# Effect of horticultural oil on oviposition behaviour and egg survival in the obliquebanded leafroller (Lepidoptera: Tortricidae)

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**Abstract**—The effects of the horticultural oil Purespray Green on oviposition behaviour and egg development in the obliquebanded leafroller, *Choristoneura rosaceana* (Harris), were investigated through dual-choice and no-choice bioassays and topical applications of oil to developing eggs. A residual 2% (*v/v*) oil spray on wax-paper and apple-leaf substrates significantly reduced both the number of eggs laid and egg survival in no-choice assays; however, this effect diminished 3 days after treatment. In dual-choice assays, females laid significantly fewer eggs on oil-treated apple leaves than on control leaves, but laid equal numbers of eggs on the oil-treated wax paper and the untreated wax-paper controls. Topical application of oil caused significant dose-dependent mortality of both newly laid eggs and eggs just before hatch, and these two egg stages were equally susceptible to the oil. Topical application of 2% oil caused >99% egg mortality. Our data indicate that gravid female *C. rosaceana* can assess and reject oil-sprayed surfaces and that the oil can kill eggs through both contact toxicity and suffocation. These characteristics suggest that highly purified horticultural oils like Purespray Green could play a role in an integrated pest management program for this important pest species.

**Résumé**—Nous avons étudié les effets de l'huile horticole Purespray Green sur le comportement de ponte et le développement des oeufs chez la tordeuse à bandes obliques, *Choristoneura rosaceana* (Harris), dans des bioessais à deux choix et sans choix et par des traitements topiques à l'huile des oeufs en développement. Dans des bioessais sans choix, un résidu de 2 % (*v/v*) de vaporisation d'huile sur du papier ciré et des substrats de feuilles de pommiers réduisent significativement tant le nombre d'oeufs pondus que la survie des oeufs; cependant, cet effet diminue 3 jours après le traitement. Dans des essais à deux choix, les femelles pondent significativement moins d'oeufs sur les feuilles de pommiers traitées à l'huile par comparaison aux témoins; cependant, les femelles pondent des nombres égaux d'oeufs sur le papier ciré traité à l'huile et sur le papier ciré témoin non traité. Le traitement topique à l'huile cause une mortalité significative reliée à la dose à la fois chez les oeufs nouvellement pondus et les oeufs juste avant l'éclosion; les deux stades embryonnaires sont également vulnérables à l'huile. Un traitement topique à l'huile à 2 % cause une mortalité des œufs >99 %. Nos données indiquent que les femelles gravides de *C. rosaceana* peuvent reconnaître et rejeter les surfaces badigeonnées d'huile et que l'huile peut tuer les oeufs à la fois par toxicité de contact et par suffocation. Ces caractéristiques indiquent que les huiles horticoles hautement purifiées, telles que Purespray Green, pourraient jouer un rôle dans un programme de lutte intégrée contre cette espèce importante de ravageur.

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## Introduction

The obliquebanded leafroller, *Choristoneura rosaceana* (Harris) (Lepidoptera: Tortricidae), is a native polyphagous insect that is widely distributed throughout temperate North America (Chapman and Lienk 1971). It is a generalist herbivore that can exploit a large number of woody plants; however, its preferred hosts include genera in the family Rosaceae, most significantly *Malus* Mill., *Crataegus* L., *Rubus* L., *Prunus* L., and *Rosa* L. (Chapman *et al.* 1968). It is a serious pest of apples (*Malus pumila* Mill.) in the Okanagan Valley in British Columbia, where it overwinters as a third or fourth instar within a silken hibernaculum and breaks diapause in the spring to feed on developing shoots (Chapman *et al.* 1968; Madsen and Proctor 1982). Adults are typically active beginning in early June, and gravid females lay eggs in masses on the surface of apple leaves (Carrière *et al.* 1995). The summer brood of larvae feed on leaves and fruit and generally cause greater fruit damage than the overwintering generation (Chapman and Lienk 1971).

In recent years the pest status of *C. rosaceana* across North America has increased, owing, in part, to the evolution of resistance in some populations to common organophosphate insecticides (Reissig *et al.* 1986; Smirle *et al.* 1998; Pree *et al.* 2001, 2002). Azinphos-methyl is currently the most commonly used organophosphate for controlling *C. rosaceana* (Difonzo 1997). However, because of concerns over worker safety and environmental impacts, all uses of azinphos-methyl in Canada will be phased out by 2012 (Pest Management Regulatory Agency 2007), with similar regulatory restrictions planned for the United States of America (Environmental Protection Agency 2008). This presents an immediate need to develop alternative control tactics that are compatible with integrated pest management programs for this insect.

Petroleum-derived horticultural oils have been employed for over a century to control various insects and mites in agricultural systems. Traditional usage in orchard systems has been restricted to dormant fruit trees because of phytotoxic impurities in oil formulations (Agnello 2002; Fernandez *et al.* 2005). Recently, highly purified horticultural-oil products have been developed that are suitable for foliar applications on pome trees during the growing period (Riedl *et al.* 1995). These oils are typically combined with an emulsifying agent and applied as summer sprays at ≤2% (*v/v*) active ingredient. Concentrations above 2% (*v/v*) can have phytotoxic effects on fruit trees and generally are not suitable for postbloom application (Riedl *et al.* 1995; Agnello 2002).

Horticultural oils can negatively impact insects and mites in several ways. Oils applied to adults enter through the spiracles, penetrate the trachea for a short distance, and impede gas exchange (Taverner 2002). Oils applied to eggs coat the surface and induce suffocation (Pearce and Chapman 1952; Fiori *et al.* 1963). Long carbon chain oils (*i.e.*, >*n*C23) are the most effective formulations for egg suffocation because they spread evenly over the surface and have low volatility (Pearce and Chapman 1952; Fiori *et al.* 1963). In addition, residual oil sprayed onto foliage may have ovicidal activity (Larew and Locke 1990; Riedl *et al.* 1995) and deter oviposition in several insect species (Larew and Locke 1990; Mensah *et al.* 1995; Sun 2002; Liu *et al.* 2006; Nguyen *et al.* 2007).

In this study we examined the effects of a residual application of *n*C23 horticultural oil on survival of *C. rosaceana* eggs and on female oviposition behaviour. Specifically, we tested the hypothesis that a residual 2% oil treatment would reduce the total reproductive output of mated female *C. rosaceana* by both deterring oviposition and reducing the survival of eggs laid on different substrates. Finally, we tested the hypothesis that a topical application of oil would have a stronger ovicidal effect on newly laid eggs than on eggs just before hatch.

## Materials and methods

### Insects and oviposition substrate materials

The specimens of *C. rosaceana* used in this study came from a laboratory-reared colony originally collected in the Okanagan and Similkameen valleys of British Columbia. Larvae were reared individually in 25 mL Solo cups (Solo Canada, Toronto, Ontario) on a modified pinto-bean-based diet (Shorey and Hale 1965) at 23 °C and 50%–60% RH under a 16L:8D photoregime. Pupae were collected weekly, separated by sex, and placed individually in clean 25 mL Solo cups until adult eclosion. Adults were collected each day, provided with water through a dental wick, and held under rearing conditions until used in bioassays. In all bioassays, adult males were 24–96 h old and adult females were 24–48 h old.

**Oil formulation and application**

Purespray Green (batch No. 655–0602, Petro-Canada, Mississauga, Ontario) is a highly purified *n*C23 horticultural mineral oil with molecular weight 325, paraffin content >99.9% (by mass), aromatic content <0.01% (by mass), and average boiling point (ASTM D 1160) 223.9 °C (Petro-Canada technical data sheet). Purespray Green is combined with a proprietary emulsifier and has been approved for organic agriculture usage in the United States of America (Organic Materials Review Institute, Eugene, Oregon). For all bioassays, control treatments consisted of distilled-water sprays. Treatment applications at the label-recommended rate of 2% oil (*v/v*) consisted of 2 mL Purespray Green in 98 mL of distilled water, a rate previously used on apples without inducing phytotoxicity (Julie Boulé, personal communication). Spraying was done with a 160 mL hand-held disposable aerosol spray gun (Preval Sprayer, Precision Valve Corporation, Yonkers, New York) onto either wax paper (McNairn Packaging Inc., Whitby, Ontario) or apple leaves collected from an unsprayed experimental McIntosh apple orchard at the Pacific Agri-Food Research Centre in Summerland, British Columbia. Sprays were applied at a rate of 1 mL / 100 $cm^2$, equivalent to the label-recommended application rate of 1000 L/ha for Purespray Green. All sprays were applied from a distance of 25 cm to substrates taped to a plastic board and inclined at a 20° angle. Only the adaxial surface of apple leaves was sprayed and leaves were oriented downward during spraying.

**Relationship between egg mass surface area and egg number**

Because individual *C. rosaceana* eggs within a newly laid egg mass are difficult to distinguish visually, an initial experiment was conducted to determine the relationship between the surface area of the egg mass and the number of eggs laid. The surface area of 35 egg masses laid on clean, untreated wax paper was measured using a digital image of each egg mass and Image Pro Plus software (MediaCybernetics Inc. 2002). The eggs were counted at the black-headed stage (Hammer 1912), when each egg is clearly visible. Egg mass surface area ($x$) was a strong predictor of the number of eggs laid per egg mass ($y$) according to the relationship $y = -29.24 + 5.781x$ ($r^2 = 0.96$, $P < 0.001$). This relationship was used to estimate the number of eggs laid per egg mass for the dual-choice and no-choice oviposition assays outlined below.

**No-choice oviposition assays**

Three no-choice oviposition experiments tested the hypothesis that a 2% residual oil treatment would have a toxic effect on eggs subsequently laid on the substrate and act as a deterrent to oviposition by female *C. rosaceana*. All assays were conducted in an environmental chamber at 23 °C and 50%–60% RH under a 16L:8D photoregime. For all experiments, single-pair matings were conducted in cylindrical wire-mesh arenas (7 cm diameter × 5 cm height) during the scotophase 24 h prior to the bioassay.

In experiment 1, wax-paper discs (7 cm diameter) were sprayed with either distilled water or 2% oil and placed on the floor of each wire-mesh arena. One mated female was introduced into each arena ($n = 23$) 1 h before the onset of scotophase and given 48 h to oviposit. In experiment 2, apple leaves treated with either distilled water or 2% oil were placed on the floor of a wire-mesh arena. To prevent leaf desiccation during the bioassay period, the arenas were placed on moist paper towels inside a clear plastic dome (50 cm × 25 cm × 15 cm). One mated female was introduced into each arena and given 48 h to oviposit. In experiment 3, apple leaves on trees were treated with distilled water or 2% oil and left for 72 h before they were picked and transported to the laboratory, where oviposition assays were conducted as in experiment 2. In all three no-choice experiments we recorded the number of egg masses laid per female and the surface area of each egg mass. Egg masses were held in an environmental chamber to develop to the black-headed stage, when the eggs could be accurately counted using a digital image of each egg mass. After all viable larvae had emerged, the remaining dead black-headed eggs were counted to determine the total number of larvae that hatched per egg mass.

**Dual-choice oviposition assays**

Dual-choice oviposition assays were conducted to test the hypothesis that 2% (*v/v*) residual oil treatment would act as a deterrent to oviposition by female *C. rosaceana*. Wax-paper assays were conducted in a Conviron environmental chamber at 23 °C and 50%–60% RH under a 16L:8D photoregime. Five mated females were transferred to a cylindrical wire-mesh oviposition arena (30 cm diameter × 10 cm height) and provided with a wet cotton wick ($n = 21$). The oviposition substrate consisted of a 30 cm diameter circle of brown waxed paper placed on the floor of the chamber, with one half of each

circle treated with 2% (*v/v*) Purespray Green and the other half treated with distilled water. After a 48-h oviposition period, the number of egg masses on the treatment and control halves was recorded and the surface area of each egg mass was measured. Egg masses touching both halves were excluded from analyses ($n$ = 2).

Dual-choice oviposition assays were conducted outside on apple leaves in the unsprayed experimental McIntosh apple orchard at the Pacific Agri-Food Research Centre between 24 July and 4 August 2006. Newly eclosed males and females were held outside for 24 h in separate 10 L buckets to acclimate to outdoor conditions prior to assays. Ten male and 10 female moths were introduced into an oviposition cage (45 cm × 45 cm × 45 cm) and provided with a wet cotton wick. Oviposition cages containing moths ($n$ = 12) were placed between apple trees on the orchard floor in the late afternoon and moths were given 24 h to mate. Apple shoots (45 cm long) with 10 mature leaves were clipped from trees, rinsed with distilled water, and allowed to dry. Shoots and leaves were taped flat to a plastic board and the leaves of one entire shoot were sprayed with either distilled water or 2% Purespray Green. After drying, two shoots from each treatment were inserted into floral picks and positioned vertically inside each oviposition cage in the late afternoon. Females were given one full scotophase during which to oviposit. The number of egg masses laid on treatment and control leaves was recorded and the surface area of each egg mass measured.

### Topical application of oil to eggs

We tested the ovicidal activity of the oil topically applied to newly laid *C. rosaceana* eggs. Egg masses laid on wax paper by individual mated females were collected immediately after oviposition and the surface area of each mass was measured as above. Egg masses were randomly assigned to treatment groups (10 per treatment) and sprayed with a 0.05%, 0.1%, 0.25%, 0.5%, or 1% emulsion of Purespray Green or a distilled-water control. After treatment, egg masses were allowed to dry in a fume hood in individual Petri dishes (3.5 cm diameter). The Petri dishes were then placed in a growth chamber at 23 °C and 50%–60% RH until development was complete, and percent hatch was recorded.

To test the effect of applying oil to eggs at the black-headed stage, egg masses laid on untreated wax paper by individual mated females were held at 23 °C and 50%–60% RH until development to the black-headed stage was complete. The eggs in each egg mass were then counted and egg masses were randomly assigned to treatment groups (10 per treatment) and sprayed with a 0.1%, 0.5%, 1%, 2%, or 3% emulsion of Purespray Green or a distilled-water control. Egg masses were allowed to dry and then placed individually in Petri dishes and held under the same conditions until larvae hatched, and percent hatch was recorded.

### Statistical analyses

In no-choice assays, treatment differences in total number of eggs laid, percent egg survival, and total number of emerged larvae were separated using two-sample $t$ tests, except in cases of significant heteroscedasticity, where the nonparametric Mann–Whitney $U$ test was used. In dual-choice oviposition assays, treatment differences in number of egg masses laid, number of eggs per egg mass, and total number of eggs laid were analysed using paired $t$ tests. For both newly laid and black-headed eggs treated topically with oil, percent egg mortality was regressed against oil concentrations between 0% and 1%. In the experiment with black-headed eggs, the 2% and 3% treatments were excluded from the analysis in order to compare the effect of oil between the two experiments; the slopes of the two regression lines were compared using a $t$ test. Proportion data were arcsine square root transformed prior to analysis, although the untransformed data are presented in the results. Significance was set at $\alpha = 0.05$ for all tests, and analyses were done using SigmaStat software.

## Results

### No-choice oviposition assays

The no-choice assays indicated that a residual 2% oil treatment reduced both the number of eggs laid by females and subsequent percent egg survival. Females laid significantly fewer eggs on both the freshly sprayed wax paper and apple-leaf oviposition substrates treated with 2% oil than on controls (Table 1). Percent egg survival on the oil-treated surfaces was significantly less than on controls (Table 1). Reductions in both the number of eggs laid and percent egg survival contributed to a significant reduction in the total number of emerged larvae on oil-treated surfaces. The freshly sprayed 2% oil

**Table 1.** Numbers of eggs laid, percent egg survival, and total numbers of larvae emerged from egg masses laid by individual *Choristoneura rosaceana* in no-choice oviposition assays on wax-paper and apple-leaf substrates treated with either distilled water or 2% Purespray Green in distilled water.

| Oviposition substrate | DAT* | *n* | Total number of eggs laid per female† | | | | Percent egg survival per female† | | | | Total number of larvae emerged | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Water | 2% oil | *t* | *P* | Water | 2% oil | *t* | *P* | Water | 2% oil | *t* | *P* |
| Wax paper | 0 | 29 | 593.7±34.9 | 440.9±34.1 | 3.1 | 0.003 | 79.9±0.02 | 52.5±0.03 | 6.3 | <0.001 | 460.3±23.0 | 231.9±23.4 | 6.9 | <0.001 |
| Apple leaves | 0 | 20–23 | 512.7±36.5 | 347.7±76.8 | NA‡ | 0.004 | 76.5±0.04 | 39.2±0.06 | 5.3 | <0.001 | 403.1±38.3 | 168.4±43.2 | 4.1 | <0.001 |
| | 3 | 21–23 | 507.9±35.2 | 445.3±48.4 | 1.1 | 0.30 | 86.3±0.04 | 76.7±0.05 | 1.5 | 0.154 | 436.8±34.6 | 326.8±38.9 | 2.1 | 0.040 |

**Note:** Values are given as the mean ± SE.
*Number of days after treatment.
†Treatment differences were evaluated by *t* test ($\alpha = 0.05$).
‡Treatment differences were evaluated by Mann–Whitney *U* test ($\alpha = 0.05$).

caused a 50% reduction ($t_{56} = 6.9$, $P < 0.001$) in the total number of emerged larvae on the wax paper and a 58% reduction ($t_{41} = 4.1$, $P < 0.001$) on the apple leaves (Table 1). When the sprayed apple leaves were allowed to age under field conditions for 3 days, the 2% oil did not significantly affect either the number of eggs laid or percent egg mortality, and caused only a small but significant 25% reduction ($t_{42} = 2.1$, $P = 0.04$) in the total number of larvae emerged (Table 1).

### Dual-choice oviposition assays

The 2% oil acted as an oviposition deterrent when applied to wax paper; females laid significantly fewer egg masses on the oil-treated half of the wax-paper disc than on the water-treated half (Table 2). There was no effect of treatment on the mean number of eggs per egg mass or on the total number of eggs laid (Table 2). When given apple leaves under more natural conditions, females laid equal numbers of egg masses on oil-treated leaves and control leaves ($P = 0.07$), but laid a significantly lower mean total number of eggs on oil-treated leaves than on control leaves ($P = 0.01$) (Table 2).

### Topical application of oil to eggs

For newly laid eggs there was a significant positive relationship between oil concentration and egg mortality ($y = 36.2 + 69.2x$, $r^2 = 0.54$, $P < 0.001$) at oil concentrations between 0% and 1% (Fig. 1). For black-headed eggs there was a significant positive relationship between oil concentration and egg mortality ($y = 34.4 + 60.1x$, $r^2 = 0.71$, $P < 0.001$) at oil concentrations between 0% and 1% (Fig. 2). Both 2% and 3% oil caused 99.5% mortality of black-headed eggs. There was no significant difference in the slopes of the regression lines for mortality between the newly laid and black-headed eggs ($t_{96} = 1.57$, $P = 0.12$), indicating that these egg stages were equally susceptible to the effects of the oil.

## Discussion

Our data show that Purespray Green can deter oviposition and exert ovicidal effects on *C. rosaceana*. No-choice and dual-choice oviposition assays both showed a significant reduction in the number of eggs laid by mated female *C. rosaceana* on substrates sprayed with 2% oil. Treatment of substrates with horticultural oil similarly reduces the number of eggs

**Table 2.** Numbers of egg masses, numbers of eggs laid per egg mass, and total numbers of eggs laid by *Choristoneura rosaceana* in dual-choice oviposition assays on wax-paper and apple-leaf substrates treated with either distilled water or 2% Purespray Green in distilled water.

| Oviposition substrate | DAT* | *n* | Number of egg masses† | | | | Number of eggs per egg mass† | | | | Total number of eggs laid† | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Water | 2% oil | *t* | *P* | Water | 2% oil | *t* | *P* | Water | 2% oil | *t* | *P* |
| Wax paper | 0 | 21 | 4.0±0.3 | 2.9±0.4 | 2.6 | 0.017 | 160.4±17.8 | 151.2±19.0 | 0.3 | 0.772 | 635.7±67.4 | 457.5±75.8 | 1.7 | 0.104 |
| Apple leaves | 0 | 12 | 6.2±0.6 | 3.6±0.8 | 2.0 | 0.072 | 318.7±18.6 | 269.7±45.2 | 1.2 | 0.271 | 1957.1±195.7 | 986.8±202.9 | 2.9 | 0.014 |

**Note:** Values are given as the mean ± SE.
*Number of days after treatment.
†Treatment differences were evaluated by paired *t* test ($\alpha = 0.05$).

laid by several key lepidopteran pests, including *Helicoverpa punctigera* (Wallengren) and *H. armigera* (Hübner) (Noctuidae) (Mensah *et al.* 1995, 2005), *Cydia pomonella* (L.) (Tortricidae) (Reidl *et al.* 1995), *Ostrinia nubilalis* (Hübner) (Crambidae) (Mensah *et al.* 2005), and *Phyllonorycter ringoniella* (Matsumura) and *Phyllocnistis citrella* Stainton (Gracillariidae) (Sun 2002; Liu *et al.* 2006).

It appears that gravid female *C. rosaceana* are able to assess and reject oil-sprayed surfaces, most likely through either chemosensory or tactile means. Female *C. rosaceana* detect and avoid conspecific egg masses under laboratory conditions, a behaviour most likely mediated by an oviposition-deterring pheromone (Poirier and Borden 1991). This suggests that female *C. rosaceana* are capable of using chemosensory means to reject an otherwise suitable surface for oviposition. Given the low volatility of Purespray Green, it is possible that contact chemoreceptors in the tarsi and ovipositor of the female (Renwick and Chew 1994) play some role in detecting the oil. Alternatively, mechanosensillae located on the tarsi and ovipositor (Ramaswamy *et al.* 1987) may allow females to physically detect the oily residue on the leaf surface and reject the treated leaf for oviposition.

Dual-choice bioassays revealed a difference in the effects of the oil that was dependent on the oviposition substrate. A 2% oil spray caused a greater reduction in the number of eggs laid on the apple leaves than in those laid on the wax paper (Table 2). This may be due to differential absorption of the oil between substrates, or the oil may mask or suppress volatiles in the host-plant leaf that are used by the female to locate and accept suitable oviposition sites (Mensah *et al.* 2005). Interestingly, the effects of residual oil treatment were not significant when leaves were allowed to age under field conditions for 3 days (Table 1). This is consistent with the results of Mensah *et al.* (2005), who found that 2% oil lost efficacy 3 days after application. This could be due to oil degradation (Cornish *et al.* 1993) or absorption into the waxy cuticle of the leaf (Hodgkinson *et al.* 2002). It suggests that multiple oil sprays over the course of the oviposition period would be necessary to maintain a consistent and effective level of oil residue on foliage. However, this may increase the risk of chronic phytoxicity (Fernandez *et al.* 2005).

The no-choice assays in the current study showed that Purespray Green is toxic to

**Fig. 1.** Relationship between percent egg mortality (mean ± SE) and oil concentration for newly laid *Choristoneura rosaceana* eggs treated topically with emulsions of 0.05%, 0.1%, 0.25%, 0.5%, and 1% Purespray Green horticultural oil and a distilled-water control ($n$ = 58).

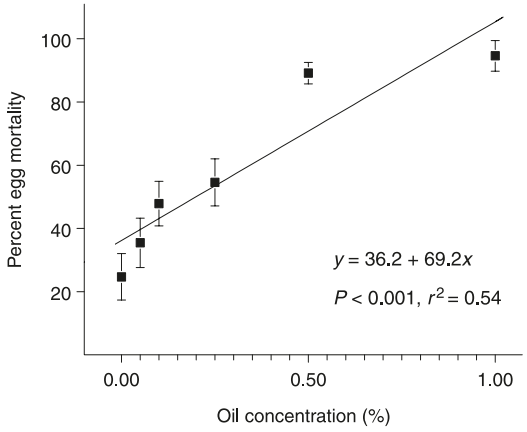
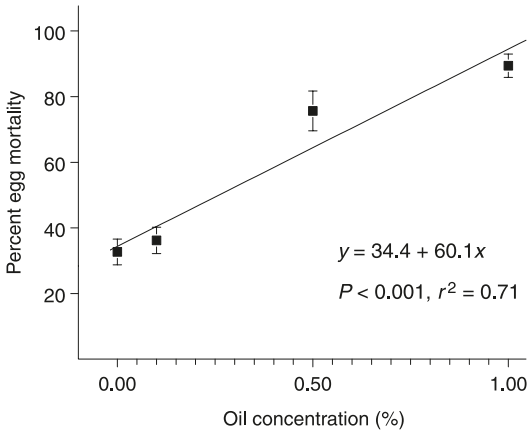



**Fig. 2.** Relationship between percent egg mortality (mean ± SE) and oil concentration for *Choristoneura rosaceana* eggs at the black-headed stage treated topically with emulsions of 0.1%, 0.5%, and 1% Purespray Green horticultural oil and a distilled-water control ($n$ = 40).




*C. rosaceana* eggs; residual spray from a fresh 2% oil treatment significantly reduced larval hatch. The reasons for this remain unclear because a residual treatment should not physically interfere with gas exchange across egg membranes — the generally accepted explanation for the ovicidal effect of oil in arthropods (Smith and Pearce 1948; Fiori *et al.* 1963; Taverner 2002). However, there is evidence that oils can be absorbed into insect membranes and displace protective lipids (Taverner *et al.* 2001). Smith and Pearce (1948) proposed that oils can penetrate the chorion of an egg and interfere with cellular processes or increase desiccation. In addition, the proprietary emulsifier added to the oil may contribute to the toxic effect; emulsifiers are known to have wide-ranging effects on many cell tissues (Taverner 2002). Although the reduction in larval hatch caused by the residual 2% oil application was statistically significant, our results suggest that it would be insufficient to provide stand-alone control of this insect.

When applied topically to either newly laid or black-headed egg masses, Purespray Green caused significant egg mortality in a dose-dependent manner. This supports the hypothesis that oils with a long carbon chain (>$n$C23), like Purespray Green, have strong ovicidal activity even at low concentrations because of their high spreading coefficient and low volatility (Pearce and Chapman 1952; Fiori *et al.* 1963). These properties allow the oil to create a physical barrier over the egg surface for an extended period of time, and eggs may be killed through a combination of anoxic conditions, a buildup of toxic metabolites, and disruption of membrane function (Smith and Pearce 1948). The finding that newly laid and black-headed eggs were similarly susceptible to the oil suggests that in the field, an oil application could be delayed until *C. rosaceana* eggs are mature; our results indicated no increased resistance to the oil in latter stages of egg development. This is in contrast to work conducted on *Grapholita molesta* (Busck) (Tortricidae) in which eggs were found to be less susceptible to oil treatments in the final third of the incubation period (Smith and Pearce 1948). Taken together, our results show that a topical application of 2% Purespray Green can effectively control *C. rosaceana* eggs at different developmental stages under laboratory conditions, although a 1% concentration was also effective and would pose a lower risk of phytotoxicity.

As growers seek alternatives to organophosphate and carbamate insecticides to control difficult pests like *C. rosaceana*, horticultural oils will play a more prominent role in integrated pest management programs. Horticultural oils show low potential for inducing insecticide resistance, low toxicity to mammals, and little impact on beneficial insects (Agnello 2002; Fernandez *et al.* 2005). This study documents the effects of horticultural oils on oviposition behaviour and egg hatch in *C. rosaceana* and the

results suggest that field trials should be conducted to further assess the efficacy of Purespray Green against this orchard pest.

There are still major obstacles to the broader acceptance and use of horticultural oils during the growing season. In many apple-producing regions, an impediment to summer oil applications is the incompatibility of oils and sulfur-based fungicides, such as Captan 50 W (Makhteshim-Agan Inc., New York), used for the control of summer diseases. Another major obstacle is growers' perception of a risk of chronic phytotoxicity, which could negatively affect tree growth and fruit quality over time (Hodgkinson *et al.* 2002; Fernandez *et al.* 2005). There was no evidence of acute phytotoxicity (*sensu* Hodgkinson *et al.* 2002) to apple foliage sprayed with 2% Purespray Green (Wins-Purdy *et al.* 2007), probably because the high paraffin content (>99.9%) and extremely low aromatic content (<0.01%) of this oil minimize these effects (Petro-Canada technical data sheet). However, more work is needed to assess the chronic impacts of multiple foliar sprays over multiple years on pome-fruit production in order to demonstrate the long-term safety of these oils and encourage a more widespread adoption of their use during the growing season.

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