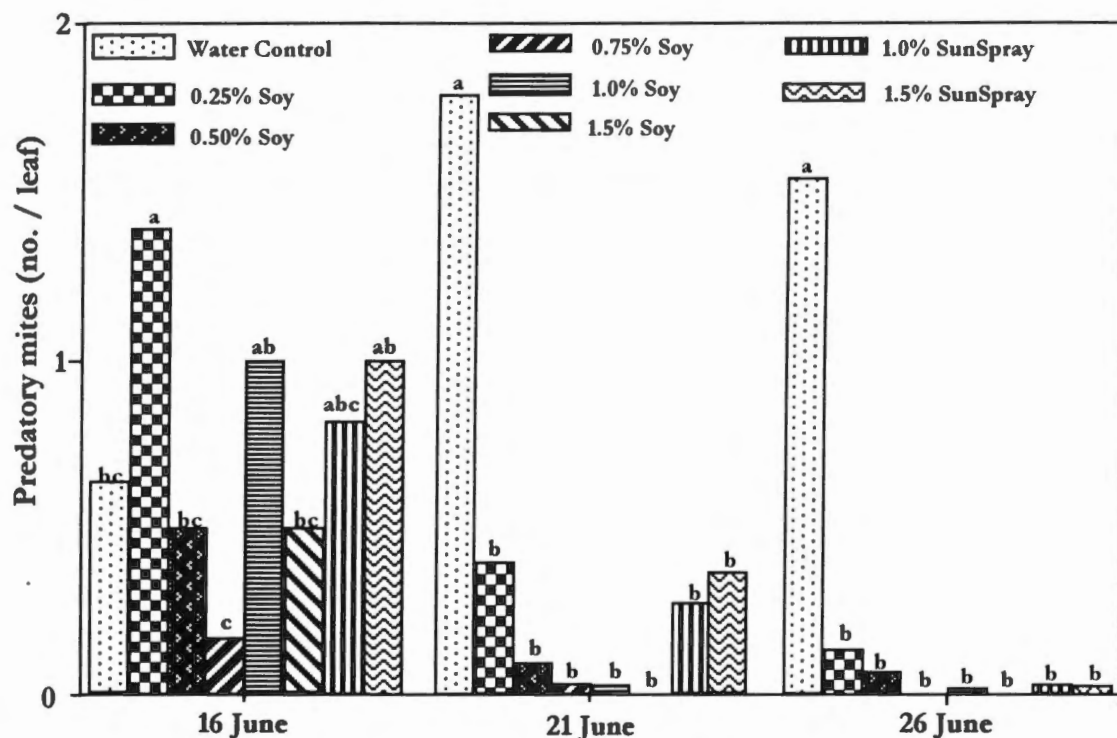


Fig. 7. Effect of soybean and petroleum oils sprays on 12, 17, and 22 June on predatory mites on burning bush. Letters represent mean separation within each date with Duncan's multiple range test ($P \leq 0.05$).

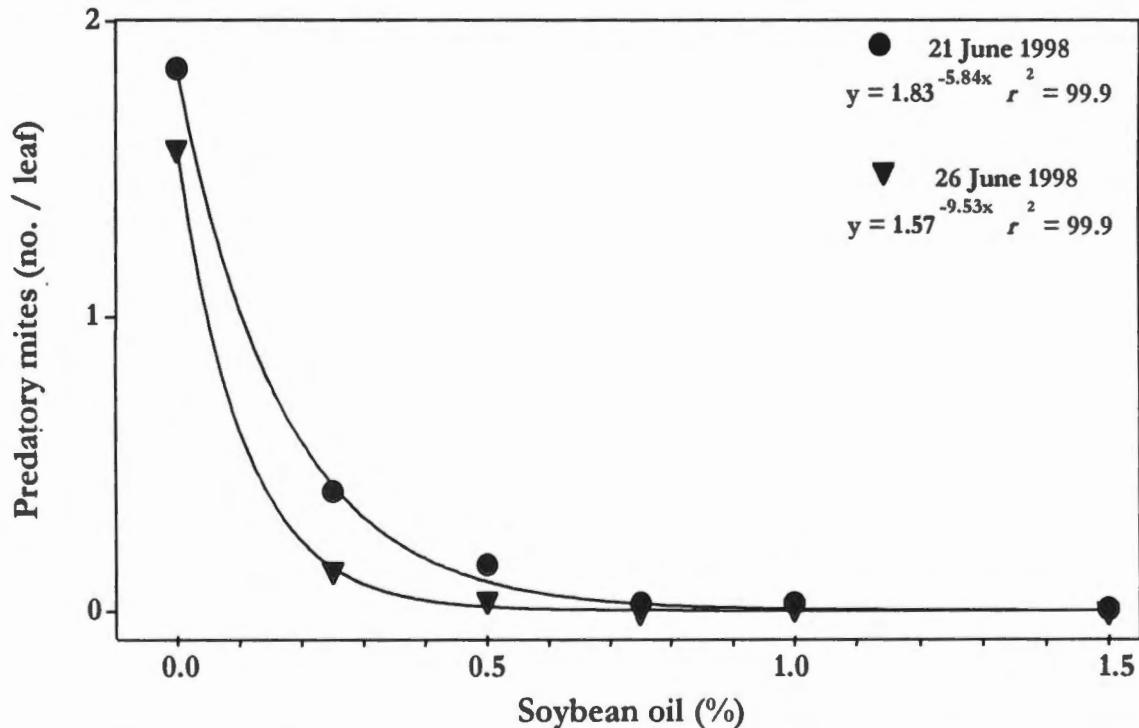


Fig. 8. Effect of repeated applications soybean oils on predatory mites on burning bush. Plants sprayed on 12, 17, and 22 June 1998.

identification). Plants sprayed with 0.25% soy, 1% soy, 1% or 1.5% Sunspray Ultra-fine Spray Oil® supported up to two fold more predatory mites than the water control. Plants sprayed with 0.25% soy oil had more predatory mites than water-treated plants. The predatory mites were not disrupted greatly by the first oil application. However, on 21 and 26 June the oil-sprayed plants had fewer predatory mites than the water control plants. Similar to the TSSM populations, numbers of predatory mites decreased after the second and third spray. Predatory mites were reduced by soy oil on 21 and 26 June ($r^2 \geq 99.9$) (Fig. 8). However, this decrease in mite numbers may have been due to predatory mite starvation or migration to the control plants, where TSSM still proliferated. On 26 June, a dramatic decrease in the levels of two-spotted mites on the control plants was evident, although numbers of predatory mites were still relatively high.

Leaf Pn rates of all treatments were equivocal on 12 (0 DAS), 13 (1 DAS), and 16 June (4 DAS) (Figs. 9a). On 18 June, only 0.5% soy and 1.5% Sunspray Ultra-fine Spray Oil® differed statistically. Net photosynthetic rates on 20 June were not different for any of the oil treatments. However, differences between the higher oil rates and the water control did occur. Sprays of 0.75% and 1.5% soy oil, and 1% and 1.5% Sunspray Ultra-fine Spray Oil® caused reductions in Pn rates 3 days after the second spray (20 June) compared to the water control. Plants treated with 1% soy oil had Pn rates higher than those treated with 1.5% soy oil, or 1 or 1.5% petroleum oil and statistically equivalent to plants treated with 0%, 0.25%, or 0.5% soy oil.

Stomatal conductance rates on all oil-treated plants had patterns similar to Pn throughout the trial (Figs. 9b). From 16 to 22 June, stomatal conductance rates on water-sprayed plants were statistically higher than on plants treated with 1.0% or 1.5% soy oil.

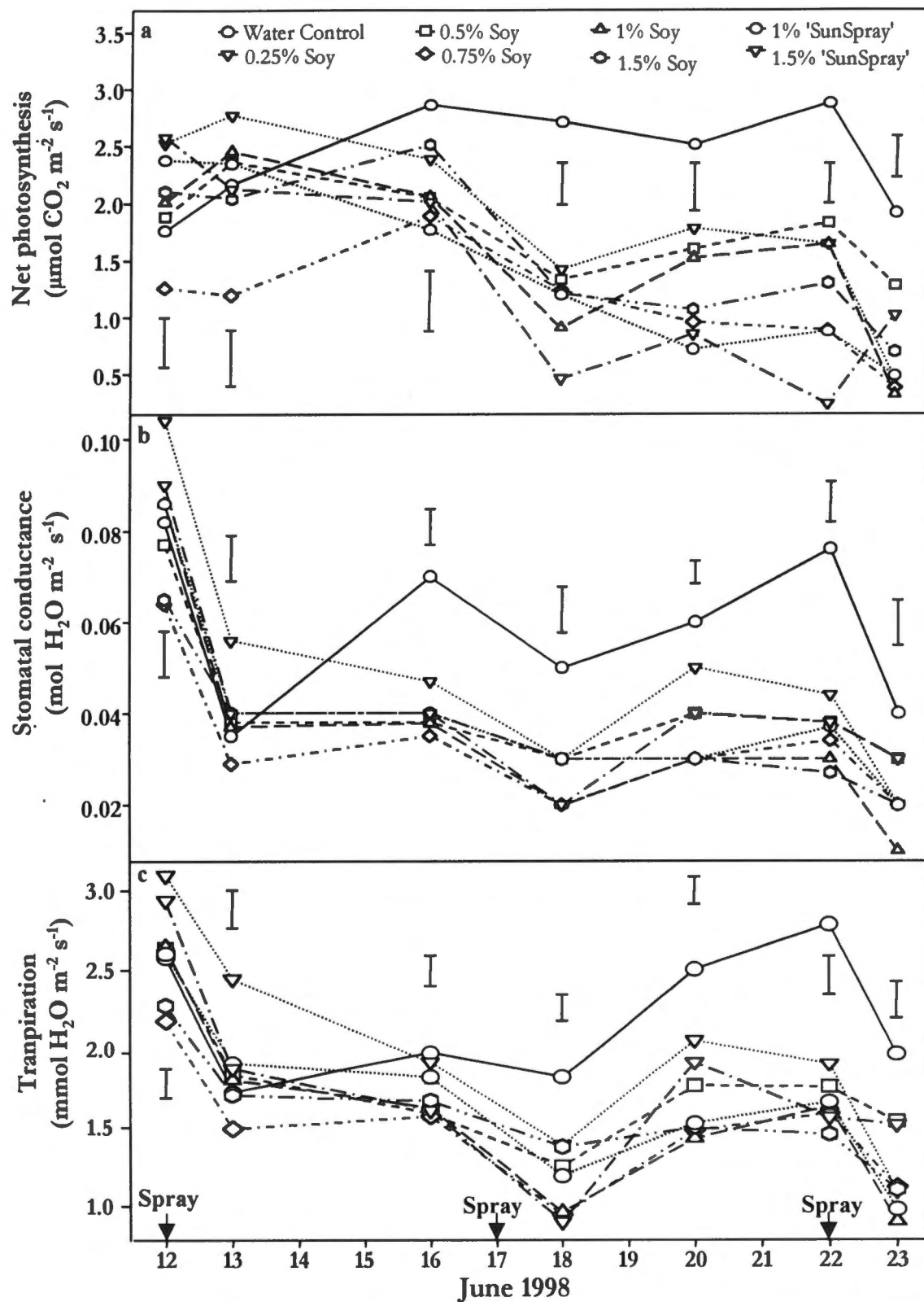


Fig. 9. Effect of soybean or petroleum oil on net photosynthesis (a), stomatal conductance (b), and transpiration (c) of mite-infested burning bush. Vertical bars represent one SE.

Transpiration rates on all treatments had similar patterns to Pn, but some statistical differences existed (Figs. 9c). Plants treated with >0.5% soy oil had lower E rates than control plants 5 days after the first spray. Transpiration rates on oil-treated plants were lower than the control plants after the second and third spray.

The contrast function of the Proc GLM procedure (SAS 6.12, 1996) compared Pn, Gs, and E rates of soy oil-treated plants with Sunspray petroleum oil-treated plants (Table 4, 5, 6). No differences in gas exchange rates were detected at any of the dates for the duration of the trial. Burning bush shrubs treated with the 1.0% or 1.5% soy oil or petroleum oil had statistically similar Pn, Gs, and E patterns for the duration of the experiment. However, on the first day following the first spray, Pn rates on 1.5% Sunspray-treated plants plummeted to almost zero (Table 4). Plants that received multiple applications of 1.0% or 1.5% soy oil tended to have higher Pn, Gs, and E rates than plants sprayed with identical rates of Sunspray Ultra-fine Spray Oil®.

Defoliation and phytotoxicity were rated on 16 June, 4 days after the first spray but 1 day before the second spray. Phytotoxicity rates showed a strong positive relationship to soy oil concentration ($r^2 = 97\%$, Fig. 10), although no differences existed between any of the soy rates. The petroleum oil treatments produced more phytotoxicity on burning bush shrubs than did the 0.25% soy oil and water (Fig. 11). Spraying 1 or 1.5% petroleum oil caused significantly more defoliation than did any of the soy oil treatments ($P \leq 0.005$, Fig. 12). Phytotoxic damage and defoliation on soy oil-treated plants was statistically equivalent to that on water-sprayed plants on 16 June (Figs. 11 and 12).

Table 4. Comparison of soybean and petroleum oil sprays on net photosynthesis ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) of *Euonymus alatus* 'Compactus' infested with two-spotted spider mites (*Tetranychus urticae*).

Treatments ^z	12 Jun	13 Jun	16 Jun	18 Jun	20 Jun	22 Jun	23 Jun
1% Soy Oil ^y	2.01 a ^x	2.45 ab	2.06 a	0.91 ab	1.52 ab	1.77 b	0.32 b
1.5% Soy Oil ^y	2.1 a	2.04 ab	2.51 a	1.21 ab	1.07 a	1.30 bc	0.68 b
1% Sunspray ^w	2.24 a	2.34 ab	1.77 a	1.15 ab	0.72 b	0.88 bc	0.49 b
1.5% Sunspray ^w	2.57 a	0.13 b	2.01 a	0.46 b	0.85 b	0.24 c	1.04 ab
Water Control	1.76 a	3.16 a	2.86 a	2.71ab	2.51 a	2.88 a	1.92 a
Contrasts							
Soy vs. Sunspray Ultra-fine	NS	NS	NS	NS	NS	NS	NS

^z Treatments applied 12, 17, and 22 June 1998.

^y Soy oil treatments emulsified with Latron B-1956® Spreader-Sticker at 10% of the oil.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

^{ns} Nonsignificant at $P \leq 0.05$.

Table 5. Comparison of soybean and petroleum oil sprays on stomatal conductance ($\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1}$) of *Euonymus alatus* 'Compactus' infested with two-spotted spider mites (*Tetranychus urticae*).

Treatments ^z	12 Jun	13 Jun	16 Jun	18 Jun	20 Jun	22 Jun	23 Jun
1% Soy Oil ^y	0.09 ab ^x	0.04 ab	0.04 b	0.02 b	0.03 c	0.03 b	0.01 b
1.5% Soy Oil ^y	0.07 b	0.04 ab	0.04 b	0.03 ab	0.03 c	0.03 b	0.02 b
1% Sunspray ^w	0.09 ab	0.04 ab	0.04 b	0.03 b	0.03 c	0.04 b	0.02 ab
1.5% Sunspray ^w	0.10 a	0.04 ab	0.04 b	0.02 b	0.04 bc	0.04 b	0.03 ab
Water Control	0.08 ab	0.04 ab	0.07 a	0.05 a	0.06 a	0.08 a	0.04 a
Contrasts							
Soy vs. Sunspray	NS	NS	NS	NS	NS	NS	NS

^z Treatments applied 12, 17, and 22 June 1998.

^y Soy oil treatments emulsified with Latron B-1956® Spreader-Sticker at 10% of the oil.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

^{ns} Nonsignificant at $P \leq 0.05$.

Table 6. Comparison of soybean and petroleum oil sprays on transpiration ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) of *Euonymus alatus* 'Compactus' infested with two-spotted spider mites (*Tetranychus urticae*).

Treatments ^z	12 Jun	13 Jun	16 Jun	18 Jun	20 Jun	22 Jun	23 Jun
1% Soy Oil ^y	2.76 ab ^x	1.80 a	1.60 a	0.85 b	1.38 c	1.67 b	0.78 b
1.5% Soy Oil ^y	2.34 b	1.69 a	1.65 a	1.32 ab	1.46 c	1.41 b	1.02 b
1% Sunspray ^w	2.71 ab	1.92 a	1.82 a	1.11 b	1.49 c	1.64 b	0.87 b
1.5% Sunspray ^w	3.09 a	1.88 a	1.58 a	0.78 b	1.93 bc	1.53 b	1.47 ab
Water Control	2.68 ab	1.71 a	2.00 a	1.82 a	2.60 a	2.92 a	1.99 a
Contrasts							
Soy vs. Sunspray	NS	NS	NS	NS	NS	NS	NS

^zTreatments applied 12, 17, and 22 June 1998.

^y Soy oil treatments emulsified with Latron B-1956® Spreader-Sticker at 10% of the oil.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

^{NS} Nonsignificant at $P \leq 0.05$.

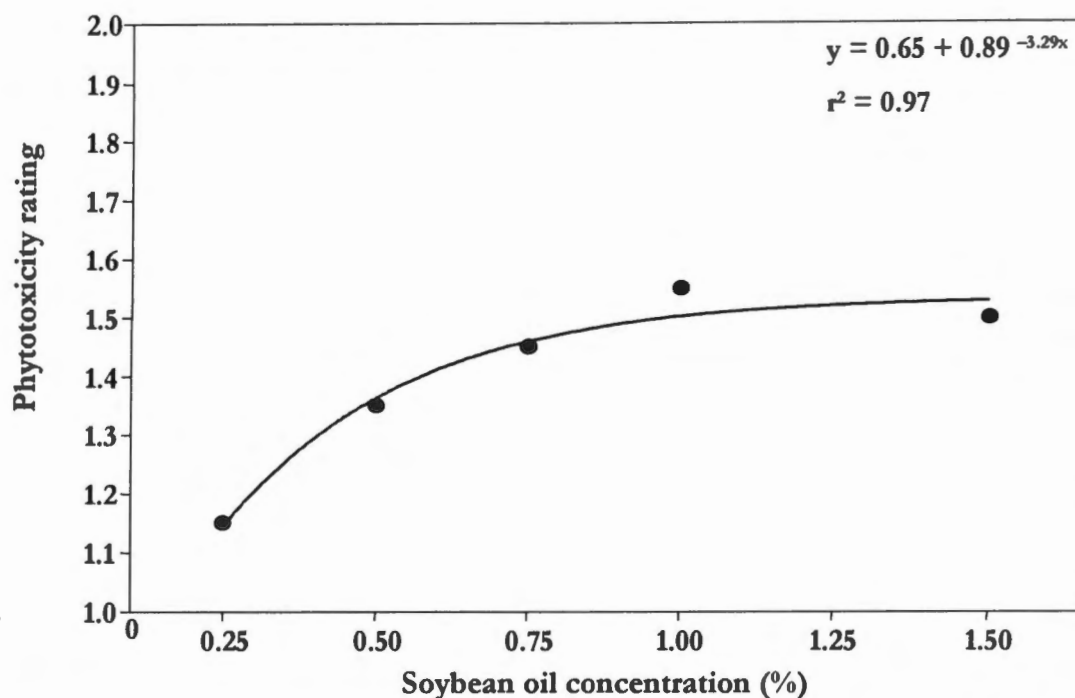


Fig. 10. Relationship between oil concentration and phytotoxicity on mite-infested burning bush plants on 16 June 1998 (4 days after the first spray). Rating scale: 1 = no visible damage; 2 = slight yellowing on some leaves.

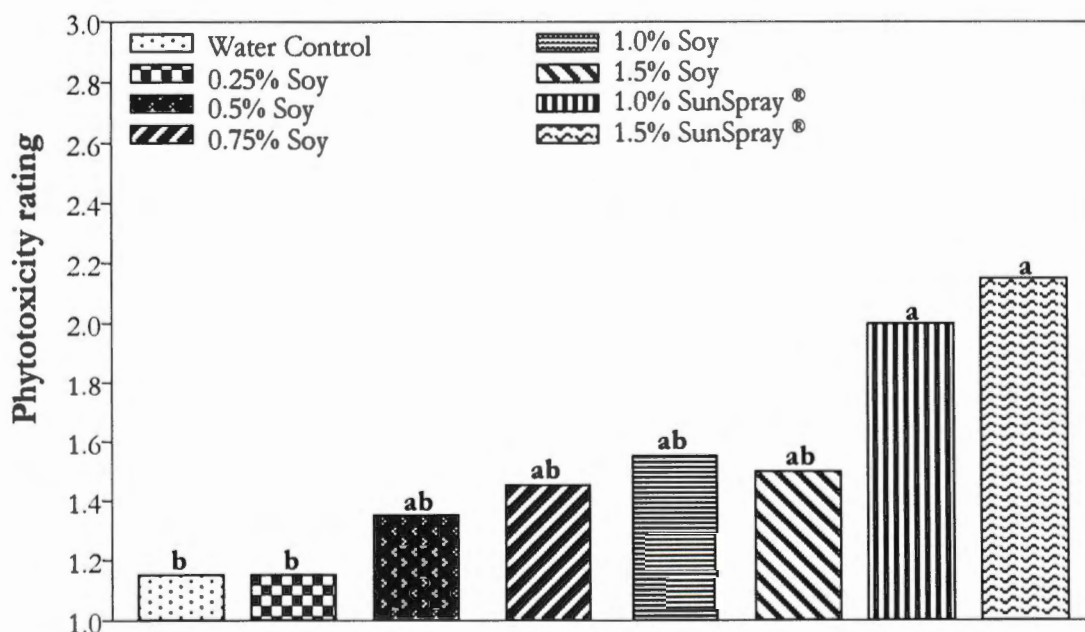


Fig. 11. Phytotoxicity on mite-infested burning bush plants on 16 June 1998 (4 days after treatment). Rating scale: 1 = no visible damage; 2 = slight yellowing on some leaves; 3 = moderate yellowing on most leaves.

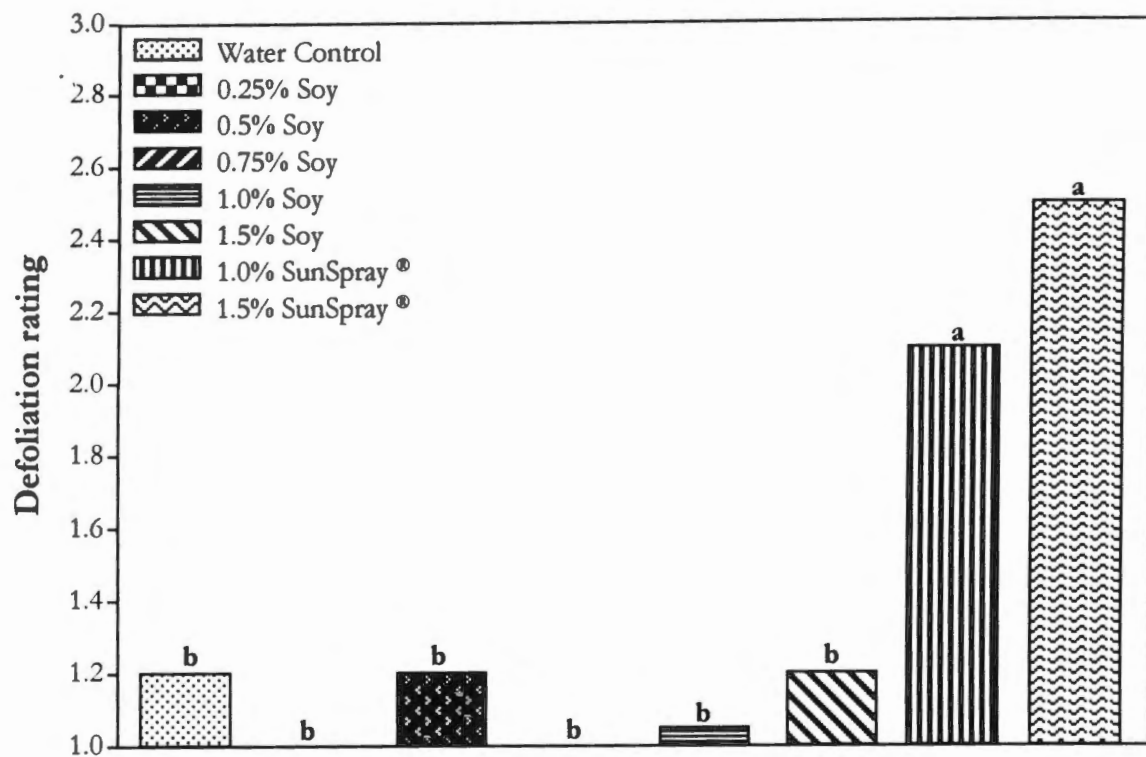


Fig. 12. Defoliation ratings (1 - 5) for mite-infested burning bush plants on 16 June 1998 (4 days after treatment). 1 = no defoliation; 2 = $\leq 30\%$ defoliation; 3 = 31% to 60% defoliation. Letters represent mean separation by Duncan's multiple range test ($P \leq 0.05$).

Experiment 4: Greenhouse-grown burning bush plants sprayed with 1.0% or 1.5% soy oil had similar Pn, Gs, and E rates as the control plants 4 DAS (Fig. 13). Plants sprayed with 1.0% or 1.5% petroleum oil had significantly lower plant gas exchange (Pn, Gs, and E) rates than the soy-treated or water-sprayed plants (Tables 7, 8, and 9).

Burning bush shrubs maintained outdoors and sprayed with 1% Sunspray Ultra-fine Spray Oil® had more erratic gas exchange (Pn, Gs, and E) patterns than plants sprayed with 1% soy oil (Fig. 14). A single 1% soy or Sunspray oil spray did not decrease Pn, Gs, or E on 17 Aug. (4 DAS) (Tables 10, 11, and 12). One day after the second spray, however, the 1% oil sprays reduced Pn, Gs, and E rates (Tables 7 - 12). All plants had equivalent Pn, Gs, and E levels four days later (23 Aug., one day prior to the third spray). Plants sprayed with 1% soybean or petroleum oil had similar reductions of Gs and E for up to seven days after the third spray (Figs. 13 and 14). Soy oil continued to suppress Pn until 14 days after the third (final) spray (Tables 7 and 10). The 1.5% soy and petroleum oil sprays had similar effects on Pn, Gs, and E as the 1.0% sprays. However, rates of Pn, Gs, and E on plants after the third application of 1.5% soy oil were the highest at the completion of the entire trial.

No severe phytotoxic damage was evident on control, 1% soy, or 1% petroleum oil-sprayed burning bush shrubs kept inside or outdoors for the duration of this trial. Plants sprayed with 1.5% of either soy or petroleum oil and in highly stressed conditions (next to the fans) had about 15% defoliation and minor phytotoxicity by 7 Sept. However, none of the plants had as much phytotoxicity or defoliation as in experiment 2.

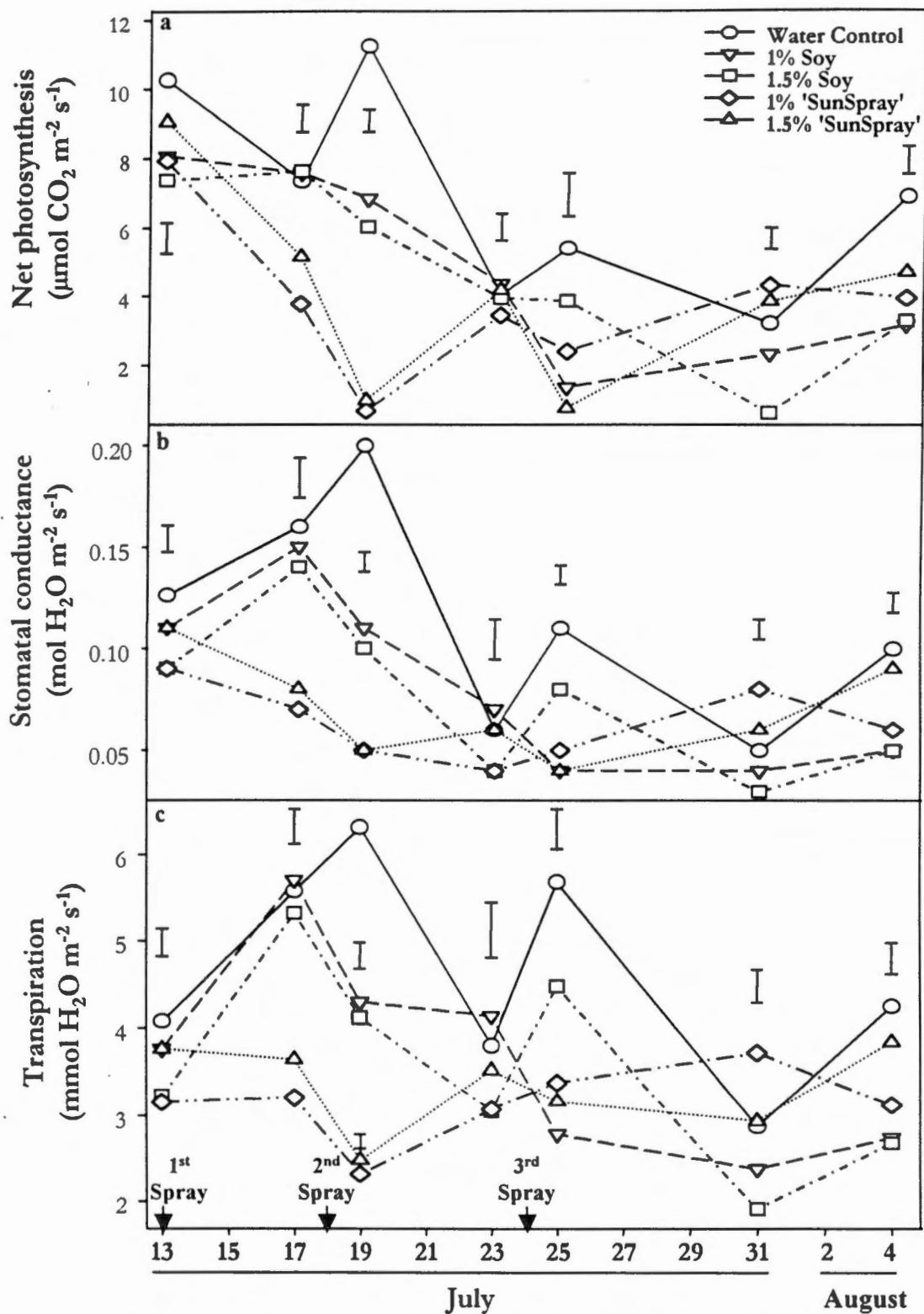


Fig. 13. Effect of multiple applications of soybean or petroleum oil on net photosynthesis (a), stomatal conductance (b), and transpiration (c) of burning bush raised inside a greenhouse. Vertical bars represent one SE.

Table 7. Comparison of soybean and petroleum oil sprays on net photosynthesis ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) of *Euonymus alatus* 'Compactus' raised inside of a greenhouse.

Treatments ^z	13 Aug	17 Aug	19 Aug	23 Aug	25 Aug	31 Aug	4 Sept
1% Soy Oil ^y	8.06 a ^x	7.58 a	6.84 b	4.36 b	1.36 b	2.34 bc	3.20 b
1.5% Soy Oil ^y	7.36 a	7.62 a	6.02 b	3.95 b	3.87 ab	0.63 c	3.32 b
1% Sunspray ^w	7.92 a	3.78 c	0.98 c	3.45 b	2.40 ab	4.34 ab	3.34 b
1.5% Sunspray ^w	9.05 a	5.14 bc	0.68 c	4.18 b	0.76 b	3.88 ab	3.84 b
Water Control	10.26 a	7.36 ab	11.24 a	4.05 b	5.40 a	3.24 ab	6.93 a
Contrasts							
Soy vs. Sunspray	NS	***	***	NS	NS	***	NS

^z Treatments applied 13, 18, and 24 June 1998.

^y Soy oil treatments emulsified with Latron B-1956® Spreader-Sticker at 10% of the oil.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

NS,*** Nonsignificant or significant at $P \leq 0.05$ or $P \leq 0.005$, respectively.

Table 8. Comparison of soybean and petroleum oil sprays on stomatal conductance ($\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1}$) of *Euonymus alatus* 'Compactus' raised inside of a greenhouse

Treatments ^z	13 Aug	17 Aug	19 Aug	23 Aug	25 Aug	31 Aug	4 Sept
1% Soy Oil ^y	0.11 ab ^x	0.15 a	0.11 b	0.07 a	0.04 c	0.04 bc	0.05 b
1.5% Soy Oil ^y	0.09 ab	0.14 a	0.10 b	0.05 a	0.08 ab	0.03 c	0.05 b
1% Sunspray ^w	0.08 b	0.07 b	0.05 c	0.05 a	0.05 bc	0.08 a	0.06 b
1.5% Sunspray ^w	0.11 ab	0.08 b	0.05 c	0.06 a	0.04 c	0.06 abc	0.07 ab
Water Control	0.13 a	0.16 a	0.20 a	0.07 a	0.11 a	0.05 abc	0.10 a
Contrasts							
Soy vs. Sunspray	NS	***	***	NS	NS	**	NS

^z Treatments applied 13, 18, and 24 June 1998.

^y Soy oil treatments emulsified with Latron B-1956® Spreader-Sticker at 10% of the oil.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

NS,**,*** Nonsignificant or significant at $P \leq 0.05$, $P \leq 0.01$, or $P \leq 0.005$, respectively.

Table 9. Comparison of soybean and petroleum oil sprays on transpiration (mmol H₂O m⁻² s⁻¹) of *Euonymus alatus* 'Compactus' raised inside of a greenhouse

Treatments ^z	13 Aug	17 Aug	19 Aug	23 Aug	25 Aug	31 Aug	4 Sept
1% Soy Oil ^y	3.76 a ^x	5.70 a	4.30 b	4.14 a	2.78 c	2.38 bc	2.74 b
1.5% Soy Oil ^y	3.22 a	5.32 a	4.12 b	3.05 a	4.48 ab	1.83 c	2.68 b
1% Sunspray ^w	3.15 a	3.20 b	2.32 c	3.08 a	3.38 bc	3.72 a	2.74 b
1.5% Sunspray ^w	3.76 a	3.64 b	2.48 c	3.53 a	3.16 bc	2.94 abc	3.22 ab
Water Control	4.08 a	5.58 a	6.32 a	3.80 a	5.68 a	2.88 abc	4.20 a
Contrasts							
Soy vs. Sunspray	NS	***	***	NS	NS	**	NS

^z Treatments applied 13, 18, and 24 June 1998.

^y Soy oil treatments emulsified with Latron B-1956® Spreader-Sticker at 10% of the oil.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

NS, **, *** Nonsignificant or significant at $P \leq 0.05$, $P \leq 0.01$, or $P \leq 0.005$, respectively.

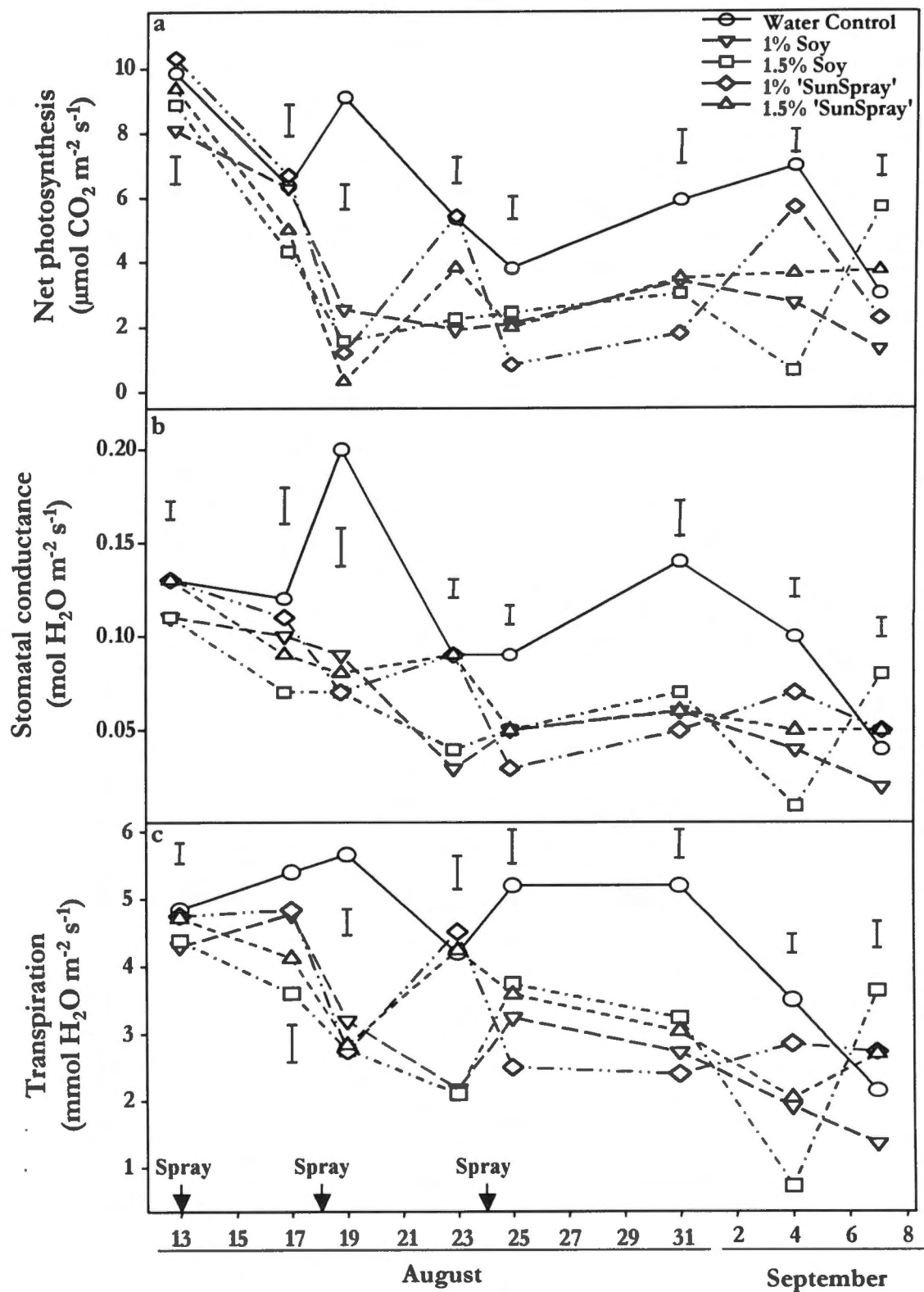


Fig. 14. Effect of multiple applications of soybean or petroleum oil on net photosynthesis (a), stomatal conductance (b), and transpiration (c) of burning bush raised outside a greenhouse. Vertical bars represent one SE.

Table 10. Comparison of soybean and petroleum oil formulations on net photosynthesis ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) of *Euonymus alatus* 'Compactus' raised outside of a greenhouse.

Treatments ^z	13 Aug	17 Aug	19 Aug	23 Aug	25 Aug	31 Aug	4 Sept	7 Sept
1% Soy Oil ^y	8.10 a ^x	6.30 a	2.54 b	1.90 b	2.08 bc	3.40 ab	2.75 cd	1.3 c
1.5% Soy Oil ^y	8.88 a	4.32 a	1.56 b	2.24 b	2.44 bc	3.02 ab	0.65 d	5.68 a
1% Sunspray ^w	10.05 a	6.70 a	1.20 b	5.42 a	0.82 c	1.80 b	5.68 ab	2.26 bc
1.5% Sunspray ^w	9.36 a	4.98 a	0.32 b	3.80 ab	1.98 bc	3.50 ab	3.65 bc	3.72 ab
Water Control	9.86 a	6.36 a	9.10 b	5.34 a	3.80 ab	5.90 a	6.98 a	2.28 bc
Contrasts								
Soy vs. Sunspray	NS	NS	NS	**	NS	NS	**	NS

^z Treatments applied 13, 18, and 24 June 1998.

^y Soy oil treatments emulsified with Latron B-1956® Spreader-Sticker at 10% of the oil.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

NS,**Nonsignificant at $P \leq 0.05$ or significant at $P \leq 0.01$, respectively.

Table 11. Comparison of soybean and petroleum oil formulations on stomatal conductance ($\text{mol H}_2\text{O m}^{-2} \text{s}^{-1}$) of *Euonymus alatus* 'Compactus' raised outside of a greenhouse.

Treatments ^z	13 Aug	17 Aug	19 Aug	23 Aug	25 Aug	31 Aug	4 Sept	7 Sept
1% Soy Oil ^y	0.11 a ^x	0.10 ab	0.09 b	0.03 b	0.05 c	0.06 b	0.04 b	0.02 c
1.5% Soy Oil ^y	0.12 a	0.07 b	0.07 b	0.04 b	0.05 bc	0.07 b	0.01 c	0.08 a
1% Sunspray ^w	0.13 a	0.11 ab	0.07 b	0.09 a	0.03 c	0.05 b	0.07 ab	0.05 ab
1.5% Sunspray ^w	0.13 a	0.09 ab	0.08 b	0.09 a	0.05 c	0.06 b	0.05 b	0.05 ab
Water Control	0.13 a	0.12 ab	0.20 a	0.09 a	0.09 ab	0.14 a	0.10 a	0.04 bc
Contrasts								
Soy vs. Sunspray	NS	NS	NS	***	NS	NS	**	NS

^z Treatments applied 13, 18, and 24 June 1998.

^y Soy oil treatments emulsified with Latron B-1956® Spreader-Sticker at 10% of the oil.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

NS, **, *** Nonsignificant or significant at $P \leq 0.05$, $P \leq 0.01$, or $P \leq 0.005$, respectively.

Table 12. Comparison of soybean and petroleum oil formulations on transpiration ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) of *Euonymus alatus* 'Compactus' raised outside of a greenhouse.

Treatments ^z	13 Aug	17 Aug	19 Aug	23 Aug	25 Aug	31 Aug	4 Sept	7 Sept
1% Soy Oil ^y	4.30 a ^x	4.78 ab	3.20 b	2.18 b	3.24 c	2.74 b	2.03 b	1.36 c
1.5% Soy Oil ^y	4.38 a	3.60 b	2.76 b	2.10 b	3.74 bc	3.24 b	0.85 c	3.64 a
1% Sunspray ^w	4.75 a	4.84 ab	2.74 b	4.52 a	2.50 c	2.40 b	2.86 ab	2.74 ab
1.5% Sunspray ^w	4.72 a	4.12 ab	2.84 b	4.24 a	3.58 c	3.04 b	2.15 b	2.70 ab
Water Control	4.84 a	5.40 ab	5.66 a	4.20 a	5.20 ab	5.20 a	3.50 a	2.00 bc
Contrasts								
Soy vs. Sunspray	NS	NS	NS	***	NS	NS	**	NS

^z Treatments applied 13, 18, and 24 June 1998.

^y Soy oil treatments emulsified with Latron B-1956® Spreader-Sticker at 10% of the oil.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

NS, **, *** Nonsignificant or significant at $P \leq 0.05$, $P \leq 0.01$, or $P \leq 0.005$, respectively.

DISCUSSION

The key to effective spider mite control involves integrating cultural and physical control methods before implementing chemical methods (Holmes and Davidson, 1984). Planting resistant varieties, removing infested plant material, watering overhead, and managing plant moisture and fertilizer levels will keep mites to a minimum (Davidson and Cornell, 1988; Dreistadt *et al.*, 1994). Nielsen (1990) reported that therapeutic sprays rather than preventative ones can efficaciously control targeted pests without the threat of pollution and monetary waste. Our research indicates that mite levels were substantially reduced after one spray of $\geq 0.75\%$ soy oil. Plants that received sprays of 0.75% to 1.5% soy oil had fewer than 1 mite per leaf 7 DAS (16 June). Mite numbers on those plants remained low for the duration of the experiment (Fig. 6). Three intense water sprays (each five days apart) in combination with predatory mites (approximately 1 mite per leaf) reduced TSSM on control plants to about 1.5 mites per leaf within two weeks.

Reduced pesticide applications can preserve natural enemies, which are also susceptible to conventional insecticides (Barrett, 1996). Plants sprayed with 0.5%, 0.75%, or 1.5% soy oil tended to have low predatory mite populations (Fig. 7). After the first spray, plants treated with 1.0% or 1.5% concentrations of soybean or petroleum oil did not have reduced populations of TSSM. The second pesticide application substantially reduced TSSM numbers to about one mite per leaf (Fig. 6). Burning bush shrubs sprayed with 1.0% or 1.5% Sunspray Ultra-fine tended to have higher numbers of TSSM and predatory mites than on 21 June. While the decrease in predatory mites on oil-treated plants may denote oil-toxicity, it is also possible that high TSSM mortality on oil-treated plants by 21 June diminished the predators' food source. Zhang and Sanderson (1992) reported that three

species of predatory mites in starved conditions demonstrated nonrandom search patterns and traveled 18-36 mm to aggregate in spider mite colonies. The stress of starvation may have stimulated gradual migration of the predatory mites to the control plants, where TSSM populations still thrived. Predatory mite numbers remained high on control plants on 26 June (1.5 mites per leaf), whereas TSSM levels decreased to about 1 mite per leaf. A 1:10 ratio of predatory mites to TSSM will provide effective control (Flint, 1995). Once mite-pest levels are reduced to tolerable levels, biological, cultural, and occasional chemical control measures should maintain this limit (Davidson *et al.*, 1988).

Summer applications of soybean or petroleum oil tended to temporarily decrease Pn, Gs, and E rates of burning bush leaves. Net photosynthesis on non-mite-infested shrubs quickly recovered from late autumn applications of 1-3% soy oil or 1% petroleum oil (Fig. 2). The overall decrease in Pn, Gs, and E rates might have been attributed to an oil accumulation of the three sprays. Oils can saturate stomata and obstruct carbon dioxide absorption, respiration, and transpiration (Davidson *et al.*, 1991). Ayers and colleagues (1975) indicated that a several commonly used synthetic pesticides also temporarily reduced net photosynthesis on apple leaves. Oils rapidly dissipate via evaporation following application (Miller, 1999). However, oils applied three times in five day intervals appear to have accumulated (Fig. 9).

The reduction in gas exchange may not be entirely attributed to the pesticides, however. Spider mites spin webs over the leaves, creating physical barriers against deterrents and suitable habitats for themselves (Dreistadt *et al.*, 1994; Jeppson *et al.*, 1975). Mites can substantially reduce net photosynthetic rates by removing the contents of 18-22 cells per minute and up to 60% of the plants' chlorophyll content (Liesering, 1960 *in*

Jeppson *et al.*, 1975). Heavily injured leaves may have low to no rates of net photosynthetic activity (Jeppson *et al.*, 1975). Wedding and associates (1958) indicated that transpiration rates of citrus increased during heavy feeding by citrus red mites, then decreased to rates below the control plants following the mite removal. Elevated transpiration rates lead to plant dessication and leaf abscission (Mason *et al.*, 1998)

Rates from 1% to 1.5% of petroleum or 0.25% to 1.5% soy oil sprayed during the summer do not appear to be phytotoxic to burning bush unless plants are stressed by multiple factors. Early to late summer applications of soy oil on mite-free and mite-infested burning bush, respectively, have not caused any observable plant damage. However, oils in conjunction with high temperatures, heavy mite infestations, or increased transpiration (from fans or mites), can cause yellowing, stem dieback, leaf abscission, and plant mortality.

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PART III

OIL EFFECTS ON APHIDS, WHITEFLIES, AND GAS EXCHANGE OF GREENHOUSE ORNAMENTALS

ABSTRACT

Experiments conducted from 1997 to 1998 evaluated the efficacies of soy oil and soy oil formulations on controlling populations of sweetpotato whitefly (*Bemisia tabaci* Gennadius) and cotton aphid (*Aphis gossypii* Glover) on 'Southern Belle Mixed' (SBM) and 'Disco Belle Mixed' hibiscus (DBM) (*Hibiscus moscheutos* L.) and 'Sammy Russell' daylily (*Heemerocallis* sp.). Summer applications of 0.5% to 2% soybean or 1% petroleum oils increased rates of net photosynthesis (Pn), stomatal conductance (Gs), and transpiration (E) relative to unsprayed, SBM hibiscus for up to nine days after spray (DAS) in 1997. An experimental soy oil formulation (K-1000) tended to lower Pn, Gs, and E rates more than applications of soy oil mixed with Latron B-1956® 3 and 7 DAS, but no significant differences were detected among oil treatments in 1997. Whiteflies were difficult to monitor since the plants were maintained uncaged: populations on SBM fluctuated while those on DBM decreased on all plants including the controls. Aphids populations were reduced immediately after each spray, but quickly recovered and repopulated the plants. Populations of aphids were reduced by $\geq 50\%$ compared to the control on both hibiscus varieties after the second spray. Aphid control on daylilies was highly correlated ($r^2 = 99.9\%$) with soy oil concentration. Overall, the soy oil - Latron B-1956® mixture most effectively controlled aphids and whiteflies on ornamentals, but must contact the targeted insects in order to control pests efficaciously.

INTRODUCTION

Pest management on ornamental nursery and landscape plants is crucial for the health and appearance of the plants. Haustellate insects, including aphids and whiteflies,

weaken plants directly by extracting photosynthate and depositing sugary exude (honeydew) onto the leaves, stems, flowers, and fruit (Campana, 1983). Sooty molds are attracted to and thrive on honeydew deposits (Pierce *et al.*, 1998), thereby interfering with light penetration, gas exchange, and photosynthesis (Nielsen, 1989). Haustellate insects are frequent vectors of plant viruses (Asjes and Blom-Barhoorn, 1994).

Synthetic pesticide sprays are usually implemented to control pests of ornamentals, although insect-resistance, phytotoxicity, and environmental pollution pose problems (Straw *et al.*, 1996; Zimmermann, 1983). Cultural methods of controlling aphids and whiteflies within a greenhouse include dislodging insects with strong sprays of water (Campana, 1983), hanging sticky traps to catch adults and honeydew-harvesting ants (Dreistadt *et al.*, 1994), acephate banding (Pierce *et al.*, 1998), and releasing native predators, such as aphid midges, lacewings, lady beetles, parasitic wasps, and predatory beetles (Stern, 1991). Weekly sprays of insecticidal soap, alcohol, horticultural (petroleum) oils, or plant oils such as garlic, citrus or neem can reduce severe infestations (Gilkeson, 1991).

Oils provide an economically and environmentally-sound alternative to synthetic pesticides, and are the only class of pesticides with low susceptibility to arthropod resistance (Butler and Henneberry, 1990b; Chapman, 1967; Davidson *et al.*, 1991; Hix *et al.*, 1999; Pierce *et al.*, 1998). Petroleum oils are currently used in nurseries and home landscapes to control insect pests (Johnson and Caldwell, 1987; Miller, 1999), including aphids (Pierce *et al.*, 1998) and whiteflies (Larew and Locke, 1990). Spraying 3% Sunspray 6E (petroleum-based horticultural oil) in laboratory and field trials repeatedly eliminated all aphids on woody ornamentals within 24 hours (Baxendale and Johnson, 1988). These researchers later achieved excellent control of the soft-bodied haustellate insects, including Boxwood

psyllid (*Psylla buxi* L.), Cottony maple scale (*Pulvinaria innumerabilis* Rathvon), Golden oak scale (*Asterolecanium variolosum* Ratzeburg), Woolly larch adelgid (*Adelges laricis* Vallot), and Calico scale (*Eulecanium cerasorum* Cockerell) with one summer application of 2-3% Sunspray 6E (1990). Pierce and associates (1998) reported that crapemyrtle (*Lagerstroemia* ssp.) sprayed with 2% or 4% Sunspray Ultra-fine Spray Oil® had lower crapemyrtle aphid (*Tinocallis kahawaluokalani* Kirkaldy) populations than the untreated controls, and the sprays could be applied during the winter to reduce first generation aphids. Xie and Isman (1995) stated that depitched tall oil derived from softwood pulp controlled green peach aphids (*Myzus persicae* Sulzer) similar to that of horticultural petroleum oils, in addition to repelling aphids ≥ 3 days. Larew and Locke (1990) affirmed that 2% Sunspray 6E sprayed on greenhouse-grown chrysanthemums repelled adult greenhouse whiteflies (*Trialeurodes vaporariorum* Westwood) ≥ 11 DAS in addition to killing first and third instar larval whiteflies.

The toxicity and repellence of plant oils, particularly cottonseed and soy oils, to insect pests have been documented. Butler and associates (1998) reported that one application of 5% soy oil significantly reduced the numbers of sweetpotato whitefly adults settling on cotton plants up to 4 DAS, as compared to the water controls. Hill and Schoonhoven (1981) achieved 84% control of the Mexican bean weevil (*Zabrotes subfasciatus* Boheman) with one application of African palm (*Elaeis guineensis* Jacq.) oil (1 ml / kg bean seed).

Preliminary research indicated that biological control methods integrated with chemical sprays in urban California communities reduced pesticide use while still managing aphids on street trees (Davidson and Cornell, 1988). Plant oils, like petroleum oils, have the unique advantage that they are non-toxic to mammals and relatively safe to the

environment, and therefore applicable in urban pest management programs (Miller, 1999).

Oils have been reported to interfere with the exchange of gases between plants and the environment. Ayers and Barden (1975) reported that a 0.25% petroleum oil spray on 'Golden Delicious' apple foliage (*Malus domestica* Mill.) significantly reduced net photosynthetic rates 6 - 11 DAS. Oils reduce transpiration during droughts by coating the stomates (Anonymous, 1994).

The genus *Hibiscus* is a member of the Malvaceae family and contains over 200 widely diverse species, including the field crop cotton (*Gossypium hirsutum* L.). The ornamental rose mallow (*Hibiscus moscheutos* L.), widely grown in U.S. gardens and landscapes, produces vigorous 0.5 meter tall plants with large blooms of white, crimson, pink, or bi-colored from early to mid-summer (Armitage, 1997). Hibiscus often are attacked by insects such as aphids, scale, whiteflies, and Japanese beetles (Dirr, 1998).

The daylily (*Heemerocallis* sp. L.) was cultivated in North China as early as 1000 B.C., where uses ranged from nutritional (flower buds and young leaves) to medicinal (roots and leaves) (Jelitto *et al.*, 1990). They are widely adaptable and thrive in sunny and sometimes shaded locations, various soil types, drought, and generally require minimal amounts of fertilizer (Armitage, 1997). Daylilies are generally pest-free, but are occasionally infested by soft-bodied insects, such as aphids and thrips, and by mites (Bryan, 1989).

The objectives of these studies were to determine if soy oil 1) efficaciously controls cotton aphids (*Aphis gossypii* Glover) (Homoptera: Aphididae) and 2) sweetpotato whiteflies (*Bemisia tabaci* Gennadius) (Homoptera: Aleyrodidae) on greenhouse-raised ornamentals; 3) influences net photosynthetic (Pn), stomata conductance (Gs), and transpiration (E) rates; and 4) causes phytotoxicity.

MATERIALS AND METHODS

Experiment 1: Research in the summer of 1997 evaluated insecticidal properties, plant gas exchange, and phytotoxicity of soy oil and petroleum oil sprays on hibiscus. *Hibiscus moscheutos* 'Southern Belle Mixed' (SBM) seeds (Park Seed Co., Greenwood, SC) were planted in seedling trays in the spring and transplanted into 2.8 liter (# 1) containers with 'Pro Mix BX' potting media on 24 Apr. 1997 (approximately six weeks after initial seeding). Each plant was fertilized with one Sierra 12-12-12 pellet (10g) on 1 May 1997. Plants were infested with cotton aphids and sweetpotato whiteflies by 28 May. Pre-spray insect quantification determined a minimum of 100 aphids and whiteflies per plant. Treatments of 0% (water control), 0.5%, 1.0%, 1.5%, or 2.0% soy oil mixed with Latron B-1956® (10% of oil concentration), or 1.0% Sunspray Ultra-fine Spray Oil® were sprayed until runoff on 2 and 11 June 1997 with a backpack mist blower (Stihl SR 400). An attempt was made to saturate the undersides of the leaves, since these are the primary residences of aphids and whiteflies. Following each spray, plants were arranged in a randomized block design (RCB) with five replications within a greenhouse. Aphid and whitefly populations were quantified by visual counts on the first through the fifth fully expanded leaves from the apical meristem. The following five-point rating scale was created to estimate aphid and whitefly numbers per five leaves: 1 = ≤ 50 ; 2 = 51 to 100; 3 = 101 to 150; 4 = 151 to 200; 5 = >200 . Aphid population counts were made on 28 May, and 2, 5, 10, 16, 19, 23, and 28 June 1997. Whitefly populations were monitored on 28 May, as well as 2, 5, 10, 16, 20, 25, and 26 June. Net photosynthetic (Pn), stomatal conductance (Gs), and transpiration (E) rates were measured using an ADC-3 model of a portable infrared gas analyzer (ADC Inc., Hoddenson, UK) on leaves between the first to third fully expanded leaves from the apical

meristem. Measurements were taken on 10, 13, 16, and 19 June. Phytotoxicity was evaluated periodically using the five-point rating scale used in the first experiment of part two.

Experiment 2: Preliminary research compared the efficacies of soy oil formulations as insecticides on *Hibiscus*; and the oil effects on Pn, Gs, and E rates, and phytotoxicity.

Hibiscus moscheutos 'Disco Belle Mixed' (DBM) seeds were planted, maintained within a greenhouse, and sprayed in the same manner as the previous experiment. Treatments of 0% (water control); 2% or 3% soy oil mixed with Latron B-1956® (10% of oil concentration); or 2% or 3% K-1000 (Central Soya, Fort Wayne, IN) were applied to runoff with a backpack mist blower on 30 May and 16 June. Plants were arranged in a greenhouse in an RCB design with seven replications. Insect populations were quantified using the same five-point rating scale as in experiment one. Cotton aphid populations were quantified on 28 May and 3, 5, 11, 19, 23, and 26 June 1997. Sweetpotato whitefly numbers were ascertained on 28 May, and 5, 11, 20, 25, and 26 June. Leaf Pn, Gs, and E rates were measured on 6, 12, 19, and 23 June with the same procedure as experiment one.

Experiment 3: Research in the winter of 1998 evaluated soy oil formulations for controlling cotton aphids on daylilies. Phytotoxicity was monitored, since ornamentals demand high aesthetic quality. Twenty-five daylilies (*Hemerocallis* 'Sammy Russell') in 2.8 liter (# 1) containers were obtained in July 1997. All dead foliage was cut removed in late summer, and plants were moved into a greenhouse. Plants were fertilized with 10g of 14-14-14 Osmocote® (The Scotts Co., Columbus, OH) on 7 Aug. 1997. Large populations of the cotton aphid were observed on emerging foliage on 17 Feb. 1998. Sprays of 0%, 0.5%, 0.75%, 1.0%, or 2.0% soy oil mixed with Latron B-1956® at 10% of oil concentration were

applied to runoff on 20 February 1998 with hand-held mist bottles. The bottles were agitated frequently by shaking to maintain the emulsion. Plants were arranged in an RCB design with five replications. On 26 Feb., dead aphids (brown) were easily distinguishable from alive aphids (green). Ten leaves were randomly removed basipetally from each plant. Insect populations were determined from 26 Feb. to 1 Mar. Periodic inspections for phytotoxicity were made for the duration of the trial.

RESULTS

Experiment 1: Hibiscus plants sprayed with 1% soybean or petroleum oil had no differences in Pn, Gs, and E rates at any evaluation (Fig. 1). The Pn, Gs, or E rates were measured eight days after the first spray (one day prior to the second spray). By then, all Pn, Gs, and E rates were all equivalent. Plants sprayed with 0.5% or 1.5% soy oil had higher Pn rates than the control plants two days after the second spray (Fig. 1a). Plants treated with 0.5% or 1% soy oil, or 1% petroleum oil had higher rates of Pn than the water-treated plants five DAS. Levels of Pn tended to remain higher for all oil-treated plants except for the final measurement date (20 June, 9 DAS), when no statistical differences were detectable.

Plants treated with petroleum or soy oil had Gs and E patterns over time similar to Pn (Fig. 1). All plants sprayed with oil had statistically higher Gs and E rates two days after the second spray. By nine days after the second spray, the Gs and E rates of all plants remained higher than the control, except for plants sprayed with 0.5% soy oil. Plants sprayed with 1% Sunspray Ultra-fine Spray Oil® tended to have lower Pn, Gs, and E levels than those treated with 1% soy oil, although not statistically different (Figs. 1b and 1c).

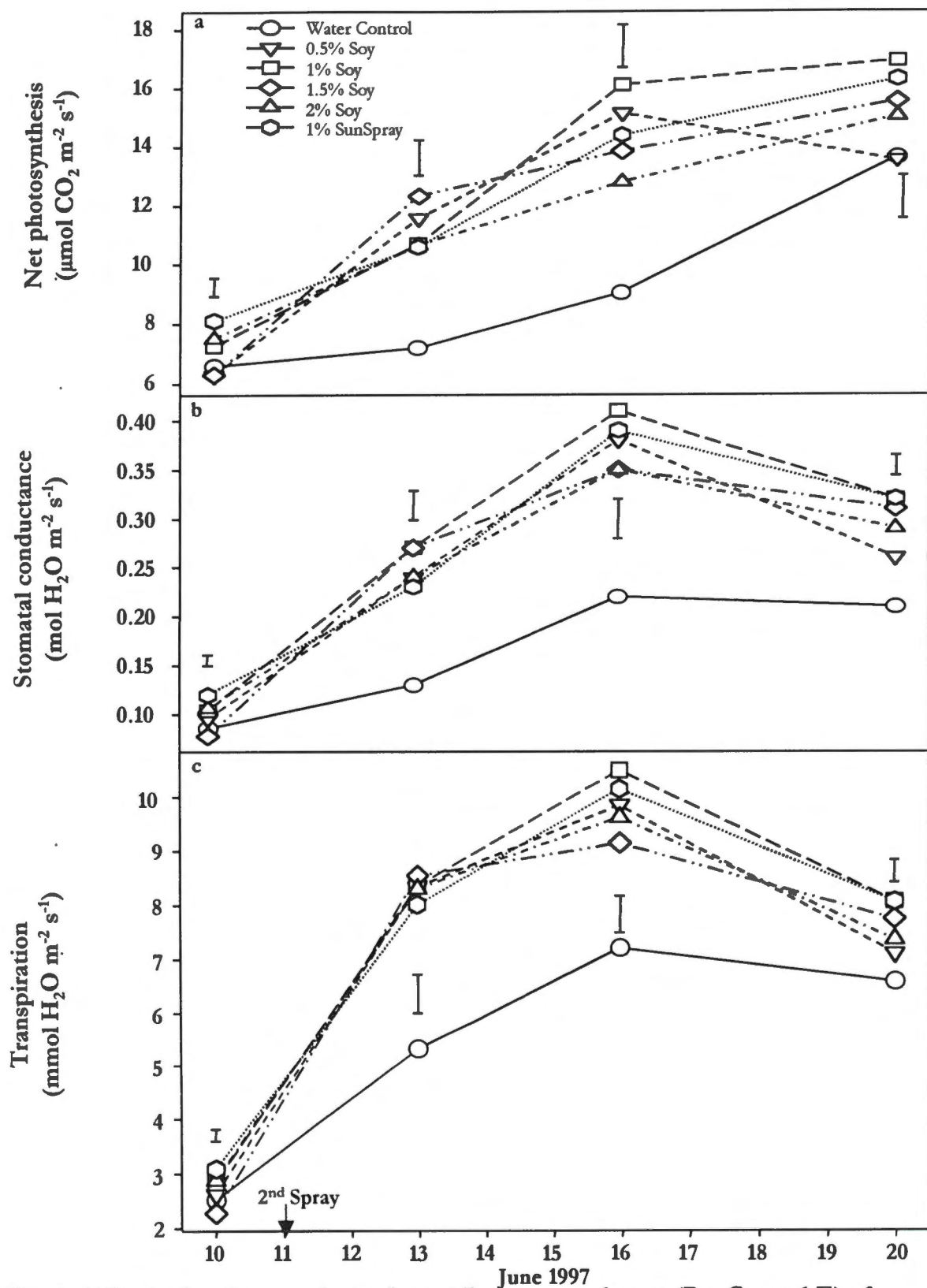


Fig. 1. Effects of soybean and petroleum oils on gas exchange (Pn, Gs, and E) of insect-infested 'Southern Belle Mixed' Hibiscus in a greenhouse. The first spray was applied 2 June. Vertical bars represent one SE.

Plant gas exchange trends were similar to patterns of insect decline and resurgence. Plants treated with the 1.5% soy oil formulations tended to have the highest Pn, Gs, and E levels (Fig. 1), low aphid populations (Fig. 2), and the fewest whiteflies (Fig. 3) four DAS.

Cotton aphid numbers on SBM hibiscus were variable prior to the beginning of the trial, with about 10 to 25 aphids/5 leaves (Fig. 2). Aphid populations sharply declined after the second spray, with a max rating of 50 aphids/5 leaves, and were further reduced to almost zero by the trial completion. Plants sprayed with 1.0%, 1.5%, or 2.0% soy oil had noticeably fewer aphids than did control plants six days after the second spray. Sprays of 1% soy or petroleum oil did not statistically differ in aphid control (Fig. 2). No winged aphids were observed throughout the trials.

All treatments, except 2% soy oil, decreased the number of whiteflies 1 DAS (Fig. 3). The 2% soy oil-treated plants continued to support the highest amount of whiteflies until the second spray, after which the colonies failed to proliferate to pre-spray populations. Control plants consistently tended to have fewer whiteflies than the oil-treated plants, although differences were rarely statistically different. Whitefly populations on the 1.5% soy oil-treated plants tended to remain low for the duration of the experiment, fluctuating between 0 and 75 insects per five leaves (ratings 0 and 1.5, respectively). Whitefly populations on 1% petroleum oil-treated plants were slightly higher 1 day after the first spray, and relatively stable after the second spray (Fig. 3). In contrast, whitefly numbers on plants sprayed with 1% soy oil steadily declined 4 days after the first spray, and sharply decreased after the second spray.

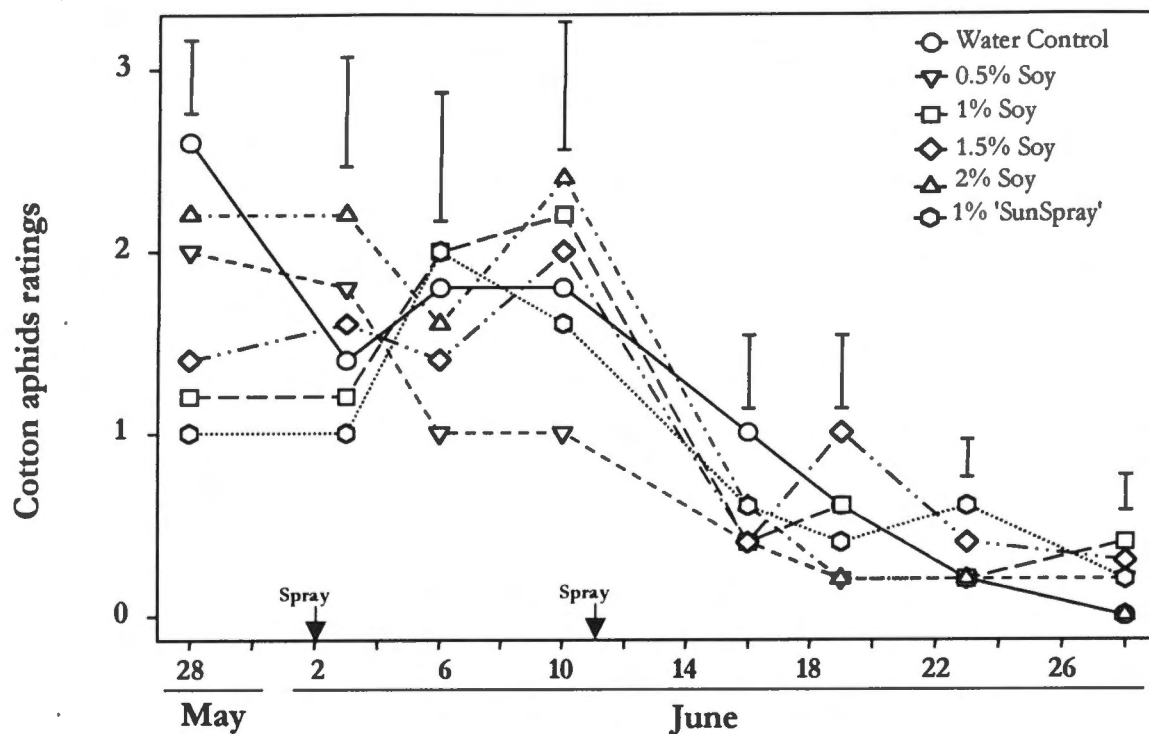


Fig. 2. Effects of soybean and petroleum oils on cotton aphids on 'Southern Belle Mixed' Hibiscus in a greenhouse. Vertical bars represent one SE. Rating scale: 1 = <50; 2 = 51-100; 3 = 101-150; 4 = 151-200; 5 = >200.

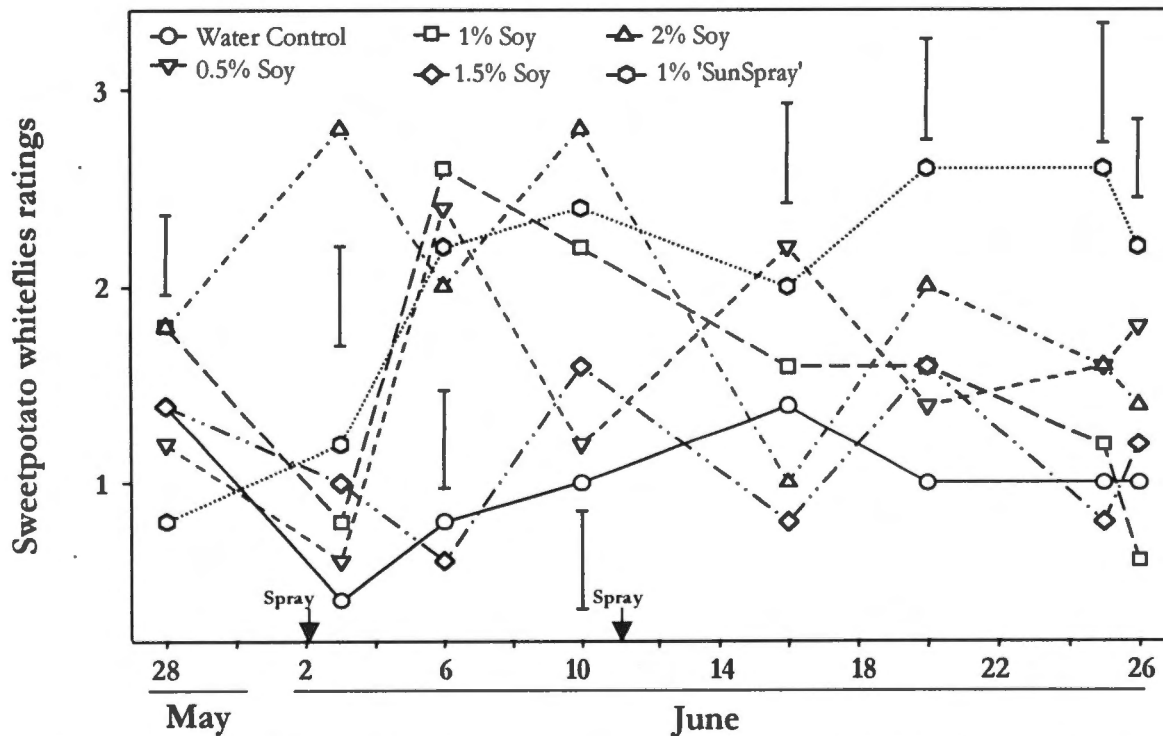


Fig. 3. Effects of soybean and petroleum oils on sweetpotato whiteflies on 'Southern Belle Mixed' Hibiscus in a greenhouse. Vertical bars represent one SE. Rating scale: 1 = <50; 2 = 51-100; 3 = 101-150; 4 = 151-200; 5 = >200.

Experiment 2: Spraying 2% or 3% soy oil did not significantly affect Pn, Gs, and E rates seven days after the first spray (30 May) (Tables 1, 2, 3). At 11 days after the first spray, the plants treated with the 2 % or 3% soy oil + Latron tended to have higher rates of Pn, Gs, and E rates than those plants treated with 2% or 3% K-1000 (Fig. 4). By 13 June (13 DAS), no differences in Pn, Gs, and E rates among treatments were detected. The second spray of K-1000 decreased Pn, Gs, and E rates plants compared to the other treatments 3 days after the second spray (16 June 1997). Rates of Pn, Gs, and E equilibrated by one week after the second spray.

There were more than 200 aphids per five leaves of each plant before spraying (Fig. 5). Cotton aphid populations on all plants declined by $\geq 50\%$ on the fifth day after the first spray, including the water control plants (Table 4). The oil-treated plants had significantly fewer aphids on the second and sixth day following the second spray ($P \leq 0.05$). The efficacies of the soy oil sprays were statistically equivalent to both K-1000 sprays at every rating following the second spray (Fig. 5).

Sweetpotato whitefly numbers were erratic throughout the trial (Fig. 6). Initial (pre-spray) populations were between 101 and 150 whiteflies per five leaves. Differences of whitefly control existed only on June 5 between the water controls and 2% K-1000-treated plants (Table 5). Whiteflies on plants treated with either 3% oil formulation appeared to increase slightly for the week after the second spray, possibly indicating a population resurgence.

Table 1. Effects of soybean oil formulations on net photosynthesis ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) of *Hibiscus moscheutos* 'Disco Belle Mixed'

Treatments ^z	6 June	11 June	13 June	19 June	23 June
2% Soy Oil ^y	10.59 a ^x	13.77 a	17.28 a	14.20 a	13.62 a
3% Soy Oil ^y	10.37 a	11.83 a	15.03 ab	13.20 a	12.61 a
2% K-1000 ^w	11.85 a	11.81 a	16.73 ab	12.00 ab	12.10 a
3% K-1000 ^w	10.20 a	13.91 a	15.3 ab	9.90 b	14.54 a
Water Control	10.33 a	11.97 a	14.65 b	14.30 a	12.16 a
Contrasts					
Soy Oil vs. K-1000	NS	NS	NS	—	NS

^zTreatments applied 30 May 1997 and reapplied 16 June 1997.

^yEmulsified with Latron B-1956® Spreader-Sticker

^xMean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^wK-1000® experimental soy emulsion

^{ns}Nonsignificant at $P \leq 0.05$.

Table 2. Effects of soybean oil formulations on stomatal conductance ($\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1}$) of *Hibiscus moscheutos* 'Disco Belle Mixed'

Treatments ^z	6 June	11 June	13 June	19 June	23 June
2% Soy Oil ^y	0.22 a ^x	0.37 a	0.48 a	0.34 a	0.36 a
3% Soy Oil ^y	0.17 a	0.35 a	0.47 a	0.31 a	0.27 b
2% K-1000 ^w	0.19 a	0.30 a	0.45 a	0.28 ab	0.31 ab
3% K-1000 ^w	0.16 a	0.40 a	0.46 a	0.21 b	0.29 b
Water Control	0.19 a	0.34 a	0.43 a	0.35 a	0.30 ab
Contrasts					
Soy Oil vs. K-1000	NS	NS	NS	—	NS

^zTreatments applied 30 May 1997 and reapplied 16 June 1997.

^yEmulsified with Latron B-1956® Spreader-Sticker

^xMean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^wK-1000® experimental soy emulsion

^{ns}Nonsignificant at $P \leq 0.05$.

Table 3. Effects of soybean oil formulations on transpiration ($\text{mmol H}_2\text{O m}^{-2} \text{s}^{-1}$) of *Hibiscus moscheutos* 'Disco Belle Mixed'

Treatments ^z	6 June	11 June	13 June	19 June	23 June
2% Soy Oil ^y	4.10 a ^x	6.40 a	8.50 a	8.30 ab	9.10 a
3% Soy Oil ^y	3.60 a	6.30 a	8.80 a	7.90 abc	7.80 b
2% K-1000 ^w	4.00 a	5.60 a	8.40 a	7.20 bc	8.21 ab
3% K-1000 ^w	3.40 a	7.20 a	8.70 a	6.70 c	8.54 ab
Water Control	3.60 a	6.40 a	8.25 a	8.70 a	8.64 ab
Contrasts					
Soy Oil vs. K-1000	NS	NS	NS	—	NS

^zTreatments applied 30 May 1997 and reapplied 16 June 1997.

^yEmulsified with Latron B-1956® Spreader-Sticker

^xMean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^wK-1000® experimental soy emulsion

^{ns}Nonsignificant at $P \leq 0.05$.

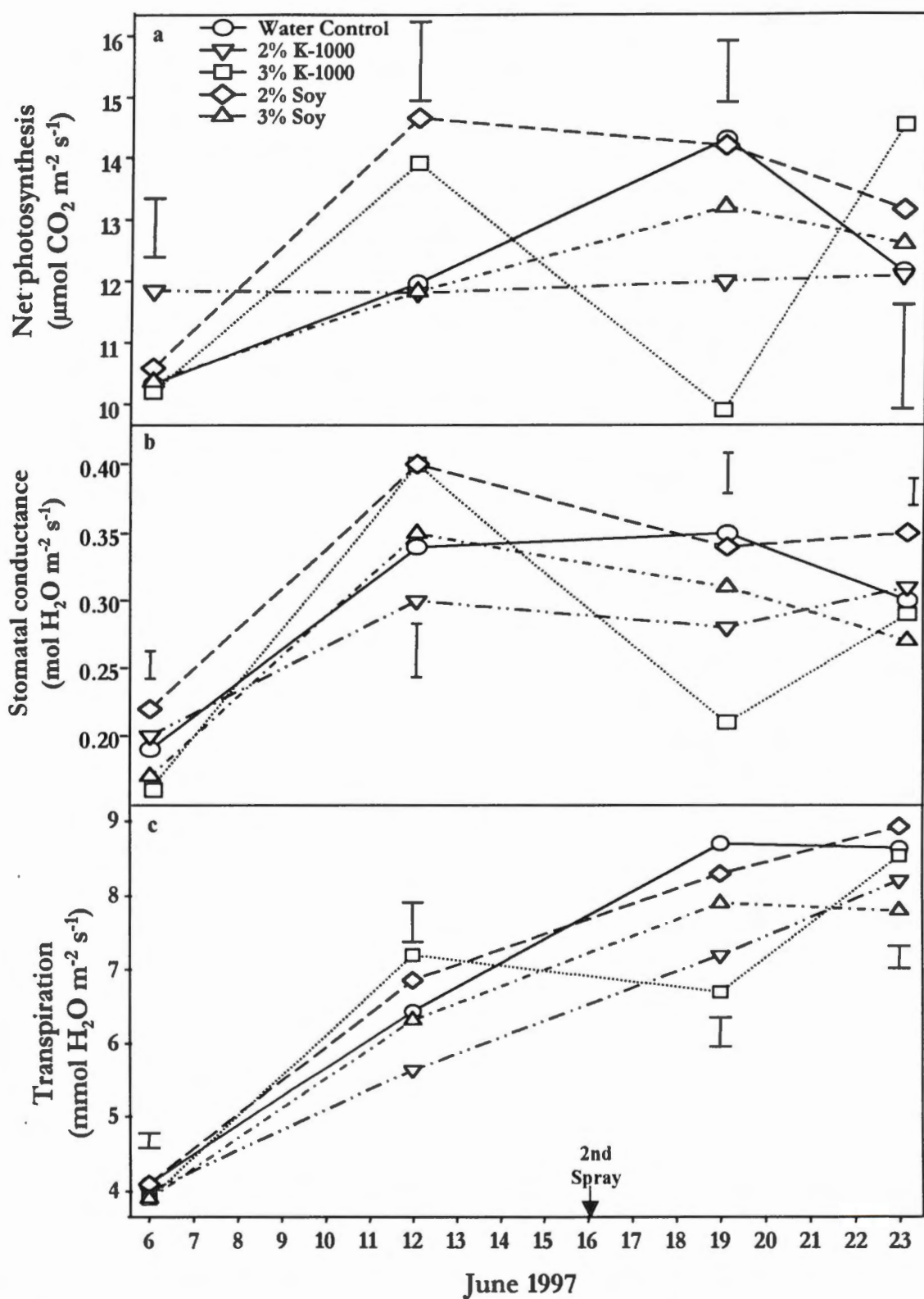


Fig. 4. Effects of soybean oil formulations on 'Disco Belle Mixed' Hibiscus net photosynthesis (a), stomatal conductance (b), and transpiration (c). Vertical bars represent one SE. Plants were initially sprayed on 30 May 1997.

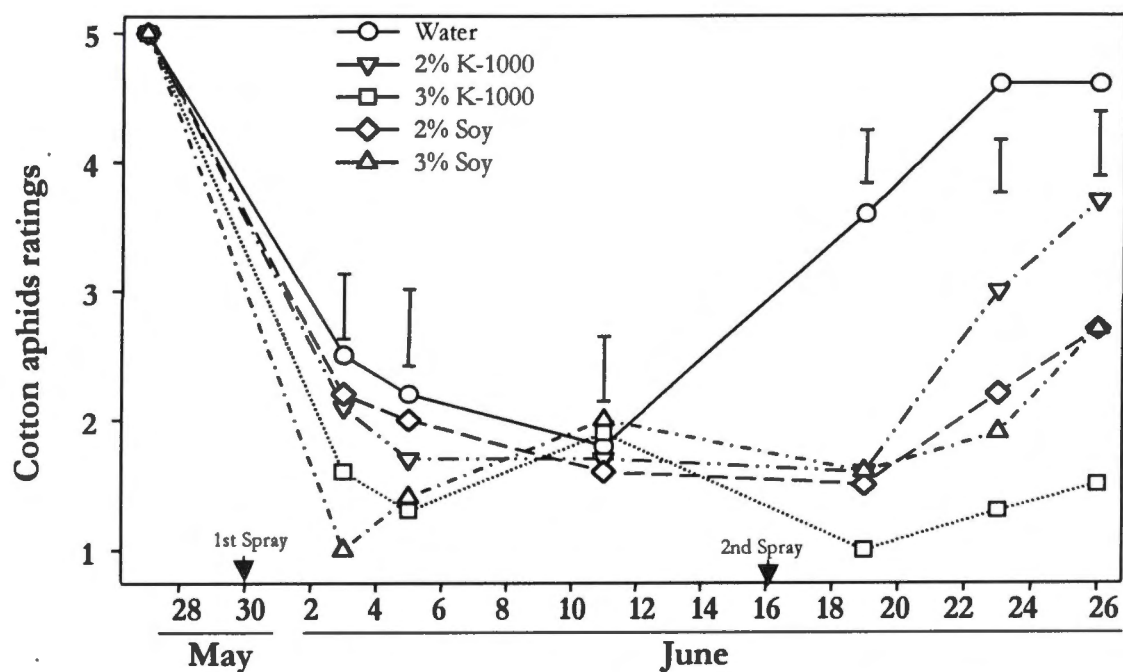


Fig. 5. Effects of soybean oil formulations on cotton aphids on 'Disco Belle Mixed' Hibiscus in a greenhouse. Vertical bars represent one SE. Rating Scale: 1 = <50; 2 = 51-100; 3 = 101-150; 4 = 151-200; 5 = >200.

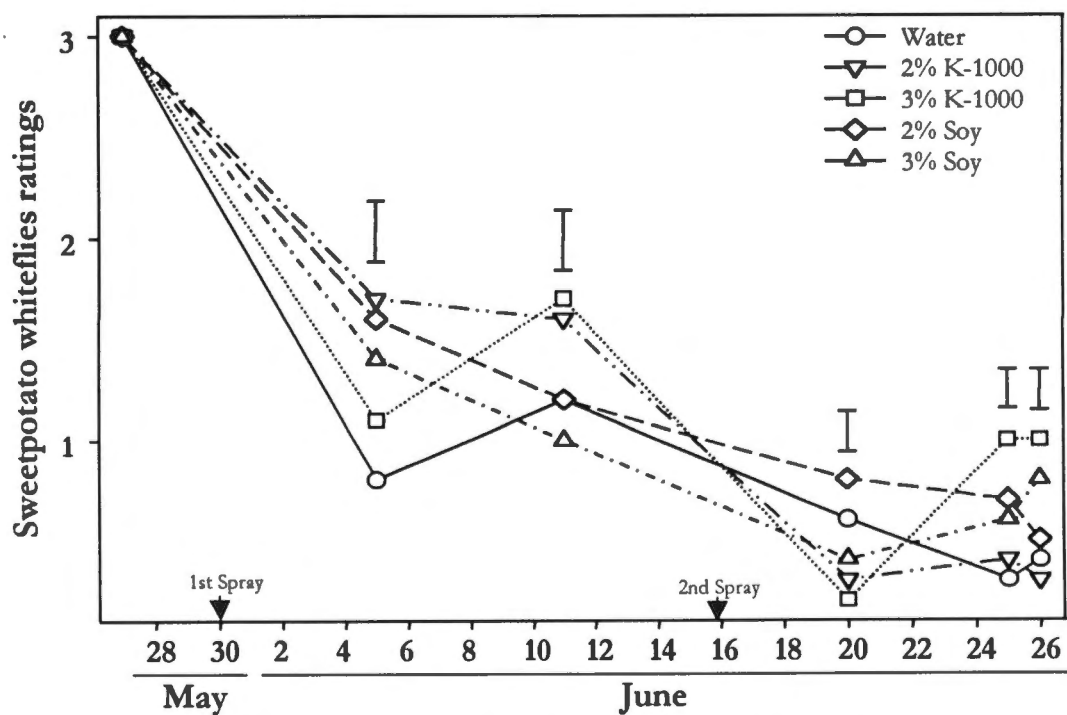


Fig. 6. Effects of soybean oil formulations on sweetpotato whiteflies on 'Disco Belle Mixed' Hibiscus in a greenhouse. Vertical bars represent one SE. Rating Scale: 1 = <50; 2 = 51-100; 3 = 101-150; 4 = 151-200; 5 = >200.

Table 4. Effects of soybean oil formulations on cotton aphids on *Hibiscus moscheutos* 'Disco Belle Mixed'

Treatments ^z	28 May	3 Jun	5 Jun	11 Jun	19 Jun	23 Jun	26 Jun
2% Soy Oil ^y	5.0 ^x a ^w	2.1 a	1.7 a	1.7 a	1.6 b	3.0 bc	3.7 ab
3% Soy Oil ^y	5.0 a	1.6 a	1.3 a	1.9 a	1.0 b	1.3 c	1.5 c
2% K-1000 ^v	5.0 a	2.2 a	2.0 a	1.6 a	1.5 b	2.2 bc	2.7 bc
3% K-1000 ^v	5.0 a	1.0 a	1.4 a	2.0 a	1.6 b	1.9 bc	2.7 bc
Water Control	5.0 a	2.5 a	2.2 a	1.8 a	3.6 a	4.6 a	4.6 a
Contrasts							
Soy Oil vs. K-1000	NS	NS	NS	NS	NS	NS	NS

^zTreatments applied 30 May 1997 and reapplied 16 June 1997.

^yEmulsified with Latron B-1956® Spreader-Sticker

^xRating Scale (insects/5 leaves): 1 = ≤50; 2 = 51-100; 3 = 101-150; 4 = 151-200; 5 = >200.

^wMean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^vK-1000® experimental soy emulsion

^{ns}Nonsignificant at $P \leq 0.05$.

Table 5. Effects of soybean oil formulations on Sweetpotato whiteflies on *Hibiscus moscheutos* 'Disco Belle Mixed'

Treatments ^z	28 May	5 Jun	11 Jun	20 Jun	25 Jun	26 Jun
2% Soy Oil ^y	3.0 ^x a ^w	1.7 a	1.6 a	0.3 ab	0.4 ab	0.3 b
3% Soy Oil ^y	3.0 a	1.1 ab	1.7 a	0.2 b	1.0 a	1.0 a
2% K-1000 ^v	3.0 a	1.6 ab	1.2 a	0.8 a	0.7 ab	0.5 ab
3% K-1000 ^v	3.0 a	1.4 ab	1.0 a	0.4 ab	0.6 ab	0.8 ab
Water Control	3.0 a	0.8 b	1.2 a	0.6 ab	0.3 b	0.4 ab
Contrasts						
Soy Oil vs. K-1000	NS	NS	NS	NS	NS	NS

^zTreatments applied 30 May 1997 and reapplied 16 June 1997.

^yEmulsified with Latron B-1956® Spreader-Sticker

^xRating Scale (insects/5 leaves): 1 = ≤50; 2 = 51-100; 3 = 101-150; 4 = 151-200; 5 = >200.

^wMean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^vK-1000® experimental soy emulsion

^{ns}Nonsignificant at $P \leq 0.05$.

Experiment 3: No dead aphids were observed on water-sprayed (control) daylilies for the duration of the experiment. Spraying plants with 0.5% or 0.75% soy oil emulsions killed 66% and 87% of the aphids, respectively. Spraying plants with 1% soy oil caused 92% mortality of the aphids. Finally, spraying 2% soybean or petroleum oil formulations provided $\leq 96\%$ control (Fig. 7). The concentrations of soy oil were significantly negatively correlated to the number of cotton aphids present on *Hemerocallis* 'Sammy Russell' following treatment ($r^2 = 99.98$) (Fig. 8). Effective control of the cotton aphid can be obtained with $\geq 1\%$ soy oil or 2% Sunspray Ultra-fine Spray Oil®. However, it was noted that aphids were present in the tight whorls of leaves, where the sprays were unable to penetrate. These surviving aphids repopulated the plants. Oil sprays did not cause any observable phytotoxicity.

DISCUSSION

Pesticides are known to lower rates of net photosynthesis and transpiration on healthy and insect-infested plants (Ayers and Barden, 1975). However, in our trials, the oil sprays appeared to temporarily elevate Pn, Gs, and E rates. Extreme insect infestations can negatively affect plant gas exchange by extracting photosynthate (energy) and littering the foliage with cast skins, honeydew, and sooty mold fungi (Barrett, 1996). Therefore, efficacious pesticides may actually increase gas exchange rates on arthropod-infested plants. We believe such scenario occurred in experiments 1 and 2. Net photosynthesis, stomatal conductance, and transpiration rates of oil treated SBM hibiscus plants remained significantly higher than that of water control plants after the second application. Gas exchange rates on SBM hibiscus increased from 12 to 16 June (Fig. 1) in correlation with

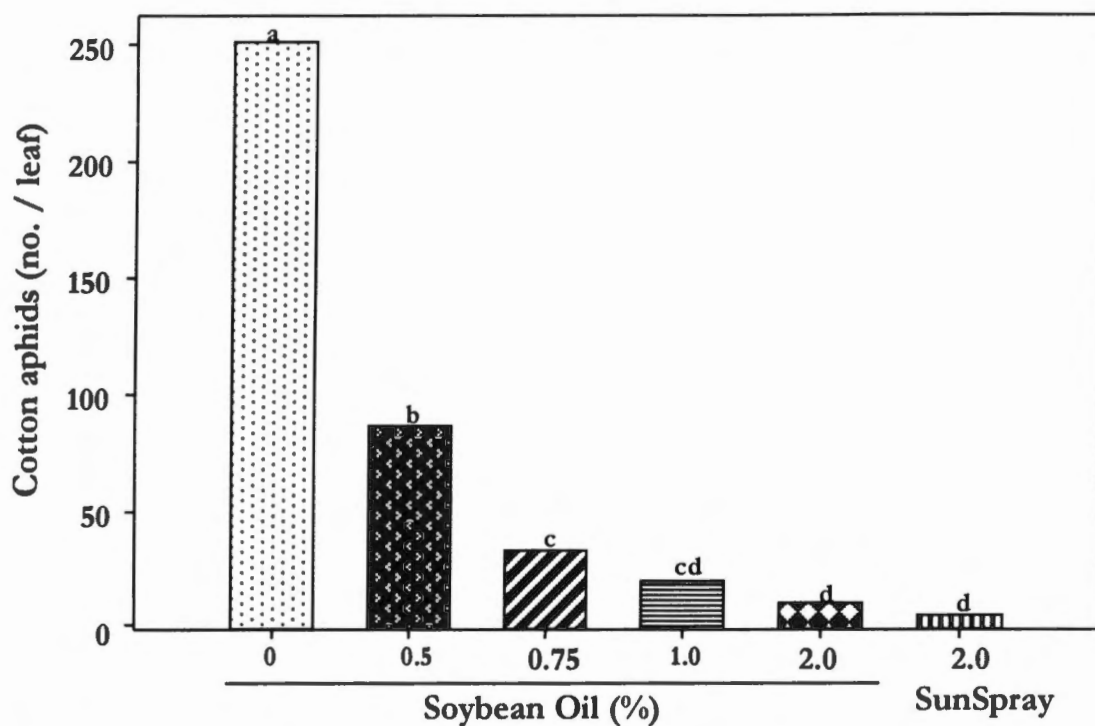


Fig. 7. Surviving cotton aphid populations after treatment with soybean or petroleum oil. Letters represent mean separation with Duncan's multiple range test, $P \leq 0.01$.

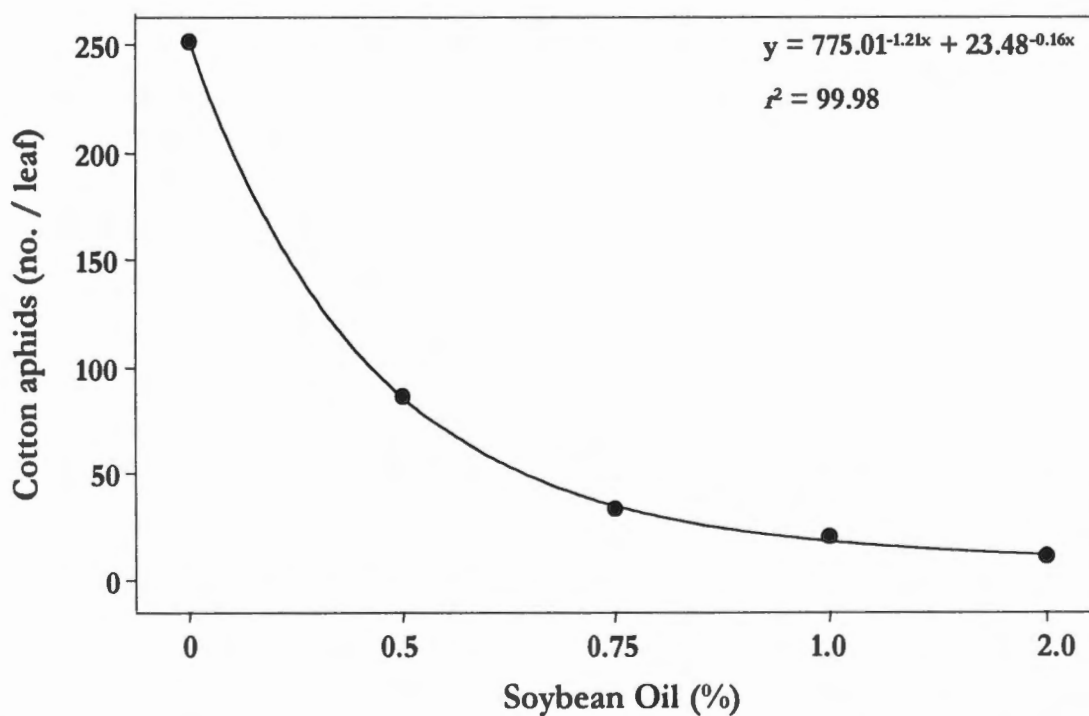


Fig. 8. Effects of soybean oil concentrations on cotton aphids on daylilies in a greenhouse.

decreased numbers cotton aphids (Fig. 2).

In experiment 1, the decline in aphid populations on control plants on 16 June indicated a natural population crash (Fig. 2). In experiment 2, aphid numbers increased following the second oil application (Fig. 5). Numbers ranged between 35-100 aphids/leaf prior to the second oil application (17 June). It is likely that the oils reduced populations sufficiently to shift the growth rate from the decay phase into the exponential phase.

Whiteflies were more difficult to monitor than aphids since the adults are exclusively winged and the plants were uncaged. The mobility of the insects within these experiments was unconstrained, thereby making it difficult to ascertain true population counts.

Therefore, whitefly population estimates reflect erratic fluctuations (Fig. 3). Plants of SBM hibiscus that received sprays of 1.5% soy oil or water (control) consistently tended to have lower whitefly residents than plants sprayed with other treatments. That is, plants that received sprays of 0.5%, 1%, or 2% soy oil or 1% petroleum oil seemingly supported higher numbers of whiteflies.

'Disco Belle Mixed' hibiscus plants supported more aphids and fewer whiteflies than the 'Southern Belle Mixed' variety. Arthropods are known to exhibit host preferences, subsisting on secondary hosts until a primary host is located (van den Bos, 1983). It is likely that the sweetpotato whiteflies preferred the DBM hibiscus variety, whereas the aphids favored the SBM hibiscus.

Our tests suggest that soy oil sprays kill contacted haustellate arthropods. Coverage was a limiting factor on daylilies, due to the tight whorls; better spray equipment may provide better aphid control. The isolating effects of greenhouses influence the efficacy of pest control methods. Specialized and exotic insect species may thrive in enclosed

environments in areas where the external conditions are unsuitable (van den Bos, 1986). Within ornamental gardens, a diverse variety of flora will harbor beneficial insects and predators (Raupp *et al.*, 1992). Water-sprayed plants within this study did show temporary reductions in insect numbers. Daily sprays with water may subdue insects between oil applications, as well as prevent an oil accumulation (Campana, 1983). The oil residues of soy oil sprays sprayed on greenhouse-grown apple trees (*Malus x domestica* Borkh.) were reduced 19%, 62%, and 82% following 0.25, 1.25, and 2.54 cm simulated rainfall, respectively (Bondada *et al.*, 2000).

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PART IV

OVICIDAL CONTROL OF AZALEA LACE BUGS
(HEMIPTERA: TINGIDAE) WITH SOYBEAN OIL

ABSTRACT

Soy oil sprayed at concentrations of 0%, 0.5%, 1.0%, and 2.0% were evaluated for ovicidal control of Azalea lace bugs (ALB) (*Stephanitis pyrioides* Scott) (Hemiptera: Tingidae) from Sept., 1997 to May, 1999. Girard's 'Renee Michelle' evergreen azaleas (*Rhododendron* sp.) were sprayed on one of three dates: late Sept., mid Dec., or Feb./Mar. Hatching lace bugs were quantified on 100 leaves per plant in mid April. All oil treatments significantly reduced lace bug numbers in both trials ($P \leq 0.05$). Azaleas treated with 1% or 2% soy oil in the second experiment (1998-99) had significantly fewer lace bug emergence than control plants ($P \leq 0.05$). Both trials revealed a strong relationship between soy oil concentration and lace bug emergence ($r^2 \geq 98.78$). Spraying oil in Sept., Dec., or late winter provided similar levels of control.

INTRODUCTION

Few parasites of azaleas (*Rhododendron* sp.) are as detrimental as azalea lace bugs (ALB) (*Stephanitis pyrioides* Scott) (Hemiptera: Tingidae), particularly in warmer regions of eastern North America (Reiley, 1992; Raupp and Noland, 1984). Lace bugs are native to Asia, but are now widespread in the continental United States (Hale *et al.*, 1995; Johnson and Lyon, 1991). The ALB was considered the second most important pest in a Maryland urban arboriculture IPM program (Holmes and Davidson, 1984).

Evergreen azaleas are among the most widely planted ornamental shrubs (Braman *et al.*, 1992b), therefore, physical and physiological damage produced by ALB is a major economic concern to nursery growers (Raupp and Noland, 1984; Balsdon *et al.*, 1996). Azaleas are naturally found in shady, understory forest dwellings, but will also grow well and

may produce more flowers in sunny environments (Bowers, 1960). Dirr (1998) described the Girard evergreen azalea hybrids as “show-stopping” and suitable for both northern and southern gardens and landscapes. The compact hybrid Girard’s ‘Renee Michelle’ resulted from a cross between ‘Boudoir’ and ‘Gumpo Pink’. It produces clear pink blooms and dark green foliage, and survives temperatures as low as -23°C (-10°F) (Dirr, 1998).

Eggs of ALB overwinter on broad-leaved evergreens (Johnson and Lyon, 1991), and hatch with emerging nymphs in late April to late May (Neal and Douglass, 1988). Nymphs molt four times (five instars) before becoming adults (Baker *et al.*, 1996). Lace bug nymphs are wingless until the fifth molt, and crawl onto the new foliage soon after emergence (Johnson and Lyon, 1991). Lace bugs are primarily found on the leaf undersides, and are evident by the cast skins and the black, varnish-like droplets of excrement (Braman *et al.*, 1992b). Lace bugs insert their stylets into stomates on the lower leaf surfaces and feed on the inner contents of mesophyll cells (Trumbule and Denno, 1995) and the upper palisade parenchyma layer (Ishihara and Kawai, 1981 *In* Buntin *et al.*, 1996). The removal of leaf cell contents results in stippling or blanching of the upper leaf surfaces (Johnson and Lyon, 1991), and resembles spider mite or leafhopper damage (Dreistadt *et al.*, 1994). Female lace bugs insert their eggs along the midribs and veins of abaxial leaf surfaces for a two to three month period (Hale and Williams, 1995), and conceal the eggs with excrement (Dreistadt *et al.*, 1994). Trumbule and Denno (1995) reported that ALB preferred to feed and oviposit on shade-grown azaleas excluded (by cages) from natural predators.

Damage inflicted by lace bugs affects plants physically as well as physiologically. Visual insect injury initially decreases the aesthetic appearance and ultimately the market value of ornamentals (Trumbule and Denno, 1995; Braman *et al.*, 1992b). White (1933)

indicated that ALB feeding reduced plant vitality. Buntin and colleagues (1996) reported that chlorophyll content, and net photosynthetic (Pn) and transpiration rates (E) of leaves had negative linear correlations with percentage of ALB feeding damage. Conversely, leaf stomatal resistance had a positive linear correlation to ALB feeding injury. Research conducted by Klingeman and associates (1998) indicated that Girard's 'Pleasant White' azaleas with 31% ALB damage had lower Pn and dark respiration rates than azaleas with $\leq 13\%$ insect damage. Severe ALB infestations often induce leaf desiccation, premature leaf abscission, and plant death (White, 1933).

Control methods for ALB have evolved within the past decade. Potter (1986) indicated that no effective control measures existed for ALB. Lace bugs are deterred with cultural methods such as pruning out damaged foliage (Dreistadt *et al.*, 1994). Natural predators such as spiders, chrysopid lacewings, coccinellid beetles, mirid plant bugs including *Stethoconus japonicus* Schumacher (Heteroptera: Miridae), predaceous mites, and parasitic wasps like *Anagrus takeyanus* Gordh (Hymenoptera: Mymaridae) (Balsdon *et al.*, 1996; Dreistadt, 1994; Neal *et al.*, 1991 and 1992; and Trumbule and Denno, 1995) reduce ALB populations. Substantial trials have been conducted to identify ALB-susceptible and resistant varieties of deciduous and evergreen azaleas (Braman *et al.*, 1992a; Schultz, 1993; and Wang *et al.*, 1998).

ALB chemical control measures are currently limited to systemic pesticides such as carbaryl (Sevin[®]) or acephate (Orthene[®]) (Balsdon *et al.*, 1993; Dreistadt, 1994). Limited research has been conducted with other chemicals. Coffelt and Schultz (1988) indicated that a June application of the plant growth regulator mefluidide diethanolamine salt solution (2-S) (52 ml/liter) retarded ALB development 11 DAS compared to untreated control

plants. The Univ. of Calif., Davis Integrated Pest Management program recommended labeled rates of horticultural (petroleum) oil or insecticidal soap to control ALB adults and nymphs (Dreistadt *et al.*, 1994).

The objectives of this research project were to determine 1) if soy oil sprays provide ovicidal control of ALB; 2) which spray date most effectively reduced ALB egg hatching; and 3) if dormant applications of soy oil cause phytotoxicity of azalea foliage.

MATERIALS AND METHODS

Experiment 1: Sixty 7.4 liters (# 3) containers of Girard's 'Renee Michelle' evergreen azaleas were placed in a 50% shade house at the Univ. of Tenn. Agric. Expt. Sta. (Knoxville, TN) in early May, 1997. Overhead irrigation, installed 23 May 1997, watered the plants twice daily. Azalea twigs infested with ALB were placed on each plant on 9 July 1997. Sprays of 0 (water control), 0.5%, 1%, or 2% soy oil (v/v in water) were pre-mixed with Latron B-1956® at 10% of respective oil concentration, and applied with a Stihl SR-400® backpack mist blower until runoff. Plants were sprayed on 25 Sept. 1997 (newly laid eggs), 15 Dec. 1997 (dormant), or 9 Feb. 1998 (late dormant). Plants were arranged in a randomized complete block design (RCB), with five replications.

Plants were arranged without foliage contact in Sept., and maintained uncovered in cold frames throughout the winter. Periodic inspections for phytotoxicity were made throughout the duration of the experiment using the five-point rating scale from Part 2: Experiment 1.

Lace bug instars (5 total) last 2 to 7 days, depending upon environmental conditions (Neal and Douglass, 1998). Newly emerged lace bugs tend to move to the young, fresh

leaves, then to the new plants following wing development. Therefore, plants were monitored regularly throughout the warmer weeks of spring. First and second instar lace bugs were observed on 31 Mar. 1997. Second and third instar lace bugs were visible and leaves were collected on 7 Apr. 1998. One hundred leaves per plant were randomly removed at the petiole with tweezers and placed in large petri plates. Parafilm M[®] laboratory sealing film (American Can Company, Greenwich, CT) wrapped around the circumference of each plate maintained insect populations. Lace bugs were quantified with a dissecting microscope from 8 to 16 April in order of replication, treatment, and spray date. Samples were observed for 10 days following counting for further lace bug emergence, but none occurred.

Experiment 2: The sixty Girard's 'Renee Michelle' azaleas from the previous year's research trial were maintained for the summer and winter of 1998 under 50% shade at the Univ. of Tenn. Agric. Expt. Sta. (Knoxville, TN). There were no differences of lace bug populations among treatments in the previous experiment, possibly due to not fully saturating the undersides of the leaves. Therefore, plants were inspected after spraying to ensure that maximum coverage was achieved. The upper and lower leaf surfaces were sprayed until runoff.

Plants were randomly selected, sprayed with a backpack mist blower, and arranged in an RCB design, with five replications. Soy oil concentrations identical to the previous year were applied on 28 Sept. 1998, 16 Dec. 1998, 5 Mar. 1999.

Periodic inspections for phytotoxicity were made for the duration of the trial using the five-point rating scale from the Part 2: Expt. 1. Azalea foliage was monitored throughout the early spring for lace bug hatching. Lace bugs in the first through third

instars were present on older leaves (1998 growth). Premature disconnection of the irrigation system caused extensive leaf abscission during the winter months. A range from 14 to 121 leaves (mean = 95) per plant were randomly removed at the petiole with tweezers and stored in plastic petri plates (diameter = 135 cm) on 21 April 1999. Parafilm M[®] laboratory sealing film was wrapped around the sides of each plate to prevent insect migration. Samples were stored at room temperature ($21^{\circ}\text{C} \pm 1^{\circ}\text{C}$) until 27 Apr., when fungus became prevalent on the remaining samples. The plates were then moved to a 10°C (50°F) controlled storage chamber.

Populations of emerged lace bugs per sample were quantified with a dissecting microscope from 22 April to 2 May 1999 in order of replication, treatment, and spray date. Total area and number of leaves per sample were obtained following insect counts to adjust for sample size variation. Leaf areas were determined with an Ikegami[®] Delta-T video imaging leaf area meter (Delta-T Devices, Utsunomiya, Japan).

RESULTS

Experiment 1: Azaleas treated with 1%, 2%, or 3% soy oil had 27%, 38%, or 39% fewer ALB, respectively, than the water control ($P \leq 0.005$) (Fig. 1). A highly significant negative relationship existed between soy oil concentration and lace bug emergence was configured ($r^2 = 99.7$). No differences in ALB hatch was detected between any of the spray dates. The oil sprays did not cause phytotoxicity to the azalea foliage in September, December, or February.

Experiment 2: In 1999, insect quantification on a leaf area basis (cm^2) (as opposed to number per leaf) revealed more dramatic reductions in viable numbers of ALB (Fig. 2).

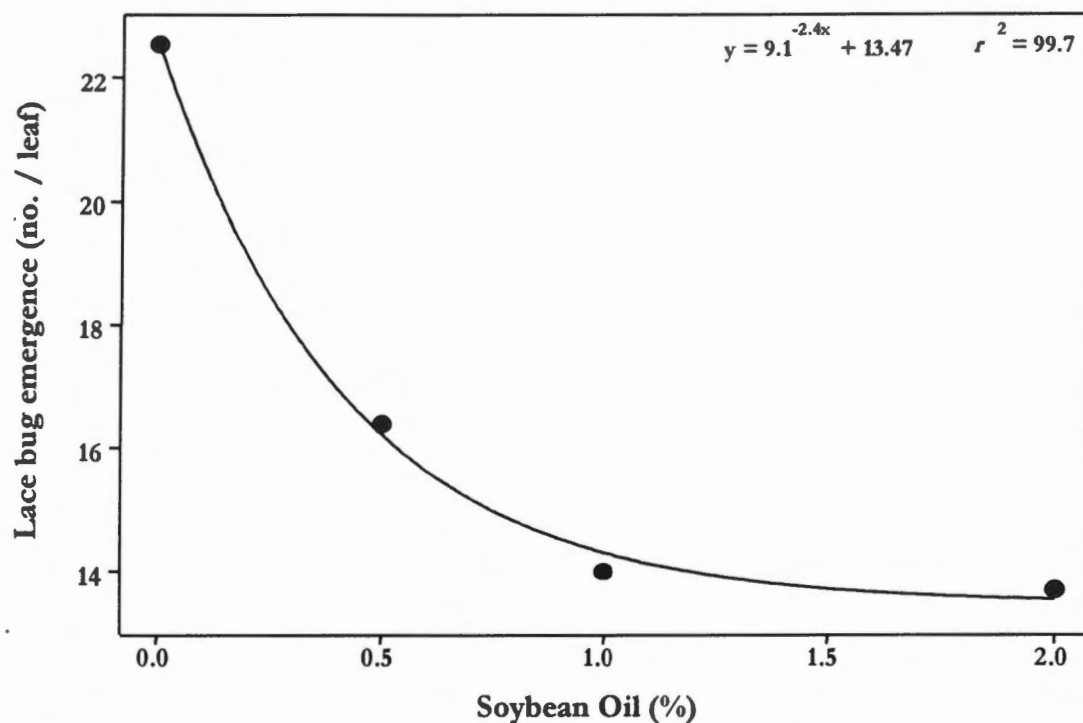


Fig. 1. Effects of repeat dormant applications of soybean oil on Azalea lace bug emergence in April 1998.

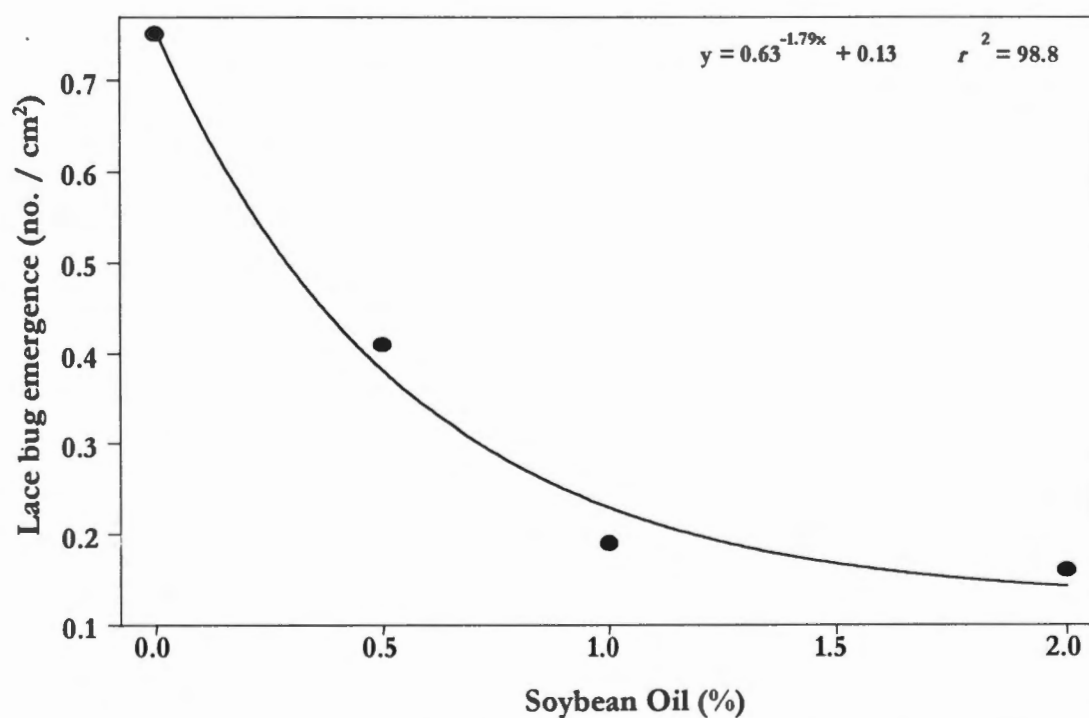


Fig. 2. Effects of repeat dormant applications of soybean oil on Azalea lace bug emergence in April 1999.

Water-sprayed plants had 0.75 lace bugs per square centimeter emerge. Plants sprayed with 0.5% soy oil supported 45% fewer lace bugs than the water-treated plants. Sprays of 1% or 2% soy oil reduced lace bugs by 75% and 78%, respectively, compared to the water control. A highly significant negative correlation between soy oil concentration and lace bug emergence existed ($r^2 = 98.8$). Once again, none of the treatments produced visible phytotoxicity.

DISCUSSION

Both experiments indicate that one dormant application of soy oil significantly lowered ALB hatching, compared to the controls (Figs. 1 and 2). Quantification of insects per cm² in the 1997-98 experiment differentiated the treatments slightly further (Fig. 3 and 4). Overall, ALB hatching reduction was oil concentration dependent. Spraying 1% soy oil appeared to provide adequate control.

Insect emergence was noticeably less in the 1997-98 experiment than in the previous year. However, the autumn water stress likely contributed to the dessication and defoliation (Smithley and Peterson, 1991) and the subsequent reduction of ALB hatching (Neal and Bentz, 1997). Overall ALB reduction was not as low as we anticipated. In a preliminary study (1996-97), plants sprayed with 1-2% soy oil had no lace bug emergence the following spring (100% control).

The oils may have penetrated the exposed egg surfaces, rendering them unable to hatch, due to suffocation, coagulation of embryonic protoplasm, conversion of the outer membrane's pliability (too hard to hatch; too soft to survive), or disruption of inner physiology (water balance, enzymes, hormones) (Davidson *et al.*, 1991). Our repeated

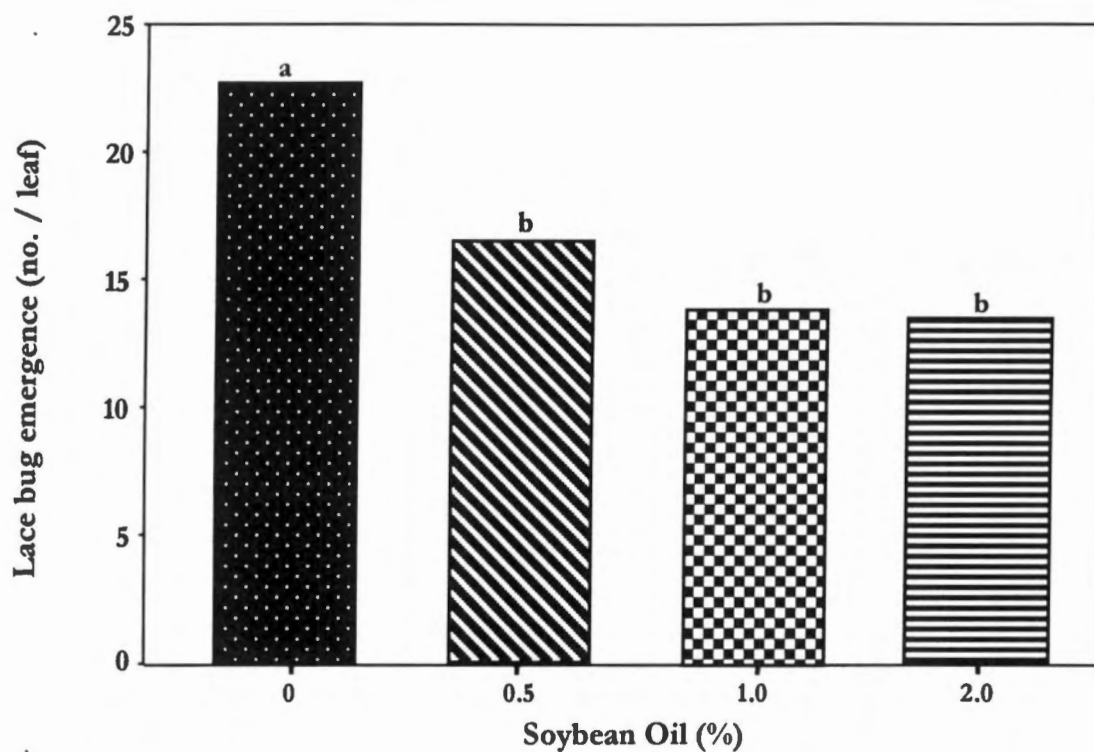


Fig. 3. Azalea lace bug emergence in April 1998 following three treatments with soy oil formulations. Letters represent mean separation with Duncan's multiple range test ($P \leq 0.05$).

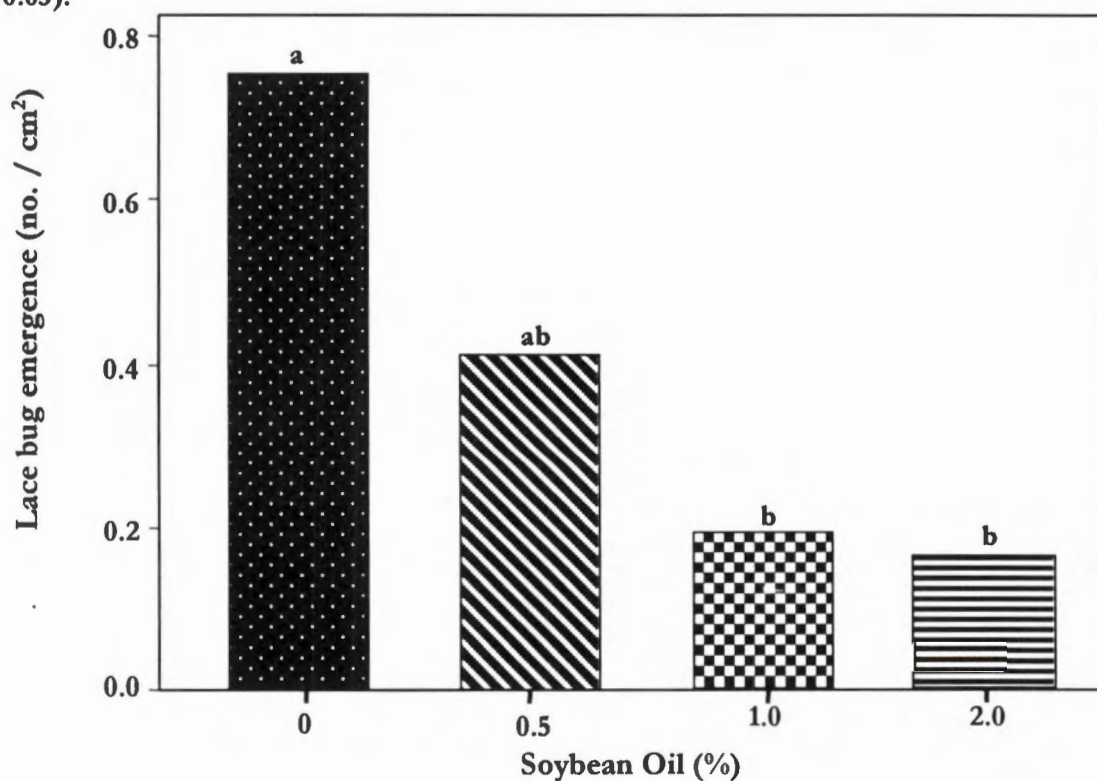


Fig. 4. Azalea lace bug emergence in April 1999 following three treatments with soy oil formulations. Letters represent mean separation with Duncan's multiple range test ($P \leq 0.05$).

studies (1997-1999) achieved only a maximum of 78% control. Several interferences may have contributed. Frass, excreted over the eggs, may provide protection (Balsdon *et al.*, 1993). Reports also indicate that ALB prefer to feed and oviposit on plants within shaded locations (Trumbule and Denno, 1995). Our studies were contained within shade houses, whereas the preliminary 1996-97 trial was left exposed in an open cold frame. Although not completely enclosed, the shade houses may have sufficiently excluded natural predators, thereby enhancing the infestation level (Trumbule and Denno, 1995). The same sixty azalea plants were used for both trials, and were therefore exposed to more severe infestations than the azaleas from the preliminary trial. Plants may have also experienced mild water and/or nitrogen stress situations, which make plants more conducive for lace bug infestations (Trumbule and Denno, 1995; Casey and Raupp, 1999).

Higher rates of soy oil may be required to more efficaciously control ALB. Dormant applications of 2-3% Sunspray Ultra-fine Spray Oil are labeled to control plant bugs on ornamentals. Dormant oil sprays are often applied at rates 1.5 to 3 times higher than verdant oil applications (Miller, 1989). Soy oil rates of up to 5% have been used for winter management of European red mite (*Panonychus ulmi* Koch), San Jose scale (*Quadraspidiotus perniciosus* Comstock), and terrapin scale (*Mesolecanium nigrofasciatum* Pergande) insects on deciduous plants (Pless *et al.*, 1995). Winter applications of 3% petroleum oil or 6% soy oil reduced San Jose crawlers by 93 - 98%, compared to the control (Hix *et al.*, 1999). Azaleas have limited sensitivity to summertime oil sprays (Johnson, 1985). Although sprays were applied during the dormant season, no phytotoxicity was observed in either of the experiments. Baxendale and Johnson (1998) applied sprays of 0-8% Sunspray 6E (in 2% increments) to dormant ornamentals, and reported no phytotoxicity. Dormant sprays pose

little threat of phytotoxicity due to the lack of foliage (on deciduous plants) in addition to the reduced solar radiation, temperatures, and humidity (Davidson *et al.*, 1991; Johnson, 1981). Further investigations should be made with higher rates of soy oil to determine an optimum rate.

Oil sprays may delay bloom on azaleas, however this feature may be favorable in climates often subjected to late freezes. Internal CO₂ levels accumulated in dormant peach trees treated with 10 or 20% crude soy oil and delayed bloom by 6 days (Myers *et al.*, 1996). Increased internal CO₂ levels may lead to bud abscission and twig dieback (Miller, 1999). Monitoring internal CO₂ and entire plant gas exchange (Klingeman *et al.*, 1998) rates will help determine if higher oil rates are negatively affecting the plants' gas exchange.

The results of our experiments indicate that soy oil has potential as an ovicide; further research should be conducted with the following modifications: 1) evaluating azaleas in shaded locations vs. azaleas in sunny locations (Trumbule and Denno, 1995); 2) testing higher rates of soy oil to configure phytotoxicity and pest management thresholds ; 3) pre-evaluating plant mineral levels to ensure no nitrogen deficits (Casey and Raupp, 1999); 4) monitoring for natural predators (Neal *et al.*, 1992; Balsdon *et al.*, 1996); and 5) evaluating summer sprays for phytotoxicity and efficacy against lace bug nymphs and adults (Balsdon *et al.*, 1993).

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PART V

SOYBEAN AND PETROLEUM OILS AFFECT PHYTOTOXICITY AND GAS EXCHANGE ON NURSERY STOCK

ABSTRACT

A series of trials were conducted between 1997 and 1998 to determine if soy oil sprays caused phytotoxicity to herbaceous and woody ornamentals. Spraying 1% - 3% soy oil temporarily reduced net photosynthetic (Pn), stomatal conductance (Gs), and transpiration (E) rates, however the rates were equivalent with the control plants within 14 days. Soybean or petroleum oil caused discoloration on blue-colored conifers in 1997. However, the blue coloration appeared to recover by the end of the trial in 1998. Miniature roses sprayed with soy oil-Latron B-1956® or soy oil-Ballistol® mixtures had the most phytotoxicity 7 to 14 days after spraying. Roses sprayed with E-Z-Mulse or Emulsion A had the least damage.

INTRODUCTION

Pesticides are used frequently in nurseries, gardens, and landscapes to manage pests and maintain plant quality (Neel and Reinert, 1975). Most of the pesticides used in urban environments are applied by untrained landscape maintenance gardeners and homeowners, regardless of the appropriateness (Freeman and Sundu, 1999). Public environmental and sociological demands encouraged the development of non-synthetic pesticide alternatives (Mizell, 1991). Horticultural oils and soaps are popular in urban dwellings because they are fatal to contacted insects but not applicators, and do not linger to disrupt beneficial predators and parasites (Miller, 1989). Modern horticultural oils and soaps are more refined than their crude counterparts and less likely to cause damage (Mizell, 1991). Nonetheless, accounts of oil-induced phytotoxicity are expansive and variable (Baxendale and Johnson, 1988a, 1988b, 1989; Davidson *et al.*, 1990; Johnson, 1980, 1985; Johnson and Caldwell, 1987;

Miller, 1989; Mizell, 1991; Retzlaff *et al.*, 1994; and Tippins, 1974). Oil applications that are used at excessively high (rates), or have impurities can penetrate leaf surfaces, causing yellowing, leaf burn, or leaf abscission (Retzlaff *et al.*, 1994). Numerous factors, ranging from environmental conditions (extremes temperatures, humidity, water stress, or ozone pollution) to human error, can work individually or in combination and damage plants (Johnson, 1985; Norris, 1988; Retzlaff *et al.*, 1994).

Initial oil sprays were developed in the 1800s, and consisted of unrefined petroleum oil or kerosene mixed with soap (Miller, 1989). These home-made pesticides were applied at rates ranging from 10% to 50% to control soft-bodied insects on dormant fruit trees, and sometimes caused serious limb and bud damage (Burroughs, 1923). In 1923, Ackerman reported that a 2% light lubricating oil mixture effectively controlled San Jose scale (Miller, 1989). The development of the “Superior oil” (70-second petroleum oil) in 1947 extended pest control into the growing season, with minimal phytotoxic hazards (Chapman *et al.*, 1962). Modern verdant spray oils refined $\geq 92\%$ (i.e. contain $\leq 8\%$ unsaturated compounds), are termed horticultural oils (Johnson, 1983).

The objectives of these experiments were 1) to determine if soy oil or petroleum oil cause phytotoxicity or alter gas exchange on deciduous and evergreen ornamentals; and 2) to determine which surfactant(s) better maintain the soy oil mixture in water.

MATERIALS AND METHODS

Experiment 1: Summer research (1997) evaluated soy oil effects on net photosynthesis (Pn), stomatal conductance (Gs), transpiration (E), and phytotoxicity on *Euonymus kiautschovicus* Loes. ‘Manhattan’ (semi-evergreen) and *Rhododendron* ‘Chetco’ (deciduous).

Thirty-six plants of each variety were potted in 18.8 liter (# 5) containers and placed inside shaded enclosures at the Univ. of Tenn. Agric. Expt. Station. 'Manhattan' Euonymus plants were arranged in an RCB design under 30% shade. 'Chetco' azaleas were also arranged in an RCB design under 50% shade. An overhead irrigation system was installed on 23 May 1997; all plants were irrigated twenty minutes in the early morning, and again for thirty minutes in the evening. 'Ridomil' soil drenches (80 ml chemical / 5 gal. water; 1 pint per pot) were applied to *Rhododendron* 'Chetco' as a prophylactic treatment on 24 July 1997.

Sprays of 0% (water control), 1%, 2%, or 3% soy oil (mixed with Latron B-1956® at 10% of the respective oil concentration), or 1% Sunspray Ultra-fine Spray Oil® were applied with a backpack mist blower until runoff on 29 July (euonymus) or 25 Aug. (azalea). An unsprayed control was also included in the treatments.

Measurements of Pn, Gs, and E were taken on one leaf per plant between the first and third fully expanded leaf from the apical meristem. Euonymus plants were measured on 28, 30 July, and 1, 5, 6, 22 Aug. 'Chetco' azaleas were evaluated on 25, 27 Aug., and 2, 8 Sept. Gas exchange data were analyzed as an RCB design consisting of six treatments, five replications, and thirty experimental units (one reading per experimental unit). Data were analyzed with the General Linear Models (GLM) procedure and Duncan's Multiple Range test (SAS 6.12, 1996).

Phytotoxicity ratings were made periodically throughout the experiment with the five-point rating scale used in the first experiment of chapter one.

Experiment 2: Thirteen species of ornamentals that are susceptible to insect and/or mite infestations were selected for the phytotoxicity screening at Kinsey Gardens, Inc. in Knoxville, TN: Littleleaf Boxwood (*Buxus microphylla* Sieb. & Zucc. 'Green Beauty'); Shore

Juniper (*Juniperus conferta* Parl. 'Blue Pacific'); Japgarden Juniper (*Juniperus procumbens* Endl. Miq. 'Nana'); Singleseed Juniper (*Juniperus squamata* Buch.-Ham ex D. Don 'Blue Star'); Dwarf Alberta Spruce (*Picea glauca* Moench Voss. 'Conica'); Eastern White Pine (*Pinus strobus* L. 'Glauc'); Anglojap Yew (*Taxus $\times$ media* Rehd. 'Densiformis'); Eastern Arborvitae (*Thuja occidentalis* L 'Pyramidalis'); Western Red Cedar (*Thuja plicata* D. Don); Bumald Spirea (*Spiraea $\times$ bumalda* Burvenich 'Anthony Waterer'); and Burkwood Viburnum (*Viburnum $\times$ burkwoodii* Burkw. & Skipw.)

All plants were grown in 3.8 liters (# 1) pots, except the yews and spruces were grown in 0.95 liter (# 0.25) containers. Plants were selected, grouped according to treatment, and sprayed with a backpack mist blower until runoff with 0% (water control), 1 or 2% soy oil (mixed with Latron B-1956® at 10% of oil concentration); 0.2% Latron B-1956®; or 2% Sunspray Ultra-fine Spray Oil® (petroleum oil) on 26 Aug. 1997. Plants were randomized in an uncovered quonset-style greenhouse in an RCB design with four replications. Phytotoxicity ratings were made on 11 Sept. and 2 Oct. with the five-point rating scale used in Part 2: Experiment 1.

Experiment 3: Ten species of ornamentals which are susceptible to soft-bodied insect and mite infestations were selected from Kinsey Gardens, Inc. in 1998. The three species of junipers discolored by oil sprays in the previous year's experiment were used again in the trial. The ornamentals tested included: Leyland Cypress ($\times$ *Cupressocyparis leylandii* Dallim & A.B. Jackson 'Emerald Isle'); Dwarf Burford Chinese Holly (*Ilex cornuta* Lindl. & Paxt. 'Burfordii'); American Holly (*Ilex opaca* Ait 'Greenleaf'); Shore Juniper (*Juniperus conferta* Parl 'Blue Pacific'); Japgarden Juniper (*Juniperus procumbens* Endl. Miq. 'Nana'); Singleseed Juniper (*Juniperus squamata* Buch.-Ham ex D. Don 'Blue Star'); Southern Magnolia (*Magnolia*

grandiflora L. 'Claudia Wannamaker'); Japanese Pieris (*Pieris japonica* Thunb. D. Don ex. G. Don 'Cavatine'); Eastern Hemlock (*Tsuga canadensis* L. Carr.); and Bigleaf Hydrangea (*Hydrangea macrophylla* Thunb. ex J.A. Murr. Ser. 'Annabelle').

Plants were selected that were healthy, insect-free, and displaying no symptoms that could be mistaken for phytotoxicity. Additionally, plants were rated with the phytotoxicity scale prior to spraying. All plants were grown in 2.8 liters (# 1), except the 10 inch (2.5 cm) hydrangeas were grown in seedling trays and magnolias were grown in 7.6 liter (# 3) containers. Treatments were sprayed on 18 Sept. 1998 with the same methods and concentrations as the previous year. Plants were separated according to species, then arranged in an RCB design with four replications. Plants were watered twice daily with an overhead irrigation spray, established by the nursery. Plants were rated for phytotoxicity and discoloration on 18, 19, 25 Sept. and 13 Oct. Plants were rated using the five-point rating scale as in the previous year's experiment. Additionally, a new five-point scale was used to rate discoloration of blue-colored evergreens: 1 = no visible damage, 2 = slight greening (discoloration) on some foliage, 3 = moderate greening on most foliage, 4 = extensive greening, 5 = greening with dieback. Rates of Pn, Gs, and E were measured on all non-coniferous plants on 19 and 25 Sept. on one fully expanded leaf within five nodes of the shoot apex.

Experiment 4: Greenhouse-grown shamrocks (*Oxalis regnellii* Miq.) in 2.8 liter (# 1) containers were stripped of foliage that might be misconstrued as phytotoxicity. Treatments of 0% (water control); 1% or 2% soy oil mixed with Latron B-1956® (at 10% of oil conc.); 0.2% Latron B-1956®; or 1% Sunspray Ultra-fine Spray Oil® were sprayed with hand-held mist bottles on 21 Apr. 1998. Spray containers were shaken frequently to

maintain the emulsion. Sprays were applied until runoff. Treatments were arranged in an RCB design, with four replications. Phytotoxicity ratings were made on 30 Apr. using the five point rating scale used in the first experiment of Part 2.

Experiment 5: Miniature 'Fashion' roses (*Rosa* sp.) were obtained and transplanted into 2.8 liter (# 1) containers in July 1998. Treatments were arranged in an RCB design with five replications. Plants were irrigated twice daily for five minutes with a spray emitter.

'Fashion' (pink) roses were sprayed with a hand-held mist bottle until runoff on 25 Sept. 1998 with the following treatments (Table 1): 1 = DC, 2 = WC, 3 = Lat, 4 = SO/Lat, 5 = AT, 6 = SO/AT, 7 = Eru, 8 = SO/Eru, 9 = Eru/Lec, or 10 = SO/Eru/Lec. Sprays contained 1% soy oil and/or 0.1% adjuvant. Plants were rated for phytotoxicity on 9 Oct. (14 DAS) using the rating scale from the first experiment of chapter one.

Experiment 6: 'Fashion' miniature rose plants (*Rosa* sp.) were grown and sprayed in the same method as those in the previous experiment. On 9 Nov. 1998, containers were organized on a bench on the east side of the greenhouse in an RCB design with four replications. 'Fashion' roses were sprayed on 16 Nov. 1998 until runoff using hand-held mist bottles. The treatments applied were: 1 = WC, 2 = Blstl, 3 = SO/Blstl, 4 = EmA, 5 = EmB, or 6 = SO/Lat (Table 1). Sprays contained 1% soy oil and/or 0.1% adjuvant. Phytotoxicity was evaluated 1 and 14 DAS with the five-point rating scale used in experiment one.

Experiment 7: 'Fiesta' miniature roses (*Rosa* sp.) were grown under the same cultural conditions as the roses in the previous experiment. 'Fiesta' (fuchsia) roses were sprayed with hand-held mist bottles until runoff on 16 Nov. 1998 with: 1 = WC, 2 = S1K, 3 = S2K, 4 = EmA, 5 = EmB, or 6 = SO/Lat (Table 1). Sprays contained 1% soy oil and/or 0.1%

Table 1. Abbreviations for soybean oil and adjuvant treatments sprayed on miniature roses

Abbreviation	Chemicals	Manufacturer
WC	Water control	-----
DC	Dry control	-----
Lat	0.1% Latron B-1956	Rohm & Haas Co. (Philadelphia, Pa.)
AT	0.06% Atlox + 0.04% Tween	ICI Americas (Wilmington, Del.)
Eru	0.1% ERUCiCHEM	Int'l Lubricants, Inc. (Seattle, Wash.)
Lec	0.01% lecithin	Chem Service (West Chester, Pa.)
Blstl	0.1% Ballistol	F.W. Klever, GMBH (Germany)
EZM	0.1% E-Z-Mulse	Florida Chemical Co. (Winter Haven, Fla.)
SO	1% soybean oil	Central Soya (Fort Wayne, Ind.)
EmA	1% Emulsion A	Michigan Molecular Inst. (Midland, Mich.)
EmB	1% Emulsion B	Michigan Molecular Inst. (Midland, Mich.)
S1K	1% Soygold 1000	Ag Environmental Products (Lenexa, Kan.)
S2K	1% Soygold 2000	Ag Environmental Products (Lenexa, Kan.)

adjuvant. Pots were organized in an RCB design with four replications. Plants were rated for phytotoxicity on 1 and 14 DAS.

Experiment 8: 'Tender' miniature roses (*Rosa* sp.) were exposed to experimental conditions identical to those in the previous two experiments. 'Tender' (white) roses were sprayed with hand-held mist bottles until runoff on 16 Nov. with: 1 = WC, 2 = Eru, 3 = SO/Eru, 4 = Eru/Lec, 5 = SO/Eru/Lec, or 6 = SO/Lat (Table 1). Sprays contained 1% soy oil and/or 0.1% adjuvant. Phytotoxicity was assessed 1 and 14 DAS.

Experiment 9: 'Orange' miniature roses (*Rosa* sp.) were sprayed with hand-held mist bottles until runoff on 18 Nov. with: 1 = WC, 2 = EZM, 3 = SO/EZM, 4 = Lat, or 5 = SO/Lat (Table 1). Sprays contained 1% soy oil and/or 0.1% adjuvant. Plants were arranged in an RCB design with four replications. Plants were rated for phytotoxicity 5 and 12 DAS.

RESULTS

Experiment 1: Summer time oil applications affected Pn, Gs, and E rates of 'Manhattan' *Euonymus* leaves on 30 Jul. (1 DAS) and 1 Aug. (3 DAS)(Fig. 1). Plants recovered from the oil sprays by 6 Aug. (8 DAS), and continued showing no differences in Pn, Gs, and E rates on 22 Aug. (24 DAS) (Tables 2, 3, 4). Petroleum oil appeared to quickly lower plant gas exchange levels by 1 DAS. Rates of Pn, Gs, and E on petroleum oil-treated plants were equivocal to those by plants sprayed with 1% or 2% soy oil within two days (1 Aug.). The temporary gas exchange reduction did not appear to adversely affect the plants. No phytotoxicity was caused by any of the treatments.

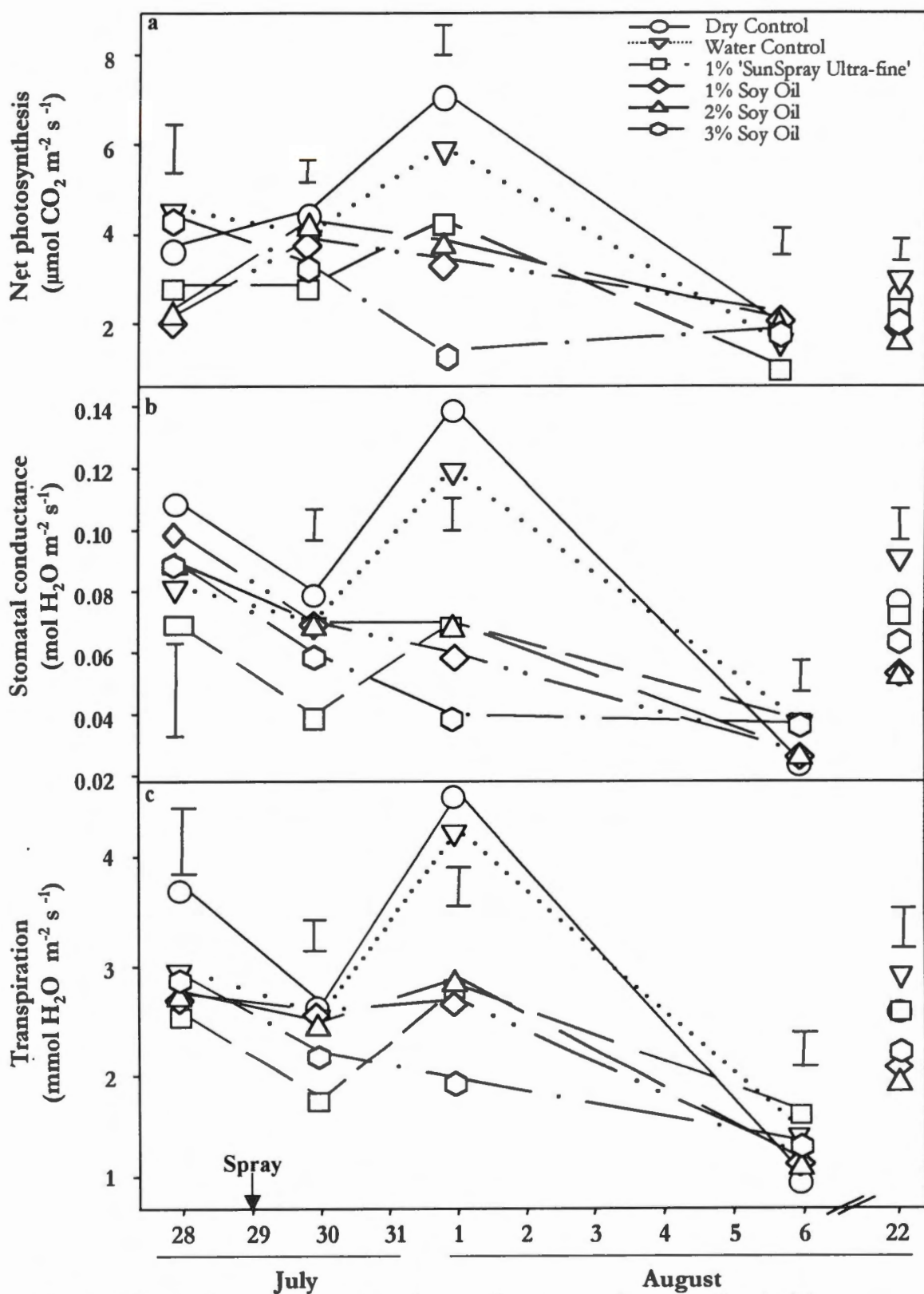


Fig. 1. Effect of petroleum or soybean oils on net photosynthesis (a), stomatal conductance (b), and transpiration (c) of 'Manhattan' spreading *Euonymus*. Vertical bars represent one SE.

Table 2. Effects of summer oil sprays on net photosynthesis ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) of *Euonymus kiautschovicus* 'Manhattan'

Treatments ^z	28 Jul	30 Jul	1 Aug	6 Aug	22 Aug
1% Soy Oil ^y	2.17 a ^x	3.92 ab	3.47 b	2.27 a	2.03 a
2% Soy Oil ^y	2.33 a	4.33 a	3.88 b	2.13 a	1.76 a
3% Soy Oil ^y	4.43 a	3.38 ab	1.40 c	1.90 a	2.12 a
1% Sunspray ^w	2.87 a	2.87 b	4.33 b	1.05 a	2.42 a
Water Control	4.60 a	4.02 ab	5.97 a	1.58 a	3.08 a

^z Treatments applied on 29 July 1997.

^y Soy oil treatments emulsified with Latron B-1956® Spreader-Sticker at 10% of the oil.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

Table 3. Effects of summer oil sprays on stomatal conductance ($\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1}$) of *Euonymus kiautschovicus* 'Manhattan'

Treatments ^z	28 Jul	30 Jul	1 Aug	6 Aug	22 Aug
1% Soy Oil ^z	0.10 a ^x	0.07 ab	0.06 b	0.03 a	0.06 a
2% Soy Oil ^y	0.09 a	0.07 ab	0.07 b	0.03 a	0.05 a
3% Soy Oil ^y	0.09 a	0.06 ab	0.04 b	0.04 a	0.07 a
1% Sunspray ^w	0.07 a	0.04 b	0.07 b	0.04 a	0.07 a
Water Control	0.08 a	0.07 ab	0.12 a	0.04 a	0.09 a

^z Treatments applied on 29 July 1997.

^y Emulsified with Latron B-1956® Spreader-Sticker..

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

Table 4. Effects of summer oil sprays on transpiration ($\text{mmol H}_2\text{O m}^{-2} \text{s}^{-1}$) of *Euonymus kiautschovicus* 'Manhattan'

Treatments ^z	28 Jul	30 Jul	1 Aug	6 Aug	22 Aug
1% Soy Oil ^y	2.75 a ^x	2.60 ab	2.70 bc	1.25 a	2.12 a
2% Soy Oil ^y	2.77 a	2.50 ab	2.90 b	1.22 a	1.98 a
3% Soy Oil ^y	2.92 a	2.22 ab	1.97 c	1.40 a	2.27 a
1% Sunspray ^w	2.57 a	1.80 b	2.83 b	1.67 a	2.62 a
Water Control	2.98 a	2.57 ab	4.25 a	1.48 a	2.95 a

^z Treatments applied on 29 July 1997.

^y Emulsified with Latron B-1956[®] Spreader-Sticker.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil[®].

Net photosynthesis was the lowest on *Euonymus* plants treated with 1% Sunspray Ultra-fine Spray Oil[®] 1 DAS (Fig. 1a) (Table 2). All of the oil treatments significantly depressed levels of Pn 3 DAS ($P \leq 0.005$). Spraying 3% soy oil caused the greatest reduction of Pn 3 DAS, which was statistically different from all other treatments. The oils did not influence Pn rates by 8 DAS, and still had no effects at 24 DAS.

Petroleum oil-treated plants had the lowest Gs rates 1 DAS (Table 3). All oil treatments depressed Gs compared to water-treated and untreated plants at 3 DAS, but all treatments were equivalent 8 DAS and remained so until the end of the experiment (24 DAS) (Fig. 1b).

Only petroleum oil-treated plants had lower transpiration rates compared to untreated plants at 1 DAS (Table 4). However, by 3 DAS all of the oil treatments had reduced E rates compared to the untreated and water-treated *Euonymus* plants. The 3% soy-treated *Euonymus* had the lowest E rates, but were similar to plants treated with 1% soy oil.

All 'Chetco' azalea plants had equivalent rates of Pn, Gs, and E prior to spraying (Fig. 2). The net photosynthetic rates were 34%, 30%, 16%, and 42% lower than control plants at 2 DAS than for plants sprayed with 1% soy oil, 2% soy oil, 3% soy oil, or 1% petroleum oil, respectively (Fig. 2a, Table 5). Net photosynthetic rates of those plants tended to remain lower than control plants 8 DAS. The oils had no effect on Pn 14 DAS (8 Sept.) ($P \leq 0.05$) (Fig. 2; Table 5).

Spraying 1-3% soy oil and 1% Sunspray caused similar reduction of stomatal conductance and transpiration rates on 'Chetco' azaleas (Fig. 2b & 2c.). Plants sprayed with 1%, 2%, or 3% soybean or 1% Sunspray had Gs rates that were 75%, 33%, 42%, and 67% as high, respectively, as the water control at 8 DAS (Table 6). Similarly, the E rates were 80%, 45%, or 53%, and 72% of the control at 8 DAS (Table 7).

Spraying 1% petroleum oil treatments tended to reduce gas exchange rates more than did the 1% soy oil. As expected, the 2% and 3% rates of soy oil produced lower rates of Pn, Gs, and E, and showed distinct separations by 2 Sept (8 DAT) (Tables 6 and 7).

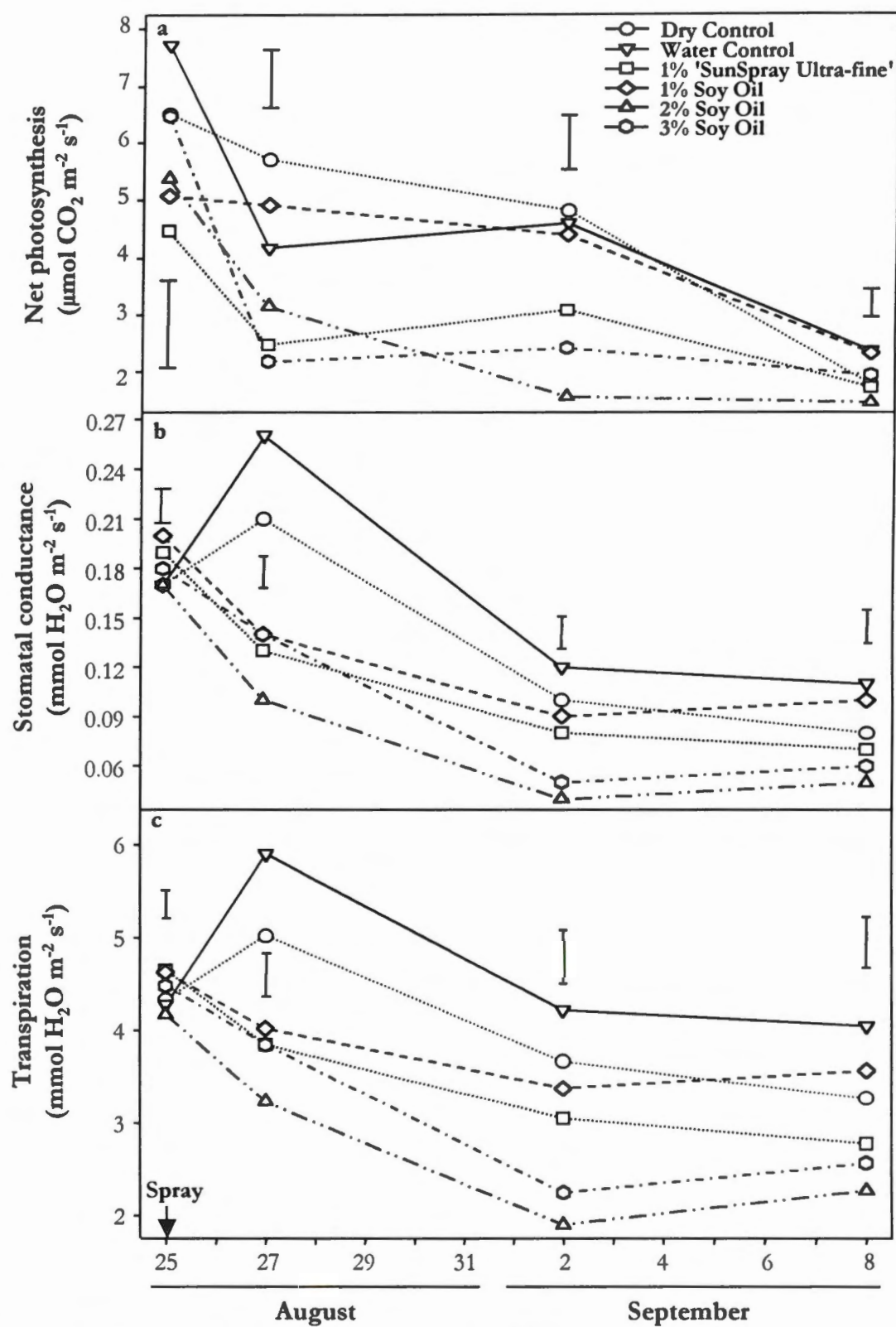


Fig. 2. Effect of soybean and petroleum oils on net photosynthesis (a), stomatal conductance (b), and transpiration (c) of 'Chetco' deciduous azaleas. Vertical bars represent one SE.

Table 5. Effects of summer oil sprays on net photosynthesis ($\mu\text{mol H}_2\text{O m}^{-2} \text{s}^{-1}$) of *Rhododendron* 'Chetco'

Treatments ^z	25 Aug	27 Aug	2 Sept	8 Sept
1% Soy Oil ^y	5.08 a ^x	4.92 ab	4.40 a	2.68 a
2% Soy Oil ^y	5.38 a	3.15 ab	1.57 a	2.42 a
3% Soy Oil ^y	6.47 a	2.18 b	2.42 a	3.04 a
1% Sunspray ^w	4.47 a	2.47 ab	3.08 a	1.76 a
Water Control	7.72 a	4.17 ab	4.60 a	2.64 a

^z Treatments applied on 25 Aug. 1997.

^y Emulsified with Latron B-1956® Spreader-Sticker.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

Table 6. Effects of summer oil sprays on stomatal conductance ($\text{mol H}_2\text{O m}^{-2} \text{s}^{-1}$) of *Rhododendron* 'Chetco'

Treatments ^z	25 Aug	27 Aug	2 Sept	8 Sept
1% Soy Oil ^y	0.20 a ^x	0.14 b	0.09 ab	0.09 a
2% Soy Oil ^y	0.17 a	0.10 b	0.04 b	0.05 a
3% Soy Oil ^y	0.18 a	0.14 b	0.05 ab	0.08 a
1% Sunspray ^w	0.19 a	0.13 b	0.08 ab	0.06 a
Water Control	0.17 a	0.26 a	0.12 a	0.09 a

^z Treatments applied on 25 Aug. 1997.

^y Emulsified with Latron B-1956® Spreader-Sticker.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

Table 7. Effects of soy oil or petroleum oil on transpiration ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) of *Rhododendron* 'Chetco'

Treatments ^z	25 Aug	27 Aug	2 Sept	8 Sept
1% Soy Oil ^y	4.63 a ^x	4.02 bc	3.38 ab	3.49 a
2% Soy Oil ^y	4.17 a	3.23 c	1.90 b	2.29 a
3% Soy Oil ^y	4.48 a	3.85 bc	2.25 b	3.18 a
1% Sunspray ^w	4.65 a	3.85 bc	3.05 ab	2.48 a
Water Control	4.28 a	5.90 a	4.22 a	3.32 a

^z Treatments applied 25 Aug. 1997.

^y Latron B-1956® Spreader-Sticker.

^x Mean separation within columns by Duncan's multiple range test, at $P \leq 0.05$.

^w Sunspray Ultra-fine Spray Oil®.

Experiment 2: Soy oil or Sunspray Ultra-fine Spray Oil® did not cause significant phytotoxicity on pyramidal arborvitae, boxwood, spirea, viburnum, Western red cedar, or Eastern white pine in 1997. Moderate to severe phytotoxicity with some dieback occurred on Japgarden juniper sprayed with 1% or 2% soy oil (Table 8). Dwarf Alberta spruce was damaged by 2% soy oil, but not by 1%. Summer application of 0.2% Latron B-1956®, 1% or 2% soy oil produced significant yellowing to yew. Immediately after spraying, loss of blue coloration was evident on 'Blue Star' and 'Blue Pacific' junipers by all oil treatments. Damage produced by 2% Sunspray Ultra-fine Spray Oil® and 1% or 2% soy oil on the blue junipers ranged from loss of blue color to foliage burn. Latron B-1956® did not cause phytotoxicity or discoloration of the blue junipers.

Alberta spruce, white pine, and yew plants sprayed with 1% soy oil displayed mild phytotoxicity, while those sprayed with 2% soy oil showed moderate phytotoxicity. Oil-damaged leaves quickly died back, revealing healthy foliage within two weeks from the spray date.

Experiment 3: The Pn, Gs, and E rates were measured 1 and 7 DAS on 'Greenleaf' American holly (Fig. 3), 'Annabelle' hydrangea (Fig. 4), and 'Claudia Wannamaker' magnolia (Fig. 5) and 1 DAS on 'Dwarf Burford' Chinese holly (Fig. 6) in 1998. The Pn rates were generally low, probably because the trial was conducted in the late summer (18 Sept.), when the sunlight is less intense than in mid-summer. Spraying 1% soy oil increased the Pn rate of 'Greenleaf' American holly (Fig. 3) and tended to increase the Pn rate of 'Annabelle' hydrangea (Fig. 4). The 1% soy oil no longer depressed Pn of American holly 7 DAS, though 2% soy oil lowered Pn to 45% of control plants. Spraying 2% Sunspray Ultra-fine

Table 8. Phytotoxicity of petroleum or soy oil sprays to nursery stock in 1997

	Phytotoxicity Ratings ^z					LSD ^w
	Water	Sunspray 2%	Latron 0.2%	Soy Oil ^y 1%	Soy Oil ^x 2%	
Alberta Spruce	1.0	2.0	2.0	2.4	2.9	1.5
Arborvitae	1.0	1.0	1.0	1.0	1.0	0.0
'Blue Pacific' Juniper	1.0	1.5	1.0	1.9	3.0	0.9
'Blue Star' Juniper	1.0	2.8	1.0	2.3	3.0	0.7
Boxwood	1.5	1.8	2.0	1.8	2.0	0.6
Japgarden Juniper	1.0	1.0	1.3	3.1	4.0	0.5
Spirea	1.0	1.0	1.0	1.0	1.0	0.0
Viburnum	1.0	1.0	1.0	1.0	1.0	0.0
Western Red Cedar	1.0	1.0	1.1	1.0	1.0	0.2
White Pine	1.6	2.2	2.5	2.0	2.7	1.2
Yew	1.0	1.0	2.0	3.0	3.5	0.0

^z Rating Scale: 1 = no visible damage, 2 = slight yellowing on some leaves, 3 = moderate yellowing on most leaves, 4 = burn, no dieback, 5 = dieback. Plants sprayed 27 Aug. 1997. Ratings were made on 11 September 1997.

^y Soy oil + 0.01% Latron B-1956.

^x Soy oil + 0.02% Latron B-1956.

^w LSD = Least significant difference ($P \leq 0.05$).

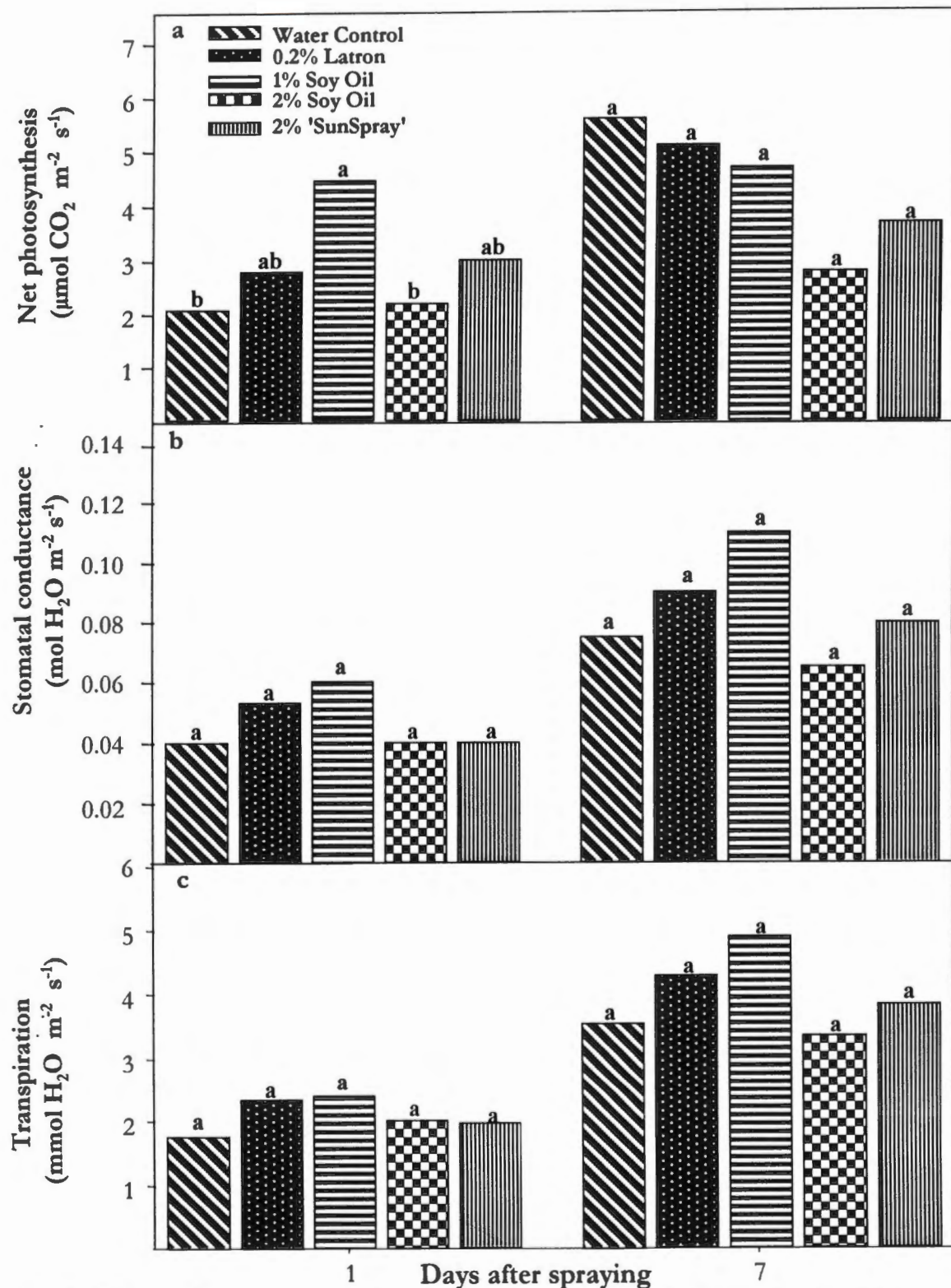


Fig. 3. Effect of petroleum and soybean oil on (a) net photosynthesis, (b) stomatal conductance, and (c) transpiration, of 'Greenleaf' American holly. Sprays applied 18 Sept. 1998. Letters within dates represent mean separation with Duncan's multiple range test ($P \leq 0.05$).

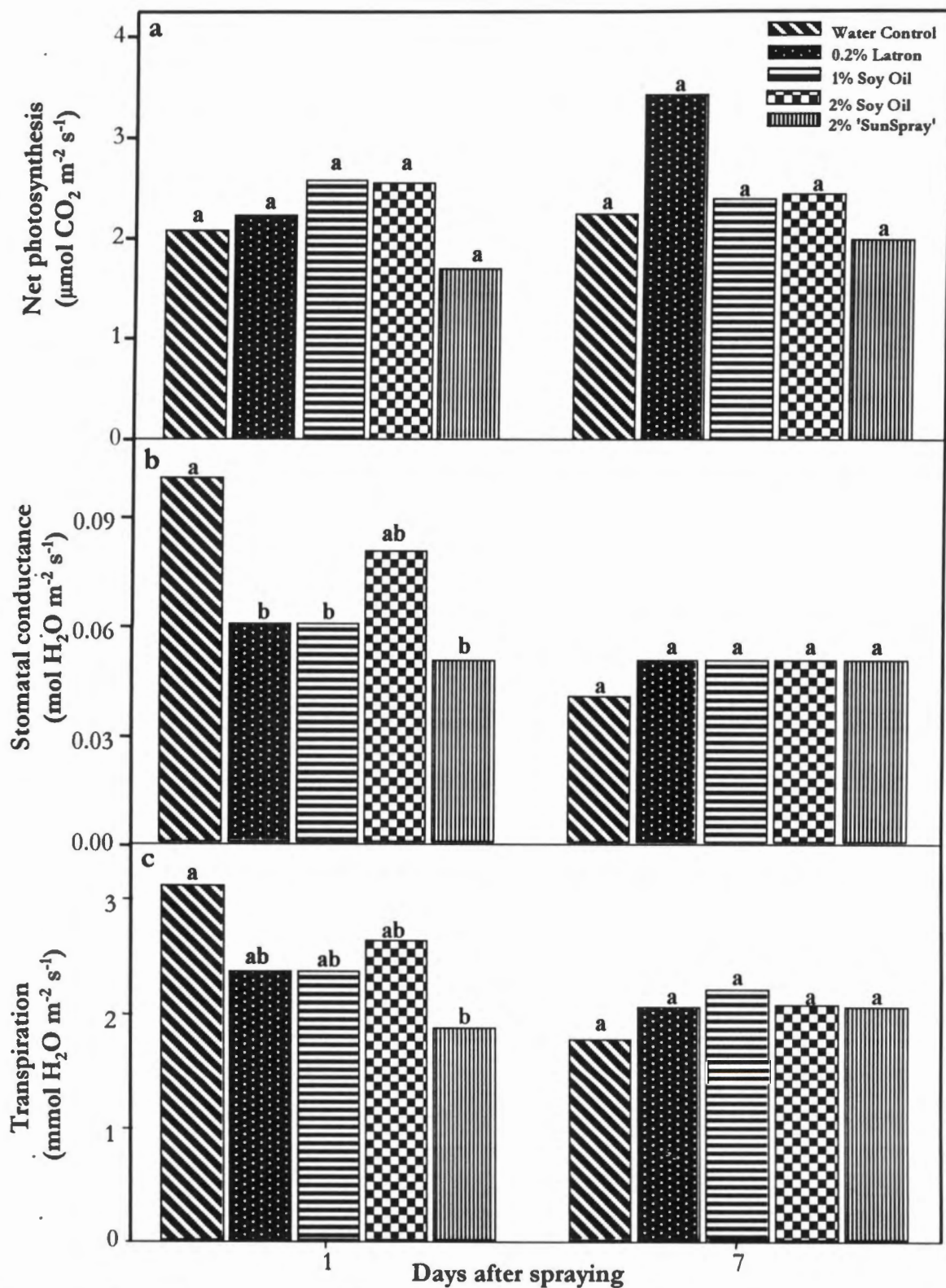


Fig. 4. Effect of petroleum and soybean oil on (a) net photosynthesis, (b) stomatal conductance, and (c) transpiration, of 'Annabelle' hydrangea. Sprays applied 18 Sept. 1998. Letters within dates represent mean separation with Duncan's multiple range test ($P \leq 0.05$).

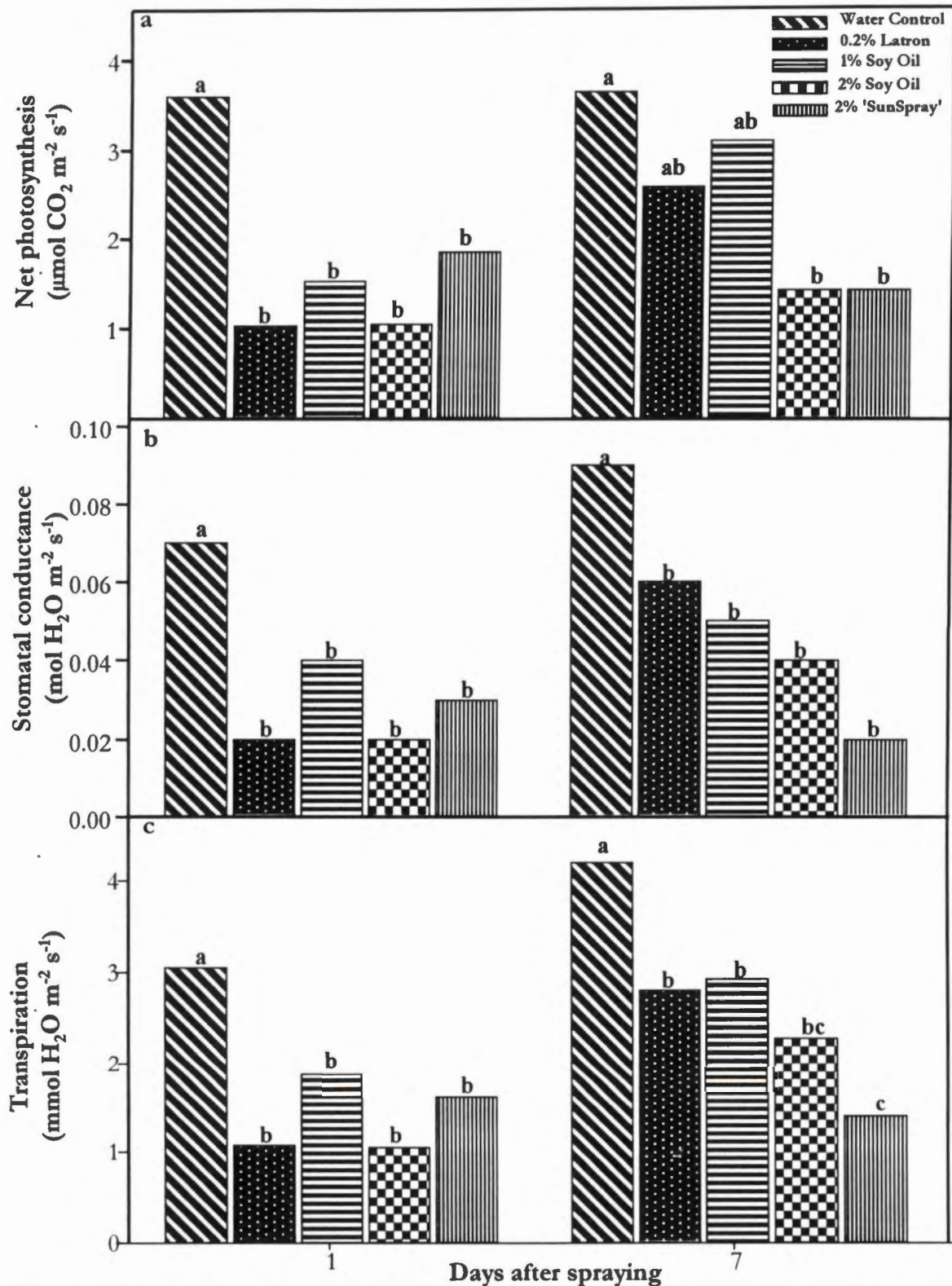


Fig. 5. Effect of petroleum and soybean oil on (a) net photosynthesis, (b) stomatal conductance, and (c) transpiration, of 'Claudia Wannamaker' magnolia. Sprays applied 18 Sept. 1998. Letters within dates represent mean separation with Duncan's multiple range test ($P \leq 0.05$).

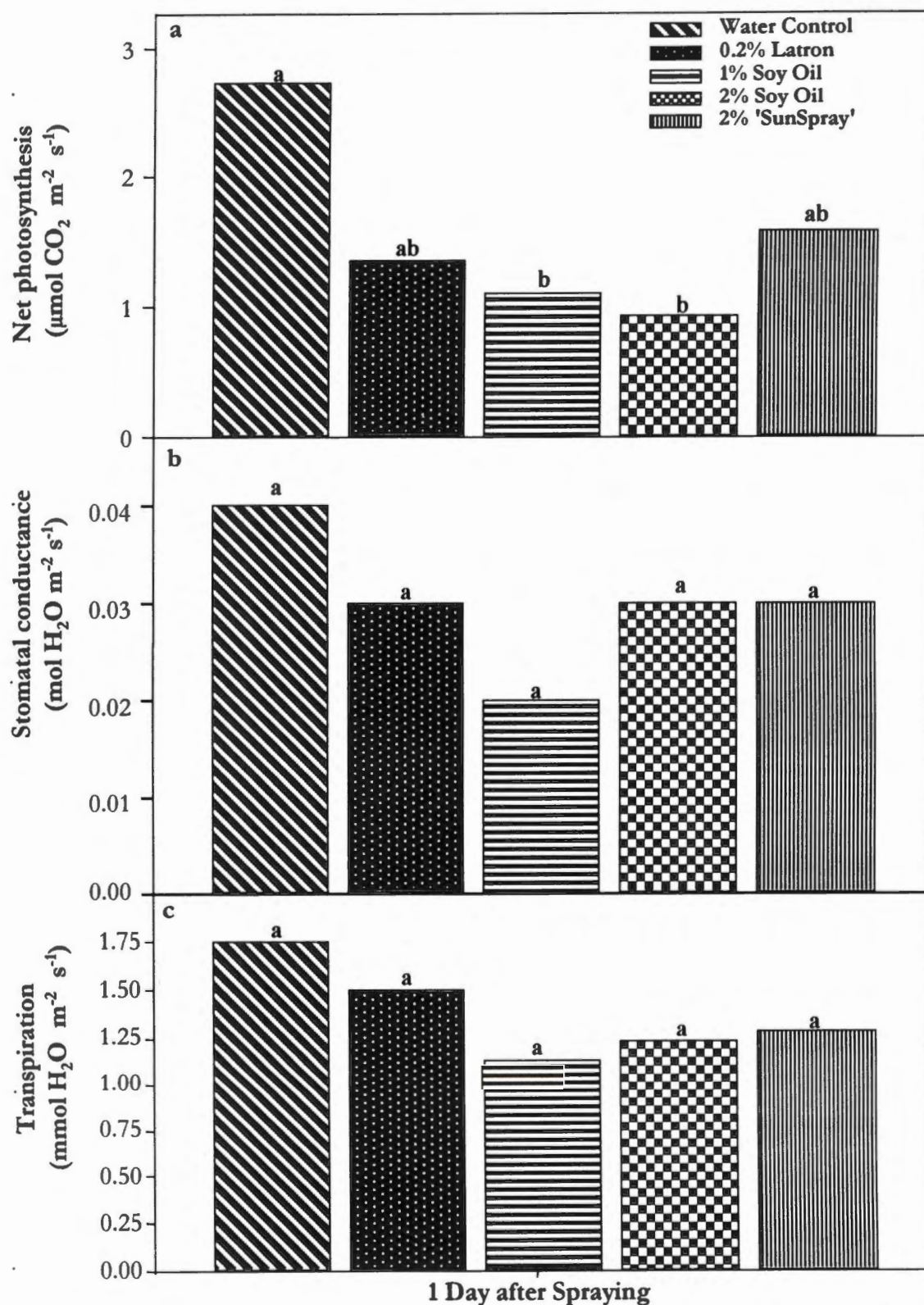


Fig. 6. Effect of petroleum and soybean oil on (a) net photosynthesis, (b) stomatal conductance, and (c) transpiration, of 'Dwarf Burford' Chinese holly. Sprays applied 18 Sept. 1998. Letters within dates represent mean separation with Duncan's multiple range test ($P \leq 0.05$).

reduced Pn of American holly to 65% of control plants 7 DAS. The oil sprays did not affect Pn, Gs, or E rates of 'Greenleaf' American holly or 'Annabelle' hydrangea 1 and 7 DAS (Figs. 3 and 4). Spraying 'Claudia Wannamaker' magnolias with 1% or 2% soy oil reduced Pn, Gs and E rates 1 DAS ($P < 0.05$) (Fig. 5). At 7 DAS, the 2% soy oil or 2% Sunspray still reduced Pn, Gs, and E. Spraying 0.2% Latron B-1956® reduced Gs and E rates and tended to reduce Pn rates. All Chinese holly Pn, Gs, and E measurements taken 7 DAS were lost due to mechanical difficulties.

Sprays of soybean or petroleum caused immediate discoloration of 'Blue Pacific' 'Blue Star', and Japgarden junipers' foliage after spraying, whereas the waxy blue color darkened to an emerald green and appeared watersoaked. Leyland cypress displayed only slight loss of the blue waxy coloring. All other plants had no discoloration or phytotoxicity. The juniper and cypress plants generally recovered the blue coloring by end of the experiment, and were rated by the nursery manager as "salable" (Table 9). The oils may be penetrating, rearranging, or removing the waxy cuticle, thereby disrupting the desirable blue-colored foliage.

Experiment 4: Shamrocks sprayed with oil were easily distinguished from those sprayed with water or emulsifier alone. The 1% soybean and 1% petroleum oil sprays caused similar amounts of phytotoxicity. The 2% soy oil treatment caused the most phytotoxicity to shamrocks, with a mean rating of 4.0 (Fig. 7). The soy oil treatments displayed significant positive correlation between oil concentration and phytotoxicity ($r^2 = 99.4$) (Fig. 8).

Experiment 5: Minimal phytotoxicity was observed on 'Fashion' roses (Table 10). Only plants treated with the soy oil-ERUCiCHEM or soy oil-Latron B-1956®

Table 9. Foliar discoloration caused by petroleum or soy oil sprays to nursery stock on 18 Sept. 1998

	Phytotoxicity Ratings ^z					LSD ^w
	Water	2% Sunspray	0.2% Latron	1% Soy Oil ^y	2% Soy Oil ^x	
American Holly	1.0	1.0	1.0	1.0	1.0	0.0
Chinese Holly	1.0	1.0	1.0	1.0	1.0	0.0
Eastern Hemlock	1.0	1.0	1.0	1.0	1.0	0.0
Hydrangea	1.0	1.0	1.0	1.0	1.0	0.0
Japanese Pieris	1.0	1.0	1.0	1.0	1.0	0.0
'Blue Pacific' Juniper	1.0	2.9	1.0	2.8	2.8	0.3
'Blue Star' Juniper	1.0	2.0	1.0	2.0	2.0	0.0
Japgarden Juniper	1.0	2.9	1.1	3.0	3.0	0.2
Leyland Cypress	1.0	2.0	1.0	2.0	2.0	0.0
S. Magnolia	1.0	1.0	1.0	1.0	1.0	0.0

^z Rating Scale: 1 = no visible damage, 2 = slight discoloration on some leaves, 3 = moderate discoloration on most leaves, 4 = burn, no dieback, 5 = dieback.

^y Soy oil + 0.01% Latron B-1956.

^x Soy oil + 0.02% Latron B-1956.

^w LSD = Least significant difference ($P \leq 0.05$).

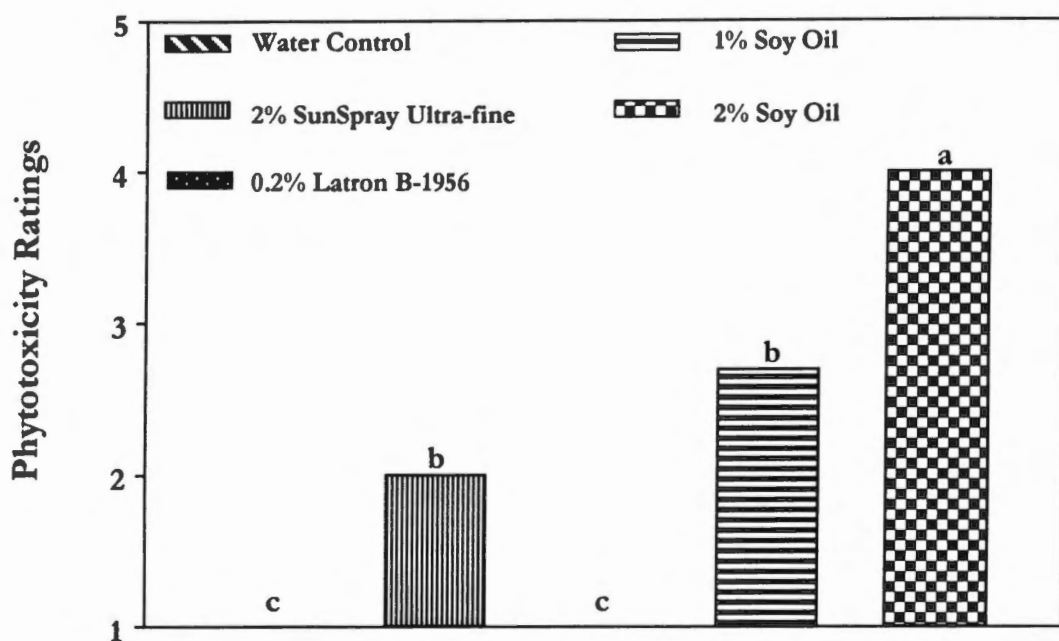


Fig. 7. Shamrock phytotoxicity ratings (1 - 5) recorded 8 DAS. Letters represent mean separation with Duncan's multiple range test ($P \leq 0.05$). Rating scale: 1 = no visible damage; 2 = slight yellowing on some leaves; 3 = moderate yellowing on most leaves; 4 = leaf burn without dieback; 5 = leaf burn with dieback.

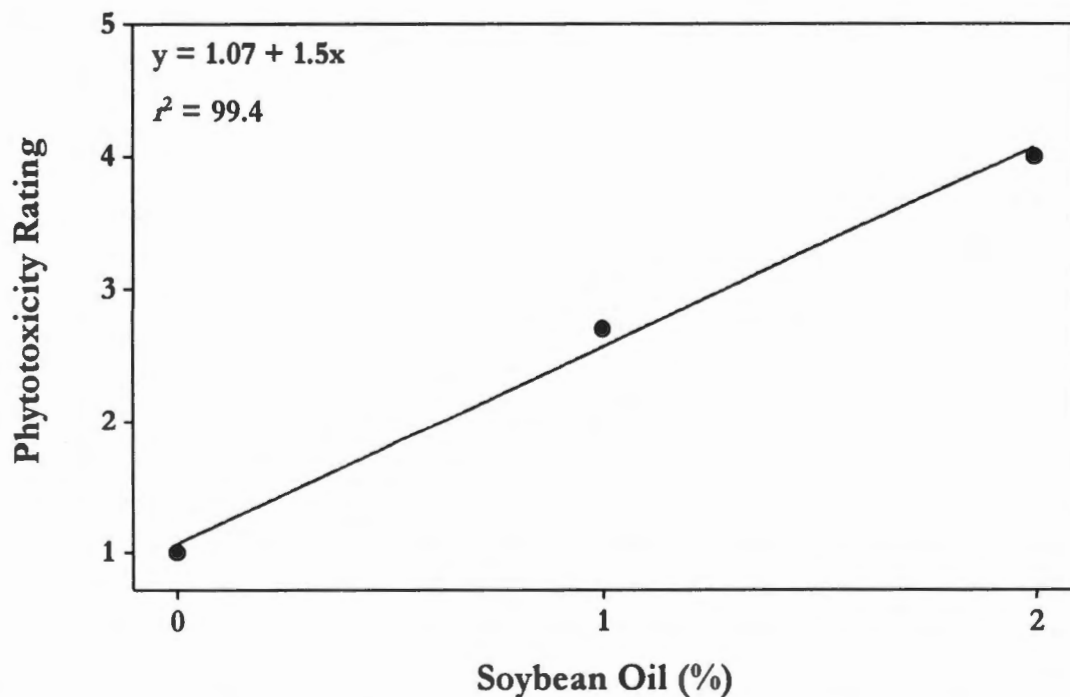


Fig. 8. Shamrock phytotoxicity ratings on soybean oil-treated plants 8 DAS. Rating scale: 1 = no visible damage; 2 = slight yellowing on some leaves; 3 = moderate yellowing on most leaves; 4 = leaf burn without dieback; 5 = leaf burn with dieback.

Table 10. Phytotoxicity of adjuvants and soy oil formulations to miniature roses (A)

Treatments	Phytotoxicity Ratings ^z				
	Expt. 5 'Fashion' ^y	Expt. 6 'Fashion' ^x	Expt. 7 'Fiesta' ^x	Expt. 8 'Tender' ^x	Expt. 9 'Orange' ^w
WC	1.0	1.1	1.3	1.6	1.0
DC	1.2				
Lat	1.2				1.3
AT	1.2				
Eru	1.1			1.6	
Eru/Lec				1.9	
Blstl		1.3			
EZM					1.2
SO/Lat	2.1	2.8	2.5	3.4	2.1
SO/AT	1.7				
SO/Eru	2.3			2.8	
SO/Eru/Lec	1.6			2.6	
SO/Blstl		3.1			
SO/EZM					1.3
EmA		1.2	2.5		
EmB		2.8	2.6		
S1K			2.8		
S2K			2.6		
LSD at ≤ 0.05	0.7	0.6	1.1	0.6	0.4

^z Rating Scale: 1 = no visible damage, 2 = slight yellowing, 3 = moderate yellowing, 4 = burn, no dieback, 5 = dieback.

^y Ratings made 9 Oct. 1998.

^x Ratings made 17 Nov. 1998.

^w Ratings made 23 Nov. 1998.

formulations had ratings >2.0 and caused significantly more yellowing of foliage than unsprayed, water control, or adjuvant-treated plants ($P \leq 0.05$). Treatments that contained soy oil tended to produce more phytotoxicity than the treatments containing only an emulsifier. The soy oil-Atlox + Tween mixture caused slight yellowing (rating = 1.7), but did not differ from the control. ERUCiCHEM, a viscous adjuvant, never mixed properly with the soy oil and lecithin, and coagulated at the bottom of the spray bottle. Therefore, it is questionable whether the yellowing caused by the soy oil-ERUCiCHEM-Lecithin or ERUCiCHEM-Lecithin mixtures was caused by the soy oil or the adjuvants since both mixtures had the same mean rating (1.6).

Experiment 6: Phytotoxic damage to 'Fashion' roses was more extensive than the previous test using this cultivar. All the soybean formulations, except for Emulsion A, caused yellowing of foliage by 1 DAS. (Table 10). The adjuvant Ballistol in water mixture caused very little phytotoxicity, but when used to emulsify soy oil, it caused the most phytotoxicity found in expts 5 and 6. Emulsion B caused yellowing of 'Fashion' roses similar to that caused by soy oil-Latron B-1956®. Plants sprayed with the soy oil-Emulsion A were not damaged (Table 10).

Experiment 7: 'Fiesta' roses had injury symptoms 1 DAS (17 Nov.; Table 10) and at the end of the experiment (30 Nov.; Table 11), and were the second most sensitive cultivar of the roses tested. Therefore, 'Fiesta' may be an excellent cultivar for future phytotoxicity tests. On 17 Nov. (1 DAS), the soy oil-Latron formulation, Emulsion A, Emulsion B, Soygold 1000, and Soygold 2000 caused similar yellowing of 'Fiesta' foliage (Table 10). There were no differences in injury ratings of plants sprayed with water, Soygold 2000, or the soy oil/Latron B-1956* mixture at the second rating (30 Nov.); all plants treated

Table 11. Phytotoxicity of adjuvants and soy oil formulations to miniature roses

Treatments	Phytotoxicity Ratings ^z			
	Expt. 6 'Fashion' ^y	Expt. 7 'Fiesta' ^y	Expt. 8 'Tender' ^y	Expt. 9 'Orange' ^y
WC	1.1	1.1	1.3	1.0
Lat				1.4
Eru			1.5	
Eru/Lec			2.1	
Blstl	1.4			
EZM				1.3
SO/Lat	2.6	1.8	3.9	1.8
SO/Eru			3.9	
SO/Eru/Lec			2.6	
SO/Blstl	3.7			
SO/EZM				1.6
EmA	1.4	2.3		
EmB	3.0	2.3		
S1K		2.6		
S2K		1.9		
LSD at ≤ 0.05	1.1	1.1	0.9	0.6

^z Rating Scale: 1 = no visible damage, 2 = slight yellowing, 3 = moderate yellowing, 4 = burn, no dieback, 5 = dieback.

^y Ratings were made 30 Nov. 1998.

with a soy oil emulsion or mixture showed slight to moderate yellowing, and all were statistically equivocal (Table 11). Plants treated with Soygold 2000 or the soy oil-Latron mixture tended to recover by 30 Nov., whereas plants sprayed with any of the other soy oil mixtures in this test still showed injury on this date.

Experiment 8: 'Tender' roses were the most sensitive to oils of all cultivars in these experiments. Roses sprayed with the soy oil-Latron treatment had the most phytotoxicity on 17 and 30 Nov. The soy oil-ERUCiCHEM-Lecithin treatment caused similar phytotoxicity to that of the soy oil/ERUCiCHEM treatment. Both the soy oil-Latron and soy oil/ERUCiCHEM formulations produced severe foliar yellowing and burn by the end of the experiment (Table 11). Slight yellowing was apparent on plants sprayed with the Eru/Lec mixture (no soy oil) on 30 Nov., and was similar to damage produced on roses sprayed with SO/Eru/Lec.

Experiment 9: 'Orange' roses had the least amount of phytotoxicity of the cultivars tested. Damage was minimal, with only the soy oil /Latron B-1956[®] mixture causing significant yellowing of foliage on 23 Nov. (Table 10). The SO/EZM formulation caused significantly less yellowing of foliage than SO/Lat, and was equivalent with the emulsifier (alone) and control treatments on 23 and 30 Nov. (Tables 10 and 11). Although slight yellowing was evident on oil-treated roses by 30 Nov., only the soy oil-Latron formulation caused significant yellowing. 'Orange' appears to be a more resilient rose cultivar, and is less desirable for future phytotoxicity evaluations.

DISCUSSION

Spraying 1% or 2% soy oil or 2% Sunspray Ultra-fine oil caused similar reduction of

Pn, Gs, and E rates on the third DAS on 'Manhattan' *Euonymus* plants (Tables 2, 3, 4). The Pn, Gs, and E rates of oil treatments had returned to the levels of the control plants by 8 DAS, and continued unaffected through 24 DAS. This indicates that these woody ornamentals had an initial and brief reduction in gas exchange, but recovered before any noticeable permanent damage occurred. Plants sprayed with 3% soy oil had significantly lower Pn and E rates on 1 Aug., (3 DAS) (Tables 2 and 4). The maximum recommended rate for horticultural oil on verdant plants is 2% (Johnson, 1983). Pesticides that are often applied by untrained individuals, may pose problems of plant toxicity (Freeman and Sundu, 1999). It is prudent to know the maximum phytotoxic threshold of pesticides. Plant injury may be amplified under stress conditions, such as insect-infestations, disease infections, temperature extremes, and water problems.

The oil effects on Pn, E, and Gs were the greatest on 'Chetco' azaleas two days after spraying (Tables 5, 6, 7). Differences in Gs and E on plants sprayed with 0%, 2%, or 3% soy oil persisted until 8 DAS (Tables 6 and 7). Once again, the reductions in plant gas exchange were temporary; Pn, Gs, and E rates were equivalent 14 DAS. Plants sprayed with 2% or 3% soy oil tended to have lower Pn, Gs, and E rates throughout the trial (Fig. 2). Azaleas are known to be oil sensitive (Miller, 1989), yet our trial indicates that a summer application of $\leq 3\%$ soy oil did not cause phytotoxicity. However, the azaleas were maintained in a shaded enclosure; heat and solar radiation can enhance phytotoxicity (Johnson, 1985).

More phytotoxicity was observed in the 1997 Kinsey Garden trial than in 1998. Additionally in 1998, the blue-colored junipers that were altered to dark green, recovered their blue coloring by the end of the test, whereby the nursery manager judged all the plants

as “salable”. Several differences between the two experiments may have contributed to these findings. The 1998 spray date was 23 days later than the 1997 trial. Therefore, the “recovery” of the blue coloring may actually be new growth from the second growth season. Plants in the 1997 test were mostly coniferous evergreens with documented oil-sensitivities (Baxendale and Johnson, 1988b), whereas plants in 1998 included many broad-leaved plants with no reported oil sensitivities.

Soy oil emulsified with Latron B-1956, ERUCiCHEM, or Ballistol caused more foliar yellowing of miniature roses than other adjuvants. Soy oil emulsified with E-Z-Mulse caused minimal phytotoxicity and should be further investigated. Emulsion A caused the least phytotoxicity of commercially prepared soy oil emulsions. ‘Tender’ and ‘Fiesta’ cultivars are highly sensitive, and excellent experimental subjects for future phytotoxicity screenings (Tables 10 and 11).

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VITA

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