

# Soybean Oil as a Summer Spray for Apple: European Red Mite Control, Net CO<sub>2</sub> Assimilation, and Phytotoxicity

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**Abstract.** Soybean [*Glycine max* (L.) Merrill] oil was applied to apple trees [*Malus sylvestris* (L.) Mill var. *domestica* (Borkh.) Mansf.] as a summer spray in six studies to determine if it controls European red mites [*Panonychus ulmi* (Koch.)], how it affects net CO<sub>2</sub> assimilation (A), and if it causes phytotoxicity. Sprays of 0.5%, 1.0%, and 1.5% soybean oil {TNsoy1 formulation [soybean oil premixed with Latron B-1956 (LAT) spreader-sticker at 10 oil : 1 LAT (v/v)]} reduced mite populations by 94%. Sprays of 1% and 2% soybean oil reduced mite populations to three and four mites per leaf, respectively, compared to 25 per leaf on water-sprayed plants. Soybean oil concentrations of 1.0% and 1.5% applied to whole trees reduced A for less than 7 days. Phytotoxicity did not occur when soybean oil was applied with an airblast sprayer at concentrations of 1.0% and 1.5% or with a mist bottle at 2%. Phytotoxicity occurred when soybean oil was applied with a mist bottle at 4% and 6%, which left soybean oil leaf residues of 0.22 to 0.50 mg·cm<sup>-2</sup>. No phytotoxicity occurred with 4% SunSpray, which resulted in a mean leaf residue of only 0.13 mg·cm<sup>-2</sup>. Spraying 1% soybean oil tended to give better mite control than 1% SunSpray Ultra-Fine oil, but caused greater oil residues and a greater reduction in A.

Pesticide usage is of continued concern in fruit production because of the potential harm to humans and wildlife, and the risk of residues in food. Oil sprays as insecticides or miticides have advantages of posing little human health hazard, little possibility of insects or mites developing resistance, and lower product cost over competitive pest-control products (Agnello, et al., 1994). Applying petroleum oil to foliage during the summer can control ERM {European red mites [*Panonychus ulmi* (Koch) Acarina: Tetranychidae]} (Agnello et al., 1994; Lawson and Weires, 1991) effectively and can reduce populations of immature aphids, mealybugs, leafhoppers, and scale insects (Johnson, 1985).

Soybean [*Glycine max* (L.) Merrill] oil is a relatively nontoxic botanical oil that may be used as a pesticide. Soybean oil is a renewable resource and is the most abundant plant oil in the United States. Because soybean oil is relatively safe, not persistent in the environment, and has no significant adverse effects on the environment, it was exempted by the EPA from normal pesticide-registration requirements (U.S. Congress, 1996). Information is needed on soybean oil efficacy on mites and insects and the effects on tree health before

it can be used as a summer insecticide spray. Petroleum oil was phytotoxic when applied at high rates to apple foliage (Agnello et al., 1994; Lawson and Weires, 1991) or in combination with sulfur-containing fungicides. In some studies, petroleum oil reduced net CO<sub>2</sub> assimilation (A) (Hoffman, 1934; Schroeder, 1935), but other researchers have reported inconsistent effects (Ayers and Barden, 1975; Ferree and Hall, 1975). The variable results may be caused by many factors, such as age or condition of the leaves, method of application, or amounts of oil residue deposited on leaves. No previous research has related oil residue to reductions in A or the occurrence of phytotoxicity. Few studies have been conducted to test soybean oil effects on apple. Soybean oil applied in the laboratory as a dip at the concentration of 0.32 mL·L<sup>-1</sup> had no effect on A (Ferree et al., 1976), but laboratory applications may not represent what occurs outdoors. Schroeder (1935) reported that spraying 2% olive oil or 2% castor oil reduced A for a longer time than 2% petroleum oil. The choice of adjuvant may influence soybean oil efficacy and phytotoxicity. Our research has shown that the adjuvant Latron B-1956 (Rohm and Haas Co., Philadelphia) will emulsify soybean oil in water if agitated. Spraying 0.2% (v/v) Latron B-1956 in water reduced the ERM population on plum foliage by 50%. However, spraying 0.2% Latron B-1956 mixed with 2% soybean oil in water reduced the mite population by >90% (Deyton and Sams, 2002). The objectives of this research were to determine the effects of soybean oil on: 1) oil residue remaining on the leaf surface; 2) apple foliage phytotoxicity; 3) A; and 4) ERM control.

## Materials and Methods

**Oils.** Degummed (slightly refined to remove gums) soybean oil (Central Soya, Fort Wayne, Ind.) was used throughout the trials. Soybean oil was premixed with Latron B-1956 (LAT) spreader-sticker at 10 oil : 1 LAT (v/v) ≈30 min prior to adding to water in a spray tank. We termed this formulation TNsoy1. The concentrations of TNsoy1 used in the experiments are actually the concentrations of the active ingredient (soybean oil). Soybean oil is not refined by distillation as are the petroleum oils; thus, the formulation is not described by distillation range. This formulation has a viscosity of 152 centipoise at 25 °C (Bondada et al., 1998). A soybean oil formulation that we termed K1000 was provided by Central Soya. The K1000 had a viscosity of ≈100 centipoise at 25 °C (unpublished data).

SunSpray Ultra-Fine Spray Oil (nC21; Sun Co., Philadelphia) was compared with the soybean oil treatments. It is a highly refined, narrow-range paraffinic oil with a viscosity of 68 centipoise at 38 °C, a 92% minimum unsulfonated residue, and a 50% distillation point at 212 °C (Davidson et al., 1991).

**Expt. 1. Oil efficacy on ERM.** In an initial study, 5-year-old 'Winesap' /MM.111 apple trees infested with adult ERM were selected in a commercial orchard in Sevierville, Tenn. The trees were sprayed to runoff with an airblast sprayer on 17 June 1996 with water (control), 1% SunSpray (v/v), 0.5%, 1.0%, or 1.5% soybean oil (TNsoy1 formulation) (v/v), or left untreated (control). Experimental units were single trees with treatments arranged in a randomized complete-block design (RCB) with four replications. The trees were spaced 4.2 m apart in the row and 7.3 m between rows. The 1.5% soybean oil treatment was chosen as the highest rate because Agnello et al. (1994) reported that spraying 2% or 3% SunSpray on stressed apple trees caused foliar lesions.

Thirty mid-shoot leaves were collected at random from each tree 11 d after treatment (DAT). Surviving motile-stage mites on the leaves were counted by brushing the leaves with a mite brushing machine (Leedon Engineering, Mi-Wuk Village, Calif.) and then using a dissecting scope to view the surviving motile-stage mites on a gridded plate. Later mite counts were discarded, because the grower sprayed a miticide. The trees received neither rain nor irrigation during the interval from spraying until sampling for mites.

**Expt. 2. Oil efficacy on ERM.** The efficacies of two formulations of soybean oil against ERM were evaluated in a second study. Six-year-old 'Blushing Golden' apple trees in a commercial orchard near Morristown, Tenn., were sprayed on 24 July 1996 with: 1) water; 2) 2% soybean oil (TNsoy1 formulation); 3) 2% soybean oil (K1000 formulation); 4) 2% SunSpray; or 5) left unsprayed (control). The trees were sprayed to runoff using a Stihl SR-400 backpack mist blower (Stihl, Virginia Beach, Va.). Treatment units were single trees and treatments were arranged in a RCB design with seven replications. The trees were spaced 5.5 m in row × 6.1 m between rows. On 2 Aug., 30 mid-shoot

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leaves were collected at random from each tree, brushed with a mite brushing machine, and surviving motile-stage mites counted. The trees received 1.63 cm of rain 2 DAT.

**Expt. 3. Oil residue and leaf A.** A third study evaluated the effects of soybean oil spray concentrations on oil deposits on leaves and on photosynthesis. Twenty 7-year-old 'Oregon Spur' /MM.111 and 15 'McIntosh Wijkik' /MM.111 (Kelsey and Brown, 1990) apple trees at the Univ. of Tennessee, Knoxville Experiment Station were sprayed with treatments on 27 June 1996. The trees were sprayed to runoff with an air-blast sprayer with 0% (water control); 0.5%, 1.0%, or 1.5% soybean oil (TNsoy1 formulation); 1% SunSpray; or 0.15% LAT. The 0.5% soybean oil and 1% SunSpray treatments were not applied to 'McIntosh Wijkik' trees because of a limited number of trees. The study used a randomized-incomplete block design (RICB) with three replications of 'McIntosh Wijkik' and four replications of 'Oregon Spur'. Data analysis indicated that soybean oil had similar effects on the two cultivars throughout the trials. The trees were trained to a modified central leader. The 'McIntosh Wijkik' and 'Oregon Spur' trees were in rows spaced 5.8 m apart. The 'McIntosh Wijkik' trees were spaced 3.7 m within rows, and the 'Oregon Spur' trees were spaced 4.6 m.

A newly fully expanded leaf was randomly selected on the south side of each tree at  $\approx 1.5$  m height and A measured 1 and 7 DAT with a model ADC-3 open system infrared gas analyzer and Parkinson leaf chamber (Analytical Development Co., Hoddesdon, U.K.). All measurements were made outdoors at  $>800 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  photosynthetic photon flux (PPF). Net  $\text{CO}_2$  assimilation, transpiration and conductance were calculated according to the methods of von Caemmerer and Farquhar (1981). Leaf temperature was calculated using the energy balance equation (Forseth and Norman, 1993). The trees received 0.53 cm of rain on 6 DAT.

The leaf was excised after measurement of A and taken to the lab for measurement of oil residue. Oil deposits were removed by dipping whole leaves in 10 mL of chloroform for 30 s. This was repeated two more times for a total of 30 mL. The chloroform was evaporated and the dried residue then weighed. The mass of the extracts from untreated controls was used as an estimate of leaf surface waxes extracted along with the oil. The data were not collected from the 0.5% soybean oil treatment. Untreated leaves had a wax layer of  $0.11 \text{ mg}\cdot\text{cm}^{-2}$  at 1 DAT.

**Expt. 4. High soybean oil concentrations.** The same trees used in Expt. 3 were later sprayed on 26 July 1996 with a wider range of soybean oil concentrations to evaluate effects on foliage. Most of the oil residue from the previous experiment was assumed to have washed off. Our research showed that 2.5 cm of simulated rain in a controlled greenhouse environment washed off  $\approx 80\%$  of the oil (Bondada et al., 2000). The trees had received 10.8 cm of rain during the interval between the sprays. One shoot per tree was sprayed until runoff with a mist bottle with water 0% (water control), 2%,

4%, or 6% soybean oil (TNsoy1 formulation) or 0.6% LAT. The 0.6% LAT treatment was equivalent to highest rate added to soybean oil in the experiment. An additional treatment of 4% SunSpray was also tested. The study was a RCB design with seven replications; three replications of 'McIntosh Wijkik' and four replications of 'Oregon Spur'.

The A rate of a newly fully expanded leaf was measured as described in Expt. 3 at 1 and 8 DAT. Net  $\text{CO}_2$  assimilation, transpiration, conductance and intercellular  $\text{CO}_2$  concentration were calculated according to the methods of von Caemmerer and Farquhar (1981). Leaf temperature was calculated using the energy balance equation (Forseth and Norman, 1993). At 1 DAT and at 8 DAT, one newly expanded leaf was removed from each shoot and taken to the laboratory for measurement of leaf oil residue as described in Expt. 3. Untreated leaves had a wax layer of  $0.15 \text{ mg}\cdot\text{cm}^{-2}$  and  $0.17 \text{ mg}\cdot\text{cm}^{-2}$  at 1 and 8 DAT, respectively. The trees received no rain by 1 DAT but received 8.3 cm of rain during the interval from spraying to 8 DAT.

**Expt. 5. Oil residues and leaf A.** The same trees as in Expts. 3 and 4 were used again in 1997 to compare soybean oil and SunSpray. One shoot per tree was sprayed until runoff on 18 Aug. with a mist bottle with 0% (water control), 1%, or 2% soybean oil (TNsoy1 formulation); or 1% or 2% SunSpray. Treatments were arranged in a RCB design with four replications of 'McIntosh Wijkik' and 'Oregon Spur'. The study was repeated on 29 Aug. on different shoots.

Single-leaf A was measured several hours after application on 18 Aug., but not on 29 Aug. Single-leaf A response to  $\text{CO}_2$  from 75 to 360  $\mu\text{mol}\cdot\text{mol}^{-1}$  was measured on one newly fully expanded leaf per shoot one DAT. The concentration of  $\text{CO}_2$  was controlled by scrubbing ambient air with soda lime. All measurements were made outdoors at saturating PPF. Several hours after spraying, one leaf was removed from each shoot for measurement of oil residues. Data from the two application dates were pooled for analysis.

**Expt. 6. Oils on ERM, A, and oil residues.** Three-year-old 'Supergold' /M.26 trees in a commercial orchard near Pikeville, Tenn., were selected that were infested with ERM. The trees were trained as slender spindles and spaced 1.5 m between trees and 5.5 m between rows. Each experimental unit had four trees with a guard tree between treatments in a row and a guard row between treated rows. Trees were left unsprayed (control), or sprayed with 0% (water control), 1%, or 2% soybean oil (TNsoy1 formulation) or 1% SunSpray on 16 July 1997. Sprays were applied with an air-blast sprayer delivering an average of 3.1 L per tree. The study used a RCB design with six replications.

Leaf oil residue was measured 2 and 7 DAT using the same procedure as in Expt. 2. Thirty mid-shoot leaves per plot were randomly sampled 8 DAT, brushed with the mite brushing machine, and mites stored in ethanol until motile-stage ERM were counted. The A rates were measured as described in Expt. 3

at 2 and 7 DAT, however, the A data for the second date was discarded because of a machine malfunction. Rainfall during the interval from spraying to 7 DAT was not recorded in the orchard but none was recorded at a nearby rainfall collecting station.

**Data analysis.** Mite count data were transformed with log10 before analysis. Data were analyzed by regression analysis with soybean oil concentration as the independent variable and A and oil residue as dependent variables. Regression analysis was also used with oil residue as the independent variable and A as the dependent variable using REG and NLIN procedures (SAS Inst., Cary, N.C.). The effects of soybean oil, SunSpray, or adjuvant were analyzed using the GLM procedure, and mean separation was performed with Duncan's multiple range test. SunSpray and soybean oil were compared with contrasts statements in each experiment.

## Results

**Expt. 1. Oil efficacy against ERM.** In the preliminary study on 'Winesap' trees, spraying soybean oil or SunSpray reduced ERM populations (Fig. 1). Untreated trees had 9.3 ERM/leaf when sampled on 28 June (11 DAT). Spraying water with the air-blast sprayer reduced ERM populations to only 60% as large as on unsprayed trees. Spraying 1% SunSpray reduced the ERM populations by 74% and 57% compared to populations on unsprayed trees and water-sprayed trees, respectively. Spraying 0.5%, 1.0%, or 1.5% soybean oil (TNsoy1 formulation) reduced ERM populations by 94%, 84%, and 84%, respectively, compared to populations on untreated trees and trees sprayed with water. None of the sprays caused phytotoxicity.

**Expt. 2. Oil efficacy on ERM.** Each of the oil formulations reduced ERM populations on apple foliage. The SunSpray and the soybean oil formulations did not differ in efficacies for ERM control. The spraying of 'Blushing Golden' trees with water with a mist-blower reduced ERM populations by 25% compared to unsprayed trees (Fig. 2). The spraying of 2% SunSpray, 2% soybean oil (TNsoy1 formulation) or K1000 formulation) reduced ERM populations to  $<10\%$  as large of populations on unsprayed trees. None of the treatments caused phytotoxicity.

**Expt. 3. Oil residues and leaf A.** Spraying 0% to 1.5% soybean oil (TNsoy1 formulation) with an air-blast sprayer left soybean oil residues 1 DAT that increased linearly with treatment concentration (Fig. 3A). Oil residues were not collected 7 DAT. There were no differences between cultivars in oil deposition or effect of oil on A. As soybean oil concentration increased to 1.5%, A was decreased linearly at 1 DAT (Fig. 3B). By 7 DAT, leaves sprayed with 0.5% to 1.5% soybean oil did not affect A. Sprays of 1% SunSpray or 1% soybean oil did not differ in oil residues at 1 DAT or A at 1 and 7 DAT. None of the treatments caused phytotoxicity or defoliation.

Spraying concentrations from 0 to 1.5% of soybean oil (TNsoy1 formulation) affected leaf

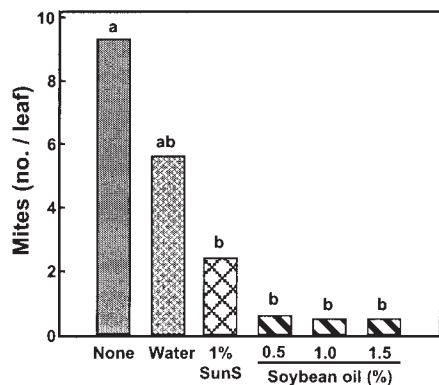


Fig. 1. Surviving European red mites on 'Winesap' apple leaves 11 d after spraying soybean oil (TNsoy1 formulation) or 1.0 % SunSpray Ultra-Fine oil (SunS) on 28 June 1996.

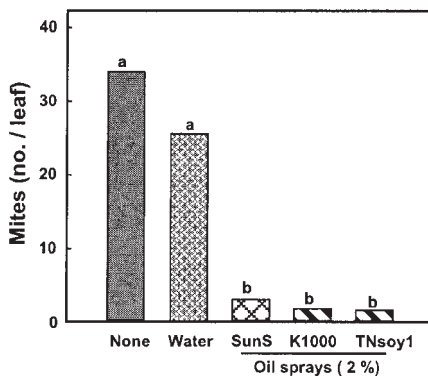


Fig. 2. Surviving European red mites on 'Blushing Golden' leaves 9 d after spraying 2% soybean oil (TNsoy1 and K1000 formulations) or 2% SunSpray Ultra-Fine oil (SunS) on 24 July 1996.

transpiration, conductance, and temperature 1 DAT (Table 1). Intercellular CO<sub>2</sub> concentration was not significantly affected by soybean oil concentrations (data not shown). At 1 DAT, transpiration and conductance decreased linearly and leaf temperature increased linearly with increasing soybean oil concentration. Soybean oil did not affect leaf temperature, transpiration, or conductance 7 DAT.

**Expt. 4. High oil concentration effects on A.** Spraying individual shoots with a mist bottle with 2%, 4%, or 6% soybean oil (TNsoy1 formulation) left larger amounts of oil residue on leaves and reduced A more than in Expt. 3. The oil residue left on leaves increased linearly with increasing soybean oil concentration (Fig. 4A). Apparently very little soybean oil residue washed off 8 DAT even though exposed to 8.3 cm of rain. The adjuvant used was a spreader-sticker and apparently reduced wash-off. Net CO<sub>2</sub> assimilation at 1 and 8 DAT decreased asymptotically as soybean oil concentration increased (Fig. 4B). In that experiment, plants sprayed with 4% soybean oil had more oil residue 1 and 8 DAT than plants sprayed with 4% SunSpray (Fig. 5A) or effects on A at 1 DAT (Fig. 5B). Soybean oil reduced A more than SunSpray 8 DAT. The SunSpray spray reduced A by 58% and soybean oil reduced A by 72% 1 DAT. By 8 DAT, 4% SunSpray no longer affected A, but 4% soybean oil reduced A by 78%. The spraying of 0.6% LAT, the adjuvant used with TNsoy1, reduced A at 1 DAT but not 8 DAT. The 4% SunSpray treatment left less residue than 4% soybean oil at 1 DAT (0.14 mg·cm<sup>-2</sup>) and at 8 DAT (0.34 mg·cm<sup>-2</sup>). Sprays of 4% or 6% soybean oil caused chlorosis and defoliation of shoots within 1 week after application (data not shown). Application of 2% soybean oil or 4% SunSpray caused no phytotoxicity.

There was a significant inverse relationship between the amount of oil residue and the reduction in A one DAT (Fig. 6). SunSpray and soybean oil did not differ in effects on A at equivalent oil residues.

**Expt. 5. Oil residues and leaf A.** In 1997, the spraying of single shoots with 1% or 2% soybean oil (TNsoy1) or SunSpray reduced A within several hours after spraying (Table 2). Soybean oil and SunSpray, both at 1%; reduced

A by 30% and 33%, respectively. Soybean oil and SunSpray, both at 2%; reduced A by 49% and 42%, respectively. The oils did not differ in effects on A. The soybean oil spray left more residue on the leaves than did SunSpray. There was no difference between the two concentrations or between the two oils in their effects on carboxylation efficiency.

**Expt. 6. Oil residues, leaf A, mite efficacy.** In 1997, the application of 1% soybean oil (TNsoy1 formulation) by air-blast sprayer left more than twice as much oil residue on leaves at 2 DAT as did 1% SunSpray (Fig. 7A). By 7 DAT, residues from 1% SunSpray or 1% soybean oil had decreased to an unmeasurable amount (data not shown), but 2% soybean oil left a residue of 0.013 mg·cm<sup>-2</sup>. Soybean oil at 2% significantly reduced A 2 DAT (Fig. 7 B), but 1% SunSpray did not.

The untreated trees, water sprayed trees, and 1% SunSpray treated trees had similar numbers of ERM/leaf 7 DAT. Spraying 1% or 2% soybean oil decreased ERM populations to <5 mites/leaf (Fig. 7C). Sprays of 1% soybean oil controlled mites as well as 2% soybean oil and better than 1% SunSpray.

### Discussion

Spraying soybean oil during the summer is a feasible treatment to reduce ERM populations on apple trees. Treatments 0.5%, 1.0%, and 1.5% soybean oil (TNsoy1 formulation) applied with an airblast sprayer reduced ERM populations by >94% compared to untreated trees. Spraying 2% soybean oil in Expt. 2 reduced the ERM population by >90%, compared

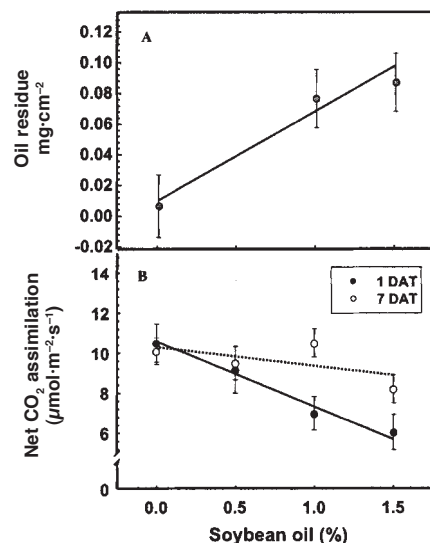


Fig. 3. (A) The relationship between soybean oil (TNsoy1 formulation) spray concentration and leaf surface oil residue 1 d (Y = 0.01 + 0.06x, r<sup>2</sup> = 0.91, P ≤ .01) after spraying. Each point is the mean of seven points, ±SE. (B) The effects of soybean oil concentration on single-leaf net CO<sub>2</sub> assimilation at 1 d (Y = 10.4 - 3.27x, r<sup>2</sup> = 0.41, P ≤ 0.01) and 7 d (Y = 10.3 - 0.94x, r<sup>2</sup> = 0.36, P = 0.40) after spraying. Each point is the mean of seven points ±SE.

to the heavily ERM-infested leaves on water-sprayed trees. Airblast applied treatments of 1% or 2% soybean oil (TNsoy1) in Expt. 6 reduced mite populations by >85%, compared to water-sprayed trees. In Expts. 1 and 2, soybean oil efficacy against ERM was not improved by increasing the oil concentration above 1.0%.

In Expt. 2, the formulation of soybean oil did not affect efficacy of ERM control. The adjuvant in K1000 is proprietary and was not tested alone for efficacy against mites. Our research on plum foliage has shown that spraying 0.2% LAT often reduced the mite populations but the combination of 2% soybean oil and 0.2% LAT significantly reduced the population more than the adjuvant alone (Deyton and Sams, 2002).

SunSpray treatments tended to be less efficacious than soybean oil at the same concentrations in Expt. 1 and Expt. 2 and had significantly less efficacy in Expt. 5. In heavy infestations, a single application of 1% SunSpray was previously reported to control mite populations inadequately (Agnello et al., 1994). Differences between the TNsoy1 and SunSpray

Table 1. Transpiration, stomatal conductance, and leaf temperature of 'McIntosh Wijcik' and 'Oregon Spur' apple leaves following application of relatively low concentrations of soybean oil (TNsoy1 formulation).

Soybean oil (%)	1 d after application			7 d after application		
	Transpiration (mmol·m <sup>-2</sup> ·s <sup>-1</sup> )	Conductance (mol·m <sup>-2</sup> ·s <sup>-1</sup> )	T <sub>l</sub> <sup>z</sup> (°C)	Transpiration (mmol·m <sup>-2</sup> ·s <sup>-1</sup> )	Conductance (mol·m <sup>-2</sup> ·s <sup>-1</sup> )	T <sub>l</sub> <sup>z</sup> (°C)
0.0	5.4	0.18	32.1	5.4	0.18	31.9
0.55	5.3	0.16	32.8	5.5	0.20	30.9
1.00	4.0	0.11	32.9	5.4	0.18	31.1
1.50	3.5	0.09	33.4	4.6	0.14	32.3
Linear trend	**	**	**	NS	NS	NS

<sup>z</sup>Leaf temperature was calculated using the energy balance equation.

ns, \*\*Nonsignificant or significant at P = 0.01, respectively.

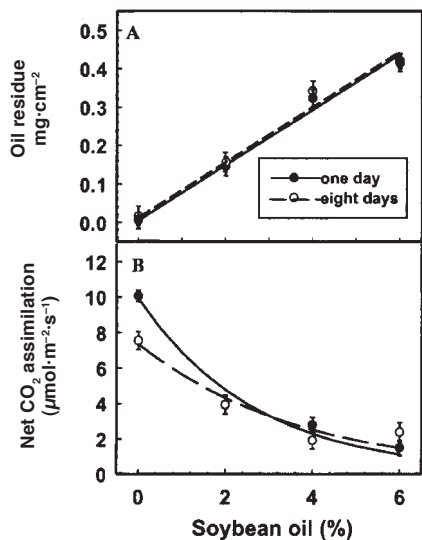


Fig. 4. (A) The relationship between applied soybean oil (TNsoy1) concentration and leaf surface oil residue on 1 d ( $Y = 0.004 + 0.072x$ ,  $r^2 = 0.92$ ,  $P \leq 0.01$ ) and 8 d ( $Y = 0.025 + 0.071x$ ,  $r^2 = 0.89$ ,  $P \leq 0.01$ ) after spraying; (B) the relationship between single-leaf net  $CO_2$  assimilation and soybean oil concentration 1 d ( $Y = 9.93 e^{-0.367x}$ ,  $r^2 = 0.97$ ,  $P \leq 0.01$ ) and 8 d ( $Y = 7.35 e^{-0.279x}$ ,  $r^2 = 0.90$ ,  $P \leq 0.05$ ) after application. Each point is the mean  $\pm$ SE of seven replications.

may be due to a difference in coverage caused by the adjuvants. SunSpray and TNsoy1 had different adjuvants, which affects the ability of the oil to remain mixed with water and to spread over the surface of the leaf. Variability in mite control was attributed to differences in oil coverage (Lawson and Weires, 1991). If residues are an indication of leaf coverage, then soybean oil may be covering the leaf and mites better than SunSpray as evidenced by greater residues. However, oil has no residual miticidal activity. Control must occur by contacting the mite and presumably by smothering it (Johnson, 1985). Ovicidal activity of soybean oil was not measured in this study.

Soybean oil can be applied at a concentration of 2% or less with no phytotoxicity to apple leaves. Rates of 4% and 6% caused leaf chlorosis and defoliation of 'Oregon Spur' and 'McIntosh Wijcik'. These concentrations are above what is needed for mite control, but were selected to determine the concentration that would cause phytotoxicity. Petroleum oil also caused apple leaf phytotoxicity at a concentration of 3% (Agnello et al., 1994), but did not in another trial (Baxendale and Johnson, 1988). In our study, SunSpray at 4% did not cause phytotoxicity, unlike soybean oil (TNsoy1), and this was most likely a result of the greater residue with soybean oil. In addition, the SunSpray was highly refined, in contrast to the soybean oil. Oils of low refinement were reported to be toxic to foliage (Knight et al., 1929). Phytotoxicity may also depend on how the oil is applied (Ferree and Hall, 1975). Both an airblast sprayer and a hand-held sprayer were used to apply the oil, and both resulted in a similar amount of residue, but no phytotoxicity.

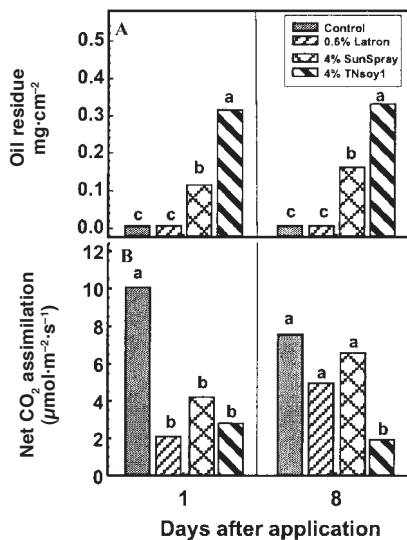


Fig. 5. (A) Oil residues on apple leaves 1 d and 8 d after spraying 4% soybean oil (TNsoy1), 4% SunSpray, or 0.6% Latron B-1956; or leaving unsprayed (control). (B) Single-leaf net  $CO_2$  assimilation 1 d and 8 d after treatment. Mean separation within day was by Duncan's multiple range test, ( $P \leq 0.05$ ,  $n = 7$ ).

Soybean oil (TNsoy1 formulation) applied at 4% and 6% and with residues ranging from 0.22 to 0.50  $mg \cdot cm^{-2}$  caused phytotoxicity, but 2% caused residues as high as 0.23  $mg \cdot cm^{-2}$  but no phytotoxicity. Based on these data, an estimated oil-residue threshold for phytotoxicity would be  $\approx 0.23 mg \cdot cm^{-2}$ . In our study, pesticide usage was limited, so it cannot be concluded that phytotoxicity would not occur at concentrations of 2% or lower when other pesticides are applied before, during, or after soybean oil application.

Soybean oil application from 0% to 4% reduced A in a concentration-dependent manner. Reduction in A by  $\geq 2\%$  soybean oil lasted longer than 8 d. Net  $CO_2$  assimilation of 'Oregon Spur' was reduced by 1.0% and 1.5% soybean oil for no longer than 7 d. This is similar to results found with other compounds that effect A (Ayers and Barden, 1975; Straw et al., 1996; van Iersel and Bugbee, 1996; Wood et al., 1984). It is not known how long A must be reduced to cause a measurable effect

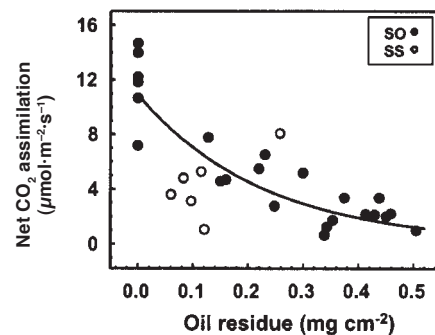


Fig. 6. The relationship between single-leaf net  $CO_2$  assimilation and leaf surface oil residue ( $Y = 10.89 e^{-4.39x}$ ,  $r^2 = 0.82$ ,  $P \leq 0.01$ ). Foliage had been sprayed with 0%, 2%, 4%, or 6% soybean oil (SO) (TNsoy1 formulation) or with 4% SunSpray (SS).

on fruit yield or quality. In previous studies, petroleum oil did not significantly reduce A in some experiments, but did in others (Ayers and Barden, 1975; Ferree and Hall, 1975). The cause of this inconsistency is unknown, but it may be due to environmental factors such as temperature or to differences in oil residue. Soybean oil caused a greater reduction in A than SunSpray in Expt. 1 and also resulted in nearly twice as much residue. When reduction in A was expressed on an oil residue basis rather than concentration basis there was little difference between petroleum and Soybean oil. This indicates that the difference in A between the two oils is most likely a result of variation in residue. There was little difference between the two oils in Expts. 2 and 3, but the range of concentrations tested may have been too small to detect differences in A or oil residue. Another factor may be the adjuvants used with each oil. When the adjuvant used with TNsoy1 oil was used alone at 0.6%, it reduced A, and may have contributed to the reduction A caused by TNsoy1. The adjuvant for the SunSpray is proprietary and was not tested.

The reduced A is hypothesized to be a result of the oil creating a barrier to gas exchange by blocking the stomates or by coating the leaf (Knight et al., 1929; van Overbeek and Blondeau, 1954). Conductance was reduced by oil application, but the effect on intercellular  $CO_2$  concentration was nonsignificant, indicating that the reduction in A was probably not entirely caused by physical limitations to  $CO_2$

Table 2. Net  $CO_2$  assimilation, leaf oil residue and carboxylation efficiency of 'McIntosh Wijcik', and 'Oregon Spur' apple leaves following application of soybean oil or SunSpray to single shoots.

Treatment	Concn (%)	Net $CO_2$ assimilation ( $\mu mol \cdot m^{-2} \cdot s^{-1}$ )	Oil residue ( $mg \cdot cm^{-2}$ )	Carboxylation efficiency ( $mol \cdot m^{-2} \cdot s^{-1} CO_2$ )
Control	0	6.34	---	0.08
Soybean oil <sup>z</sup>	1	4.44	0.07	0.06
	2	3.24	0.17	0.06
SunSpray	1	4.21	0.04	0.06
	2	3.67	0.07	0.04
Contrast:				
Control vs oil		**	**	**
Soy oil vs. SunSpray		NS	**	NS
1% vs. 2% Soy oil		NS	**	NS
1% vs. 2% SunSpray		NS	NS	NS

<sup>z</sup>TNsoy1 formulation.

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

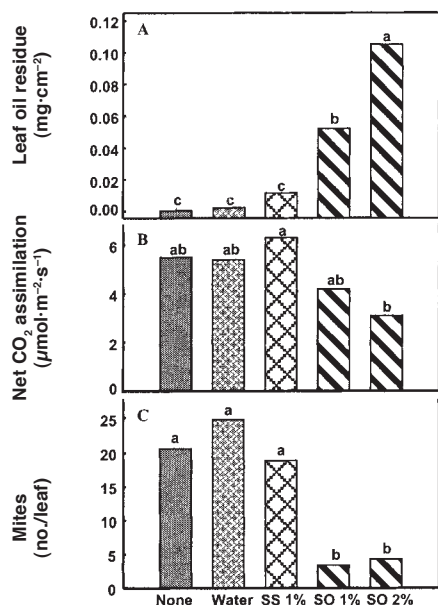


Fig. 7. (A) Oil residue and (B) net CO<sub>2</sub> assimilation of apple leaves 2 d after treatment with soybean oil (SO) (TNsoyl formulation) or SunSpray (SS), and (C) European red mite populations 7 d after treatment application. Mean separation within day was by Duncan's multiple range test, ( $P \leq 0.05$ ,  $n = 8$ ).

diffusion. The reduction in carboxylation efficiency by oil application further supports this conclusion. The slope of the response of A to intercellular CO<sub>2</sub> concentration is an estimate of carboxylation efficiency, and a reduction indicates a mesophilic limitation of A (Farquhar et al., 1980). The effect of oil on A may also have been due to the reduction in transpiration (Tr). Soybean oil (TNsoyl formulation) reduced Tr in both the high- and low-concentration studies. The lower Tr rate can lead to higher leaf temperature since Tr is important for leaf cooling. The optimum temperature for A in apple is 27 °C (Seeley and Kammereck, 1977). Leaf temperature of the controls was above the optimum, so the increase in leaf temperature of leaves sprayed with soybean oil may have resulted in decreased A. From these results it

appears that the reduction in A is, at least in part, physiological.

This study evaluated soybean oil as a potential summer miticide for apple trees. Soybean oil can be applied at concentrations of 1% with a small, temporary effect on A, no occurrence of phytotoxicity, and significant control of the European red mite. At this concentration, the soybean oil leaves 75% greater oil residue on leaves than SunSpray.

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