Factors Affecting Reductions in Photosynthesis Caused by Applying Horticultural Oil to Grapevine Leaves

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Abstract. Phytotoxicity of horticultural oil, applied shortly before antifungal sulfur, was evaluated for 23 grape cultivars. Oil application significantly reduced accumulation of soluble solids in berries of 9 of 23 cultivars, but there was no relationship with visible foliar injury. Treatment of leaves of *Vitis labrusca* 'Catawba' with 1.5% JMS Stylet-Oil reduced leaf net photosynthesis (P_n) by 50% to 60% and of *Vitis vinifera* 'Chardonnay' by 20% to 30% 1 day after application. P_n was reduced only when the lower (abaxial) leaf surface was treated; treatment of only the adaxial leaf surface had little effect. The P_n depression in 'Catawba' persisted 3 to 4 weeks, whereas reductions in 'Chardonnay' persisted less than 2 weeks. The P_n -depressing effect of oil was not significantly ameliorated by real or simulated rainfall, and washing the lower leaf surfaces with water and detergent also had only limited effect. There was no significant difference in P_n depression from oil applications made in the middle of the day (stomata open) compared to application in the evening (stomata closed), or from oil applied at higher versus lower application pressure. The greater sensitivity of 'Catawba' than 'Chardonnay' to P_n depression by oil may be related to the amount of oil retained by the leaves; the pubescent lower leaf surfaces of 'Catawba' retained more than twice as much spray emulsion as did the more glabrous leaves of 'Chardonnay'. Visible injury was mild in both cultivars, with small water-soaked lesions developing more commonly on 'Chardonnay' than on 'Catawba' leaves. Spray oil retention data for additional cultivars suggested that differences in retention can explain a portion of the differences in horticultural oil phytotoxicity.

Oils have been variously used in agriculture as herbicides, insecticides, acaricides, fungicides, or adjuvants for other pesticides. Some oils are approved for use in organic crop production (criteria defined under the US Organic Foods Production Act of 1990). Depending on composition, oils can cause visible plant injury symptoms, including leaf necrosis, chlorosis, and leaf drop, which can develop rapidly (acute injury caused by low-boiling point or light oils), or more slowly (chronic injury caused by heavy or high-boiling oils) (Baker, 1970; Dallyn, 1953; Gauvrit and Cabanne, 1993; Van Overbeek and Blondeau, 1954). Contemporary horticultural oils have been refined to remove the acidic, aromatic, and overly volatile fractions that are responsible for most visible symptoms, but highly refined oils may still physically interfere with gas exchange and reduce photosynthesis as well as transpiration.

Reductions in photosynthesis after oil treatment have been reported for a range of crops (Baker 1970; Gudin et al., 1976; Lancaster et al., 2002) and plant species, and are sometimes accompanied by significant reductions in fruit sugar accumulation (Ayers and Barden, 1975; Ferree et al., 1976; Schrader and Kammereck, 1996). Horticultural oils are used for control of grape powdery mildew [*Erysiphe (Uncinula) necator*], and appear to have good eradicant activity against this disease (Castellani and Matta, 1964; Northover and Schneider, 1996) if tissue coverage is sufficient. However, reduced grape sugar accumulation, delayed crop maturation, and reductions in crop yield and vine vigor have been detected even in the absence of visible symptoms (Finger et al., 2002; Northover and Homeyer, 1998).

To minimize deleterious effects of oil, we must understand the effects of application frequency, rate, and volume, and possible differences in cultivar response to oil. Finger (2000) and Finger et al. (2002) reported that photosynthesis of oil-treated grapevine leaves measured up to 14 d after oil application was reduced to various degrees, but those studies did not fully explore how long photosynthesis

was depressed by an oil spray. Delay of berry sugar accumulation and reductions in berry weight, cluster weight, and pH were significant in some, but not all experiments. Lower spray volume and application only to the fruit zone reduced harmful effects, but may also compromise mildew control. Two cultivars ('Chardonnay' and 'Cabernet Sauvignon') were studied by Finger et al. (2002), but treatment and site differences allowed neither direct comparison of the cultivars nor a determination to what extent photosynthesis depression was affected by subsequent rainfall. In this context, Schrader and Kammereck (1996) raised the question whether it might be possible to wash off oil residues after insect control had been achieved.

Objectives of the current study were to examine the influence of cultivar and environmental features (rainfall and stomatal opening at time of application) on the extent and duration of photosynthesis depression caused by horticultural oil application to grapevines. The goal was to better understand how oils may be used in a grape disease management program while minimizing harm to vines.

Materials and Methods

Cultivar comparison field trial. Cultivar differences in visible foliage injury and delayed fruit maturation in response to oil were examined in 1998 in a vineyard at the Agricultural Research and Extension Center in Winchester, Va. The vineyard contained five three-vine plots, completely randomized, of 23 wine grape cultivars, planted between 1989 (most cultivars) and 1993. The *V. vinifera* cultivars were grafted to 'C-3309' rootstock; *Vitis* hybrids were ungrafted. All vines were cordon-trained to a midwire bilateral cordon system, spur-pruned, and shoots were positioned upright. Vines were planted 2.1 m apart. Vineyard rows were oriented north to south and were 3.7 m apart. A 1-m herbicide strip was maintained under the trellis and a permanent grass (mix of tall and creeping red *Festuca* species) strip between rows. Other vineyard details are found in Wolf and Miller (2001). In addition to the treatments described below, the vines were subjected to a typical, disease-preventative spray schedule that included azoxystrobin, fenarimol, myclobutanil, and triadimefon. The cultivar planting was removed after the 1998 season.

JMS Stylet-Oil (JMS Flower Farms, Inc., Vero Beach, Fla.) contains 97.1% paraffinic oil (the remainder is emulsifier) and has a 50% distillation point of 224 °C at 10 mm Hg, a boiling point range of 313 to 427 °C at ambient pressure, a viscosity of 70 s Saybolt at 38 °C or about 13 mm²·s⁻¹ (13 centistokes) at 40 °C, and a density of 0.86 kg·L⁻¹ (Simons et al., 1995). JMS Stylet-Oil in water emulsion (1.5%, by volume) was applied to three plots of each cultivar, while two comparable plots of the same cultivar served as untreated controls. Oil treatments were applied until runoff to both sides of the canopy using a hand gun attachment on a pressure sprayer operated at about 1400 kPa. A plastic sheet mounted between

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wooden poles was used to prevent spray drift onto adjacent rows. The first treatment was applied after bloom (5 June, maximum temperature 21 °C), at a volume of 5550 L·ha⁻¹. The second application was made one month later (7 July, maximum temperature 29 °C) at 4680 L·ha⁻¹, because an effort was made to decrease the spray volume while still achieving full coverage. Sulfur (Microthiol Special, 80%, ElfAtochem, Philadelphia, Pa.) was applied at 3.4 kg·ha⁻¹ with an air-blast sprayer to the entire vineyard on 9 June (maximum temperature 21 °C), 4 d after the first oil application.

Visible foliar injury was assessed 1 and 2 weeks after each oil application. Symptoms of leaf reddening, chlorosis, necrotic spots, scorch, stippling, and soaked appearance were recorded along with an estimate of the affected percentage of the leaf area in the canopy.

Fruit maturation was monitored weekly by collecting 50-berry samples from each plot beginning 20 Aug. Final harvest date of a particular cultivar was based on a combination of primary fruit chemistry (²Brix, pH and titratable acidity) and varietal aromas and flavors present in the fruit (Wolf and Miller, 2001). Fruit samples were frozen for storage, then thawed, weighed, and analyzed for soluble solids concentration (SSC), pH, and titratable acidity using methods described by Finger et al. (2002).

Potted-plant trials. Plants of own-rooted *Vitis labrusca* 'Catawba' were potted in or before 1998, and experiments in 1998 and 1999 were conducted with greenhouse-grown 'Catawba' plants in a greenhouse. Grafted *Vitis vinifera* 'Chardonnay' were potted in May 2000. Unless otherwise mentioned, experiments reported here were conducted with both 'Catawba' and 'Chardonnay' plants from late June through early September of 2000, with plants that had been held outdoors for at least a month to allow leaves to develop under natural summer conditions of light and temperature. Vines were grown in 15- or 21-cm-diameter pots filled with Promix BX peat-based potting mix (Premier Horticulture, Inc., Red Hill, Pa.) with 10% to 15% (v/v) loamy field soil added, and fertilized with Sierra 17-6-12 slow-release fertilizer with micronutrients (Scotts-Sierra Horticultural Products Co., Marysville, Ohio). They were sprayed occasionally with mancozeb and sulfur, or fenarimol to prevent disease development, and carbaryl to prevent Japanese beetle damage.

Fully expanded, midshoot leaves were tagged, and net photosynthetic rate (P_n) and stomatal conductivity were measured using a portable photosynthesis system (LI-6200; LI-COR, Inc., Lincoln, Nebr.). Measurements were taken outdoors or, on days with threatening rain, in a greenhouse, either in natural sunlight or, on cloudy days, under a 1200-W discharge spotlight (Rembrandt model 2510 Piccolo; De Sisti Srl, Rome, Italy; photosynthetically active radiation 850-1000 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at a distance of 3 to 4 m). Light saturation for grape leaves occurs around 700 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (Smart and Robinson, 1991). Care was taken that all plants were held in the same light conditions before photosynthesis

measurements (i.e., all in the sun, or all in the shade). Readings were taken in saturating light, and the RH in the cuvette was kept within a range no greater than about 10% for all readings on a given date by adjusting airflow through the LI-6200 desiccant. Temperatures in the cuvette generally ranged from 25 to 35 °C and readings commenced when the CO₂ concentration was 320 ppm.

Individual leaves were sprayed until thoroughly wet (beyond runoff) with 1.5% (by volume) JMS Stylet-Oil emulsion in water, using either a hand-pump spray bottle, or a backpack sprayer (model 425; Solo, Newport News, Va.) at about 345 kPa. In tests where only one leaf side was to be treated, care was taken to protect non-treated surfaces with plastic bags and cardboard shields. Sprayed leaves were allowed to dry, and the plants were left outdoors (or, in 1998 and 1999, held in a greenhouse). Unless otherwise mentioned, each experiment consisted of treatment application followed by several measurements of net photosynthetic rate and stomatal conductance of 8 to 10 replicate leaves. Measurement intervals varied between experiments.

Because the P_n reduction varied somewhat from experiment to experiment, and in 2 of 11 experiments with 'Catawba' was unusually small, an experiment was conducted to determine whether the time of day of oil application affected P_n depression. Grape leaves open their stomata early in the morning, and darkness causes them to close (Mullins et al., 1992). Oil has been reported to penetrate stomata of some plants when applied in light, but not when applied in the dark, when stomata are closed (Dallyn, 1953; Van Overbeek and Blondeau, 1954). Oil sprays were applied to lower leaf surfaces of 'Catawba' or 'Chardonnay' in either early afternoon (1300 to 1400 HR) or just after nightfall (about 2030 HR) with the backpack sprayer. At the latter time, stomatal conductance of leaves placed under a light was near 0, indicating that stomata were indeed closed. At both times, oil was applied at two pressures, either low, meaning that the oil emulsion was gently applied at a sprayer pressure of <100 kPa from about 60 cm distance so that droplets arrived at the leaf surface with little kinetic energy, and high where sprayer pressure at 345 kPa was used to spray the emulsion forcefully against the leaf surface from 5 to 7 cm distance.

The effects of wet conditions or washing of oil-treated leaf surfaces on the degree of P_n depression were examined. In 1998, both oil-treated and control plants were placed on a greenhouse mist bench for 1 d after each measurement, with nozzles activated periodically for 10 s at a time, resulting in about 2.5 to 3 cm of precipitation per day. In two tests in 2000, plants were left outside exposed to natural rain, or under occasional artificial sprinkling (20 to 40 mm between P_n measurements). For a more stringent test of washing, and because it had been found that oil on leaf undersides was responsible for effects on P_n , leaf undersides that had been sprayed with oil the previous day were washed off with forceful water sprays (three 10-s washes over a time span of 10 min).

In one of the tests, this washing was preceded by application of about 2 g·L⁻¹ of a dishwashing detergent solution (Ultra Joy; Proctor and Gamble, Cincinnati, Ohio).

Retention of oil emulsion by leaves. A series of experiments was conducted in 2000 and 2004 to determine cultivar differences in foliar retention of oil spray. Leaves were obtained from potted 'Catawba' and 'Chardonnay' plants that had been held outdoors since shoot elongation, or from several vineyards in northern and western Virginia, because the Winchester cultivar planting (Table 1) was no longer available. Fully expanded midshoot leaves were brought to the lab in plastic bags in a cooler, taking care not to crush them. For emulsion retention studies, all but 0.5 cm of the petiole was cut off and the leaf was weighed, held upside down at a 45° angle and the abaxial side sprayed with 1.5% JMS Stylet-Oil (by volume in water) using a hand spray bottle until thoroughly wet. Leaves were then held vertical, shaken gently five times to remove excess liquid, and weighed again. In 2004, leaf areas were estimated with the aid of a flatbed scanner and pixels were counted using Photoshop 7.0 (Adobe Systems Inc., San Jose, Calif.).

To test whether a relationship between emulsion retention and P_n inhibition found in 'Chardonnay' and 'Catawba' extended to other cultivars, 'Primitivo' and 'Sangiovese' were selected because they showed the clearest retention differences in two August 2000 tests. In late August 2000, the undersides of tagged leaves of the two varieties in a southwestern Virginia vineyard were sprayed with 1.5% JMS Stylet-Oil, and allowed to dry for 3 h before P_n was measured on six leaves per treatment. For measurements on detached shoots from the same vineyard blocks, shoots were cut early in the morning, their bases were immediately immersed in water, and a piece of stem was cut off under water to maintain water uptake. Then leaves were tagged, and undersides of half of them were sprayed with oil. Photosynthesis measurements were taken the following day (10 leaves per treatment).

Statistical analysis. SAS software, PC version 7 and Mac OS version 6.12 were used (SAS Institute, Inc. Cary, N.C.). Treatment differences were analyzed by the GLM procedure for analysis of variance. Leaf injury estimates were arcsine-transformed to equalize variances; all variables were inspected for homogeneity of variance across treatments. If the F test was significant at $P \leq 0.05$, treatments were separated using Duncan's new multiple range test. Pair-wise comparisons in the field trial were made with Student's *t* test. Pearson product-moment correlations were calculated with the CORR procedure.

Results

Cultivar comparison field trial. Foliage injury and reductions in fruit quality following oil application (plus one sulfur application) in 23 cultivars are shown in Table 1. Some cultivars had significantly more visible injury than others, as indicated by a significant (*P*

≤ 0.0001) interaction between treatment and cultivar. Foliage symptoms associated with oil applications initially included oil-soaked appearance, leaf stippling, scorch, and later development of necrosis and chlorosis or reddening. Two weeks after the second oil spray, cultivars such as 'Nebbiolo', both 'Cabernet Sauvignon' clones, and 'Limberger' had $\leq 5\%$ of their canopy affected by oil (Table 1). Other cultivars showed visible injury on 15% to 50% of their foliage, although red leaf discoloration also developed in non-oil-treated vines of 'Charbono' (38%) and 'Fer Servadou' (30%). Percent of canopy visibly injured in the oil treatment differed significantly from percent injury in the corresponding control for 12 of the 23 cultivars (Table 1).

Reductions in SSC, berry weight, and changes in pH due to oil treatment were statistically significant ($P=0.0001$) when all cultivars were analyzed together, whereas changes in titratable acidity were not significant. Variety by treatment interactions were significant at $P < 0.01$ for all of these variables, except for pH where the interaction was significant at $P=0.02$. The reduction of SSC caused by oil was significant for nine cultivars, while the reduction in berry weight was significant for seven, and the change in pH for five (Table 1).

Despite these differences in foliage injury and fruit characteristics among cultivars, there was no relationship between the amount of visible injury and indicators of fruit maturity. Among the variables shown in Table 1, none of the correlations between foliar injury and changes in measures of fruit quality due to oil were significant.

Potted plant trials. Application of 1.5% JMS Stylet-Oil to only the lower leaf surface resulted in substantial suppression of P_n , whereas application to only the upper leaf surface had very little effect (Fig. 1). On 'Catawba', 1 or 2 d after oil application to the upper and lower leaf surface, the average P_n was 92% and 54%, respectively of that of control leaves (the lower-surface value varied from 18% to 94% in different tests, including tests in 1998 and 1999). In comparison, the average P_n of 'Chardonnay' leaves was reduced to 73% and not reduced at all, at 1 or 2 d after oil application to the lower and upper leaf surface, respectively. The P_n depression of 'Catawba' leaves took about 3 to 4 weeks to dissipate, on 'Chardonnay' often no more than 2 weeks (Fig. 1), presumably because the initial P_n depression for 'Chardonnay' was smaller. Differences in stomatal conductance generally paralleled differences in photosynthesis. Visible symptoms in potted-plant experiments were limited to small oily spots, occasional mild stippling, and an occasional yellow leaf, and these were more evident in 'Chardonnay' than in 'Catawba' leaves, and more prevalent when lower rather than upper leaf surfaces were treated.

Because the P_n reduction varied from test to test, and in two of 11 tests with 'Catawba' was unusually small, oil application in early afternoon (stomata open) was compared with application in the evening (stomata closed). In 'Catawba', a somewhat greater P_n depres-

sion from midday application was seen at 4 d after treatment but not at 1 d after treatment (Table 2); differences in Chardonnay were insignificant. A slightly greater effect of high-pressure application was seen in 'Catawba' 1 d after application, but not at 4 d, and not in 'Chardonnay' (Table 2).

These results suggested that immediate penetration of oil emulsion through stomata plays no major role, and because a preliminary test suggested that the effects of oil might be reduced when the oil is washed off by precipitation, we examined the effects of wet conditions or washing of oil-treated leaf surfaces. Mist bench treatment of oil-treated plants in 1998 appeared to reduce photosynthetic inhibition in one test (difference statistically significant at 5 but not at 2 and 10 d after treatment; $n=6$), but not in a subsequent test ($n=8$) at 2, 6, and 10 d after treatment. Leaving plants outside exposed to natural rain, or under occasional artificial sprinkling had no effect on P_n inhibition by prior oil application. A more targeted and thorough wash treatment of the lower leaf surfaces with water, with or without detergent, had at best a very modest ameliorative effect on oil-induced P_n depression 1 d later (statistically significant in only one set of measurements, Table 3).

Retention of oil emulsion by leaves. Oil emulsion retention by leaves differed consistently between 'Catawba' and 'Chardonnay' (Table 4). Data shown are for thorough wet-

ting of leaf undersides beyond runoff, which showed clearer differences than when leaves were sprayed with lesser volumes. When leaf undersides were sprayed with the backpack sprayer until just before runoff in one test, 'Chardonnay' retained oil emulsion equivalent to 123 of oil/cm² and 'Catawba' 150 $\mu\text{g}\cdot\text{cm}^{-2}$. When spraying was continued until drops started to coalesce and run off, 'Chardonnay' retained 105 $\mu\text{g}\cdot\text{cm}^{-2}$ and 'Catawba' 175 $\mu\text{g}\cdot\text{cm}^{-2}$ of oil.

When additional cultivars were tested for emulsion retention (Table 4), a partial relationship between emulsion retention and the soluble solids reduction seen in our field test (Table 1) appeared present for some cultivars. For example, 'Petit Verdot' had only modest visible injury, but a large SSC reduction and relatively high emulsion retention, whereas 'Vidal Blanc' also had only modest visible injury, but a small SSC reduction, and lower emulsion retention. Leaf areas were not determined in the 2000 experiments, but cultivar differences with respect to leaf weight per unit area (data not shown) were small in the 2004 tests.

In order to test whether the relationship between emulsion retention and P_n inhibition found in 'Chardonnay' and 'Catawba' extended to other cultivars, 'Primitivo' and 'Sangiovese' were selected because they showed the clearest retention differences in the two August 2000 retention tests (Table 4). 'Primitivo' experienced greater P_n depression than 'San-

Table 1. Increase in leaf injury symptoms (2 weeks after the second oil application), and change in berry weight, soluble solids concentration, and pH of wine grape cultivars treated twice with 1.5% (by volume) JMS Stylet-Oil in water and once with sulfur.

Cultivar ^a	Canopy symptoms (%)		Change in berry wt (g) ^y	Change in soluble solids	
	In oil treatment ^y	Increase ^y		(°Brix) ^y	Change in pH ^z
Cabernet Sauvignon 6	4 g ^x	-1	-0.21*	-1.1	0.0
Cabernet Sauvignon 8	4 fg	2	-0.14	-1.5	0.0
Charbono	47 a	9	0.24	-2.0*	0.1
Chardonnay	18* bc	18	-0.17*	2.9	0.2*
Chardonnay 4	7* defg	7	-0.18	-1.5	0.0
Fer Servadou	16 bcd	-14	-0.25	-1.4*	0.0
Gruner Veltliner	9* cdefg	9	-0.29	-2.1	0.1
Limberger	5 efg	3	-0.18	-0.8	0.0
Malvasia Bianca	13* bcde	13	-0.96*	-0.8	0.1*
Mataro	8 cdefg	7	-0.15	-1.1	0.1
Muscat Ottonel	12* bedef	11	-0.32	-2.4*	0.1
Nebbiolo	4* fg	4	-0.29*	-1.8	0.0
NY62.122.1	53 a*	46	-0.54*	-3.0*	0.1*
Petit Manseng	7* defg	7	-0.07	-3.9*	0.0
Petit Verdot	10* bcdefg	7	-0.27*	-3.0	0.0
Refosco	9 cdefg	0	-0.14	-0.6	0.1*
Sangiovese	6 efg	2	-0.42*	1.1	0.1*
Syrah	8 cdefg	2	-0.25	-1.8*	0.0
Tannat	7* defg	7	-0.21*	-1.6	0.1
Traminette	13* bcde	12	-0.28	-1.3	0.0
Valdepeñas	11 bcdef	-1	-0.23	-1.6	0.0
Vidal Blanc	7* defg	7	-0.20	-0.3	0.1
Viognier	20 b	15	-0.45*	-2.3*	-0.1
Average values	Injury		Berry wt	Soluble solids	pH
Control	6	NA	2.00	21.8	3.84
Oil-treated	13	NA	1.74	20.4	3.89

^aAll cultivars are *V. vinifera*, except for 'Chardonnay', 'NY62.122.1', 'Traminette', and 'Vidal Blanc', which are interspecific *Vitis* hybrids.

^yValue for oil-treated vines minus value for control.

^zLetters following numbers indicate significant differences (Duncan's new multiple range test, $P \leq 0.05$) between cultivars as determined by visual estimates of percentage of canopy affected by symptoms of phytotoxicity.

*Significantly different from the control value for the cultivar (Student's *t* test) at $P \leq 0.05$.

Fig 1. Time course of photosynthesis depression after oil application to upper and lower surfaces of 'Catawba' or 'Chardonnay' grape leaves (experiments not conducted at the same time). Error bars show standard error of the mean; each data point is based on 10 ('Catawba') or 12 ('Chardonnay') P_n readings.

giovese' did ($P = 0.01$), although individual readings were quite variable. Average P_n for 'Primitivo' was 14% of that in the control (6% in field measurements with 6 measurements per cultivar-treatment combination, and 17% for detached shoots with 10 measurements per cultivar-treatment combination) and for 'Sangiovese' 38% (33% in field measurements, $n = 6$, and 41% for detached shoots, $n = 10$). However, in June and September of 2004, no

emulsion retention differences were observed between these two cultivars for leaves from the same vineyard as in 2000 (Table 4); P_n was not measured in 2004.

Discussion

Photosynthesis was appreciably depressed by oil application only when the undersides of leaves were treated. Grape leaves are hy-

postomatous (Mullins et al., 1992), and it has been shown repeatedly that application of oils to leaf surfaces with stomata leads to greater leaf penetration as well as more visible injury (Dallyn, 1953; Kelley, 1930a; Rohrbach, 1934) and greater depression of transpiration (Kelley, 1930b) and photosynthesis (Dallyn, 1953; Kelley, 1930a; Rohrbach, 1934) than application to surfaces without stomata. Several authors have shown that oils of viscosities similar to JMS Stylet-Oil can also slowly penetrate through intact cuticles without stomatal openings (Ginsburg, 1931; Knight et al., 1929; Kùlps and Hein, 1972), but if penetration through the upper surface took place in our grape leaves, it was not enough to affect photosynthesis.

When oil application volumes are lowered, coverage of lower leaf surfaces may be compromised before coverage of upper surfaces is affected, especially when spray guns rather than airblast sprayers are used; this may be a reason for the effect of oil on photosynthesis to be particularly sensitive to spray volume (Finger et al., 2002).

Our results from application in light or dark indicate that stomata do not have to be open at the time of application for photosynthesis depression to occur. This contrasts with reports by Dallyn (1953) and Van Overbeek and Blondeau (1954) for lighter oils than JMS. Van Overbeek and Blondeau (1954) stated "If an emulsion of light oil is sprayed on young plants in the light when the stomata are open, the plants are killed. If the same emulsion is applied during the night when the stomata are closed, the plants are not harmed." With respect to spray pressure, when using oil as a mildew-eradicator spray, some growers will gun the spray material into the clusters to obtain thorough coverage. Our data indicate that this should have no more effect on leaf P_n depression than less forceful sprays.

Because we could not alleviate the P_n depression by washing off oil, and because of the translucent, soaked appearance observed in the field when oil sprays were followed by humid weather, we believe that JMS Stylet-Oil does penetrate slowly into intercellular spaces after application, either through closed stomata or after they open again, or through the cuticle which is thinner on the lower than on the upper leaf surface (Mullins et al., 1992). Such slow penetration has been reported repeatedly in studies with oils of similar viscosity (Kùlps and Hein, 1972; Lavile, 1963). The manufacturer of JMS Stylet-Oil states that a one-half to three-quarters of an inch (12 to 20 mm) of rain will wash most oil deposit from the leaves (Simons et al., 1995) [see also Bondada et al. (2000), who measured 80% removal of soy oil by 25 mm rain]. Because wet conditions or washing had minimal effects on P_n depression, it seems plausible that much of the surface deposit needed for antifungal action is removed, but not any oil that has penetrated into intercellular spaces, so that insecticidal and fungicidal residues are washed off well before P_n depressing levels dissipate.

The photosynthesis depression due to JMS Stylet-Oil on grape leaves lasted from a few

Table 2. Effect of oil application at different times (1300 to 1400 or 2030 HR) and at high or low pressure.

Spray timing	Spray pressure	Net photosynthesis ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)			
		Catawba		Chardonnay	
		1 d AOA ^z	4 d AOA	1 d AOA	4 d AOA
Early afternoon	Low	4.3 b ^y	5.8 bc	6.3 b	10.5 ab
Early afternoon	High	3.0 b	5.0 c	6.4 b	11.0 ab
Evening	Low	4.7 b	8.1 b	7.6 ab	9.7 ab
Evening	High	3.4 b	7.0 bc	6.8 ab	8.8 b
Not treated		10.3 a	13.6 a	9.7 a	11.6 a
Significance, early afternoon vs. evening		NS	$P = 0.01$	NS	NS
Significance, high vs. low pressure		$P = 0.049$	NS	NS	NS

^zAOA = after oil application.

^yNumbers followed by the same letter are not significantly different according to Duncan's new multiple range test at $P \leq 0.05$; $n = 8$.

^{NS}Nonsignificant. Interactions between application timing and pressure were not significant.

Table 3. Effect of washing undersides of oil-treated leaves with water or with detergent solution on depression of net photosynthesis.

Cultivar	Treatment	Net photosynthesis ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)				
		Test 1 (n = 6)			Test 2 (n = 8)	
		1 d AOA ^a BW ^b	1 d AOA AW ^b	7 d AOA	2 d AOA AW ^b	10 d AOA
Catawba	Oil, not washed	3.2	3.9	4.2	2.1	8.9
	Oil, water-washed	3.6	2.0	9.3 ^c	3.3	10.0
	Oil, detergent-washed	---	---	---	3.9	10.7
	No oil	13.1	11.7	13.7	11.2	12.5
Chardonnay	No oil, detergent-washed	---	---	---	9.9	14.6
	Oil, not washed	8.4	7.3	10.0	---	---
	Oil, water-washed	7.1	7.7	9.8	---	---
	No oil	9.6	9.0	10.9	---	---

^aAOA = after oil application; leaves were washed 1 day after oil application.

^bBW = before washing, AW = after washing.

^cSignificantly different from oil-not washed treatment. Other differences between washed and not washed were not significant at $P \leq 0.05$. Cultivar effect (Test 1) and oil versus no oil were significantly different on all measurement dates.

days ('Chardonnay') to about 3 weeks (some tests with 'Catawba'). A similar range has been observed in other studies with various spray oils applied to citrus (Riehl and Wedding, 1959; Wedding et al., 1952), with soy oil applied to burning bush (Lancaster, 2002), and with soy oil and SunSpray Ultrafine spray oil applied to apple (Moran, 2003). Riehl and Wedding (1959) equated the duration of photosynthesis depression with duration of oil-soaked appearance of leaves, but this was not the case in our potted-plant tests in which soaked appearance occurred only to a very limited extent.

The difference in P_n depression duration between 'Chardonnay' and 'Catawba' is most likely due to differences in oil retention. 'Catawba' has a high density of prostrate hairs on the lower leaf surface and retained more than twice as much spray liquid as the glabrous leaves of 'Chardonnay'. With respect to symptom development (mild in both cultivars), 'Chardonnay' appeared more susceptible than 'Catawba'. Leaf emulsion retention tests used a high volume spray that resulted in runoff because this seemed realistic for a situation where a treatment providing thorough penetration into clusters is required. After runoff, the quantity of oil on the lower leaf surface (weighted average of tests) ranged from 88 $\mu\text{g}\cdot\text{cm}^{-2}$ ('Chardonnay') to 168 $\mu\text{g}\cdot\text{cm}^{-2}$ ('Catawba'). Values reported in the literature are usually based on treatment of both leaf sides.

Oil deposits of 150 $\mu\text{g}\cdot\text{cm}^{-2}$ of citrus leaf did not consistently depress photosynthesis, but 300 to 600 μg increasingly depressed P_n (Riehl and Wedding, 1959). Increasing soybean oil deposits on apple increased the degree of P_n reduction, with a 50% reduction occurring around 158 $\mu\text{g}\cdot\text{cm}^{-2}$ (Fig. 6 in Moran et al., 2003) and an estimated residue threshold of about 230 $\mu\text{g}\cdot\text{cm}^{-2}$ for phytotoxicity (visible injury).

Our cultivar comparison showed that sensitivity to visible injury and to soluble solids depression varies somewhat, but that differences among the cultivars tested were not large. Differences in oil retention may be one factor contributing to cultivar differences in P_n depression. Pubescent tomato (Antonious and Synder, 1993), soybean (Ennis et al., 1952) and apple leaves (Hall et al., 1997; Kelley 1930a for pubescent younger leaves) retained more spray deposit than did more glabrous leaves. Factors other than cultivar probably affect oil retention as well, for example, use of surfactants in other spray materials, age of leaf (Hall et al., 1997), and possibly growing conditions.

The application of sulfur 4 d after the first oil spray may have exacerbated the phytotoxic effects of oil in the field test. Ferree et al. (1999) reported a reduction of net photosynthesis of apple leaves by sulfur, especially when mixed with oil. Finger (2000) examined the interactions between the effects of oil at 1.5%

by volume and sulfur at 10 $\text{kg}\cdot\text{ha}^{-1}$ in a test on 'Seyval' grapevines. Oil suppressed P_n in measurements 10 and 14 d after the first application and 8 d after the second application, whereas sulfur suppressed net photosynthesis only in one measurement, 8 d after the second treatment, especially in the presence of oil. The sulfur by oil interaction was insignificant for all measurements. While this test with the interspecific hybrid 'Seyval' did not reveal a pronounced effect of sulfur, it is uncertain whether other cultivars would respond in the same fashion. None of the cultivars in the cultivar planting appeared to be particularly sensitive to sulfur phytotoxicity under normal usage rates and ambient temperatures.

These studies have shown that quality of coverage of the lower leaf surface determines the degree of photosynthesis depression, that subsequent washing has limited effect, that modest differences in response to oil application exist among cultivars, and that differences in the amount of spray retained can contribute to cultivar differences in photosynthesis depression. Frequent use of oils may be inadvisable, and when eradicant activity is needed, it would be useful to compare the utility of alternatives (e.g., sulfur or bicarbonate) to that of oil.

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Table 4. Retention of oil emulsion by grape leaves of different cultivars. All cultivars are *V. vinifera* with the following exceptions: 'Catawba' (*V. labrusca*), 'Traminette', and 'Vidal blanc' (interspecific *Vitis* hybrids).

Cultivar	Emulsion retention (% of leaf fresh wt)				Emulsion retention ($\text{mg}\cdot\text{cm}^{-2}$)	
	July 2000 n = 5	August 2000 n = 5	August 2000 n = 5	September 2000 n = 10	June 2004 n = 12	September 2004 n = 12
Cabernet Sauvignon	---	29 bcd ^a	34 ab	---	10.3 bc	13.0 a
Catawba	84 a	69 a	---	76 a	14.6 a	12.6 ^a a
Chardonnay	29 b	30 bc	---	32 c	6.6 e	7.5 c
Malvasia	---	26 bcd	28 bc	---	9.6 cd	8.8 c
Muscat Ottonel	---	---	27 bc	29 c	---	---
Petit Manseng	---	---	---	50 b	---	---
Petit Verdot	---	---	---	50 b	11.2 b	12.5 b
Primitivo	---	36 b	37 a	---	8.6 d	8.8 c
Sangiovese	---	19 d	25 c	---	8.1 d	8.3 c
Traminette	---	---	---	---	11.4 b	9.0 c
Vidal Blanc	---	24 cd	24 c	---	9.2 cd	8.1 c
Viognier	---	---	---	35 c	11.3 b	10.6 b

^aNumbers in a column followed by the same letter are not significantly different according to Duncan's new multiple range test at $P \leq 0.05$.

^bGreenhouse-grown leaves of Catawba were used in this experiment only.

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