EFFECTS OF HORTICULTURAL OILS ON PHOTOSYNTHESIS, FRUIT MATURITY, AND YIELD OF WINE GRAPES

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(Abstract)

In field experiments conducted in northern Virginia during 1998, oils reduced photosynthesis, fruit maturity, and crop yield. 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). Net assimilation rate (NAR), soluble solids concentration (SSC), and berry size were reduced by oil treatments when compared to an untreated control. Also in 1998, a 1.5% (v/v) oil/water emulsion at 5550 L/ha and 4680 L/ha was applied to 23 wine grape cultivars. Eleven cultivars had significant foliar injury but injury was not related to reductions in fruit maturity. Experiments conducted in 1999 determined if reduced spray volumes or applications to only the fruit zone minimize reductions in NAR and SSC. Chardonnay and Cabernet Sauvignon were treated with JMS Stylet oil (1.5%) using 5600 L/ha or 1870 L/ha applied to the whole canopy or 930 L/ha applied to the fruit zone. The NAR of 5600 L/ha treated Cabernet Sauvignon was significantly lower than the NAR of control and other oil treatments on three measurement dates. The NAR of Chardonnay in the 5600 L/ha treatment was significantly lower than the NAR of control treatments in three measurements. Cabernet Sauvignon SSC was reduced by the 5600 L/ha and 1870 L/ha treatments, relative to the water treated control, on three sample dates but not at harvest. The SSC of Chardonnay in the 5600 L/ha treatment was reduced at harvest as compared to all other treatments. The SSC of Chardonnay in the 1870 and 930 L/ha treatments was reduced relative to the water control. Low volumes of oil caused less reduction in NAR and SSC; however, there are concerns about the efficacy of oils used at low volumes due to poor coverage.

DEDICATION

This thesis is dedicated to my parents, Michael and Mary Finger, because they always let me have a sip of their wine.

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CHAPTER ONE
REVIEW OF LITERATURE

Oils have been used to control many pests and diseases in horticultural crops. Dormant oil applications can be used on fruit and ornamental crops to control aphids, mites, scales, and leaf rollers. The oils act by smothering the pest's eggs. Summer oil applications smother pests or suppress feeding and can be used to control mites and scales. Fungal diseases, including some leaf spots, powdery mildews, and rusts have also been controlled by oils. Powdery mildew control may represent the most valuable use for horticultural oils in Virginia vineyards. Because they are eradicants, oils could provide an important supplement to traditional control methods if they can be incorporated into disease management programs without adversely affecting vine physiology or fruit development.

Powdery mildew: Powdery mildew [*Uncinula necator* (Schw.) Burr.] is one of the most wide-spread fungal diseases of grapes (*Vitis* spp.). Because powdery mildew develops normally in a range of humidity levels, it is the major disease in dry climates such as California (Gubler and Hirschfelt, 1992). *V. vinifera* (L.) cultivars are highly susceptible to powdery mildew as are Asiatic grape species (*V. amurensis, V. armata, V. davidii, V. romaneti*); American grape species (*V. aestivalis, V. berlanderi, V. candicans, V. labrusca, V. riparia, V. rupestris*) are much less susceptible (Pearson and Goheen, 1988). In susceptible varieties, severe powdery mildew infections can cause heavy losses, decreasing yield, quality and marketability of the grape crop as well as reducing vine growth and winter hardiness.

U. necator, which causes powdery mildew, produces conidia from its mycelia that cover the leaf surface. The conidia give the fungus its characteristic white, dusty or powdery appearance. Powdery mildew is thought to overwinter as cleistothecia on the bark of grapevines in Virginia. In the spring, water stimulates the release of ascospores from the overwintering cleistothecia. Ascospores are then water-splashed or blown to infection sites. Early infections appear as small chlorotic or shiny spots on the upper leaf surface of exposed leaves or a white web of mycelia and conidia on the bottom surface of exposed leaves and both surfaces of shaded leaves. The primary infection often occurs on leaves or shoots close to the bark (Gubler and Hirschfelt,

1992). In some grape growing areas, if disease pressure was high in the previous growing season, buds can be infected with hyphae during development. The mycelia remain dormant on the inner bud scales during the winter. Their growth is reactivated after bud break and they cover the new shoot with mycelium and produce many conidia. The emerging infected shoot will appear light colored because of its mycelia and conidia covering and is called a "flag shoot" (Pearson and Goheen, 1988).

The conidia produced by the primary infection are carried by the wind and give rise to secondary infections. Powdery mildew requires an active host and can infect all green tissues of the grapevine after bud break. It produces haustoria that penetrate the epidermal cells of the infected tissue. Cells neighboring infected epidermal cells may become necrotic (Pearson and Goheen, 1988). Young or emerging leaves that become infected may become distorted or stunted. Infected petioles and rachises become brittle and break (Gubler and Hirschfelt, 1992). Red or brown lesions appear on green shoots when they become infected. Clusters become infected around bloom.

Powdery mildew infections can reduce fruit set and yield. Because the epidermal cells of infected berries are killed, infection also can result in fruit scarring and splitting. Scarred berries are not marketable as fresh fruit and have off flavors (Gubler and Hirschfelt, 1992). Split berries are susceptible to infection by fruit rots such as *Botrytis cinerea* Pers.(Pearson and Goheen, 1988). Berries can also be stunted by early infection (Gubler and Hirschfelt ,1992). Ough and Berg (1979) found that wine made from mildewed fruit had lower acidity and higher soluble solids concentrations than wine made from uninfected fruit. The wine from infected fruit also browned faster. In sensory evaluations, off flavors were detected in the wine. Pool *et al.*. (1984) detected off flavors in wine made from fruit with as little as 3% of the berries infected with powdery mildew. They also found that acid concentrations in infected fruit were elevated. Because acid reduction is a result of metabolic processes occurring in the fruit during development, this indicated that the infected fruit was not developing normally. Increased acids also cause decreased wine quality.

Losses caused by powdery mildew include both the immediate loss of yield due to poor fruit set or infection and longer term losses caused by reductions in vine growth and cold hardiness (Pearson and Goheen, 1988). If infection is severe, the photosynthesis rates and water use efficiency decrease (Lakso *et al.*, 1982). Lakso *et al.* in New York (1982) found that destruction of the palisade cell layer of the leaves of White Riesling (a cultivar susceptible to powdery mildew) by powdery mildew resulted in a greater decrease in photosynthesis than in Concord leaves (a less susceptible cultivar) that appeared to have similar levels of powdery mildew infection. Visual estimations of disease development were inaccurate predictors of physiological damage to the grapevine. Reduced photosynthesis may contribute to the reduced size of powdery mildew infected grapevines measured by Pool *et al.*. (1984). They also found that during a cold winter, many of the buds of infected vines were killed. Bud death related to powdery mildew infection lead to substantial economic losses in colder climates.

Disease control: To avoid these losses, grapes must be protected from powdery mildew. It is important to begin disease management programs early in the season to reduce the inoculum potential; late season disease problems often result from inadequate early control (Bettiga, 1989; Gubler and Hirschfelt, 1992). Cultural methods that improve air movement and sunlight penetration in the canopy can reduce the incidence and severity of powdery mildew infection but do not reduce disease to levels acceptable for commercial production. However, cultural methods such as leaf removal do have a significant effect when used in combination with fungicides (Chellemi and Marois, 1992). In the leaf removal experiment done by Chellemi and Marois (1992), diseased berries were found in the interior of the canopy. The reduced disease incidence in treatments that combined leaf removal and fungicides may have been caused by creating a microclimate at the berry surface that was not conducive to disease development. Leaf removal also may improve fungicide penetration into the canopy, improving the effectiveness of the fungicides.

Sulfur was the first effective fungicide used to control powdery mildew (Pearson and Goheen, 1988). Because it is still effective and is inexpensive, sulfur is still commonly used in vineyards. Sulfur works as a protectant by preventing spore germination (Grove, 2000). Elemental sulfur is approved for use in organically grown vineyards in California (Thomas *et al.*, 1993).

Unfortunately, use of sulfur in the spring may be limited by its ineffectiveness below 18°C and phytotoxicity above 30°C (Pearson and Goheen, 1988). Some wineries have excluded the use of sulfur near harvest because sulfur residue on the fruit can interfere with fermentation during wine making. Sulfur residues can cause objectionable aromas (Thomas *et al.*, 1993), and Schutz and Kunkee (1977) found that elemental sulfur in the must can cause the production of hydrogen sulfide by the yeasts during fermentation.

Newer fungicides for control of powdery mildew include the sterol biosynthesis inhibitors or SI fungicides. These products interfere with the formation of cell membranes (Grove, 2000). The narrowness of SI fungicides' mode of action has led to resistance problems which have decreased their effectiveness. Strains of powdery mildew resistant to SI fungicides have been found in many grape growing regions (Aloi *et al.*, 1990; Erickson and Wilcox, 1997; Gubler *et al.*, 1994; Steva *et al.*., 1989). Ypema and Gubler (1997) found that resistance developed fastest during periods of high disease pressure, especially when warm temperatures caused reproduction to occur quickly. The rapid production of ascospores resulted in an increased number of resistant strains (Gubler *et al.*, 1996). Resistance also developed more quickly in vineyards where SI fungicides were used exclusively (Gubler *et al.*, 1994). In France, Steva (1994) found that SI fungicides have a strong selective effect on natural populations. Reduced rate sprays selected for resistant strains more strongly than sprays using the full recommended rate of fungicide.

The use of strategies to avoid resistance development is very important. Tank mixes of SI fungicides and sulfur cannot be used as an anti-resistance strategy because the two fungicides are antagonistic (Steva, 1994). But spray programs which alternate SI fungicide applications with fungicides with different modes of action have been very effective in slowing the development of powdery mildew resistance (Steva, 1994). Other resistance avoidance strategies include: limiting the number of sprays of one type of fungicide, using careful timing of sprays in the early season to control disease when the population is small, and blocking sprays to insure that no single type of fungicide is used in several sprays in a row (Grove, 2000). By changing the metabolism of the plant, SI's may change the aroma compounds present in the mature fruit (Aubert *et al.*, 1998). However, fungicides present as residues on the fruit and in the must are

eliminated or greatly reduced during the wine making process (Garcia-Cazorla, and Xirau-Vayreda, 1994; Navarro *et al.*, 1999).

Strobilurins are fungicides which were recently developed to control several grape diseases including powdery mildew and are now being labeled for use in vineyards. They are organic compounds with structures modeled after natural compounds produced by certain fungi found in rotting wood. Their mode of action is to inhibit spore germination by disrupting the mitochondrial electron transport system and therefore the cell's ability to produce energy. The strobilurins are mildly systemic and have some curative activity. However, because they have a site specific mode of action, they are recommended only for preventative use to avoid the development of resistance and maintain their effectiveness. (Grove, 2000)

Fungicides are used on 93% of the grape acreage in the United States (Fernandez-Cornejo,1998). This reliance on fungicides and the need for new fungicides to rotate with SI's and strobilurins to avoid resistance has led to interest in alternative fungicides. Government regulation has also led to a greater interest in pesticide alternatives. In accordance with the Food Quality Protection Act (FQPA) passed in 1996, the EPA will be reviewing the registration and tolerances of approximately 9000 pesticides and the use of some products may be restricted or eliminated (Johnson, 1997). A report from Washington State University estimated that the loss of sulfur from the powdery mildew control arsenal would cost the Pacific Northwest grape industry $37.5 million and the loss of SI fungicides would cost as much as $11.9 million. The loss of sulfur or SI fungicides would also challenge grape grower's ability to control powdery mildew and produce marketable crops (Hansen, 1997). The FQPA explicitly recognizes the importance of reduced-risk pesticides and supports quick review of these products to help them reach the market to replace some of the older, potentially riskier, chemicals (Uri, 1997).

Many chemicals and organisms have been investigated as possible controls of grape powdery mildew. Biocompatible products, such as phosphates, are able to control powdery mildew and have low toxicity (Reuveni and Reuveni, 1995). Another mineral, silicon, may be used by plants as a defense mechanism to powdery mildew infection (Bowen *et al.*, 1992) and can reduce grape powdery mildew infection without adverse effects but does not control the disease as well as

conventional fungicides (Reynolds *et al.*, 1996). In New York, English-Loeb *et al.* (1999) found that populations of a Tydeid mite can reduce powdery mildew cleistothecia production by 50%. Because powdery mildew grows on the leaf surface, it is vulnerable to mite predation making mites a potential biological control agent for the disease in the limited areas where the Tydeid mite occurs naturally. Integrated pest management strategies, which reduce the amount of pesticides used, are also encouraged by provisions in the FQPA. These strategies can be effective and economical when used in vineyards (Fernandez-Cornejo,1998).

Oils: The fungicidal properties of mineral oils and vegetable oils, both also biocompatible products, have been known for a long time. In 1930, Martin and Salmon investigated the fungicidal properties of several types of oil in order to find a replacement for sulfur. They found that, with good coverage, mineral oils used at a rate of 2% killed fungal diseases of hops plants. They suggested that oil acts by smothering the fungus. However, when applied during warm weather oil caused severe injury to leaves (chlorosis, margin burn, and stippling). They attributed the phytotoxic effects to aromatic hydrocarbons and sulfur compounds in the oil and proposed that higher quality oils without these impurities would not be phytotoxic to green plant tissues. Vegetable oils were also found to be effective fungicides with necessary rates varying with oil type. The vegetable oils did not cause injury to growing hops plants. (Martin and Salmon, 1931)

Calpouzos (1966a) found that oils have both protectant and therapeutic properties and possibly act by inhibiting hyphal growth of *Mycosphaerella musicola*, the cause of banana leaf spot. Castelliani and Matta (1964) discovered that oil stopped conidia germination of powdery mildew on cucumber leaves and slowed mycelial growth. The advantages of oils listed by Calpouzos (1966a) are: superior disease control, effectiveness at low rates, low cost, and little or no toxicity to humans or animals. More recently, other researchers have found mineral and vegetable oils to provide good control of fungal diseases and present oils as a possible alternative to more toxic and more expensive synthetic fungicides (Horst and Kawamoto, 1992; Northover and Schneider, 1996). Because the action of oil is not directed at a specific physiological process, but seems to physically smother the pest, resistance to oil's mode of action should be slow to develop.

Oils can control powdery mildew on many horticultural crops. Pasini *et al.* (1997) discovered that mineral (JMS Stylet oil) and vegetable (canola) oils act as a physical or chemical barrier to protect the foliage of roses from penetration by powdery mildew. The oils gave satisfactory control alone and their efficacy improved when combined with bicarbonate applications (Horst *et al.*, 1992; Pasini *et al.*, 1997). Pre-inoculation treatment with a refined mineral oil (Sun Spray Ultra Fine oil) prevented the establishment of powdery mildew on euonymus foliage (Ziv and Hagiladi,1993). In a study considering the efficacy of several biocompatible fungicides, McGrath and Shishkoff (1999) found that JMS Stylet oil controlled powdery mildew on winter squash, muskmelon, and pumpkin better than all other biocompatible products tested. The oil suppressed powdery mildew and increased yield relative to an untreated control. However, oil was not as effective as conventional fungicides. McGrath and Shishkoff suggested that oils could be used in rotation with conventional products. Mineral oil (Sun Spray Ultra Fine) is also an effective control for powdery mildew of lilac (Clement *et al.*, 1994).

Calpouzos (1966a) also recognized that oils, unfortunately, may injure or affect the physiology of the treated plant. ^{14}C uptake was reduced in banana leaves treated with oil, indicating reduced photosynthesis. Transpiration was also reduced, leading Calpouzos to suggest that oil acts as a physical barrier that interferes with gas exchange. Phytotoxic properties of oils on bananas are caused by oil penetration of the leaf tissues, but improved oil quality can reduce the effects (Calpouzos, 1966b).

Several studies have shown that oil reduces the photosynthetic rate of apples (Ayers and Barden, 1975; Ferree and Hall, 1975; Ferree *et al.*, 1976; Schroeder, 1935). Spotts *et al.* (1975) found that the reduction in photosynthesis caused by repeated applications of oil to apple trees resulted in a loss of yield. The photosynthetic rate of citrus crops also is reduced by oil applications (Wedding *et al.*, 1952). Repeated oil applications reduced the yield of orange trees by affecting both fruit set and quality (Dean *et al.*, 1978). Both vegetable and mineral oils reduced the photosynthetic rate of pecans for 21 days after application (Wood and Payne, 1986). Vegetable oil (soybean oil) caused a greater reduction in photosynthesis initially but the recovery to normal photosynthesis rates was faster in foliage treated with vegetable oil than in foliage treated with mineral oil.

Naim and Neumann (1978) proposed that the reduction in photosynthesis caused by silicone and paraffinic oils is a result of oil penetration of the leaf cuticle. They found that oil was capable of penetrating the cuticle of bean leaves. The diffusion of gas through silicone oil is 10^4 times slower than through air. Decreased CO_2 movement from the air into cells would limit photosynthesis. Even if oil did not penetrate the leaf, resistance to gas movement through the cuticle and stomates would be limited by oil coating. Gudin *et al*. (1976) found that low viscosity mineral oil penetrated the interstomatal regions of the cuticle of tomato leaves. A rapid penetration of a large volume of oil caused leaf scorch by removing a portion of the epidermis and exposing the palisade tissue that became desiccated. The slower penetration of higher viscosity oil into the leaf did not cause scorch but did reduce photosynthesis. Therefore, the presence or absence of leaf scorch does not indicate the physiological effects of oils on plants.

Oil use in grapes: Castelliani and Matta (1964) found that mineral oils control grape powdery mildew. The efficacy of mineral oils and vegetable oils in controlling powdery mildew in grapes has been shown in several production areas (Bervejillo *et al.*, 1999; Muza and Travis, 1993; Northover and Homeyer, 1999; Wilcox and Riegel, 1998). The mineral oils commonly used are highly refined petroleum oils with medium viscosity. JMS Stylet oil (JMS Flower Farms, Inc., Vero Beach, FL.) was initially developed to suppress transmission of stylet borne plant pathogens. It is labeled for use in vineyards as a fungicide for the control of powdery mildew and botrytis, and as an insecticide and acaricide to treat mealybug, mite, leafhopper, and whitefly infestations. SunSpray Ultra Fine oil (Sun Company, Inc., Marcus Hook, PA) is a similar oil labeled as an insecticide for control of mealybugs, mites, and leafhoppers in vineyards.

Northover and Schneider (1996) were able to control grape powdery mildew with JMS Stylet oil and Sun Spray oil. Both types of oils provided control when applied protectively 1 to 4 days before inoculation. In pre- and post-lesion applications, the oils smothered already established lesions and reduced the foliage area covered with powdery mildew colonies. Vegetable oils (canola, safflower, and soybean) had similar post-lesion curative activity, but their effect was less persistent than that of the mineral oils. Conventional fungicides had no curative effect. Oil also showed antisporulative action against the powdery mildew fungus, reducing the number of

conidia rinsed from leaves 7 days after treatment. Northover and Schneider proposed that because oils have curative properties, they could be useful in a disease program which times fungicide applications according to disease risk.

Dell *et al.* in California (1998b) found that JMS Stylet oil used at a rate of 2% (935 L/ha) on a 14-day spray schedule significantly reduced the incidence of grape powdery mildew compared to an unsprayed control. When applied on an 18-day schedule, oil caused less of a reduction in mildew incidence, perhaps because the longer spray interval allowed for reinfection and resulted in higher disease levels. The control achieved was equivalent to that by SI fungicides, which led the researchers to suggest that oil could be used to reduce or avoid resistance problems of SI fungicides. The effect of oil on fermentation was also investigated in this study. After adding volumes of oil 9 to 12 times that which would normally be found as residues on fruit, juice was fermented and the yeast growth and sugar consumption were monitored. Even at high rates, the oil did not affect yeast growth or sugar use, showing no detrimental effects on fermentations.

In work by Henriquez *et al.* (1998), JMS Stylet oil, used alone and mixed with sodium bicarbonate provided good control of grape powdery mildew. The oil and sodium bicarbonate mixture was as effective as conventional fungicides in controlling the disease. Oils did not affect the organoleptic quality of the fruit and no phytotoxic effects were observed. In a paper presented at an organic agriculture meeting, Bourbos *et al.* (1999) stated that mineral oil used at a rate of 1.15% v/v oil/water with four applications during the growing season provided control of grape powdery mildew which was comparable to control provided by sodium bicarbonate alone.

An Australian study by Azam, Gurr, and Magarey (1998), showed that a canola oil derivative prevented foliar symptoms of powdery mildew on potted vines as effectively as sulfur or SI fungicides. They also found that decreasing the concentration of oil used from 2% to 1% decreased the amount of control achieved. This agrees with work done by Wicks *et al.* (1999), who found that increasing either the volume or concentration used in mineral oil applications increased the effectiveness of oils. Wicks stated that because oil is phytotoxic at high volumes and rates, a balance between efficacy and potential foliage damage must be found. The ability of

oil to control powdery mildew is dependent on good coverage. Wicks found that when oil was used at low volumes (1% v/v in water at 1000 L/ha), powdery mildew infections occurred in the interior of the canopy where the spray material did not penetrate. Even using volumes of 2000 L/ha, the powdery mildew control achieved was inferior to conventional fungicides. Because of this limitation, Wicks feels that low volume applications are insufficient for control of powdery mildew. In fungicide research, Wilcox and Riegel (1996) found that JMS Stylet oil used at rates of 1.5 or 2% is much more effective in controlling powdery mildew than a 1% rate. They also found that using reducing spray volumes from 1872 L/ha to 936 L/ha eliminated visible phytotoxicity problems but also reduced the control achieved with oil (Wilcox and Riegel, 1998).

As in other crops, oils may cause injury to grape leaves and decrease yield or delay fruit maturity. Northover and Homeyer (1998) found that 4 or 5 applications of JMS Stylet oil or SunSpray oil using a rate of 1% v/v oil/water and a volume of 1500 L/ha provided excellent control of powdery mildew but depressed total soluble solids by as much as 3.5 Brix. The varieties affected included Seyval, Vidal, Chardonnay, Riesling, and Cabernet Sauvignon. Concord was not affected. Titratable acidity and pH of juice and yield were only negligibly affected. Grapevines treated with oils at 2% v/v in 937 L/ha water (Muza and Travis, 1993) and 1% v/v in 500 to 2000 L/ha water (Wicks *et al*., 1999) exhibited signs of phytotoxicity including leaf yellowing and leaf margin burn. Northover and Schneider (1996) described minor leaf necrosis (leaf flecking) which appeared 1 to 2 weeks after oil applications.

CHAPTER TWO
EFFECTS OF HORTICULTURAL OILS ON THE PHOTOSYNTHESIS, FRUIT MATURITY AND YIELD OF WINE GRAPES

Introduction

Because grape growers rely heavily on fungicides to control powdery mildew, the addition of new fungicides to the disease management arsenal could be useful to both control the disease and avoid the development of resistance to other chemicals. All chemicals commonly used to control powdery mildew, sulfur sterol inhibitors (SI) and strobilurins, have limitations. Sulfur is ineffective at low temperatures and phytotoxic at very warm temperatures. Its use is also limited in the pre-harvest period because sulfur residues can interfere with fermentation. Care must be taken in the use of SI's and strobilurins because strains of powdery mildew resistant to SI's have been found in several grape growing regions (Aloi *et al.*, 1990; Erickson and Wilcox, 1997; Gubler *et al.*, 1994; Steva *et al.*, 1989) and resistance to strobilurins also may develop. Alternative fungicides are needed to rotate with traditional fungicides to delay resistance development and for use as eradicants when conventional disease control programs fail.

In early research done to find a replacement for sulfur, Martin and Salmon (1931) found that oils are effective fungicides and probably act by smothering the fungi. Since then, oils have been used to control fungal diseases such as powdery mildew in many horticultural crops (Calpouzos, 1966). Oils provide good disease control and are less toxic and less expensive than other fungicides (Horst and Kawamoto, 1992; Northover and Schneider, 1993). Fungi are less likely to develop resistance to oils than to other chemicals because the mode of action of oils is not directed at a specific physiological process.

In 1964, Castelliani and Matta found that oils controlled powdery mildew in grapes. More recently, Northover and Schneider (1996) found that mineral and vegetable oils have both protectant and eradicant activity. Oil applied after infection smothered and eliminated powdery mildew lesions on grape leaves. Fermentation is not affected by oil residues (Dell *et al*., 1998).

Unfortunately, oil use may also adversely affect vine physiology and fruit maturity. Oil phytotoxicity has been observed in several crops, including grapes (Muza and Travis, 1993). In several horticultural crops, photosynthesis rates were reduced by mineral and vegetable oils (Gudin *et al*., 1976; Wedding *et al*., 1952; Wood and Payne, 1986). Prolonged suppression of photosynthesis decreases vine growth because carbohydrate production is reduced. Fruit maturity may also be delayed by reductions in photosynthesis because sugars are not available for translocation from leaves to developing fruit (Mullins *et al*., 1996). Northover and Homeyer (1998) found that repeated oil applications delay sugar accumulation in the fruit of several grape varieties.

Given these concerns, further research is needed to determine if oils can be included in disease management programs. The purpose of this research is to quantify reductions in photosynthesis and delays in fruit maturity caused by oils and to determine if detrimental effects of oil can be minimized by limiting spray volumes or the area of the canopy to which oils are applied. In addition, the varietal response to possible phytotoxic effects of oils and the relationship between phytotoxicity and fruit maturity were investigated.

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 oil (Sun Company, Inc., Marcus Hook, PA). The active ingredient of both products is paraffinic oil (Table 1). Degummed soybean oil was also used in experiment 1 in 1998.

Experiment 1: Effects of horticultural oils on photosynthesis, fruit maturity, and yield of Cabernet Sauvignon and Chardonnay grapevines - 1998

Vineyards: The Chardonnay vineyard was located at the Alson H. Smith Jr. Agricultural Research and Extension Center in Winchester, VA. Chardonnay vines, which were 9 years old in 1998, were planted 2.1 m apart in rows, trained to an open-lyre, divided canopy, and cordon-trained and spur-pruned (Smart and Robinson, 1999). Cordons were 1.1 m above the ground and separated horizontally by 0.9 m. Shoots were positioned vertically, upright. The vineyard rows

Table 1. Physical characteristics of oils.

	% active ingredient	50% distillation point (°C)	Viscosity (centipoise at 40°C)
JMS Stylet Oil (JMS, 1994)	97.1[z]	224	13.15 [x]
Sun Spray UltraFine Oil (Sun Spray)	98.8[z]	212	[w]
Refined soybean oil (Pryde, 1980)[y]	[w]	[w]	28.86

[z]Active ingredient is paraffinic oil. Inert ingredient is an emulsifier.
[y]Value is not for degummed soybean oil used in experiment 1.
[x]Viscosity = 70 sec at 100°C.
[w]The viscosity of Sun Spray UltraFine oil was not available.

were 3.7 m apart and oriented north/south. The Cabernet Sauvignon vines were in the Oaksworth Vineyard in Loudoun County, Virginia. The rows were 3.7 m apart and were oriented generally north/south. The vines were trained to a Casarsa trellis system (unilateral cordon) and spur-pruned. Shoots were positioned upright from a cordon 1.5 m above the ground. The Cabernet Sauvignon vines were 11 years old in 1998.

Experimental Design and Treatments: Approximately one week after bloom, plots in each vineyard that had vines of similar vigor and shoot length were chosen for use in the experiment. Chardonnay plots contained 3 vines each, Cabernet Sauvignon plots contained 2 vines each. Treatments were randomly assigned to five replicates in both vineyards. Shoots were thinned to 15 shoots per cordon meter by removing an average of 3 shoots per vine. Crop was standardized to avoid confounding effects of varied crop load on photosynthesis and fruit maturity. Clusters were thinned 3 weeks after bloom to 40 clusters/vine by removing an average of 5 clusters/vine. The Chardonnay was shoot trimmed in early-June and late-July. The Cabernet Sauvignon was trimmed once, in July. Trimming maintained shoot length at approximately 17 nodes.

In the Chardonnay vineyard, treatments were applied on 9 June, 22 June, and 3 August (Figure 1) using a hand held spray nozzle attached to an airblast sprayer operated at approximately 1400 KPa and sprayed until run off. Both the interior and exterior of the east and west sides of the canopy were sprayed. A plastic sheet mounted between two wooden posts was used to prevent oil from being sprayed on neighboring plots.

<u>Chardonnay treatments:</u>

Control (unsprayed)

JMS Stylet oil - 6200 L/ha of a 1.5 % (v/v) emulsion of oil in water

Soybean oil - 6200 L/ha of a 1.5 % (v/v) emulsion of oil in water

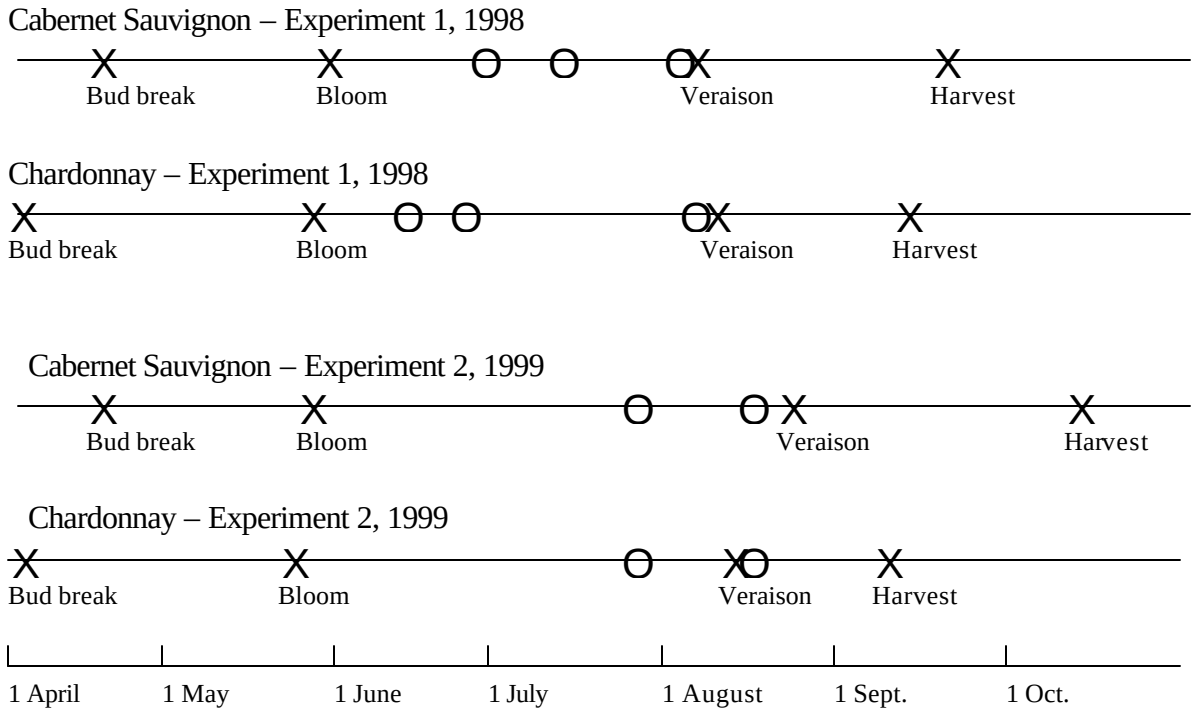
Oil was applied to the Cabernet Sauvignon on 23 June, 10 July, and 27 July (Figure 1) using a 12 L backpack sprayer.

<u>Cabernet Sauvignon treatments:</u>

Control (unsprayed)

JMS Stylet oil - 2440 L/ha of a 1.5% (v/v) oil in water emulsion

Figure 1. Phenology and timing of oil applications to Cabernet Sauvignon and Chardonnay in experiments 1 and 2, 1998 and 1999.



O = date of oil application

Soybean oil - 2440 L/ha of a 1.5% (v/v) oil in water emulsion
Sun Spray UltraFine oil - 2440 L/ha of a 1.5% (v/v) oil in water emulsion

Experimental vines in both vineyards were included in pest management programs typically recommended in Virginia (Pfeiffer *et al*., 1998). Powdery mildew fungicides used included azoxysrtobin, fenarimol, myclobutanil, sulfur, and triadimefon. Sulfur was avoided for at least one week before and one week after oil applications.

Five weeks after bloom, point quadrat analysis (PQA) as described by Smart and Robinson (1999) was performed in all treatment plots to determine canopy density. A metal probe was inserted horizontally into the canopy's fruit zone fruit zone at 0.3 m intervals. Probe contacts with leaves, clusters, and gaps were recorded and used to calculate the number of leaf layers, percent exterior fruit, and percent gaps.

$$\text{Leaf layers} = \frac{\text{total \# of leaf contacts}}{\text{number of probes}}$$

$$\%\ \text{exterior fruit} = 100 \times \frac{\text{\# of exterior fruit}}{\text{total \# of fruit contacted}}$$

$$\%\ \text{gaps} = 100 \times \frac{\text{\# of canopy gaps}}{\text{number of probes}}$$

Photosynthesis measurements: Leaf net assimilation rate (NAR) was used as an indicator of the photosynthetic activity of the Chardonnay and Cabernet Sauvignon vines. Readings were taken after each oil application, except the first application in the Chardonnay vineyard, using a portable photosynthesis measurement system (Model LCA2, The Analytical Development Co. [ADC], Ltd., Hoddesdon, England) with a leaf chamber (ADC PLC-7504). All readings were taken on clear, sunny days with PAR above 700 $\mu mol/m^2/s$, the light saturation level of vinifera grape leaves (Smart and Robinson, 1999). Readings were done between 10:00 am and 4:00 pm on well watered vines. Mature, mid-shoot leaves were used. Eight measurements per plot were taken in the Chardonnay. Five measurements were taken in each Cabernet Sauvignon plot.

NAR was calculated using a formula adapted by Lakso from Long (1992):

$$\text{NAR} = \frac{\text{F}}{\text{A}} (\Delta \text{CO}_2) \left(\frac{\text{1-X}e}{\text{1-X}o} \right)$$

$$F = 0.3 \times 0.0446428 \left(\frac{273.15}{273.15 + Xs} \right)$$

A = area of leaf chamber = 0.000625 m^2 = 6.25 cm^2

ΔCO_2 = change in concentration of CO_2 in air passing through the leaf chamber ppm × volume × 10^{-6}

$$Xe = Xs \times \left(\frac{RH\mathit{leaf}}{100} \right)$$

$$Xo = Xs \times \left(\frac{Rh\mathit{noleaf}}{100} \right)$$

X*s* = variable for the mole fraction of water vapor at a given temperature

RH*leaf* = relative humidity of air in chamber with leaf

Rh*noleaf* = relative humidity of air in chamber without a leaf.

Fruit maturity: Three fruit samples (80 berries/plot of Chardonnay and 50 berries/plot of Cabernet Sauvignon) were taken at 2-week intervals between veraison and harvest. The first Chardonnay sample was taken 13 August; the first Cabernet Sauvignon sample was taken 11 August. Fruit samples were weighed and frozen. It is recognized that freezing berry samples causes precipitation of potassium tartrate, which leads to elevated pH and reduced titratable acidity (Zoecklein *et al*., 1995). After thawing the fruit, pH, soluble solids, and titratable acidity were analyzed. A hand-held refractometer (Model 10430, Reichert Scientific Instrument, Buffalo, NY) was used to determine soluble solids concentration. pH was determined using a portable pH meter (Model AP5, Fisher Scientific, Denver, CO). Titratable acidity was determined using a procedure described in Zoecklein *et al*., 1995. Two ml of juice was added to 100 ml of distilled water and titrated to a pH of 8.2 using 0.1N NaOH. Ten ml of juice was then added and the solution was again titrated to 8.2. The amount of NaOH used to reach pH 8.2 after the 10 ml of juice was added was recorded. Titratable acidity was calculated using the equation:

$$\text{Titratable acidity (g/L)} = \frac{(\text{ml NaOH used}) \times (0.075) \times (1000) \times (\text{NaOH actual normality})}{10 \text{ ml juice}}$$

Yield components and pruning weights: The number of clusters per vine was counted at harvest and each vine's yield and cluster weight determined. Oil-treated Chardonnay was not harvested at the same time as the control but was harvested when the SSC reached 21° Brix. Pruning weights were recorded for control and treatment vines during dormant pruning.

Experiment 2: Effect of 3 spray volumes of JMS Stylet oil on photosynthesis, fruit maturity, and yield of Cabernet Sauvignon and Chardonnay grapes - 1999.

Vineyards: The Cabernet Sauvignon vineyard was located at the Alson H. Smith Jr. AREC in Winchester, VA. The spacing and training of the Cabernet Sauvignon was the same as in the Chardonnay vineyard used in 1998. The Chardonnay vines were in the Oaksworth Vineyard in Loudoun County, Virginia. The spacing and training of these vines was the same as that of the Cabernet Sauvignon used in 1998, except the Chardonnay rows were oriented east/west.

Experimental Design and Treatments: As in 1998, plots with vines of similar vigor and shoot lengths were chosen for use in the experiment. Cabernet Sauvignon plots contained 3 vines each. Chardonnay plots contained 2 vines each. Treatments were replicated four times in both vineyards, except the water check which was replicated only three times in the Cabernet Sauvignon vineyard. The control treatment was not used in the Cabernet Sauvignon. Shoots were thinned 2 weeks after bloom to 17 shoots per cordon meter by removing an average of 6 shoots/vine. Crop was standardized to avoid confounding effects of varied crop load on photosynthesis and fruit maturity. Clusters were thinned 4 weeks after bloom to 40 clusters per vine by removing an average of 15 clusters per vine. Shoot trimming, to maintain shoot length at approximately 17 nodes, was done once in June and once in July in the Cabernet Sauvignon vineyard and once in July in the Chardonnay vineyard.

Treatment applications were made in the Cabernet Sauvignon vineyard on 21 July and 9 August (Figure 1). In the Chardonnay vineyard, applications were made on 20 July and 11 August (Figure 1). Treatments were applied using a hand held spray nozzle attached to a sprayer operated at approximately 560 KPa. The sprayer had six small tanks. The spray material for each treatment replicate was measured into separate tanks to ensure the proper volume was applied to each plot. The same five treatments were used in both vineyards. The oil used for all oil treatments was JMS Stylet oil.

Treatments:

Control (no applications made)

Water check – 1870 L/ha water

930 L/ha of 1.5% v/v oil in water emulsion applied only to the fruit zone
1870 L/ha of 1.5% v/v oil in water emulsion applied to the full canopy
5600 L/ha of 1.5% v/v oil in water emulsion applied to the full canopy

As in 1998, experimental plots were included in the normal disease management program, avoiding sulfur applications for one week before and after each oil application.

After the canopy was full, PQA was performed in all treatment plots to determine canopy density. The same procedure was used in 1999 as had been used in 1998. In each vineyard, the number of leaf layers, percent exterior fruit, and percent gaps were calculated for each treatment.

Photosynthesis: Two NAR measurements were made after each treatment application using the same photosynthesis measurement system and calculations as were used in 1998. Eight measurements were taken in each Cabernet Sauvignon plot on 23 July, 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 made in the Chardonnay vineyard on 16 and 31 August and 10 September. Samples were analyzed using the same methods used in 1998. Berry weight, soluble solids concentration, and pH were determined for all samples. Titratable acidity was only determined for the final sample of each variety.

Yield components and pruning weights: The same yield components were determined in 1999 as in 1998. The number of clusters per vine was counted and each vine's yield and cluster weight determined. Pruning weights were recorded during dormant pruning.

Experiment 3: Varietal differences in susceptibility to foliage injury caused by JMS Stylet oil and relationship to delay of fruit maturation - 1998
Vineyard: The wine-grape variety vineyard was located at the Alson H. Smith Jr. AREC in Winchester, Virginia. Vines were planted 2.1 m apart. Vineyard rows were oriented north/south and were 3.7 m apart. The training system was a midwire bilateral cordon system with shoots

positioned vertically upright (Smart and Robinson, 1999). Vines were cordon trained and spur pruned. White cultivars included were Chardonel, Chardonnay #4, Gruner Veltliner, Malvasia Bianca, Muscat Ottonel, Petit Manseng, Traminette, Vidal Blanc, and Viognier. Red cultivars included were Cabernet Sauvignon #6 and #8, Charbono, Fer Servadau, Limberger, Mataro, Nebbiolo, NY62.122.1, Petit Verdot, Refosco, Sangiovese, Syrah, Tannat, and Valdepenas. Fifteen vines of each variety were planted in five, 3-vine plots. Each plot was 6.4 m long. The plots of each variety were arranged randomly in nine vineyard rows.

Experimental Design and Treatments: Applications of a 1.5 % (v/v) JMS Stylet oil in water emulsion were made to three 3-vine plots of each variety. Two 3-vine plots served as an untreated control. The treatments were applied to both the east and west using a hand held spray nozzle attached to an airblast sprayer operated at approximately 1400 KPa and sprayed until run off. A plastic sheet mounted between wooden posts was used to prevent spray drift and penetration though the canopy onto neighboring vines. The first treatment was applied after bloom was completed in all cultivars (7 June), a second one month later (7 July). For the first application a volume of 5550 L/ha was used. The volume used in the second application was lower, 4680 L/ha, because an effort was made to decrease the spray volume while still achieving full coverage.

A standard disease management program was used in the vineyard. Sulfur was applied two days after the first oil application.

Phytotoxicity: One week and two weeks after each treatment application, an assessment of phytotoxicity was made. The occurrence of symptoms (leaf reddening, chlorosis, necrotic spots, scorch, stippling, and soaking) was recorded along with an estimate of the percent of the leaf area in the canopy affected.

Fruit maturity: To determine the effects of oil sprays on fruit maturity, fruit samples (50 berries/plot) were collected from all experimental plots beginning 20 August. Samples were taken once a week through the harvest date for each variety. Each variety was harvested separately as the fruit reached maturity. Fruit maturity indicators from control plots were used to

determine harvest dates. Because different varieties mature at different rates, the number of samples collected for each variety ranged from 2 to 6. After freezing, fruit samples were weighed and soluble solids concentration, pH, and titratable acidity was analyzed using the same methods described for Experiment 1.

Experiment 4: Effect of oil and sulfur interactions on photosynthesis and fruit maturity of Seyval grapevines – 1998

Vineyard: The Seyval vines used for this experiment were located at the Alson H. Smith Jr. AREC in Winchester, Virginia. Vines were trained to the same midwire bilateral cordon system described for Experiment 3 (Smart and Robinson, 1999).

Experimental Design and Treatments: Twelve 3-vine plots were chosen for use in this experiment. Shoots were thinned to 12 shoots per cordon meter by removing an average of 6 shoots per vine. Crop was standardized to avoid confounding effects of varied crop load on photosynthesis and fruit maturity. Clusters were thinned 4 weeks after bloom to 20 clusters/vine by removing an average of 14 clusters/vine. Seyval vines were shoot trimmed in early-June and late-July to maintain shoot length at approximately 17 nodes.

In each plot, one vine was sprayed with 1.5% v/v SunSpray Ultra-Fine oil and water and one vine with 1.5 % v/v JMS Stylet oil and water. The third vine was not sprayed with oil or water. One day after the oil application, sulfur was sprayed on one cordon of each vine in the panels (Figure 2). All treatments were made using a 12 L backpack sprayer. Treatments were made on 6, 7 July and 28, 29 July. An average of 2200 L/ha of oil emulsion was used and 10 kg/ha of sulfur was used.

Photosynthesis: NAR measurements were made on 17, 21 July and 5 August using the same photosynthesis measurement system and calculations as were used in Experiment 1. Two measurements were made on mature, mid-shoot leaves from each treatment replicate.

Fruit Maturity: Three, 40-berry samples were taken from each treatment at harvest. Samples were analyzed using the same methods used in Experiment 1. Berry weight, soluble solids concentration, pH and titratable acidity were determined for all samples.

Yield components and pruning weights: The same yield components were determined as in Experiment 1. The number of clusters per vine was counted and each vine's yield and cluster weight determined. Pruning weights were recorded during dormant pruning.

Statistical analysis:

Statistical analysis was done using SAS-PC (version 6.12) software (SAS Institute, Inc. Cary, NC). Dependent variables measured in each part of this work were analyzed using one-way ANOVA to determine treatment significance. If the F-test was significant at $P \leq 0.05$, treatments were separated using Duncan's new multiple range test. To detect relationships between foliage injury and soluble solids concentration, pH, titratable acidity, or berry size, linear and quadratic regression analysis was done on data collected from Experiment 3. Means from groups of related treatments in Experiment 4 were analyzed using contrasts of means with one degree of freedom.

Results

Experiment 1: Effects of 3 horticultural oils on net assimilation rate (NAR), fruit maturity, and yield of Cabernet Sauvignon and Chardonnay grapes, 1998.

NAR:

NAR measurements were made after each treatment application in the Cabernet Sauvignon vineyard. Eight days after the first oil application the NAR of all oil treatments was reduced (Table 2). The NAR of the Sun Spray oil treatment was significantly lower than the NAR of the JMS Stylet oil treatment. On 13 July, the NAR of soybean oil and Sun Spray oil treated vines was lower than the NAR of the untreated control. JMS Stylet oil did not cause a significant

Figure 2. Arrangement of JMS Stylet oil, SunSpray Ultra-Fine oil (1.5% v/v oil in water at 2050 L/ha) and sulfur (9 kg/ha) treatments applied to 12 Seyval plots on 7 and 28 July 1998, Winchester, VA.

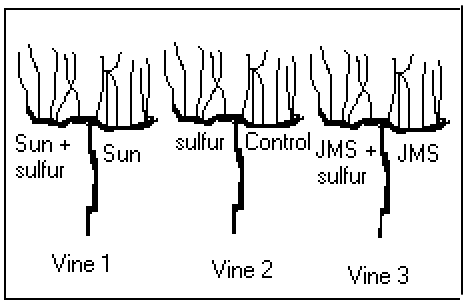


Table 2. Leaf net assimilation rates of Cabernet Sauvignon in response to 1.5 % v/v oil treatments (2240 L/ha) applied on 23 June, 10 July, and 27 July 1998, Leesburg, VA.

	Net assimilation rate ($\mu mol \cdot m^{-2} \cdot sec^{-1}$)		
Treatment	1 July (8)[z]	13 July (3)	28 July (1)
Control	12.5 a[y]	11.8 a	16.3 a
JMS Stylet oil	10.5 b	10.3 ab	12.7 b
Soybean oil	9.4 bc	8.5 b	12.9 b
Sun Spray oil	8.7 c	8.5 b	13.1 b

All means were calculated from 25 observations.

[z]Numbers in parentheses following dates are the number of days elapsed since last oil treatment.

[y]Means, within columns, followed by a common letter are not significantly different at $P \leq 0.05$ using Duncan's new multiple range test.

reduction in NAR on 13 July (Table 2). One day after the third oil application was made (28 July) the NAR of all oil treatments was significantly lower than the control (Table 2).

The NARs measured in Chardonnay in both oil treatments were significantly lower than the NAR of the control on both 1 July and 4 August (Table 3). Measurements from the JMS Stylet oil plots were significantly higher than from the soybean oil plots. On both dates, the NAR measured in soybean oil plots was less than one half the rate of the control (Table 3).

Canopy characteristics:

Vines in the Cabernet Sauvignon soybean oil treatment plots had significantly fewer leaf layers than vines from all other treatment plots (Appendix A). There were no other significant differences in the canopy characteristics of the Cabernet Sauvignon experimental plots although there was wide variation in the percent of exterior fruit among treatments. There were no differences among the canopy characteristics of the Chardonnay experimental plots (Appendix B). Except for necrosis where oil pooled on leaves, the oils did not cause visible injury to the foliage of either variety.

Fruit maturity measurements:

Soluble solids concentration: The only significant differences among the Cabernet Sauvignon soluble solids concentrations (SSC) occurred in the 11 August sample. The SSC measured in JMS Stylet oil and Sun Spray UltraFine samples was significantly lower than that of the control samples (Table 4). The control and JMS Stylet oil means differed by 2.6° Brix. Despite the delay of soluble solids accumulation in oil-treated fruit measured in the first sample, there were not significant differences in Cabernet Sauvignon SSC on 27 August or at harvest (Table 4). The control and JMS Stylet oil SSC means differed by only 0.4° Brix.

SSC of Chardonnay from both oil treatments was significantly lower than the SSC of the control on all three sample dates (Table 5). JMS Stylet oil-treated Chardonnay had significantly higher SSC than soybean oil-treated. The SSC of JMS Stylet oil samples and the soybean samples were 0.9° brix and 2.8° brix lower than the control, respectively, at harvest (Table 5). JMS Stylet oil

Table 3. Leaf net assimilation rates of Chardonnay in response to 1.5 % v/v oil treatments (6200 L/ha) oil treatments applied on 9 June, 22 June, and 3 August 1998, Winchester, VA.

	Net assimilation rate ($\mu mol \cdot m^{-2} \cdot sec^{-1}$)	
Treatment	1 July (9)[z]	4 August (1)
Control	13.0 a[y]	11.4 a
JMS Stylet oil	9.4 b	7.6 b
Soybean oil	4.2 c	5.4 c

All means were calculated from 40 observations.

[z]Numbers in parentheses following dates are the number of days elapsed since last oil treatment.

yMeans, within columns, followed by a common letter are not significantly different at $P \leq 0.05$ using Duncan's new multiple range test.

Table 4. Soluble solids concentration, pH, titratable acidity, berry and cluster weight, crop per vine, and pruning weight of Cabernet Sauvignon treated with 2240 L/ha of 1.5 % v/v oil/water on 23 June, 10 July, and 27 July 1998, Leesburg, VA.

	Soluble solids concentration (%)		
Treatment	11 August	27 August	14 September
Control	15.3 a[zy]	19.6	22.1
JMS Stylet oil	12.7 c	18.9	21.7
Soybean oil	14.2 ab	19.1	21.2
Sun Spray oil	13.7 bc	18.4	21.2

	pH		
Treatment	11 August	27 August	14 September
Control	2.83 a[y]	3.33 b	3.56
JMS Stylet oil	2.78 b	3.34 b	3.68
Soybean oil	2.85 a	3.41 a	3.65
Sun Spray oil	2.79 b	3.29 b	3.65

	Titratable acidity (g/L)	
Treatment	27 August	14 September
Control	0.70 [y]	0.52
JMS Stylet oil	0.74	0.49
Soybean oil	0.77	0.53
Sun Spray oil	0.68	0.45

	Berry weight (g)		
Treatment	11 August	27 August	14 September
Control	1.0 [y]	1.3	1.2
JMS Stylet oil	0.8	1.2	1.2
Soybean oil	0.9	1.3	1.3
Sun Spray oil	0.9	1.2	1.3

Treatment	Cluster weight (g)	Crop weight (kg/vine)	Pruning weight (kg/vine)
Control	47.4[x]	2.4[x]	1.2 [x]
JMS Stylet oil	57.6	3.5	1.3
Soybean oil	60.8	2.8	1.0
Sun Spray oil	56.4	3.5	1.4

[z]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.
[y]Means were calculated from five, 50-berry samples.
[x]Means were calculated from 10 observations.

Table 5. Soluble solids concentration, pH, titratable acidity, 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, Winchester, 1998.

	Soluble solids concentration (%)		
Treatment	13 August	26 August	8 September
Control	16.0 a[zy]	18.5 a	21.3 a
JMS Stylet oil	14.6 b	17.6 b	20.4 b
Soybean oil	12.3 c	15.8 c	18.5 c

	pH		
Treatment	13 August	26 August	8 September
Control	3.00 c[y]	3.54 c	3.67 c
JMS Stylet oil	3.04 b	3.71 b	3.86 b
Soybean oil	3.08 a	3.75 a	3.95 a

	Titratable acidity (g/L)	
Treatment	26 August	8 September
Control	0.89 ab[y]	0.71
JMS Stylet oil	0.83 b	0.65
Soybean oil	0.93 a	0.67

	Berry weight (g)			
Treatment	15 July	13 August	26 August	8 September
Control	1.0 a[y]	1.5 a	1.6 a	1.6 a
JMS Stylet oil	0.7 b	1.1 b	1.3 b	1.3 b
Soybean oil	0.7 b	1.1 b	1.3 b	1.3 b

Treatment	Cluster weight (g)	Crop weight (kg/vine)	Pruning weight (kg/vine)
Control	127.4 a[x]	2.5 a[x]	4.5 a[x]
JMS Stylet oil	103.5 b	2.2 ab	4.0 b
Soybean oil	103.1 b	2.1 b	4.2 b

Control plots were harvested on 8 September. JMS Stylet oil plots were harvested on 16 September. Soybean oil plots were harvested on 21 September.

[z]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.

[y]Means were calculated from five, 80-berry samples.

[x]All means are calculated from the 15 vines in each treatment.

and soybean oil-treated Chardonnay took 8 and 13 days, respectively, longer than the control to reach 21° Brix.

pH: The mean pH of Cabernet Sauvignon samples (Table 4) 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. At harvest, there were no significant differences in pH (Table 4)

The pH of Chardonnay control samples was significantly lower than the pH of oil treatment samples on all sample dates. Soybean oil treatment fruit samples were significantly less acidic than either the control or JMS Stylet oil (Table 5).

TA: There were no significant differences among the titratable acidity (TA) of Cabernet Sauvignon treatments on either sample date (Table 4). The TA measured in Chardonnay soybean oil treatment samples (Table 5) was significantly higher than the TA of JMS Stylet oil samples taken on 26 August. At harvest, there were no significant differences among the TA means of Chardonnay fruit samples (Table 5).

Berry weight: There were no significant differences in the berry weights of Cabernet Sauvignon (Table 4) on any date. Because we observed that berries on clusters from oil-treated Chardonnay appeared smaller than those of control vines, an early sample of Chardonnay fruit was made and weighed 15 July (Table 5). The weight of Chardonnay berries sampled from control plots was significantly greater than the weight of berries from both oil treatments on all sample dates (Table 5).

Yield components and pruning weights:

Pruning weight, cluster weight, and crop weight of Cabernet Sauvignon were not affected by oil treatment (Table 4). The cluster weight and crop weight of the oil-treated Chardonnay were significantly lower than means from the control (Table 5). Soybean oil treated Chardonnay also had a significantly lower pruning weights than the control (Table 5).

Experiment 2: Effect of 3 spray volumes of JMS Stylet oil oils on photosynthesis, fruit maturity, and yield of Cabernet Sauvignon and Chardonnay grapes, 1999.

NAR:

Cabernet Sauvignon plots in Winchester which were treated with 5600L/ha of JMS Stylet oil applied to the whole canopy had the lowest NAR on all measurement dates, except 3 August, 13 days after the first oil application (Table 6). The NAR of the 5600 L/ha treatment was less than half that of the water treatment on 12 August, 3 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. On all other dates, the NAR of the 1870 L/ha treatment, 930 L/ha treatment and water treatment were not significantly different, although there was a trend for the NAR of the control and 930 L/ha treatment to be higher than the NAR of the 1870 L/ha treatment (Table 6). The difference between the water and 1870 L/ha treatment NAR was greatest on 23 July and 12 August, 2 and 3 days after the first and second oil applications, respectively (Table 6).

The NAR of the 5600 L/ha and 1870 L/ha treatments in the Leesburg Chardonnay were significantly lower than the NAR of the control and water treatments on all dates, except 19 August (Table 7). The NAR of the 5600 L/ha treatment was not significantly different from that of any other treatment except the control on 19 August. The NAR of the 930 L/ha and 1870 L/ha treatments were significantly lower than the NAR of the control and water treatments on 19 August (Table 7). The 930 L/ha NAR was also significantly lower than the control and water treatments on 16 August. The NAR of the control and water treatments were never significantly different; contrasts of these two treatments were not significant. Evidence of differences between the NAR means of the water and 930 L/ha treatments was provided by contrasts for all dates except 28 July. In 1999, NAR increased as the time since the last oil application increased, except after the second application in the Chardonnay (Tables 6 and 7).

Canopy characteristics:

There were no significant differences among the canopy characteristics of the Cabernet Sauvignon or Chardonnay treatment plots in 1999 (Appendix C and Appendix D). As in 1998, the only visible injury caused by the oils were necrotic spots where oil pooled. Chardonnay

Table 6. Leaf net assimilation rates of Cabernet Sauvignon in response to 1.5% v/v JMS Stylet oil treatments applied at 3 different volumes on 21 July and 9 Aug 1999, Winchester, VA.

	Net assimilation rate ($\mu mol \cdot m^{-2} \cdot sec^{-1}$)			
Treatment	23 July (2)[z]	3 August (13)	12 August (3)	17 August (8)
Water[y]	9.6 a[w]	11.3	8.6 a	9.1 a
930 L/ha[x]	8.7 ab	11.5	8.5 a	10.0 a
1870 L/ha	7.8 b	10.9	7.6 a	8.8 a
5600 L/ha	5.0 c	10.6	3.2 b	6.2 b

Means were calculated from 32 observations.

[z]Numbers in parentheses following dates are the number of days elapsed since last oil treatment.

[y]Water was applied at a volume of 1870 L/ha.

[x]The 930L/ha treatment was applied only to the fruit zone. All other treatments were applied to the whole canopy.

[w]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.

Table 7. Leaf net assimilation rates of Chardonnay in response to 1.5% v/v JMS Stylet oil treatments applied at 3 different volumes on 20 July and 10/11 August 1999, Leesburg, VA.

	Net Assimilation Rate ($\mu mol \cdot m^{-2} \cdot sec^{-1}$)			
Treatment	22 July (2)[z]	28 July (8)	16 August (6)	19 August (9)
Control	8.9 a[w]	9.9 a	13.2 a	9.7 a
Water[y]	9.2 a	9.9 a	11.9 a	8.9 ab
930 L/ha[x]	8.0 a	8.9 ab	9.8 b	7.4 c
1870 L/ha	6.1 b	8.2 b	8.8 b	7.4 c
5600 L/ha	4.5 c	8.0 b	10.0 b	8.1 bc

Means were calculated from 20 observations.

[z]Numbers in parentheses following dates are the number of days elapsed since last oil treatment.

[y]Water was applied at a volume of 1870 L/ha.

[x]The 930L/ha treatment was applied only to the fruit zone. All other treatments were applied to the whole canopy.

[w]Means, within columns, followed by a common letter are not significantly different at $P \leq 0.05$ using Duncan's new multiple range test.

vines also showed symptoms of mineral or water deficiency; interveinal chlorosis, reddening and senescence of older leaves, which were severe in some plots.

Fruit maturity measurements:

SSC: The SSC of fruit sampled from Cabernet Sauvignon 5600 L/ha plots were lower than all other treatment samples on the first 3 sample dates (Table 8). The 1870 L/ha treatment had a significantly lower SSC than the water treatment on all sample dates except 12 October. The SSC of the water treatment control and 930 L/ha treatment were never significantly different. At harvest, there were no significant differences among the SSC of Cabernet Sauvignon fruit samples (Table 8).

The Chardonnay samples had no significant differences among fruit SSC on 16 or 31 August (Table 9). There were never significant differences among the SSC of oil-treated Chardonnay in 1999 (Table 9). At harvest, the SSC of the water treatment was higher than the SSC of all oil treatments, but was not significantly different from the untreated control SSC (Table 9). A single 1870 L/ha application of JMS Stylet or Sun Spray UltraFine oil on 4 August significantly delayed the accumulation of soluble solids of Chardonnay in the Winchester vineyard while not affecting other components of fruit maturity or yield (Appendix E).

pH: There were no significant differences in the pH of Cabernet Sauvignon fruit samples in 1999, except on 1 September. On that date, the pH of the 5600 L/ha treatment sample was lower than the pH of the 930 L/ha and water control samples (Table 8). The pH of Chardonnay samples were not significantly different on any of the three sample dates (Table 9).

TA: In 1999, titratable acidity was determined only for the harvest samples. The TA of Cabernet Sauvignon fruit 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 8). The water control also had a significantly lower TA than the 5600 L/ha treatment. There were no significant differences in the TA measured in the Chardonnay harvest samples (Table 9).

Table 8. Soluble solids concentration, pH, titratable acidity, berry and cluster weight, crop per vine, and pruning weight of Cabernet Sauvignon treated with 1.5 % v/v JMS Stylet oil using 3 different volumes on 21 July and 11 August, Winchester, 1999.

	Soluble solids concentration (%)[w]			
Treatment	1 September	17 September	1 October	12 October
Water[z]	18.6 a[x]	19.9 a	20.5 a	20.4
930 L/ha[y]	18.4 ab	19.0 ab	20.1 ab	19.9
1870 L/ha	17.3 bc	18.1 bc	19.0 bc	19.2
5600 L/ha	16.4 c	17.5 c	18.6 c	18.8

	pH[w]			
Treatment	1 September	17 September	1 October	12 October
Water	3.35 a	3.58	3.71	3.64
930 L/ha	3.38 a	3.58	3.69	3.59
1870 L/ha	3.31 ab	3.53	3.68	3.61
5600 L/ha	3.29 b	3.52	3.66	3.57

	Titratable acidity (g/L) [w]
Treatment	12 October
Water	0.41 bc
930 L/ha	0.38 c
1870 L/ha	0.44 ab
5600 L/ha	0.46 a

	Berry weight (g) [w]			
Treatment	1 September	17 September	1 October	12 October
Water	1.4	1.6 a	1.6 ab	1.5
930 L/ha	1.4	1.5 ab	1.5 b	1.5
1870 L/ha	1.4	1.6 a	1.6 a	1.6
5600 L/ha	1.3	1.4 b	1.5 b	1.5

Treatment	Cluster weight (g)	Crop weight (kg/vine)	Pruning weight (kg/vine)
Water	188.0	6.1	1.7
930 L/ha	176.5	5.9	1.7
1870 L/ha	185.9	6.3	1.6
5600 L/ha	181.6	6.1	1.6

[z]Water was applied at a volume of 1870 L/ha.
[y]The 930L/ha treatment was applied only to the fruit zone. All other treatments were applied to the whole canopy.
[x]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.
[w] 930 L/ha, 1870 L/ha, and 5600 L/ha treatment means were calculated from 4 samples. Water treatment means were calculated from 3 samples.
[v]930 L/ha, 1870 L/ha, and 5600 L/ha treatment means were calculated from 12 observations. The water treatment mean was calculated from 8 observations.

Table 9. Soluble solids concentration, pH, titratable acidity, berry and cluster weight, crop per vine, and pruning weight of Chardonnay treated with 1.5 % v/v JMS Stylet oil using 3 different volumes on 20 July and 10/11 August 1999, Leesburg, 1999.

	Soluble solids concentration (%)[w]		
Treatment	16 August	31 August	10 September
Control	14.6 [x]	19.0	19.0 ab
Water[z]	15.2	19.6	19.6 a
930 L/ha[y]	14.9	18.4	18.4 bc
1870 L/ha	13.0	18.2	18.2 bc
5600 L/ha	14.3	18.3	17.9 c

	pH[w]		
Treatment	16 August	31 August	10 September
Control	2.91	3.41	3.62
Water	2.86	3.33	3.49
930 L/ha	2.87	3.38	3.55
1870 L/ha	2.87	3.43	3.61
5600 L/ha	2.82	3.36	3.50

	Titratable acidity (g/L)[w]
Treatment	10 September
Control	0.50
Water	0.53
930 L/ha	0.51
1870 L/ha	0.49
5600 L/ha	0.50

	Berry weight (g)[w]		
Treatment	16 August	31 August	10 September
Control	1.4	1.6	1.8
Water	1.6	1.7	1.9
930 L/ha	1.6	1.8	1.9
1870 L/ha	1.4	1.7	1.7
5600 L/ha	1.3	1.6	1.7

Treatment	Cluster weight (g)[v]	Crop weight (kg/vine)[v]	Pruning weight (kg/vine)[v]
Control	105.6	5.2	1.0
Water	118.3	5.9	0.9
930 L/ha	118.3	6.4	0.9
1870 L/ha	114.9	5.6	1.1
5600 L/ha	94.8	5.0	0.7

[z]Water was applied at a volume of 1870 L/ha.
[y]The 930L/ha treatment was applied only to the fruit zone. All other treatments were applied to the whole canopy.
[x]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.
[w]Means were calculated from 4 samples.
[v]All treatment means are calculated from 8 observations.

Berry weight: There were no significant differences among the weights of Cabernet Sauvignon berries sampled on 1 September and at harvest (Table 8). There were no significant differences in the berry weights of Chardonnay samples on any date (Table 9).

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 in 1999 (Table 8 and Table 9). There was wide variation in mean cluster weights, and crop weights in both vineyards.

Experiment 3: Cultivar differences in susceptibility to foliage injury caused by JMS Stylet oil and relationship to delay of fruit maturation

There was a significant interaction between treatment and variety in the percent of the canopy visibly injured by oil at P ⦸ 0.05. Varieties such as Nebbiolo, both Cabernet Sauvignon clones, and Limberger did not appear severely injured, with 5% or less of their canopy being affected (Appendix F). Other varieties appeared much more sensitive to the phytotoxic effects of oils and suffered visible injuries on 20 to 50% of their foliage. In 11 of the 23 cultivars, the percent of the canopy visibly injured by oil was significant (Appendix F). Types of foliage injury caused by oil applications included leaf stippling, scorch, chlorosis, reddening, and soaking.

Despite the interaction between variety and treatment, there were no significant relationships between the amount of injury and indicators of fruit maturity. The variations in fruit SSC, pH, TA, and berry weight could not be explained by differences in the amount of injury seen. Oil treated Petit Manseng, which had 7% injured foliage, had a 3.9° Brix reduction of SSC, while oil treated Vidal Blanc, with a similar amount of injury, only had a reduction of 0.3° Brix (Appendix F).

Although injury caused by oils could not be used to predict delays in fruit maturity, oil treatment did reduce SSC in red and white wine grape cultivars (Table 10). SSC rose following similar patterns in control and oil treated fruit of red and white varieties but was significantly lower in oil treated fruit in all samples (Appendix G). In 9 cultivars, the reduction of SSC caused by oil

Table 10. Soluble solids concentration, pH, titratable acidity and berry weight of red and white wine grape cultivars at harvest from control (no oil application) and oil treated plots (1.5% v/v JMS Stylet oil/water applied on 7 June at 5550 L/ha and 7 July at 4680 L/ha), Winchester, 1998.

Color/Treatment	SSC (%)	pH	TA (g/L)	Berry weight (g)
Red cv. control	21.2	3.91	0.57	1.9
Red cv. oil	20.2	3.95	0.56	1.7
Significance [z]	*	ns	ns	*
White cv. control	22.2	3.74	0.65	2.2
White cv. oil	20.6	3.83	0.60	1.8
Significance [z]	*	ns	ns	*

Red cultivar control means were calculated from 26 samples. Red cultivar oil treatment means were calculated from 39 samples. White cultivar control means were calculated from 20 samples. White cultivar oil treatment means were calculated from 30 samples.

[z] Means are significantly different at $P \leq 0.05$ (*) or not significant (ns) using the students t-test.

was significant (Appendix G). There were no significant differences between the pH, TA, or berry weight of the control and oil treatment in either red or white cultivars (Table 10).

Experiment 4: Effect of oil and sulfur interactions on photosynthesis and fruit maturity of Seyval grapevines – 1998

NAR:

The NAR of oil treated Seyval was consistently lower than the NAR of Seyval not treated with oil (Table 11). The contrast of sulfur and no sulfur treatments was only significant on 5 August, when the sulfur vs. no sulfur, oil vs. oil + sulfur, and no oil + sulfur vs. oil + sulfur all showed significant differences between means (Table 11).

Fruit maturity:

The same contrasts used for NAR did not reveal any treatment differences among SSC, pH, TA, or berry weight means (Table 11).

The treatments caused very little visible foliage injury in the Seyval vineyard. Light stippling and a few chlorotic leaves in the lower canopy of oil treated vines were the only visible symptoms caused by both oil only and oil plus sulfur treatments. Yield components and pruning weights were not affected by oil or sulfur treatments (Table 11). None of the contrasts found significant differences among the yield components or pruning weight means.

Discussion

Photosynthesis:

In 1998, 6200 L/ha applications of soybean oil to Chardonnay caused the greatest depression of NAR (Table 3). Chardonnay foliage treated with soybean oil had a greasy coating which persisted through harvest even on 2440 L/ha treated foliage. These leaves were warm to the touch compared to control leaves on 4 August when the final NAR measurements were taken. The oil coating may have inhibited transpiration and reduced the evaporative cooling of soybean oil treated leaves. JMS Stylet and Sun Spray UltraFine oil coating did not appear as persistent as soybean oil. Mineral oil-treated leaves remained cool. The apparent persistence of and the

Table 11. Net assimilation rate and harvest (25 August) soluble solids concentration, pH, titratable acidity, berry weight, cluster weight, crop weight, and pruning weight of Seyval treated with 1.5% v/v oil in water (2050 L/ha) on 7 and 28 July and sulfur (9 kg/ha) on 8 and 29 July, 1998, Winchester, VA.

	Net assimilation rate ($\mu molCO_2 \times m^{-2} \times s^{-1}$)		
Treatment	17 July (10)[y]	21 July (14)	5 August (8)
No oil	15.3 [z]	14.7 [z]	14.3 [z]
No oil + S	15.4	14.7	13.8
JMS Stylet oil	12.3	13.6	12.2
JMS Stylet oil + S	12.1	13.9	10.9
Sun Spray oil	12.3	12.9	13.1
Sun Spray oil + S	12.5	14.0	11.9
P values from contrasts of Seyval treatments			
Sulfur vs. no sulfur	0.9826	0.2176	0.0179
Oil vs. no oil	0.0001	0.0097	0.0001
Oil vs. oil + S	0.9746	0.1442	0.0167
JMS vs. Sun Spray	0.7862	0.5773	0.0665
No oil + S vs. oil + S	0.0002	0.1979	0.0002

Means were calculated from 24 observations.

Treatment	SSC (%)	pH	TA (g/L)	Berry weight (g)
No oil	21.4 [z]	3.7 [z]	0.8 [z]	1.9 [z]
No oil + S	21.7	3.7	0.8	2.0
JMS Stylet oil	20.6	3.6	0.8	1.9
JMS Stylet oil + S	20.5	3.6	0.8	1.9
Sun Spray oil	20.5	3.6	0.7	2.0
Sun Spray oil + S	20.7	3.6	0.7	1.9

Means were calculated from 3 samples.

Treatment	Cluster weight (g)	Crop weight (kg/vine)	Pruning weight (kg/vine)
No oil	265.8 [z]	2.9 [z]	0.6 [z]
No oil + S	244.2	2.9	0.7
JMS Stylet oil	275.2	3.3	0.6
JMS Stylet oil + S	250.2	2.9	0.5
Sun Spray oil	263.6	3.1	0.6
Sun Spray oil + S	256.4	2.8	0.6

Means were calculated from 12 observations.

[z]There are no significant differences among the means in each column at $P \leq 0.05$.
[y]Numbers in parentheses following dates are the number of days elapsed since last oil treatment.

severity of the reductions in photosynthesis caused by soybean oil was surprising because Ferree *et al*. (1976) found that vegetable oils caused no depression in apple leaf photosynthesis. They did find, however, that a 70 second mineral oil reduced photosynthesis rates to 15% of the rate of a water treated control. Northover and Schneider (1996) found that the fungicidal effects of vegetable oils, including soybean oil, were less persistent the effects of mineral oils.

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. Gudin *et al*. (1976) found that low viscosity oil (32 centiStokes at 22°C) caused a greater reduction in photosynthesis of tomato leaves than high viscosity oil (2.37 cSt at 22°C). The low viscosity oil penetrated the tomato leaf cuticle, while the high viscosity oil remained on the leaf surface. Naim and Neumann (1978) found that silicone oil penetrated bean leaves inhibiting CO_2 diffusion in the intercellular spaces of the palisade and mesophyll tissues. Paraffin oil did not penetrate the leaf surface and only increased diffusion resistance at the stomatal openings, which caused less reduction in photosynthesis than the penetration by silicone oil. The viscosity of refined soybean oil is 28.86 centipoise at 40°C (Pryde, 1980). Refined soybean oil is less viscous than JMS Stylet oil. It is not certain if the viscosity of the degummed soybean oil used in this experiment is the same as refined soybean oil. If it is, the greater reductions in NAR caused by soybean oil can not be explained by soybean oil penetrating the leaf tissue. The volatility of the oils also may differ. The mineral oils may be more volatile than the soybean oil. If so, soybean oil would remain on the leaf surface, slowing gas exchange. The mineral oils would volatilize more quickly, reducing the amount of oil on the leaf and allowing more rapid gas exchange. The observation that the oil coating of soybean oil-treated foliage remained visible longer than the coating on mineral oil-treated leaves supports the more rapid dissipation of the mineral oils.

It was unclear if the differences in the severity of NAR reduction in 1998 were caused by varietal differences between Cabernet Sauvignon and Chardonnay or the difference in the volume of oil used. Treatments in 1999 included two 1.5% JMS Stylet oil treatments at 5600 L/ha and 1870 L/ha applied as a protectant to the whole canopy. Also, to determine if oil used as an eradicant and applied only to the fruit zone would reduce NAR and delay fruit maturity, a 930 L/ha

treatment was included. Powdery mildew outbreaks in Virginia often first appear as cluster infections and spread to the canopy. Oil applied to clusters early in a powdery mildew outbreak might arrest the infection before it is spread to the foliage.

The first 5600 L/ha oil treatment reduced NAR significantly more than the 1870 L/ha and 930 L/ha treatments in the Chardonnay vineyard (Table 7). Reductions of NAR were significant two days after the first application and after the second application in the Cabernet Sauvignon (Table 6). Ferree and Hall (1975) found that photosynthesis of apple leaves was reduced more by dipping, which provides complete coverage, than by sprayed applications. It is not surprising that a low volume of oil, applied only to the fruit zone caused the least reduction. It is probable that not all leaves used for measurements in the low volume treatment were sprayed with oil. Measurements were taken using leaves 1 to 2 nodes above the distal cluster. The leaves may have been above the canopy area sprayed.

The NAR of Chardonnay in the 5600 L/ha treatment was lower than that of the 1870 L/ha and 930 L/ha, water check, and control treatments after the first oil application (Table 7). After the second application, the 5600 L/ha treated vines had a higher NAR than the 1870 L/ha and 930 L/ha treatments, but remained lower than the water check and control (Table 7). During the 1999 growing season, there was little rainfall until September (Appendix H). The Chardonnay in the Leesburg vineyard was not irrigated and in the beginning of August showed symptoms of water stress. Because water deficits have a major effect on stomatal aperture and photosynthesis (Ferrini *et al*., 1995; Naor *et al*., 1994), the differences in NAR among treatments may have been complicated by the effects of water stress. Water stress may also have contributed to the drop in NAR seen in all Chardonnay treatments between 16 August and 19 August (Table 7).

Yield components and pruning weights:

Reduced photosynthesis early in the season could reduce yield by reducing carbohydrates available to the developing fruit. Three, 6200 L/ha oil applications to Chardonnay reduced berry, cluster, and crop weights (Table 5). The NAR of oil-treated Chardonnay was severely reduced in 1998 (Table 3). The number of clusters per vine was standardized so crop weights were not influenced by differences in cluster number. Fruit set affects cluster weight and is

influenced by photosynthate availability. Defoliation, reducing the production of carbohydrates in the early stages of berry growth, resulted in poor fruit set and symptoms of early bunch stem necrosis (Candolfi-Vasconcelos and Koblet, 1990; Caspari *et al*., 1998). Removing sinks (roots and shoot tips), which compete with clusters for carbohydrates, increased the number of berries per cluster (McArtney and Ferree, 1999). Because oils were applied to the Chardonnay two weeks after bloom, fruit set may have already occurred (Coombe, 1973) and the cluster and crop weights were probably a result of the reduction in berry size. Photosynthate supply, in large part determined by photosynthesis rate, directly influences berry size. During stage I of ripening, berry size is determined by cell division. Decreased carbohydrate availability limits cell division, reducing berry size at harvest (Ollat and Gaudillere, 1998). During stage III of ripening, berry size is determined largely by carbohydrate accumulation that increases the osmotic potential of the ripening berry (Matthews et al., 1987). Oil treatments also reduced the berry size of red and white cultivars during the 1998 season (Table 10). Although yield has not been affected in other oil experiments in grape (Northover and Homeyer, 1998,1999), oils did reduce fruit set and yield of oranges (Dean *et al*., 1978).

Pruning weights of oil-treated Chardonnay were also reduced in 1998 (Table 5). Between fruit set and harvest, clusters are stronger sinks for photosynthate than trunks and roots (Hale and Weaver, 1962). When photosynthesis is limited by oils, carbohydrate movement to the vegetative structures of the vine may be reduced and decrease growth. In 1999, it was observed that bud break and shoot development was delayed in the Chardonnay vines that had been treated with oil in the previous season. No data were collected in these plots during the 1999 season but it was observed that fruitfulness and vigor of the vines were 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 (Thomas and Barnard, 1937). Carbohydrates stored in woody parts of the grapevine are necessary for shoot growth before leaves begin exporting photosynthates early in the season (Roper and Williams, 1989). Although carbohydrate accumulation in the permanent structures of the vine was not measured, reduced photosynthate production by oil-treated grapevines may reduce storage of carbohydrates and affect vigor and yield in subsequent seasons.

Fruit Maturity:

The component of fruit maturity most often affected by oil applications in both 1998 and 1999 was SSC. In all experiments, SSC of oil-treated fruit tended to be lower than that of control fruit. Oil-treated Chardonnay took up to thirteen days longer than Chardonnay from the control plots to reach 21° Brix in 1998. A single late season oil application in 1999 reduced the Chardonnay fruit soluble solids concentration by over 1.5 °Brix (Appendix E). pH and titratable acidity were not affected in all experiments. Northover and Homeyer (1998) 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. Ripening of cucurbits was delayed by 690 L/ha applications of 1.5% JMS Stylet oil (McGrath and Shishkoff, 1999). Sugar accumulation in the fruit is dependent on leaf photosynthesis and a shift in translocation which results in the import of carbohydrate into the fruit rather than to growing vegetative structures (Glad *et al*., 1992). 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 (Hawker, 1969; Possner *et al*., 1983). Reduced photosynthate production in oil treated leaves has a greater direct effect on sugar accumulation than acid reduction as fruit matures.

There was no relationship between the amount of visible injury caused by oil and berry size, SSC, or acidity of different cultivars, but oil did cause significant visible injury to the foliage of 11 wine grape cultivars (Appendix F). The types of injury varied from many chlorotic leaves and large scorched areas to a light stippled necrosis. Three 6200 L/ha oil applications to Chardonnay in 1998 and 5600 L/ha oil applications made to Cabernet Sauvignon and Chardonnay in 1999 caused necrosis only where oil pooled on the leaves. Neither of these varieties had severe visible injury, but their photosynthesis rates and SSC at harvest were depressed by some of the oil treatments. Some injury may have been caused by interactions between oil and sulfur because sulfur was applied just two days after the first oil application. It is not recommended that sulfur and oil be applied within two weeks of each other due to possible phytotoxic interactions (JMS, 1994; Sun Spray). An alternating program of oil and sulfur applied on a seven day schedule caused shoot tip burn (Dell and Gulber, 1998a). However,

Seyval vines treated with oil or oil and sulfur in Experiment 4 showed no differences in visible injury or fruit maturity (Table 11).

The difference in amount and type of injury caused by oil may be due in part to varietal differences in the leaf cuticle or trichomes. In work on tomato leaves, Gudin and Syratt (1976) found that different rates and volumes of oil penetrating the leaf cuticle resulted in different degrees of injury. Oil might be prevented from rapidly penetrating grape leaves with thick cuticles on their upper epidermis or a thick covering of trichomes on their lower epidermis. More waxy or hairy leaves would not be prone to scorching caused by oil quickly penetrating the leaf tissue. Large scorched and stippled necrotic areas of leaves were often seen first as soaked appearing areas on the leaves. Soaking may indicate where oil penetrated the leaf or oils have caused cells to become leaky. Penetration of the leaf by oils has also been used to explain reductions in photosynthesis because CO_2 moves much more slowly through oil than through air (Naim and Neumann, 1978). Even if oil does not penetrate into the leaf, slow diffusion of CO_2 through oil on the leaf surface would reduce gas exchange. Measurements of NAR were made using healthy looking leaves so differences in photosynthetic activity among treatments were not affected by obvious injuries.

Although lower volume oil applications affected NAR, SSC, and yield less than high volume applications, reducing spray volumes may not be practical. The efficacy of oils as a fungicide depends on good coverage. Wicks and colleagues (1999) found that powdery mildew infections occurred in the inside of canopies due to poor coverage when 500 to 2000 L/ha of 1% v/v oil and water was used. Wilcox and Riegel (1999) found that reducing spray volumes by 50% significantly reduced the effectiveness of JMS Stylet oil as a fungicide. They also found that reducing the concentration of oil from 1.5% to 1.0 % significantly reduced efficacy (Wilcox and Riegel, 1996). Disease incidence was not assessed in my study, so it is unclear if the 1870 L/ha treatment could adequately control powder mildew. However, it was observed that the 1870 L/ha sprays did not provide full coverage of clusters. The sides of clusters facing the interior of the canopy were not coated with oil, leaving them susceptible to powdery mildew infection. In addition to leaving leaves of the upper canopy unprotected, the 930 L/ha treatment applied only to the fruit zone did not provide full coverage on the clusters. Without full coverage, an existing

powdery mildew infection would not be eradicated. Other researchers have achieved good powdery mildew control on clusters using 1870 L/ha of 1.5 % JMS Stylet oil/water (Wilcox and Riegel, 1998) or 936 L/ha of 2% JMS Stylet oil/water (Muza and Travis, 1993). Dell *et al*. (1998) found that 935 to 1379 L/ha of 2% JMS Stylet oil/water applied five times during the growing season significantly reduced powdery mildew incidence and severity on clusters. The control achieved was comparable to that by SI fungicides.

The poor coverage observed in Experiment 2 was probably due to the application method used. Oil was applied at 1400 kPa in 1998 and only 560 kPa in 1999. Wilcox and Riegel (1998) used a boom sprayer which generated 2069 kPa of pressure. The producer recommends applications of 1 to 2% JMS Stylet oil using 500 L/ha of water at 1400 to 2450 kPa (JMS, 1994) for fungicidal use. The Sun Company recommends 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 (Sun Spray). The use of low volume oil applications may be practical with adequate spray pressure and air movement. If a low pressure, hand held sprayer is used, high volumes should be used to ensure good coverage.

Despite the potential delay in fruit maturity, horticultural oil is still a valuable tool for fighting powdery mildew infections. New York IPM recommendations list JMS Stylet oil as a product to be used as a supplement to conventional programs and as an early season protectant (Weigle and Kovach, 1998). 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 (Candolfi-Vasconcelos *et al*., 1999). Oil could also be used as an inexpensive, late season protectant, applied after harvest to keep vines free of powdery mildew until leaf drop and reduce inoculum for the next season. If oils are used late in the season, care must be taken to use volumes of oil that provide good disease control but do not seriously reduce carbohydrate production and affect current and possibly long term vine vigor and yield. California disease control recommendations include the use of oils early in the season. Because photosynthesis rates should recover as the amount of oil on the foliage decreases over time, this may also be a practical use for oils if limited carbohydrate production does not reduce fruit set or affect berry development.

The most valuable use of oils is as an eradicant. Oils can be used as a supplement to traditional control methods to eliminate infections when a disease management program fails. The risk of resistance development makes the use of SI or strobilurins as eradicants inadvisable and sulfur is only effective as a protectant. Oils could be used to save grape crops when powdery mildew infections become serious. Powdery mildew infections often first occur on the clusters. When infection is detected high volumes of oil, to ensure good coverage, should be applied to the fruit zone. This method of oil use would eradicate the infection on the clusters before it spreads to the foliage. By applying oil only to the fruit zone, reductions in photosynthesis and resulting reductions in fruit maturity and yield would be limited.

Conclusion

Horticultural oils inhibit photosynthesis, probably by slowing gas exchange. Higher volumes of oil applied during the season cause greater decreases in photosynthesis than lower volumes. In addition to reducing photosynthesis, oils can delay the accumulation of soluble solids in the maturing fruit. Because oils probably limit photosynthesis by blocking gas exchange rather than by causing physical damage to the leaf tissue, reductions in photosynthesis occur in the absence of visible symptoms of phytotoxicity.

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APPENDICES

Appendix A. Canopy characteristics of Cabernet Sauvignon treated with 1.5 % v/v oil (2240 L/ha) on 23 June, 10 July, and 27 July 1998 as determined by point quadrat analysis, Leesburg, VA.

Treatment	Leaf layers	% exterior fruit	% gaps
Control	3.1 a[z]	27.2	2.0
JMS Stylet oil	3.3 a	19.4	0.0
Soybean oil	2.6 b	61.4	4.0
Sun Spray oil	3.1 a	51.6	2.0

Means were calculated from 50 observations.

[z]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.

Appendix B. Canopy characteristics of Chardonnay treated with 1.5 % v/v oil (6200 L/ha) oil on 9 June, 22 June, and 3 August 1998 as determined by point quadrat analysis, Winchester, VA.

Treatment	Leaf layers	% exterior fruit	% gaps
Control	1.6	74.0	8.8
JMS Stylet oil	1.6	66.1	12.5
Soybean oil	1.7	67.1	8.8

Means were calculated from 210 observations.
Within each column, means are not significantly different at $P \leq 0.05$.

Appendix C. Canopy characteristics of Cabernet Sauvignon treated with 1.5% v/v JMS Stylet oil using 3 different volumes on 21 July and 9 Aug 1999 as determined by point quadrat analysis, Winchester, VA.

Treatment	Leaf layers	% exterior fruit	% gaps
Water[z]	1.8	56.3	0.8
930 L/ha	1.6	60.5	6.5
1870 L/ha	1.6	59.1	5.6
5600 L/ha	1.8	57.7	2.9

Means were calculated from 168 observations.
Within each column, means are not significantly different at $P \leq 0.05$.
[z]Water was applied at a volume of 1870 L/ha.

Appendix D. Canopy characteristics of Chardonnay treated with 1.5% v/v JMS Stylet oil using 3 different volumes on 20 July and 10/11 August 1999 as determined by point quadrat analysis, Leesburg, VA.

Treatment	Leaf layers	% exterior fruit	% gaps
Water[z]	3.1	32	0
930 L/ha	3.0	18	0
1870 L/ha	2.6	55	5
5600 L/ha	2.8	60	0

Means were calculated from 40 observations.
Within each column, means are not significantly different at $P \leq 0.05$.
[z]Water was applied at a volume of 1870 L/ha.

Appendix E. Soluble solids concentration of Chardonnay as affected by a single application of water, JMS Stylet oil, or Sun Spray UltraFine oil at 1870 L/ha on 4 August 1999, Winchester, VA.

	Soluble solids concentration (%)		
Treatment	1 September	14 September	22 September
Water	19.8 [z]	21.0	21.4 a
JMS Stylet oil[y]	18.9	19.9	19.7 b
Sun Spray oil[y]	18.8	19.9	19.8 b

Means were calculated from 3 samples.

[z]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.

[y]Oils were used at a rate of 1.5% v/v oil/water.

Appendix F. Phytotoxic injury, soluble solids concentration, pH, titratable acidity, and berry weight of wine grape cultivars treated with 1/5% v/v JMS Stylet oil/water on 7 June and 7 July, Winchester, 1998.

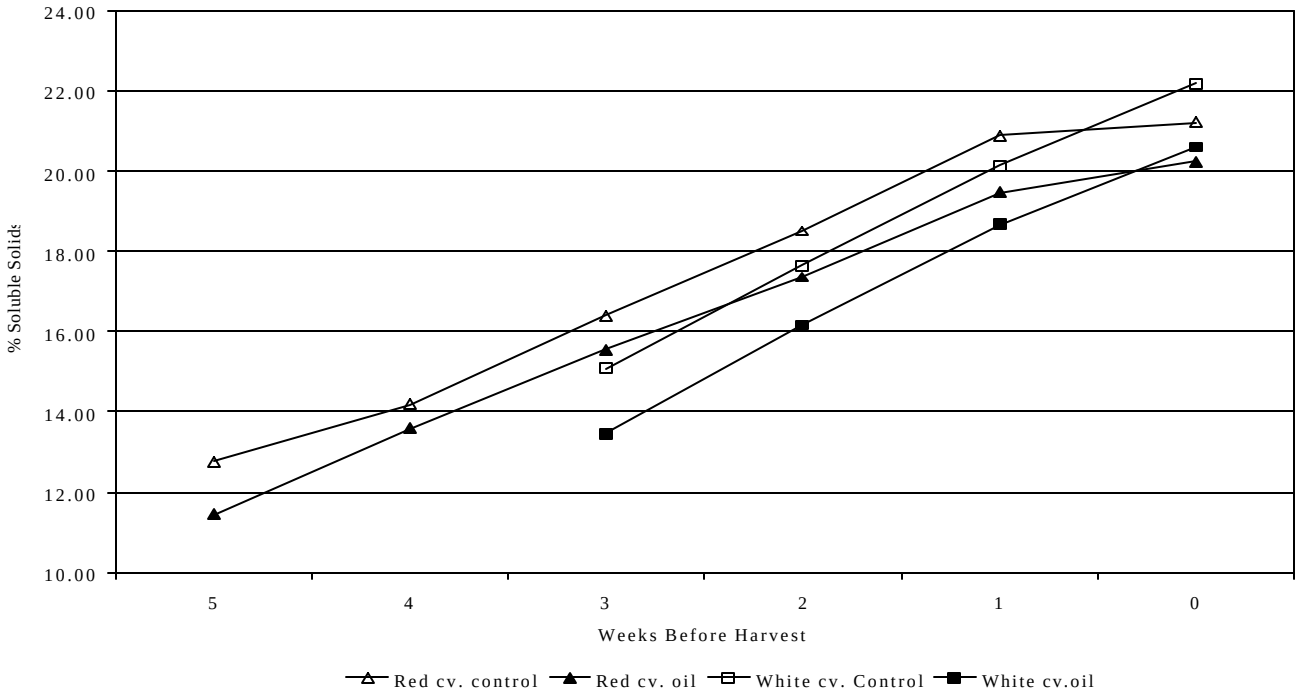
Variety	Treatment	% Canopy injured	Berry weight (g)	% Soluble solids	pH	Titratable acidity (g/L)
Cab. Sauvignon 6	Control	5	1.2 [y]	21.4	4.0	0.47
	Oil	4 (d)[z]	1.0	20.3	3.9	0.54
Cab. Sauvignon 8	Control	3	1.6	21.6	4.0	0.43
	Oil	4 (d)	1.5	20.1	4.0	0.44
Charbono	Control	38	2.6	19.4 [y]	4.1	0.42
	Oil	47 (a)	2.8	17.4	4.2	0.40
Chardonnay 4	Control	0 [y]	1.7	22.7	3.7	0.82
	Oil	7 (d)	1.5	21.2	3.7	0.79
Chardonel	Control	0 [y]	2.3	23.0	3.3	0.90 [y]
	Oil	20 (bc)	2.3	21.0	3.4	0.80
Fer Servadou	Control	30	1.9	21.5 [y]	4.0	0.45 [y]
	Oil	40 (b)	1.6	20.1	4.0	0.50
Gruner Veltliner	Control	0 [y]	2.0	23.0	3.9	0.54
	Oil	9 (d)	1.7	20.9	4.0	0.50
Limberger	Control	3	2.1	20.0	3.7	0.68
	Oil	5 (d)	1.8	18.8	3.7	0.67
Malvasia Bianca	Control	1	3.9 [y]	19.1	3.7 [y]	0.56
	Oil	13 (bcd)	3.0	18.2	3.8	0.60
Mataro	Control	2	2.2	22.2	4.0	0.53
	Oil	8 (d)	2.1	21.1	4.1	0.58
Muscat Ottonel	Control	1 [y]	2.4	21.3 [y]	4.1	0.47
	Oil	12 (bcd)	2.1	18.9	4.2	0.41
NY62.122.1	Control	8 [y]	2.7 [y]	23.3 [y]	4.0 [y]	0.53
	Oil	53 (a)	2.2	20.3	4.1	0.50
Nebbiolo	Control	0 [y]	1.8 [y]	22.7 [y]	3.7	0.88
	Oil	4 (d)	1.5	20.9	3.7	0.89
Petit Manseng	Control	0 [y]	1.0	27.6 [y]	3.8	0.77
	Oil	7 (d)	0.9	23.7	3.8	0.71
Petit Verdot	Control	3 [y]	1.2 [y]	23.0 [y]	3.8	0.73 [y]
	Oil	10 (cd)	0.9	20.0	3.8	0.82
Refosco	Control	9	2.2	19.0	4.0 [y]	0.44 [y]
	Oil	9 (d)	2.1	18.4	4.1	0.39
Sangiovese	Control	4	2.6 [y]	20.6	3.9 [y]	0.45
	Oil	6 (d)	2.3	19.7	4.0	0.46
Syrah	Control	6	1.6	22.9 [y]	4.1	0.55
	Oil	8 (d)	1.3	21.1	4.1	0.52
Tannat	Control	1 [y]	1.9 [y]	23.8	3.7	0.83
	Oil	7 (d)	1.7	22.2	3.9	0.73
Traminette	Control	1 [y]	2.0	19.5	3.5	0.63
	Oil	13 (bcd)	1.7	18.2	3.5	0.61
Valdepenas	Control	13	1.7	22.3	4.0	0.54
	Oil	11 (bcd)	1.5	20.6	4.0	0.41
Vidal Blanc	Control	0	1.9	22.2	3.7	0.55
	Oil	7 (d)	1.7	21.9	3.8	0.59
Viogner	Control	5 [y]	1.5 [y]	24.1 [y]	3.9	0.60
	Oil	20 (cb)	1.1	21.8	3.8	0.68

Control means were calculated from two samples. Oil treatment means were calculated from three samples.

[z] Letter in parenthesis indicates significant differences by cultivar as determined by visual estimates of % canopy affected by symptoms of phytotoxicity.

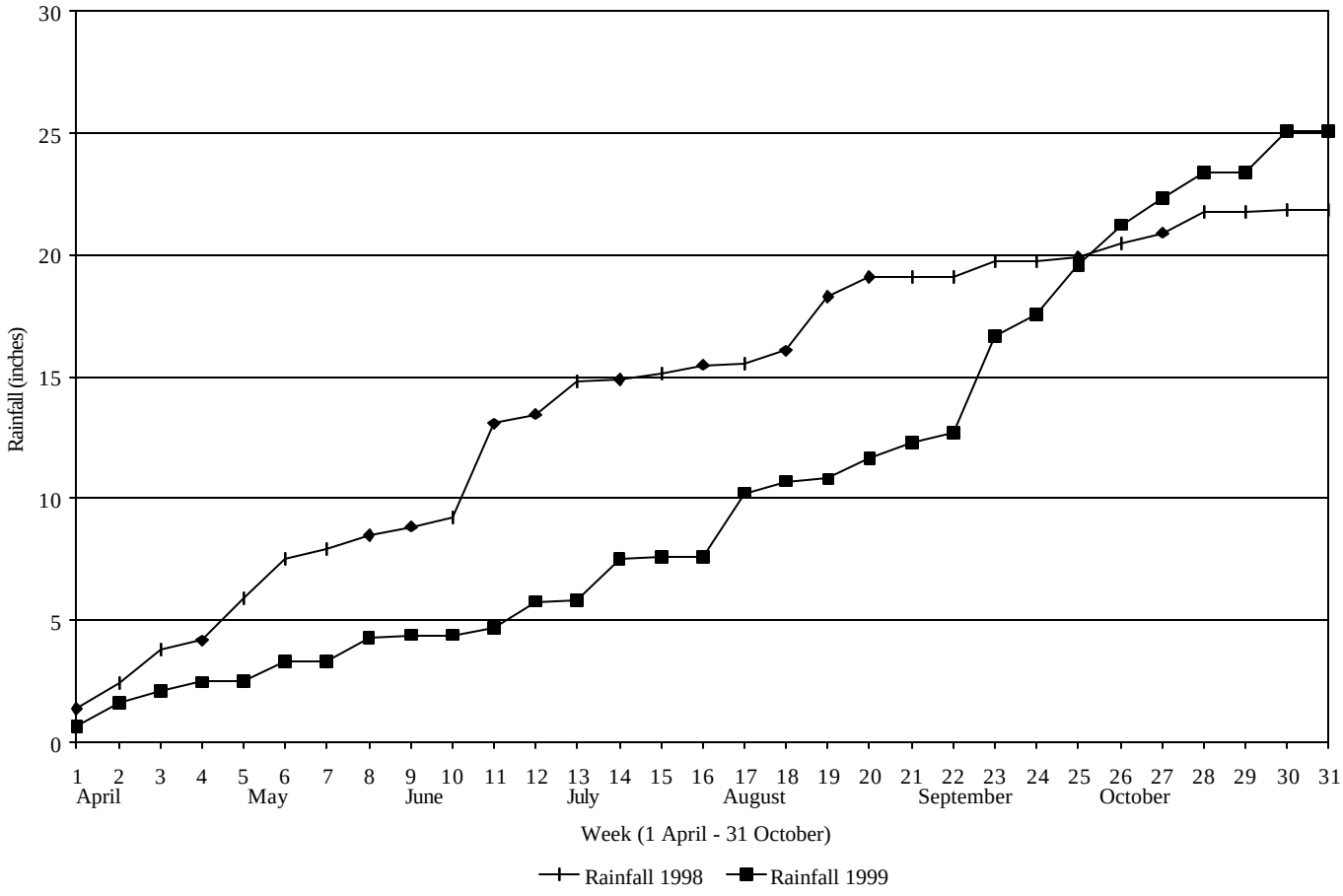
[y] For cultivar, variable means are significantly different at $P \leq 0.05$ using student's t-test.

Appendix G. Fruit soluble solids concentration of red and white grape cultivars from control (no oil application) and oil treated plots (1.5% v/v JMS Stylet oil/water applied on 7 June at 5550 L/ha and 7 July at 4680 L/ha), Winchester, 1998.



First berry samples were taken on 20 August 1998.
Control means were calculated from 2 samples, oil treatment means were calculated from 3 samples.

Appendix H. Cumulative rainfall in Winchester, VA vineyard, 1 April - 31 October 1998, 1999.



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