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ACTIVITY OF SOME BIORATIONAL INSECTICIDES ON SILVERLEAF WHITEFLY

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Abstract. **We compared the insecticidal and repellant properties of a soap, a mineral oil, and a surfactant-like extract of *Nicotiana gossei* Domin., with a pyrethroid (bifenthrin) against silverleaf whitefly *Bemisia argentifolii* Bellows & Perring. An extract of seeds from the neem tree *Azadirachta indica* A. Juss. was also used in some tests. All materials tested by leaf-dip bioassay were highly toxic to young *B. argentifolii* nymphs, but mineral oil and a synthetic pyrethroid (bifenthrin) were more toxic to all whitefly stages and more repellant to adults than insecticidal soap or *N. gossei* extract. Residues of insecticidal soap and *N. gossei* extract were toxic to adult whiteflies only when wet. Toxicity of mineral oil, and to a lesser extent insecticidal soap, was greatly reduced when these materials were applied with a Potter Spray Tower, whereas bifenthrin was equally toxic whether sprayed or dipped. Thus, coverage was more critical to the functioning of oil and soap, which depend on topical activity, than to bifenthrin which has an internal mode of action.**

The term "biorational" insecticide was coined but not defined by Djerassi et al. (1974). These authors contrasted biorational insecticides to broad-spectrum chemical insecticides by their species-specificity (low toxicity to non-target organisms) and gave examples of naturally derived and synthetic materials. We believe that the term biorational insecticide could be defined as: **any type of natural or synthetic material active against pest populations but relatively innocuous to non-target organisms, and therefore non-disruptive to biological control**. Target specificity reduces risks to user and consumer health, environmental and ecological stability, and beneficial arthropods, thereby favoring biological control. In Florida, we have been able to observe effective biological control of silverleaf whitefly (SLWF) *Bemisia argentifolii* Bellows & Perring (formerly *B. tabaci* Gennedius) in weeds and crop systems where broad-spectrum insecticides were not sprayed (Stansly et al., 1994). However, growers of intensively sprayed, high value crops, such as tomato, would probably be unwilling to suspend insecticides altogether because of perceived risk of losses from pests and insect-vectored diseases. Substitution of biorational for broad-spectrum insecticides could help create a crop environment where chemical and biological control could co-exist.

Insecticides effective against SLWF which might fit our definition of biorational include certain surfactants, oils, some plant extracts, insect growth regulators, and the systemic chloronicotinyls (e.g. imidacloprid). Growth regulators are an important component of the integrated management of *Bemisia* on cotton in Israel (Horowitz & Ishaaya, 1994) and at least one of them, buprofezin, has been shown to be compatible with whitefly parasitoids under certain conditions (Gerling and Sinai, 1994). We focused on surfactants, represented by an insecticidal soap and a plant extract containing sugar esters, and oils, represented by a light mineral oil. Additional plant extracts, especially those of neem seed (*Azadirachta indica* A. Juss.), will also be considered.

Soaps and oils have been used as insecticides at least since the 18th century (Metcalf and Metcalf, 1993). It has been stated that soaps function as insecticides by disrupting the lipoprotein matrix of cellular membranes (Puritch, 1981). However, Dills and Menusan (1935) showed that soap solutions penetrated aphid trachea, implying, perhaps, that mortality was caused by suffocation. Soaps are reported to be most active against soft bodied arthropods, and therefore somewhat specific against soft bodied pests as compared to their natural enemies. An example, given by Puritch (1981) illustrated differential susceptibility of greenhouse whitefly and its parasite *Encarsia formosa* Gahan to Safer Soap (potassium salts of fatty acids). Dills and Menusan (1935) determined that sodium and potassium salts of oleic acid (oleates) were the most toxic soaps to bean and rose aphid, followed by laurates and caprates.

Potassium salts of fatty acids are still the most commonly used surfactant insecticides. However, synthetic detergents have been shown to have insecticidal properties (Butler et al., 1988; 1989; 1993; Butler and Henneberry 1990), and might be expected to replace soaps in agriculture as they have in households because of their solubility in water containing bivalent cations. One liquid detergent we tested gave an LC-

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50 for young nymphs of 0.076 compared to 0.149 for M-Pede insecticidal soap (49% potassium salts of fatty acids) which contained twice the active ingredient (T. X. Liu, unpublished data). However, the detergent was phytotoxic at concentrations equivalent to the field rate of insecticidal soap and caused some yield loss at first harvest when applied twice weekly at rates as low as 0.5% (equivalent to 1% insecticidal soap, Vavrina and Stansly, unpublished data).

Petroleum oil sprays have been used for pest control for more than 100 years, first as dormant oil sprays for deciduous tree crops. Applications of mineral oil as foliar sprays have increased as improvements in purity and surfactant systems have reduced rates and risks of phytotoxicity (Davidson et al., 1991). Oils are thought to act through suffocation by blockage of spiracals. However, they are also thought to interfere with host searching by coating receptor organs (Simons, 1992) resulting in repellency of adult aphids and whiteflies (Butler et al., 1989, Larew and Locke, 1990). Repellency may also be the basis of the ability of mineral oils to slow the spread of non-persistent, aphid-borne (Simons, 1982) and whitefly-borne viruses in the field (P. Stansly, unpublished data). Although a wider range of pests is controlled by mineral oils than by soaps, oils may also be more toxic to beneficial organisms, particularly from direct contact with sprays (Davidson et al., 1991). Toxicity of oil residues as much as a week old to the armored scale parasitoid *Aphytis holoxanthus* in the field has been reported (Rosen, 1967).

Both detergents and oils have shown potential as suppressive agents for *B. tabaci* Gennadius and/or *B. argentifolii* populations on cotton and vegetables (Butler et al., 1989; 1993; Butler and Henneberry, 1990). The insecticidal and repellant properties of an insecticidal soap, a mineral oil, a surfactant-like extract of *Nicotiana gossei* Domin., and a pyrethroid insecticide (bifenthrin) have been tested against SLWF in our laboratory and greenhouse. In general, a leaf-dip method of application (100% coverage) was utilized. However, a spray tower application method was also used to compare efficacy under conditions of less than 100% insecticide coverage of leaves. Interactions between application methods and insecticide have given us some insight into the strengths and limitations of these materials as insecticides. The objectives of these studies were to elucidate the activity of mineral oil, insecticidal soap, and certain botanical extracts on SLWF.

Materials and Methods

SLWF used in this study was obtained from D. Schuster in Bradenton, FL in 1990, and was identified as *B. tabaci* 'Biotype B' in 1992 (T. M. Perring, University of California Riverside, personal communication) and as *B. argentifolii* in 1994 (A. C. Bartlett, USDA-ARS, Phoenix, AZ, personal communication). Bioassays were conducted to test the toxicity of insecticide residues on leaves to adult SLWF, and contact toxicity to eggs and nymphs (Liu and Stansly, 1995a). Four insecticides were tested: M-Pede® (an insecticidal soap), Sunspray® Ultra-fine Spray Oil (mineral), extract of *N. gossei* (a mixture of surfactant-like esters of sucrose and glucose), and bifenthrin, a pyrethroid, with purified (reverse osmosis) water as control. In further tests, SLWF mortality on tomato leaves containing young nymphs sprayed at 10 psi with a Potter Spray Tower® (Burkard Manufacturing Co. Ltd., Rickmansworth, Hertfordshire, England) was compared with mortality on infested leaves dipped as above (Liu and Stansly, 1995b). Margosan-O® (an extracted concentration of azadirachtin + 10% neem oil) was evaluated in these tests in addition to the materials listed above. Deposition on treated tomato leaves was estimated using a tracer dye (FD&C Blue #1, Warner-Jenkinson, St. Louis, MO). Dye concentration in a 10-ml wash from each sprayed or dipped sample was determined by measuring optical density using a Perkin Elmer Lamda 6 UV/VIS spectrophotometer (Perkin Elmer Co., New Haven, CT). Mass deposition ($\mu g/cm^2$) was computed on the basis of dye concentration and leaf surface area.

Bioassays of adults were conducted by dipping whitefly-free tomato leaves in serial dilutions of insecticides, air-drying for 2 h, and exposing 15 unsexed adults to leaves in 0.-9 liter cup cages for 24 h (Liu and Stansly, 1994). Contact bioassays were also conducted on tomato leaves infested with uniform cohorts of three whitefly developmental stages: eggs (24 h old, mean of 94 per leaf), young nymphs (7 d old, mostly first instars, mean of 54 per leaf), and old nymphs (14 d old, mostly third instars, mean of 67 per leaf). Mortality of young nymphs was determined by microscopic examination after a 4-day incubation period, and of eggs and old nymphs by eclosion/emergence after an appropriate incubation period. There were eight replicates in each experiment and experiments were repeated three times. Data were submitted to probit analysis, a regression procedure of the log-transformed dose against percent mortality which gives the slope of the dosage mortality curve, its fiducial limits, and concentration lethal to 50% of the population (LC-50) (SAS Institute, 1988).

Repellency of insecticides was studied by using a "leaf wheel" made of six 20-ml glass vials filled with water and taped around a central vial with its opening pointed downward into which was place a wooden dowel (30-cm long and 1.0 cm in diameter) (Liu and Stansly, 1994). The dowel was inserted into a plastic pot filled with potting media so that the leaf-wheel mimicked a plant with 6 leaves. Each water-filled vial held one tomato leaf which had been dipped in insecticide solutions as above with the addition of Garlic Barrier (Garlic Res. Labs, Los Angeles, CA, 1:10 ratio v/v) and air-dried. Leaf-wheels were placed among heavily infested tomato plants in a greenhouse and the number of adults on the leaves was recorded at 30 min, 1, 2, and 4 h, and 1, 2, 5, and 7 days.

Two-leaflet artificial plants were used to study the effects of leaf age, leaf height, and leaf surface orientation in choice and no-choice tests (Liu and Stansly, 1995c). Bamboo stakes with the attached vials and leaves were inserted individually into soil-filled plastic pots to mimic an upright plant. Twenty such artificial plants were randomly arranged in a cage into which 400 unsexed whiteflies (10 adults/leaflet) were introduced. Effects of insecticide residues on oviposition were studied by exposing whiteflies to individual insecticide-treated tomato leaves which were air dried and used as test leaves in the artificial plants. The number of eggs on each leaflet was recorded after 24 h and reported as eggs per cm^2 leaf area.

Tomatoes were transplanted 29 Jan. 1990 directly adjacent to three beds of 100% tomato mottle geminivirus-infected (TMoV) tomato (Stansly and Cawley, 1992). Plots were nine beds wide and 7.5 m long. A randomized complete block design with four replications contained three treatments: JMS Stylet Oil, bifenthrin at two rates or esfenvalerate (depending on subplot), and an unsprayed check. Treatment applications began 12 Feb. and continued twice weekly until harvest using a tractor-mounted hydraulic boom sprayer driven by a diaphragm pump. Six drop lines held a maximum of 18 nozzles fitted with ceramic hollow cone tips (Albuz® ATR Brown delivering ca. 1.00 liter/min @ 28 kg/cm²) calibrated from 572 to 878 liters/ha as nozzles were added. Whitefly immatures were counted at weekly intervals on the terminal leaflet of the 5th, 6th, or 7th leaf from the top (depending on plant maturity) of six randomly selected plants per subplot. Adult whiteflies were sampled by inverting the third leaf from the top of three randomly chosen plants per subplot. Plants affected by tomato mottle geminivirus were marked as symptoms appeared.

Liquid Tide (Procter & Gamble, Cincinnati Ohio 45202) at 0.25% sprayed either twice a week, or once a week alternated with a crop oil (JMS Stylet Oil at 0.75%) was tested for efficacy. Comparison treatments were tank mixes of labeled rates of esfenvalerate + chlorpyrifos or fenpropathrin + methamidophos alternated with endosulfan at 10- or seven-day intervals respectively, and to an alternation of fenpropathrin with methamidophos with endosulfan every seven days (Stansly et al., 1991). Overall rates per hectare of fenpropathrin and methamidophos were the same in both treatments employing these materials. Applications began the second week after transplant and continued for seven weeks. Applications to half the plots assigned to each treatment were made with the hydraulic sprayer described above and the other half with an airboom sprayer provided with 4 drop nozzles per row (Airtec Sprayers Inc., Winterhaven FL). Coverage was monitored with water-sensitive paper. Plots were two rows wide and 7.6 m long, and there were eight replications of each material. Two seedlings infected with TMoV were set in each plot to provide an inoculum source. Whitefly immatures were counted on the terminal trifoliate of the sixth leaf from the top of three randomly selected plants per plot at 2-week intervals (N=4). Adult whitefly were counted on four alternate weeks by carefully inverting the 3rd leaf from the top of three randomly-chosen plants per plot. All plants were inspected weekly for TMoV symptoms. Data were subjected to analysis of variance with mean separation using the least significant difference test ($P < 0.05$) (SAS Institute, 1988).

Results and Discussion

Toxicity to eggs and nymphs of SLWF. Oil was the most toxic material to eggs at field rates or lower when applied by leaf dip, followed by bifenthrin and soap (Figure 1). Rate responses were erratic, especially for soap, which did not increase in activity (about 10% mortality) over a 10-fold range of concentrations between 0.2 and 2%. In contrast, mortality response to concentrations of 0.5% to 1% oil increased from 23.3% to 87.8%. The oil-water emulsion applied by leaf dip would separated rapidly upon contact with the leaf surface, leaving a thin film of oil. Therefore, the effect of higher concentrations of emulsified oil in the spray mix would be to increase the thickness of the oil film, thereby decreasing permeability to air. Apparently, an oil film of lethal thickness was formed on eggs treated with oil emulsions between 0.1% and 0.5% concentration. Recovery of FD&C blue dye from tomato leaves dipped in a mixture of 1000 ppm dye and 1% (10,000 ppm) emulsified mineral (Sunspray) oil was 1.82±0.47 μg/cm². Given a ratio of oil to dye of 10:1, we would estimate that a uniform film of approximately 18 μg/cm² oil, 0.225 μm thick, is required to achieve close to 90% egg mortality.

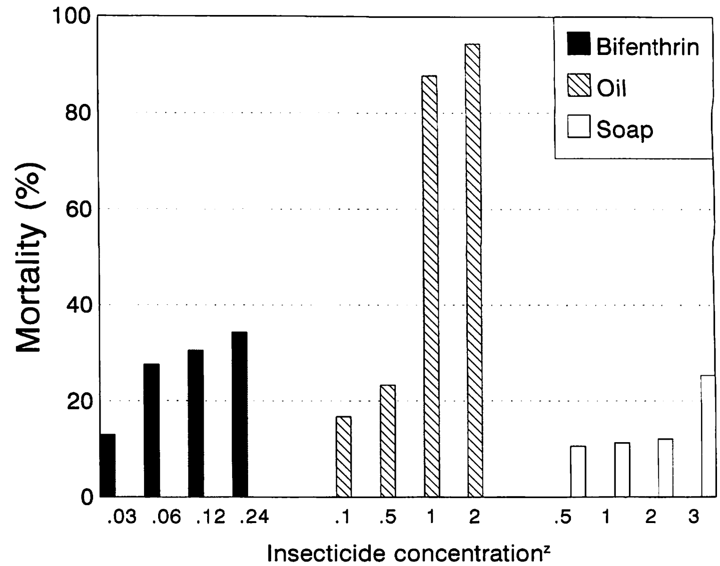

Figure 1. Toxicity of insecticides to eggs of *B. argentifolii.*

Recommended field application rates of all materials tested by leaf dip bioassay were highly toxic to young nymphs (seven-day), inducing mortalities of 90% or more. The LC-50 for bifenthrin increased 100-fold with the increase in age, from 0.001 g/liter for young nymphs to 0.106 g/liter for old nymphs (Table 1). The corresponding values for oil were 0.032% for young nymphs to 0.088% for old nymphs, only a 2.6-fold increase. The effects of nymphal age on response to insecticidal soap and *N. gossei* extract were intermediate between those of bifenthrin and oil. The LC-50 of insecticidal soap for third instar nymphs was relatively high, fully one quarter of the highest recommended field rate.

Effects of coverage. Interesting differences were obtained, depending on material tested, when results from the leaf-dip and Potter Spray Tower bioassays were compared. Mortality of whitefly nymphs from bifenthrin, and to a lesser extent aneem extract (Margosan-O), was largely independent of application method. In contrast, Sunspray (mineral) oil was more efficacious when applied as a dip than as a spray, and insecticidal soap gave somewhat intermediate results (Figure

Table 1. Toxicity of insecticides to *B. argentifolii* on tomato leaves in laboratory bioassays.

Insecticide[z]	n	Slope±SE	LC_{50}	95% FL[y]	[x]X^2
			Young Nymphs		
Bifenthrin	5,694	0.87±0.09	0.001	0.001-0.002	0.9
Mineral oil	4,992	1.01±0.10	0.032	0.018-0.050	10.4
Insecticidal soap	4,992	1.71±0.15	0.149	0.110-0.197	9.4
N. gossei extract	4,581	1.35±0.09	0.008	0.006-0.009	6.2
			Old Nymphs		
Bifenthrin	5,980	1.23±0.11	0.106	0.087-0.132	2.0
Mineral oil	4,112	1.35±0.16	0.088	0.051-0.139	10.5
Insecticidal soap	3,607	2.22±0.18	0.507	0.433-0.584	0.7
N. gossei extract	3,793	1.66±0.17	0.014	0.010-0.020	8.3

[z]Units: bifenthrin is in g (a.i.)/liter, and all others are in percent concentration (v/v for mineral oil and insecticidal soap, respectively, and w/v for *N. gossei* extract).
[y]Fiducial limits.
[x]$X^2 > 12.6$ (tabular X^2 with df = 6, $P = 0.05$).

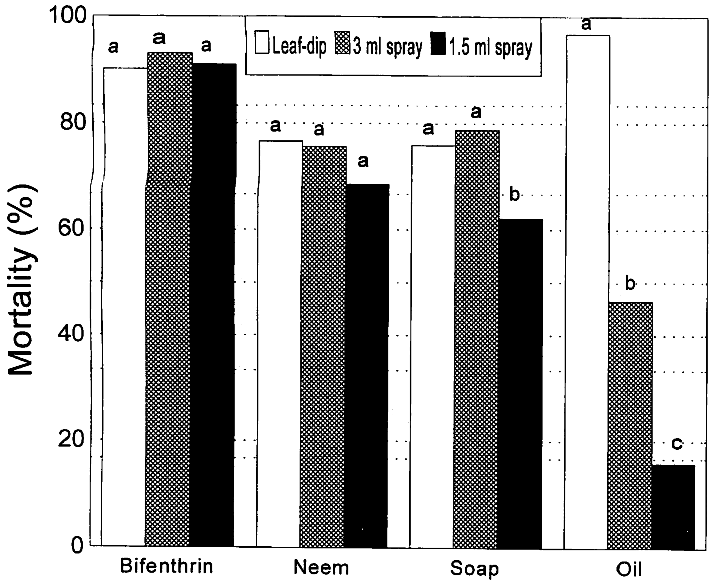

Figure 2. Effect of bioassay method on response of young (mostly first) instar SLWF nymphs to residues on leaves dipped in diagnostic concentrations of insecticide: 6 g/liter bifenthrin, 1% mineral oil, 1% insecticidal soap solution.

The same letter above mortality bars for different rates of the same insecticide are not significantly different (LSD, P < 0.05).

2). Mode of action provided an explanation of these results. The activity of bifenthrin was the same whether applied as a dip or as a fine spray, which is consistent with a systemic mode of action in the organism. A few drops of concentrated material impinging on the cuticle appeared sufficient for penetration of a lethal dose in most cases. In contrast, dilute oil emulsions were extremely toxic when applied as dips but lost activity when sprayed, especially when droplet size was decreased by increasing pressure. Similar results were obtained when Sunspray oil was applied by leaf dip and Potter Spray Tower to the European red mite, *Panonychus ulmi* (Koch) (Angello et al., 1994). These effects were consistent with a topical mode of action, such as suffocation. If insecticidal soap acted topically by dissolving cuticle, a similar dependence on coverage might be expected. Soap did lose some activity at low spray volume, or when sprayed rather than used as a dip at low concentration. However, there were no differences between high and low pressure sprays. Thus, the behavior of soap in regard to coverage was intermediate between bifenthrin and oil. A mode of action more consistent with these results than cuticle dissolution might be interference with gas exchange (drowning) due to invasion of the tracheae by water of low surface tension.

Leaf dips provided a good model for evaluating mortality of whitefly nymphs expected from an efficient spray of materials such as bifenthrin and neem extract for which uniform, though incomplete coverage was sufficient to cause maximum mortality. In contrast, leaf dips tended to over-estimate mortality achievable from sprays of materials such as mineral oil, and to a lesser extent, insecticidal soap, with topical modes of action requiring total coverage for maximum effect.

Toxicity and repellency to adults. Rate responses for bifenthrin were excellent as reflected in low chi-square values for the probit model, whereas chi square values for oil were significant, reflecting poor fit of the dosage mortality curve to the probit model (Table 2). The response to oil departed

Table 2. Toxicity of insecticides to *B. argentifolii* adults on tomato leaves in laboratory bioassays.

Insecticide[z]	n	Slope±SE	LC_{50}	95% FL[y]	[x]X^2
Bifenthrin	2,160	0.90±0.11	0.034	0.023-0.045	6.8
Mineral oil	2,160	2.12±0.46	0.290	0.130-0.620	18.9[x]
Insecticidal soap	n/a[w]				
N. gossei extract[v]	2,160	1.53±0.26	0.590	0.370-1.250	14.0[x]

[z]Units: bifenthrin is in g (a.i.)/liter, and all others are in percent concentration (v/v for mineral oil and insecticidal soap, respectively, and w/v for *N. gossei* extract).
[y]Fiducial limits.
[x]$X^2 > 12.6$ (tabular X^2 with df = 6, $P = 0.05$).
[w]Mortalities were too low to compute LC_{50}
[v]Concentration of 0.59% caused severe phytotoxicity on tomato leaves.

from the model by the rapid increase in mortality, from 23.3% to 87.2% over the concentration interval of 0.25% to 0.5%, followed by a leveling off at higher concentrations. In other words, a threshold concentration occurred within the 0.25 and 0.5% concentration range, after which oil became effective. One explanation is that the oil-water emulsion applied by leaf dip would break down rapidly upon contact with the leaf surface, leaving a thin film of oil. The effect of higher concentrations of oil in the spray mix would be to increase the thickness of the film. The conclusion is that films deposited by uniform concentrations of 0.5% and higher were able to trap and hold adult whiteflies whereas thinner films were not. The critical film thickness to trap adults would be somewhere between 0.067 and 0.13 $\mu g/cm^2$ by the same arguments as given above in regard to egg mortality.

Residues of insecticidal soap proved to be largely ineffective against adult whiteflies, such that LC-50 values could not be obtained. However, if adults were exposed to wet residues on leaves dipped in 1% insecticidal soap, the response was almost four-fold higher than from dry residues (33.9% vs. 10.6%). In contrast, the response to bifenthrin or oil was similar whether residues were wet or dry. This result confirmed earlier field observations that detergents only functioned while wet (Butler et al., 1993), and would seem to support the tracheal invasion mode of action. Growers could capitalize on the moisture requirement of surfactant insecticides by spraying soaps and detergents at night or early morning.

Repellent responses of adults to insecticides followed trends similar to mortality responses. Bifenthrin and oil acted as effective repellents to adult whiteflies whereas surfactants and a garlic extract did not. Oviposition preference on artificial plants indicated that repellency of bifenthrin and mineral oil overrode oviposition preferences for young leaves vs old leaves and high leaf position vs. low leaf position (Figure 3).

Field trials. The ability of twice-weekly sprays of mineral oil (JMS Stylet Oil) and bifenthrin to reduce SLWF populations and suppress movement of TMoV in the field were compared. Lowest numbers of eggs plus crawlers, sessile nymphs and adults were observed on plants sprayed with bifenthrin, followed by mineral oil and finally control plants (data not shown). Spread of ToMV from an adjacent source of infection caused clumped distributions of affected plants among plots so that treatment differences were not significant until seven weeks after transplanting when significantly more plants became symptomatic in control plots (1.7±0.62) compared to plants treated with oil (0.56±0.23%) or pyrethroid (0.42±0.3%).

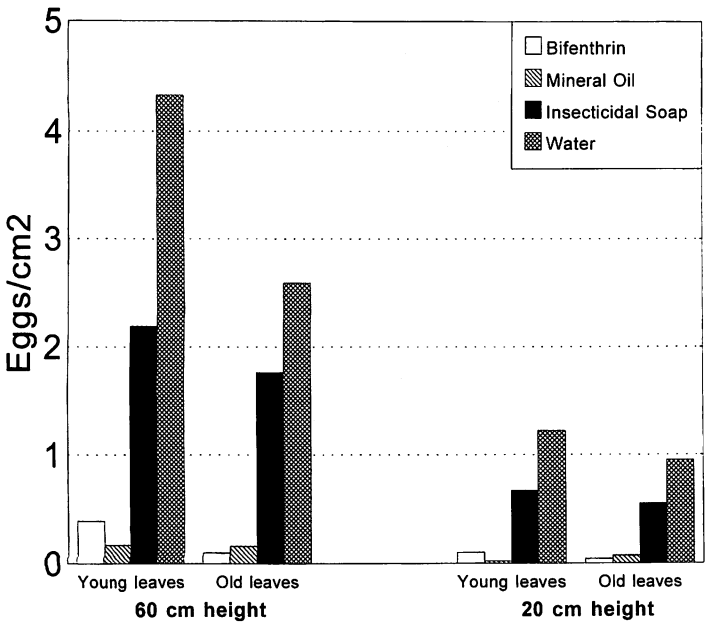

Figure 3. Oviposition preference of *B. argentifolii*: effects of leaf age, leaf position and insecticide residues.

Fewest nymphs plus pupae (2.3±0.82 per leaflet) were observed on plants sprayed with detergent twice a week; significantly less than either the control (5.0±1.6), the oil/detergent alteration (4.6.± 1.5), or esfenvalerate + chlorpyrifos alternated with endosulfan (4.4±1.4). Significantly fewer immature whiteflies (2.8±0.59) were found on plants sprayed with the airboom sprayer than on unsprayed plants, with the hydraulic sprayer intermediate. Also, underleaf coverage as determined by visual assessment of water-sensitive paper was ranked significantly higher with the airboom sprayer than the hydraulic sprayer. Lowest weekly geminivirus incidence through 47 days post-planting occurred in plots sprayed with detergent twice a week (10.5%±2.2) or once a week alternated with mineral oil (10.1±2.3) compared to the control (18.3%±3.3). These two experiments demonstrated the ability of oils and detergents to significantly reduce whitefly populations and the movement of whitefly-vectored virus in the field.

Conclusion. Biorational insecticides can play a role in whitefly management. Mineral oil was persistent and highly toxic to all whitefly stages, although coverage was critical. Oil residues were also highly repellent to whiteflies. Unfortunately, mineral oil is known to cause considerable mortality to some lifestages of certain beneficial arthropods such as eggs of *Chrysoperlla rufilabris* (D. Schuster and D. Dean, unpublished data) and *Encarsia pergandiella* adults (Liu, unpublished data). Surfactants such as insecticidal soap, household detergents, and plant extracts containing sugar esters were effective against whitefly nymphs, but not against other stages except for moderate activity of wet residues against adults. In addition, insecticidal soap has been seen to be non toxic to all stages of *Chrysoperlla rufilabris* (D. Schuster and D. Dean, unpublished data) and *Encarsia pergandiella* adults (T. X. Liu, unpublished data). These characteristics should earn oil and surfactant insecticides a role in management of SLWF.

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