Table 5. Comparison of the number of live *P. citrella* larva per leaf in treatments in Experiment 3 ($\alpha = 0.05$)

Comparisons of the treatments	Date	p
The Mirbazar region	22-July-2010	0.000
conventional orchard *vs*. just the mineral oil treatment	12-August-2010	0.000
	17-August-2010	0.000
	15-July-2011	0.000
	29-July-2011	0.151
	12-August-2011	0.000
The Moghricola region	22-July-2010	0.009
conventional orchard *vs*. just the mineral oil treatment	12-August-2010	0.007
	17-August-2010	0.522
	15-July-2011	0.194
	29-July-2011	0.099
	12-August-2011	0.316

to orchards without synthetic insecticides in eight comparison steps, was more. Their "p" values are shown in table 5.

Discussion

When mineral oil spray and synthetic pesticides were compared, there were no differences in their abilities to suppress the *P. citrella* infestation and the visible symptoms of phytotoxicity. The risk of acute phytotoxicity increases if oils are poorly mixed and applied when trees are stressed, and temperatures are extreme (Rae *et al*. 1996). The current study demonstrates that under favourable conditions, up to 3 sprays of 0.9% mineral oil can be used without causing acute phytotoxicity. To determine chronic phytotoxicity, which can result from long-term use of oils, a citrus orchard which is managed by using pesticide-free protocols was chosen in the county of Babolsar, of the Mazandaran Province. All pests in the orchard were controlled by a 0.7–1.5% mineral oil spraying, two or three times a year starting in 1993; no pesticides were used and no chronic phytotoxicity was reported (Damavandian 2007).

In California, mineral oils are recommended to be used on citrus for two or three major pests, the California red scale, *Aonidiella aurantii* Maskell, and the citrus red mite, *Panonychus citri* McGregore (Davidson *et al*. 1991). In France, mineral oil provided good control of *P. ulmi* Koch on fruit trees (Girantet *et al*. 1997). According to Rae *et al*. (1996), 3–4 sprays of mineral oil at an interval of 6–7 days will provide effective control of the citrus leafminer. In Iran, mineral oil on citrus controlled citrus brown scale, *Chrysomphalus dictyospermi* Morgan (Damavandian 1993), citrus wax scale, *Ceroplastes floridensis* comstock (Damavandian 2003), citrus rust mite, *Phyllocoptruta oleivora* Ashmed (Damavandian 2005), citrus red mite, *P. citri* McGregor (Damavandian 2007), and orange pulvinaria scale, *Pulvinaria aurantii* Cockerell (Damavandian 2010).

Field trails demonstrated that a dilute application of ≥ 0.65% mineral oil controls *P. citrella* as effectively as synthetic pesticides (Table 4). When oils are used, they must be applied as thorough coverage flushes, namely high volume sprays requiring up to 3 l of water per 5-year-old Thomson novel tree.

Experiment 2 demonstrated that 0.95% mineral oil (EC) controlled *P. citrella* as effectively as Confidor, and 0.5% mineral oil plus Abamectin, with the population being reduced 77, 78, and 85%, respectively (Fig. 2). The most effective control of *P. citrella* was achieved with the use of 0.5% oil plus Abamectin. When Abamectin was mixed with 1% oil, 94–100% larva mortality was reached (Rae *et al*. 1996).

Abamectin has demonstrated nematicidal, acaricidal, and insecticidal activity (Lasota and Dybas 1991). Abamectin breaks down rapidly (< 1 days) when exposed to sunlight or when present as a thin film (Clark *et al*. 1995). Reservoirs of the chemical can remain within the mesophyll layer of leaves, particularly when this chemical is applied with oil (Lasota and Dybas 1991). Thus, Abamectin becomes much more accessible to pests such as the leafminer, than to their predators or parasites. Morse *et al*. (1987) found that field-weathered residues of Abamectin did not cause residual mortality to three selected beneficial arthropods of citrus (*Aphytis melinus* De Bach; mealybug destroyer, *Cryptolaemus montrouzieri* Mulsant; and *Euseius stipulates* Athias-Henriot). These characteristics indicate that Abamectin could be used for integrated pest management in citrus. In contrast, current recommendations in Florida limit the use of Abamectin to three applications per year (Knapp 1995) so as to manage resistance. Among pesticides, Abamectin was ranked as a very dangerous pesticide (Metcalf and Luckmann 1994). It should be recommended only in very urgent cases. Meanwhile the use of Abamectin, Confidur, and Dursban led to a severe infestation of the citrus red mite *Panonychus citri* (personal observation). These pesticides were said to have eliminated the predatory mite, *Amblyseius oddoensis* Vander Merwe and Ryke (Keetch 1968), although the mentioned synthetic pesticides are registered and have been used for many years against the citrus leafminer in northern Iran. Therefore, use of these pesticides in integrated pest management programs does not seem logical.

Mineral spray oil has been used traditionally to control small, relatively immobile insects. The oil is said to suffocate the insects (Ebeling 1950; Davidson *et al*. 1991). Najar-Rodriges *et al*. (2008), though, observed no signs of oil accumulation within the trachea. They believed

Table 6. Cost of different treatments when applied at 1,000 l/ha (350 trees/ha)

Treatments	Concentration [AI/l00 l of water]	Price [$/kg or l AI]	Cost [$/ha]
Confidor	80 ml	11.66	9.328
Dursban	200 ml	6.25	12.5
Mineral oil (EC)	650 ml	0.83	5.395
Abamectin + EC	20 + 350 ml	3.75 + 0.83	3.655
Abamectin + EC	20 + 500 ml	3.75 + 0.83	4.9

AI – Active ingredient

that rapid penetration of oil through the insect's body and accumulation in the nerve ganglia has the direct effect of suppressing synaptic transmission in the insect's ganglia. In both ways of controlling pests, mineral oil should contact the pests. Beattie *et al*. (1995) indicated that the proportion of dead larva in mines in which oil treatments were used, was similar to the control. Whereas in the Fenoxycarb and Methidation treatments, the proportion of dead larva was significantly higher than in the control. On the other hand, according to their study, mineral oil caused a significant reduction in *P. citrella* damage which is similar to our results (Fig. 2). This reduction may refer to mineral oil acting as an ovipositional deterrent to the pest. Mature citrus trees can sustain a *P. citrella* population up to 0.74% mines per susceptible leaf without incurring economic loss (Huang *et al*. 1989), with regard to control over 70% *P. citrella* by mineral oil (Fig. 2).

Based on results of this study, in the Mazandaran citrus orchards, a 0.65% concentration of mineral oil provided appropriate control, and cost the least compared to conventional insecticides (Table 6). In northern Iran, farmers sometimes use the above-mentioned insecticides every 12 days the during tree budding period, against the citrus leafminer. Many times, as we stated before, some pests, such as the citrus red mite *P. citri*, are exposed and the use of acaricides such as Nisoron (hexythiazox) caused the mentioned costs. Therefore, three steps of oil spraying in 5–6 days intervals at a cost of 16 ($/ha) would be the more effective and economical method. Whereas the use of synthetic pesticides and these iteration numbers and conventional acaricide Nisoron cost about 53 ($/ha).

In conclusion, mineral oil spraying should be able to provide adequate control under most circumstances and can replace the synthetic pesticides that are applied in the Mazandaran citrus orchards. In addition, applying just mineral oil in mature commercial citrus orchards for several successive years resulted in less damage from the citrus leaf miner. It is important to note, that farmers must thoroughly agitate the oil/water emulsion so that all the foliage is covered, and the temperature should be between 0°C and 35°C and > 20% relative humidity (RH) (Beattie 1990; Davidson *et al*. 1991). The timing of the spraying is also crucial, the spray must be applied as soon as the largest leaves of a flush are > 1 cm in length (Rae *et al*. 1996). Every 5–6 days, the spraying should be repeated until the flush hardens and is no longer susceptible to attack.

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