

# Effects of Horticultural Oils on the Photosynthesis, Fruit Maturity, and Crop Yield of Winegrapes

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The effects of horticultural oils on grapevine photosynthesis, fruit maturity, and crop yield components in field experiments were evaluated. Three applications of a 1.5% (v/v) oil/water emulsion were made to Chardonnay and Cabernet Sauvignon vine canopies at 6200 L/Ha (Chardonnay) and 2440 L/Ha (Cabernet Sauvignon) in 1998 using several horticultural oils. Net assimilation rates (NAR) and fruit soluble solids concentrations (SSC) were reduced in both cultivars by all oils, as compared to the control. In addition, berry weights, cluster weights, crop per vine, and vine pruning weights were all reduced by oil treatments to Chardonnay vines. Experiments in 1999 sought to determine if reduced spray volumes or applications to only the fruit zone minimized reductions in NAR and SSC. Chardonnay and Cabernet Sauvignon were treated twice with JMS Stylet-Oil™ (1.5%) using 5600 L/Ha or 1870 L/Ha applied to the whole canopy or 930 L/Ha applied only to the fruit zone. The NAR of 5600 L/Ha-treated Cabernet Sauvignon was significantly lower than the NAR of 1870 L/Ha oil-treated vines on three of four subsequent measurement dates. The NAR of Chardonnay in either the 1870 or 5600 L/Ha whole canopy oil treatments was significantly lower than the NAR of the water treatment at all measurement dates. Oil application to only the fruit zone (930 L/Ha) reduced the negative impact on NAR. Cabernet Sauvignon fruit SSC was consistently reduced by the 5600 L/Ha and 1870 L/Ha treatments, relative to the water-treated control. Similarly, the SSC of Chardonnay fruit in the 1870 and 5600 L/Ha treatments was consistently reduced compared to controls. Oil effects on fruit pH and titratable acidity were occasionally observed. While horticultural oils may serve as effective fungicides, our results highlight the potential negative impacts they can have on fruit composition and fruitfulness if used excessively.

**Key words:** Horticultural oil, photosynthesis, crop yield components, powdery mildew, NAR

Horticultural oils have been used to control aphids, mites, scales, leaf rollers, as well as some fungal diseases. Martin and Salmon [17] showed that oils have fungicidal properties, perhaps by smothering the fungi. Since then, oils have been used to control fungal diseases such as powdery mildew in many horticultural crops [2]. In 1964, Castellani and Matta [4] found that oils controlled powdery mildew in grapes. More recently, Northover and Schneider [23] reported that mineral and vegetable oils have both protectant and eradicant activity on grape leaves.

All chemicals currently used to control grape powdery mildew (*Uncinula necator*) have limitations. Sulfur is ineffective at low temperatures and sometimes phytotoxic at temperatures greater than 32°C. The use of sulfur is also limited in the preharvest period because sulfur residues can interfere with fermentation. Care must also be exercised with the sterol biosynthesis-inhibiting (SBI) fungicides and with the more recently introduced strobilurins because of the potential for resistance development [40]. Powdery mildew resistance to SBI fungicides

has been documented in several grape-growing regions [1,7,11,30]. Because oils have eradicant activity against grape powdery mildew and could be used if or when conventional disease control programs fail, they could provide an important supplement to traditional chemical controls. Also, fungi are less likely to develop resistance to oils than to many other chemicals because the mode of action of oils is probably not directed at a specific biochemical target site. Oils are low in toxicity, thought to be environmentally benign, and less expensive than many other fungicides [15,23]. Fermentation is not affected by oil residues [6].

One drawback to horticultural oils is that they may impair physiologic function and delay fruit maturity. Oil phytotoxicity has been observed in several crops, including grapes [19], and photosynthesis rates were reduced by mineral or vegetable oils in several horticultural crops [12,33,39]. Impaired photosynthesis can retard sugar accumulation and will reduce vegetative growth if prolonged suppression occurs [18]. Northover and Homeyer [21] found that repeated oil applications delayed sugar accumulation in the fruit of several grape cultivars.

Given these concerns, research was needed to understand the impact of oils in a grape disease management program. Our specific intent was to quantify reductions in photosynthesis and delays in fruit maturity caused by oils and to determine if those negative features could be minimized while maintaining effective rates or volumes of oil application.

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## Materials and Methods

The mineral oils used in this project were JMS Stylet-Oil™ (JMS Flower Farms, Inc., Vero Beach, FL) and Sun Spray UltraFine™ (Sun Company, Inc., Marcus Hook, PA). A non-degummed soybean oil was also used in 1998. JMS Stylet-Oil contained 97.1% paraffinic oil (the remainder is emulsifier) with a 50% distillation point of 224°C, a viscosity of 70 sec Saybolt at 100°F [16] or approximately 13 mm<sup>2</sup>/sec (13 centistokes) at 40°C, and a density of 0.85 kg/L. The Sun Spray oil [31] contained 98.8% paraffinic oil, with a 50% distillation point of 212°C, and we measured a viscosity of approximately 15 mm<sup>2</sup>/sec at 40°C and a density of 0.85 kg/L. The non-degummed soybean oil (Central Soya, Decatur, IN) had a viscosity of 37 mm<sup>2</sup>/sec at 40°C, and a density of 0.92 kg/L.

**1998: Effects of horticultural oils.** *Vines:* Chardonnay vines grown at Virginia Tech Agricultural Research and Extension Center (AREC) in Winchester, Virginia were used. The vines were nine years old in 1998, spaced 2.1 m apart in 3.7-m wide rows, trained to an open-lyre system, and cordon-trained and spur-pruned. Cabernet Sauvignon vines were grown in a commercial vineyard in Leesburg, Virginia, and were 11 years old in 1998. The Cabernet vines were trained to a Casarsa trellis system (1.9-m unilateral cordon) and spur-pruned. Shoots originated from spurs and were positioned upright from a cordon 1.5 m above the ground. Row spacing was 3.4 m.

*Experimental design and treatments:* Experimental plots were selected approximately one week after bloom on the basis of comparable vine size and uniformity of shoot length. Chardonnay plots consisted of three vines each; Cabernet Sauvignon plots consisted of two. Within each vineyard, treatment plots were replicated five times in a completely randomized design, with border plots between treatment plots, appropriate for hand-gun spray application. Shoot density was standardized to 15 shoots per meter of cordon by removing an average of three shoots per vine. Crop was standardized to avoid the potential, confounding effects of varied crop levels on photosynthesis and fruit ripening. Clusters were thinned three weeks after bloom to 40 clusters per vine, removing an average of five clusters per vine. The Chardonnay shoots were hedged in early June and late July, while the Cabernet Sauvignon vines were hedged once in July. Shoots of both cultivars retained approximately 17 primary leaves after hedging.

The Chardonnay treatments consisted of unsprayed control, JMS Stylet-Oil, or soybean oil. Both oils were applied to entire canopies as a 1.5% (v/v) emulsion of oil in water. Treatments were applied on 9 June, 22 June, and 3 August using a hand-held spray nozzle attached to an air-blast sprayer operated at approximately 1400 kPa. Chardonnay full bloom and veraison dates in 1998 were ca. 30 May and 5 August, respectively. The oil/water treatments were liberally applied, ensuring that all fruit clusters and foliage were well wetted. Both the interior and exterior of the Chardonnay divided canopies were sprayed. A 3-meter high plastic sheet mounted between two wooden posts was used to prevent oil from contacting nontarget vines. Based on usage, the volume of oil/water used was calculated as 6200 L/Ha, much of which ran off foliage and fruit.

Treatments used with the Cabernet Sauvignon were unsprayed control, JMS Stylet-Oil, soybean oil, or Sun Spray UltraFine oil. A 1.5% (v/v) emulsion of oil in water was applied to entire canopies at a postdetermined rate of 2440 L/Ha. Treatments were applied on 23 June, 10 July, and 27 July using a 12-L backpack sprayer. As with the Chardonnay, an effort was made to wet all leaf area and fruit clusters, spraying both sides of the canopy. Cabernet Sauvignon full bloom and veraison dates in 1998 were ca. 3 June and 5 August, respectively.

Because the objective of this study was to evaluate only the physiological consequences and not the fungicidal efficacy of oils, the vines in both vineyards were subjected to a pest management program typical for Virginia [24]. Powdery mildew fungicides used included azoxystrobin, fenarimol, myclobutanil, sulfur, and triadimefon. Sulfur was not applied for at least 10 days before and after oil applications in the Cabernet Sauvignon vineyard and was not applied to the Chardonnay after May 20.

Canopy densities of treatment plots were quantified five weeks after bloom to isolate possible effects of canopy density on fruit composition. A point quadrat analysis (PQA), as described by Smart and Robinson [28], was used to characterize cluster exposure, leaf layers, and canopy gaps.

*Photosynthesis measurements:* Leaf net assimilation rate (NAR) was used as an indicator of the photosynthetic activity of vines in both experiments. Readings were taken with a portable photosynthesis measurement system (model LCA2; Analytical Development Co. [ADC], Ltd., Hoddesdon, England) with leaf chamber (ADC PLC-7504). All readings were taken on clear days with light levels typically at or above 1500  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$ . Readings were done between 1000 and 1600 hr using fully expanded, midshoot leaves that had no visible symptoms of injury. Eight measurements were taken in each Chardonnay plot; five in each Cabernet Sauvignon plot. NAR, transpiration rate (E), and stomatal conductance ( $g_s$ ) were calculated using formulas that accounted for leaf chamber area, gas flow, ambient temperature, humidity, and CO<sub>2</sub> differential across the leaf chamber [9]. The mole fractions of water vapor at the leaf chamber inlet and outlet were calculated from tabular saturated mole fraction values [20], based on our chamber air temperature and actual RH.

*Fruit maturity:* Three fruit samples (80 berries/plot of Chardonnay and 50 berries/plot of Cabernet Sauvignon) were taken at two-week intervals between veraison and harvest. Soluble solids concentration (SSC) was determined with a hand-held refractometer (model 10430; Reichert Scientific Instruments, Buffalo, NY), pH was determined using a portable pH meter (model AP5; Fisher Scientific, Denver, CO), and titratable acidity (TA) was determined by procedures in Zoecklein et al. [41].

*Yield components and pruning weights:* Clusters per vine and total crop per vine were determined at harvest, from which average cluster weights were calculated. The harvest of Cabernet Sauvignon was dictated by the vineyard owner and corresponded to a SSC of approximately 22 Brix in the control plots, at which point all treatments were harvested. Harvest of oil-treated Chardonnay was delayed beyond that of the control to determine the time required for oil-treated vines to reach a

comparable fruit SSC (21 Brix). Cane pruning weights were recorded for all plots during the ensuing dormant pruning.

**1999: Effect of spray volume of JMS Stylet-Oil.** *Vineyards:* Cabernet Sauvignon vines were grown at Virginia Tech AREC in Winchester, Virginia. The spacing and training was identical to that described for the Chardonnay used in 1998. Chardonnay vines used in 1999 were grown in a commercial vineyard in Leesburg, Virginia, with spacing and training identical to that described for the Cabernet Sauvignon used in 1998.

*Experimental design and treatments:* As in 1998, plots with vines of similar vigor and shoot lengths were chosen immediately before initial treatment application. Cabernet Sauvignon plots contained three vines each; Chardonnay contained two.

Treatments consisted of: (1) an unsprayed control; (2) water only, applied to entire canopy at a rate of 1870 L/Ha; (3) JMS Stylet-Oil applied only to the fruit zone as a 1.5% (v/v) emulsion in water at a volume of 930 L/Ha; (4) JMS Stylet-Oil applied to the entire canopy as a 1.5% (v/v) emulsion in water at a volume of 1870 L/Ha; and (5) JMS Stylet-Oil applied to the entire canopy as a 1.5% (v/v) emulsion in water at a volume of 5600 L/Ha.

Treatments were replicated four times in a completely randomized design in each vineyard, except that the water-only treatment on Cabernet Sauvignon was only replicated three times. Shoot density and crop adjustment, as well as shoot hedging, were similar to methods described for 1998. Treatment applications were made in the Cabernet Sauvignon vineyard on 21 July and 9 August. Cabernet Sauvignon full bloom and veraison dates in 1999 were ca. 26 May and 17 August, respectively. In the Chardonnay vineyard, applications were made on 20 July and 11 August. Chardonnay full bloom and veraison dates in 1999 were ca. 23 May and 7 August, respectively. Treatments were applied using a hand-held spray nozzle attached to a sprayer operated at approximately 560 kPa.

*Photosynthesis:* Two NAR measurements were made after each treatment application using the same apparatus and calculations as in 1998. Eight measurements were taken in each Cabernet Sauvignon plot on 23 July, and 3, 13, and 17 August. Five measurements per Chardonnay plot were made on 22 and 28 July and 16 and 19 August.

*Fruit maturity:* Cabernet Sauvignon fruit samples (80 berries/plot) were taken on 1 and 17 September and 1 and 12 October. Fruit samples (50 berries/plot) were taken in the Chardonnay vineyard on 16 and 31 August and 10 September. Berry weight, soluble solids concentration, and pH were determined for all samples as in 1998. TA was only determined for the final sample of each cultivar.

*Yield components and pruning weights:* Crop yield components were determined in 1999 as in 1998. Cane pruning weights were recorded during the subsequent dormant period. Flower clusters and shoots were counted on all treatment vines before bloom in 2000 to determine if 1999 season treatments affected subsequent year fruitfulness.

*Statistical analysis:* Statistical analyses of all data were performed using SAS-PC (version 7) software (SAS Institute, Inc. Cary, NC). Treatment effects were analyzed using one-way ANOVA. For the 1998 data, treatment means were compared using Duncan's new multiple range test because only three or four means were compared and the treatments were unrelated. Preplanned single degree of freedom, nonorthogonal contrasts were used to compare means with the 1999 data.

## Results

**1998: Effects of oil on net assimilation rate (NAR), fruit maturity, and yield of Cabernet Sauvignon and Chardonnay grapevines.** The oils did not cause visible injury to the foliage of either cultivar, except for small necrotic areas where oil pooled on leaves. We did note that soybean oil imparted a persistent, oily appearance to the leaves and fruit. Those tissues were warm to the touch on sunny days, compared to control leaves, whereas mineral oil-treated leaves remained cool, apparently transpiring. Residues of JMS Stylet-Oil and Sun Spray UltraFine oil did not appear as persistent as the soybean oil. When we kept dishes of each oil in a gentle air stream at 25°C for several days, the JMS and Sun Spray oils lost about 61 and 55  $\mu\text{g}\cdot\text{cm}^{-2}\cdot\text{day}^{-1}$ , respectively, but the soybean oil experienced no measurable weight loss.

Canopy densities of Cabernet Sauvignon five weeks after bloom averaged 3.1 to 3.3 leaf layers in all treatments, except the soybean oil treatment plots, which averaged 2.6 leaf layers. There were no other significant differences in the canopy characteristics of Cabernet Sauvignon plots, and no significant differences in the Chardonnay plots, as measured by point quadrat analyses [9].

*NAR:* The NAR of all oil treatments was reduced, relative to controls, when measured eight or nine days after the first oil application (Table 1). The NAR of the Sun Spray oil treatment was significantly lower than the NAR of the JMS Stylet-Oil treatment at that point. Reapplication of oil sustained the depression of NARs by soybean and Sun Spray oils when measured on 13 July, and for all three oils on 28 July (Table 1). The NARs measured in Chardonnay treated with either oil were significantly lower than the NAR of the control on both 1 July and 4 August

**Table 1** Single leaf net assimilation rates of Cabernet Sauvignon and Chardonnay in response to three 1.5 % v/v oil treatments (2240 and 6200 L/Ha, respectively) in 1998.

Treatment	Net assimilation rate ( $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$ )				
	Cabernet Sauvignon			Chardonnay	
	1 Jul (8) <sup>a</sup>	13 Jul (3) <sup>a</sup>	28 Jul (1) <sup>a</sup>	1 Jul (9) <sup>a</sup>	4 Aug (1) <sup>a</sup>
Control	12.5 a <sup>b</sup>	11.8 a	16.3 a	13.0 a	11.4 a
JMS Stylet-Oil	10.5 b	10.3 ab	12.7 b	9.4 b	7.6 b
Soybean oil	9.4 bc	8.5 b	12.9 b	4.2 c	5.4 c
Sun Spray oil	8.7 c	8.5 b	13.1 b	na	na

<sup>a</sup>Numbers in parentheses following dates are the number of days elapsed since last oil treatment.

<sup>b</sup>Means, within columns, followed by a common letter are not significantly different at  $p \leq 0.05$  using Duncan's new multiple range test.

(Table 1). In addition, soybean oil caused a greater depression in NARs than did JMS Stylet-Oil on both dates. Calculations of  $E$  and  $g_s$  also showed corresponding reductions in these gas exchange variables with oil treatment. Values of  $g_s$  ( $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$ ) with Cabernet Sauvignon on 1 July were 251 (control), 183 (JMS Stylet-Oil), 155 (soybean oil), and 132 (Sun Spray oil), where all oils differed from the control ( $p \leq 0.05$ ). Similarly,  $g_s$  ( $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$ ) values with Chardonnay on 4 August were 302 (control), 191 (JMS Stylet-Oil), and 122 (Sun Spray oil), where all treatment means significantly differed from each other ( $p \leq 0.05$ ). While absolute values of  $E$  and  $g_s$  differed with date, the general response was a correlative decline in transpiration and stomatal conductance with decreased NAR (data not shown).

**Fruit maturity:** The only significant differences among the Cabernet Sauvignon SSC occurred with the 11 August sample, at which time the SSC measured in JMS Stylet-Oil and Sun Spray UltraFine samples was significantly lower than that of the control samples (Table 2). Despite the initial delay of SSC accumulation in oil-treated fruit, there were no significant differences in Cabernet Sauvignon SSC on 27 August or at harvest. The pH of Cabernet Sauvignon samples from control and soybean oil plots was significantly higher than the pH of JMS Stylet-Oil and Sun Spray UltraFine oil samples on 11 August (Table 2). A greater pH persisted for the soybean oil on 27 August; however, there were no pH differences at harvest on 14 September

**Table 2** Fruit soluble solids concentration and pH of Cabernet Sauvignon treated with 2240 L/Ha of 1.5 % v/v oil/water on 23 June, 10 July, and 27 July 1998.

Treatment	Soluble solids concn (Brix)			pH <sup>b</sup>		
	11 Aug	27 Aug	14 Sep	11 Aug	27 Aug	14 Sep
Control	15.3 a <sup>a</sup>	19.6	22.1	2.83 a	3.33 b	3.56
JMS Stylet-Oil	12.7 c	18.9	21.7	2.78 b	3.34 b	3.68
Soybean oil	14.2 ab	19.1	21.2	2.79 b	3.41 a	3.65
Sun Spray oil	13.7 bc	18.4	21.2	2.85 a	3.29 b	3.65

<sup>a</sup>Means, within columns, followed by a common letter, or no letter, are not significantly different at  $p \leq 0.05$  using Duncan's new multiple range test.

<sup>b</sup>Fruit pH was determined on previously frozen samples that resulted in a 0.1 to 0.2 pH unit increase in apparent pH [29].

**Table 3** Fruit soluble solids concentration, pH, titratable acidity (TA), berry and cluster weight, crop per vine, and pruning weight of Chardonnay treated with 1.5 % v/v oil/water at 6200 L/Ha on 9 June, 22 June, and 3 August 1998. Control plots were harvested on 8 September, JMS Stylet-Oil plots on 16 September, and soybean oil plots on 21 September.

Treatment	Soluble solids concn (Brix)					pH					TA (g/L)	
	13 Aug	26 Aug	8 Sep	16 Sep	21 Sep	13 Aug	26 Aug	8 Sep	16 Sep	21 Sep	26 Aug	8 Sep
Control	16.0 a <sup>a</sup>	18.5 a	21.3 a			3.00 c	3.54 c	3.67 c			8.9 ab	7.1
JMS Stylet-Oil	14.6 b	17.6 b	20.4 b	22.0 a		3.04 b	3.71 b	3.86 b	3.62		8.3 b	6.5
Soybean oil	12.3 c	15.8 c	18.5 c	20.5 b	20.3	3.08 a	3.75 a	3.95 a	3.65	3.66	9.3 a	6.7

  

Treatment	Berry wt (g)						Cluster wt (g)	Crop wt (kg/vine)	Pruning wt (kg/vine)
	15 July	13 Aug	26 Aug	8 Sep	16 Sep	21 Sep			
Control	1.0 a	1.5 a	1.6 a	1.6 a			127.4 a	5.4 a	2.5 a
JMS Stylet-Oil	0.7 b	1.1 b	1.3 b	1.3 b	1.3		103.5 b	4.3 b	2.2 ab
Soybean oil	0.7 b	1.1 b	1.3 b	1.3 b	1.2	1.3	103.1 b	4.3 b	2.1 b

<sup>a</sup>Means, within columns, followed by a common letter, or by no letter, are not significantly different at  $p \leq 0.05$  using Duncan's new multiple range test.

(Table 2). There were no significant differences among treatments in titratable acidity (TA) or berry weights of Cabernet Sauvignon on any sample date [9].

The SSC of Chardonnay from both oil treatments was significantly lower than the SSC of the control on all three common sample dates (Table 3). Soybean oil depressed SSC more than JMS Stylet-Oil. The harvest of JMS Stylet-Oil and soybean oil-treated Chardonnay was delayed 8 and 13 days, respectively. Soybean oil-treated fruit began to rot before attaining 21 Brix. The pH of Chardonnay control samples was significantly lower than the pH of oil treatment samples on all sample dates (Table 3). The TA measured in Chardonnay soybean oil treatment samples was significantly higher than the TA of JMS Stylet-Oil samples collected on 26 August (Table 3), but differences in TA among treatments were not significant on 8 September.

**Yield components and pruning weights:** Cabernet Sauvignon cane pruning weights, berry weights, cluster weights, and crop per vine were unaffected by oil [9]. By contrast, either oil reduced berry weights, cluster weights, and crop per vine, and soybean oil reduced cane pruning weights of Chardonnay vines (Table 3).

**1999: Effect of spray volume of JMS Stylet-Oil on photosynthesis, fruit maturity, and crop yield of Cabernet Sauvignon and Chardonnay grapevines.** NAR: Cabernet Sauvignon plots in Winchester that were treated with 5600 L/Ha of JMS Stylet-Oil applied to the whole canopy had the lowest NAR on all measurement dates, except 3 August (Table 4), 13 days after the first oil application. The NAR of the 5600 L/Ha treatment was less than half that of the water treatment on 12 August, three days after the second oil application. The NAR measured in the 1870 L/Ha treatment was significantly lower than the NAR of the water treatment on 23 July. NAR of the 930 L/Ha (fruit zone) treatment tended to be greater than that of the 1870 L/Ha whole canopy treatment on all dates, but significantly so only on 17 August. And, excepting 3 August, the NAR of the 5600 L/Ha treatment was significantly less than that of the 1870 L/Ha treatment (Table 4).

**Table 4** Leaf net assimilation rates of Cabernet Sauvignon and Chardonnay in response to 1.5% v/v JMS Stylet-Oil treatments applied at three different volumes in 1999.

Treatment <sup>a</sup>	Net assimilation rate ( $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$ )							
	Cabernet Sauvignon				Chardonnay			
	23 Jul (2) <sup>b</sup>	3 Aug (13)	12 Aug (3)	17 Aug (8)	22 Jul (2)	28 Jul (8)	16 Aug (6)	19 Aug (9)
1. Control	-	-	-	-	8.9	9.9	13.2	9.7
2. Water, 1870 L/Ha, WC	9.6	11.3	8.6	9.1	9.2	9.9	11.9	8.9
3. Oil, 930 L/Ha, FZ	8.7	11.5	8.5	10.0	8.0	8.9	9.8	7.4
4. Oil, 1870 L/Ha, WC	7.8	10.9	7.6	8.8	6.1	8.2	8.8	7.4
5. Oil, 5600 L/Ha, WC	5.0	10.6	3.2	6.2	4.5	8.0	10.0	8.1
<b>Contrasts (Pr &gt; F)<sup>c</sup></b>								
1 vs. 2	-	-	-	-	ns	ns	ns	ns
2 vs. 4	0.017	ns	ns	ns	< 0.0001	0.007	0.0005	0.02
3 vs. 4	ns	ns	ns	0.09	0.003	ns	ns	ns
4 vs. 5	0.0001	ns	< 0.0001	0.001	0.01	ns	ns	ns

<sup>a</sup>Applied to whole canopy (WC) or fruit zone (FZ) only.

<sup>b</sup>Numbers in parentheses following dates are the number of days elapsed since last oil treatment.

<sup>c</sup>Significance of single degree of freedom, non-orthogonal contrasts between preselected treatment combinations.

The NAR of the 1870 L/Ha treatment in the Chardonnay was significantly lower than the NAR of the water treatment on all dates (Table 4). The NAR of the 5600 L/Ha treatment was not significantly different from that of the 1870 L/Ha treatment, except on 22 July. The NAR of the 1870 L/Ha treatment was also lower than that of the 930 L/Ha treatment on 22 July. The control and water treatments never differed. NAR tended to recover with elapsed time after oil application (Table 4).

**Canopy characteristics:** Canopy characteristics of the Cabernet Sauvignon or Chardonnay vines did not differ among plots in 1999 [9]. As in 1998, the only visible injury caused by the oils was the occasional occurrence of small, necrotic spots where oil pooled.

**Fruit maturity measurements:** The SSCs of fruit sampled from Cabernet Sauvignon 1870 and 5600 L/Ha plots (whole canopy application) were consistently lower than the fruit SSCs of water-treated plots and were lower than the SSC of the 930 L/Ha

fruit zone treatment on the first three sample dates (Table 5). Fruit SSC did not differ between the 1870 and 5600 L/Ha rates. At harvest, water-treated plots of Cabernet Sauvignon still had greater SSC than did corresponding 1870 L/Ha oil plots (Table 5). There were no significant differences in the pH of Cabernet Sauvignon fruit samples in 1999, except on 1 September (Table 5). On that date, the pH of the 1870 and the 5600 L/Ha treatments was lower than the pH of the 930 L/Ha and water samples. The TA of Cabernet Sauvignon fruit at harvest from the 930 L/Ha treatment was significantly lower than the TA of fruit from the 1870 L/Ha and 5600 L/Ha treatments (Table 5).

Significant depressions in Chardonnay juice SSCs occurred with the 1870 L/Ha oil treatment, relative to the same volume of water only, on all three sample dates (Table 6). A similar depression occurred with the 5600 L/Ha treatment, as inferred from the lack of significant differences between the 1870 and 5600 L/Ha treatments. The fruit zone only (930 L/Ha) treatment was

**Table 5** Fruit soluble solids concentration, pH, titratable acidity (TA) (one date), and berry weights of Cabernet Sauvignon treated with 1.5 % v/v JMS Stylet-Oil at three different volumes on 21 July and 11 August 1999.

Treatment <sup>a</sup>	Soluble solids concn (Brix)				pH				TA (g/L)	Berry wt (g)			
	1 Sep	17 Sep	1 Oct	12 Oct	1 Sep	17 Sep	1 Oct	12 Oct	12 Oct	1 Sep	17 Sep	1 Oct	12 Oct
1. Water, 1870 L/Ha, WC	18.6	19.9	20.5	20.4	3.35	3.58	3.71	3.64	4.1	1.4	1.6	1.6	1.5
2. Oil, 930 L/Ha, FZ	18.4	19.0	20.1	19.9	3.38	3.58	3.69	3.59	3.8	1.4	1.5	1.5	1.5
3. Oil, 1870 L/Ha, WC	17.3	18.1	19.0	19.2	3.31	3.53	3.68	3.61	4.4	1.4	1.6	1.6	1.6
4. Oil, 5600 L/Ha, WC	16.4	17.5	18.6	18.8	3.29	3.52	3.66	3.57	4.6	1.3	1.4	1.5	1.5
<b>Contrasts (Pr &gt; F)<sup>b</sup></b>													
1 vs. 3	0.05	0.002	0.08	0.08	ns	ns	ns	ns	ns	ns	ns	0.02	ns
2 vs. 3	0.08	0.05	0.06	ns	0.03	ns	ns	ns	0.007	ns	ns	0.007	ns
3 vs. 4	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.08	0.03	0.009	0.06

<sup>a</sup>Applied to whole canopy (WC) or fruit zone (FZ).

<sup>b</sup>Significance of single degree of freedom, non-orthogonal contrasts between preselected treatment combinations.

**Table 6** Soluble solids concentration, pH, titratable acidity (TA) (one date), and berry weight of Chardonnay treated with 1.5 % v/v JMS Stylet-Oil using three different volumes on 20 July and 10 August 1999.

Treatment <sup>a</sup>	Soluble solids concn (Brix)			pH			TA (g/L)	Berry wt (g)		
	16 Aug	31 Aug	10 Sep	16 Aug	31 Aug	10 Sept	10 Sep	16 Aug	31 Aug	10 Sep
1. Control	14.6	19.0	19.0	2.91	3.41	3.62	5.0	1.4	1.6	1.8
2. Water, 1870 L/Ha, WC	15.2	19.6	19.6	2.86	3.33	3.49	5.3	1.6	1.7	1.9
3. Oil, 930 L/Ha, FZ	14.9	18.4	18.4	2.87	3.38	3.55	5.1	1.6	1.8	1.9
4. Oil, 1870 L/Ha, WC	13.0	18.2	18.2	2.87	3.43	3.61	4.9	1.4	1.7	1.7
5. Oil, 5600 L/Ha, WC	14.3	18.3	17.9	2.82	3.36	3.50	5.0	1.3	1.6	1.7
<b>Contrasts (Pr &gt; F)<sup>b</sup></b>										
1 vs. 2	ns	ns	ns	ns	ns	0.02	ns	ns	ns	ns
2 vs. 4	0.01	0.03	0.006	ns	ns	0.02	ns	ns	ns	0.08
3 vs. 4	0.03	ns	ns	ns	ns	ns	ns	ns	ns	ns
4 vs. 5	ns	ns	ns	ns	ns	0.04	ns	ns	ns	ns

<sup>a</sup>Applied to whole canopy (WC) or fruit zone (FZ).

<sup>b</sup>Significance of single degree of freedom, non-orthogonal contrasts between preselected treatment combinations.

initially (16 August) less affected by oil than the 1870 L/Ha treatment, but that difference did not persist. The juice SSC of untreated vines did not differ from that of the water-treated vines (Table 6). The pH and TA of Chardonnay fruit were generally unaffected; however, the untreated control and the 1870 L/Ha oil treatment had the greatest pH levels at harvest (Table 6).

**Berry weight:** Cabernet Sauvignon berry weights were affected by oil application, with a significant reduction in weight recorded between the 1870 and 5600 L/Ha application at each sample date (Table 5). Small but significant treatment differences were also noted on 1 October. Oil effects on Chardonnay berry weights were less pronounced, with a slight depression in berry weight of the 1870 L/Ha oil-treated fruit, relative to water-treated, noted at harvest (Table 6).

**Yield components and pruning weights:** There were no significant differences among any of the yield components of the four treatments in either the Cabernet Sauvignon or the Chardonnay [9]. Crop per vine averaged 5.9 to 6.3 kg for the Cabernet Sauvignon and 5.0 to 6.4 kg for the Chardonnay. Flower clusters per shoot were reduced by the higher rate of whole canopy oil application in the year after treatment (Table 7). Cane pruning weights averaged 1.6 to 1.7 kg per vine for the Cabernet, and 0.7 to 1.1 kg per vine for Chardonnay [9].

## Discussion

Visible injury of oil-treated foliage was slight in these experiments. Three 6200 L/Ha oil applications to Chardonnay in 1998 and two 5600 L/Ha oil applications made to Cabernet Sauvignon and Chardonnay in 1999 caused slight necrosis only where oil pooled on the leaves. Neither of these cultivars had other visible injury, although we have observed phytotoxicity when oils were applied temporally close to sulfur application, and with certain other cultivars [9].

Leaves used for NAR measurements appeared normal, without noticeable chlorosis or necrosis. Nonetheless, NAR was reduced considerably after oil application, to an extent dependent on the time elapsed since application. The NAR reductions in

**Table 7** Flower clusters per shoot of Cabernet Sauvignon and Chardonnay in the 2000 season following treatment with three different volumes of 1.5% v/v JMS Stylet-Oil in 1999.

Treatment <sup>a</sup>	Cabernet Sauvignon Winchester	Chardonnay Leesburg
1. Control	<sup>b</sup>	0.78
2. Water, 1870 L/Ha, WC	1.28	0.81
3. Oil, 930 L/Ha, FZ	1.20	0.70
4. Oil, 1870 L/Ha, WC	1.26	0.75
5. Oil, 5600 L/Ha, WC	1.07	0.53
<b>Contrasts (Pr &gt; F)<sup>c</sup></b>		
1 vs. 2	<sup>b</sup>	ns
2 vs. 4	ns	ns
3 vs. 4	ns	ns
4 vs. 5	0.006	0.04

<sup>a</sup>Applied to whole canopy (WC) or fruit zone (FZ).

<sup>b</sup>Treatment not used.

<sup>c</sup>Significance of single degree of freedom, non-orthogonal contrasts between preselected treatment combinations.

1999 may have been influenced by dry weather, as only 75 mm of rain (long-term average about 188 mm) was recorded for June and July at Winchester [9]. The Chardonnay in the Leesburg vineyard was not irrigated and had begun to exhibit drought stress by August. Water deficits, if pronounced, will reduce transpiration and photosynthesis [27]. Differences in NAR observed among treatments may therefore have been affected by drought. Water stress may also have contributed to the drop in NAR seen in all Chardonnay treatments between 16 and 19 August 1999.

The most obvious oil effect on grape yield and quality was a delay in fruit sugar accumulation in both 1998 and 1999. Oil-treated Chardonnay plots took up to 13 days longer than control plots to reach 21 Brix in 1998. Fruit pH and titratable acidity were less affected by oil application. Northover and Homeyer [21] observed depressed soluble solids accompanied by a limited effect on acidity in grapevines after four or five 1500 L/Ha oil applications using a rate of 1% v/v oil/water. Sugar accumulation in the fruit is dependent on leaf photosynthesis and a shift

in translocation, which result in the import of carbohydrate into the fruit rather than to growing vegetative structures [10]. Changes in pH and titratable acidity are caused by metabolic changes within the berry. After veraison, acid synthesis is inhibited and acids are converted into sugars [14,25]. Therefore, reduced photosynthate production in oil-treated leaves would be expected to have a greater direct effect on sugar accumulation than on acid reduction as fruit matures.

Heavy application (6200 L/Ha) of oil reduced berry weight, cluster weights, and crop per vine of Chardonnay in 1998, but differences were not statistically significant in 1999. Fruit set affects cluster weight and is influenced by photosynthate availability. Because oils were applied to the Chardonnay two weeks after bloom, fruit set had already occurred and the effects on cluster and crop weights were principally due to reduced berry size. Oil treatments reduced the berry weights of a range of winegrape cultivars in a separate 1998 study [9]. The effects of oil on vine performance in the year of application (1999 experiment) were also manifest in the following season as a reduction in the average number of flower clusters borne on shoots. While oils have been reported to reduce set and yield of oranges [6], we believe that ours is the first evidence that oils can reduce grape yields, including a reduction in fruitfulness in the year after application.

Pruning weights of Chardonnay were reduced by oil treatment in 1998. Between fruit set and harvest, clusters are stronger sinks for photosynthates than are trunks and roots [13]. When photosynthesis is limited, carbohydrate movement to the vegetative structures of the vine may be reduced. In 1999, it was observed that budbreak and shoot development were delayed in the Chardonnay vines that had been treated with oil in the previous season. No data were collected from these plots in 1999, but fruitfulness and vigor of the vines were visibly diminished. Previous season treatment with JMS Stylet-Oil appeared to delay development more than soybean oil. Carbohydrate accumulation in the annual wood is closely associated with the fruitfulness of developing buds; if starch accumulation is limited, yield may be reduced in the following year [32]. Carbohydrates stored in woody parts of the grapevine are necessary for shoot growth before leaves begin exporting photosynthates early in the season [26]. Although carbohydrate accumulation in the permanent structures of the vine was not measured, the lowered NAR of oil-treated grapevines may reduce carbohydrate storage and affect vigor and yield in subsequent seasons.

It was unclear if the differences in the severity of NAR reduction in 1998 were caused by varietal differences between Cabernet Sauvignon and Chardonnay, site differences, or the difference in the volume of oil used. To address the effect of application volume, treatments in 1999 compared two different rates of 1.5% JMS Stylet-Oil (5600 versus 1870 L/Ha) applied as a protectant to the whole canopy. Also, a 930 L/Ha treatment was included to determine if oil used as an eradicant and applied only to the fruit zone would reduce NAR and delay fruit maturity. Young grape clusters are very susceptible to powdery mildew infection, and fruit infection can lead to serious sensory flaws in the resultant wine. The rationale for testing the effects of oil application only to the fruit zone was that a powdery mil-

dew infestation of fruit might be arrested by oil directed only at the fruit zone. Our results suggest that limiting the oil/water application to the fruit zone does minimize the negative impact of oil on fruit chemistry. However, in a 1996 test to assess efficacy of 1% JMS Stylet-Oil against *Botrytis* bunch rot, six or seven oil applications mainly to the fruit zone of Seyval or Chardonnay grapes (470 L/Ha) reduced SSC by 1.0 or 1.3 Brix, respectively, at harvest (Baudoin, unpublished data). Noticeable chlorosis and necrotic stippling of basal leaves developed in that test.

A reduction in the spray volume reduced the negative impacts on NAR, SSC, and crop yield; however, the efficacy of oil as a fungicide depends on thorough tissue coverage. Wicks and colleagues [35] found that powdery mildew infections initially occurred within canopies due to poor coverage when 500 to 2000 L/Ha of 1% v/v oil/water were used. Wilcox and Riegel [38] found that reducing spray volumes from 1872 to 936 L/Ha after bloom reduced powdery mildew control by JMS Stylet-Oil. Efficacy of powdery mildew protection was not assessed in our study, but neither the 1870 L/Ha whole-canopy spray nor the 930 L/Ha fruit-zone spray provided complete coverage of clusters. The interior side of many clusters was incompletely covered, leaving those surfaces susceptible to powdery mildew infection. Without full coverage, an existing powdery mildew infection would not be eradicated. Other researchers have achieved good powdery mildew prevention on clusters using 1870 L/Ha of 1.5% JMS Stylet-Oil/water [37] or 936 L/Ha of 2% JMS Stylet-Oil/water [19]. Dell et al. [6] found that 935 to 1403 L/Ha of 2% JMS Stylet-Oil v/v with water, applied six times during the growing season with a hand-gun sprayer, significantly reduced powdery mildew incidence and severity on clusters. The incomplete coverage observed in our 1999 tests was a function of application methods. Oil was applied at 1400 kPa in 1998 and only 560 kPa in 1999. JMS Flower Farms recommends [16] applications of 1 to 2% JMS Stylet-Oil using 500 L/Ha of water at 1400 to 2450 kPa for fungicidal use. The Sun Company recommends [31] that Sun Spray UltraFine oil be used in dilute sprays of over 1260 L/Ha, but lower volume sprays can be used in an airblast sprayer. Coverage resulting from high-performance, airblast sprayers would likely have been better than that provided by our systems, but airblast sprayers were not an option given the small-plot nature of our experiments.

The severity of the reduction in NAR caused by the 6200 L/Ha soybean oil treatment as compared to the 6200 L/Ha JMS Stylet-Oil treatment may have been caused by differences in the physical properties of the oils. Soybean oil was clearly less volatile and more viscous than the other two oils. Nevertheless, low viscosity oil has sometimes caused a greater photosynthesis reduction than more viscous oil, if the low viscous oil penetrated the leaf, while the more viscous oil remained on the leaf surface [12]. Our measured reductions in E and  $g_s$ , which occurred concomitant to reductions in NAR, lead us to believe that the oil effect on NAR was primarily of a stomatal nature. However, oil-induced heating of leaves above ambient temperature may have exerted some nonstomatal effects on photosynthesis [8].

Despite the real or potential delay in fruit maturity, horticultural oil is still a valuable tool for fighting powdery mildew infections. New York State Integrated Pest Management rec-

ommendations list JMS Stylet-Oil as a possible supplement to conventional programs and as an early season protectant [34]. Oil is also recommended for use as a supplement in Oregon, but with the warning that the use of oils may cause a reduction in fruit soluble solids [3]. Oil could also be used as an inexpensive, late-season protectant, applied after harvest to keep vines free of powdery mildew, and other foliar pathogens, and to reduce inoculum for the next season. Perhaps the most valuable use of oils is as an eradicant: to eradicate colonies if a conventional disease management program fails. The risk of resistance development makes the use of SBI or strobilurin fungicides as eradicants inadvisable, and sulfur is a better protectant than eradicant. Oils could be used to salvage a grape crop if powdery mildew reached epidemic proportions, especially when powdery mildew becomes established on the clusters. Sprays directed at the fruit zones, at volumes sufficient to wet all cluster surfaces, could arrest the disease while minimizing the negative effects of oil on leaf gas exchange.

### Conclusions

Horticultural oils reduced grapevine photosynthesis rates, transpiration and stomatal conductance. The response was volume and frequency dependent, with high volumes of oil causing greater decreases in photosynthesis than lower volumes, and with NAR reductions sustained by repeated oil application. In addition to reducing photosynthesis, oils delayed the accumulation of soluble solids in fruit. Components of crop yield, including flower clusters per shoot in the subsequent year, were reduced when oil/water was applied at very high volumes (such as 5600 L/Ha).

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