Efficacy evaluation of different methods for the control of woolly apple aphid (*Eriosoma lanigerum* [Hausmann]) in organic apple growing

M. Kelderer[1], E. Lardschneider[1] and R. Schütz[2]

Abstract

*Since the woolly apple aphid (*Eriosoma lanigerum*) is still one of the major problems in organic apple orchards, at the Research Centre Laimburg several methods for the control of this pest were tested over the last years. The effect of applications of plant protection products at different timings, of various pruning methods (used in combination with and without hail netting), and of conventional and novel rootstocks on woolly apple aphid infestations was evaluated. Adequate timing of applications of plant protection products enabled to improve pest control, and promising results were achieved with novel rootstocks.*

Key words: woolly apple aphid, apple, organic farming, late autumn- and early spring-applications, rootstocks

Introduction

Due to the not synchronized development of the parasite *Aphelinus mali* (Haldeman) with its host *E. lanigerum* under Central European climatic conditions, this natural enemy is rarely effective enough to prevent infestations (Hetebrügge *et al*., 2006). The second most important natural antagonist of woolly apple aphid, the European earwig *Forficula auricularia* (Linnaeus), usually starts to move into trees and to feed on woolly apple aphids from the third nymphal stage (approx. mid July) onwards. At this point, however, the summer populations of *E. lanigerum* are already present, and extensive damage to trees may already have occurred (Gobin *et al*., 2008). In addition, population levels of *F. auricularia* generally vary considerably among fruit orchards, and the impact of other predators, belonging to the *Chrysopidae* (Schneider) and *Coccinellidae* (Latreille) families, on the pest populations is considered negligible. In fact, based on his studies, Immik (2002; referred to in Hetebrügge, 2004), concluded that these natural enemies can not be considered potential candidates for woolly apple aphid control. For these reasons, human intervention is deemed necessary for effective *E. lanigerum* control.

During the period of vegetative growth of the crop, *E. lanigerum* is well-protected by fluffy white waxy material, the so-called wool, secreted by the aphids. Insecticides acting by contact are therefore not effective. Also insecticides with semisystemic activity, such as azadirachtin- or neem oil-based products, have been tested, but their effectiveness is usually insufficient. The reasons for this could be a naturally occurring dilution of the active substance(s) in plant tissues caused by the growth of the plant, and/or differences in the concentration of active substance(s) among the tested products, which are obtained by using different extraction and manufacturing processes (Caldwell *et al*., 2013). Other plant protection products that are increasingly being used for woolly aphid control, are paraffin oil-based products, applied also in combination with sulphur-based products. Up to now, these products have commonly been applied before bud break (early spring) with partial and fluctuating success. Additional studies to improve their efficacy were therefore

[1] Land- und Forstwissenschaftliches Versuchszentrum Laimburg, 39040 Post Auer, Südtirol, Italien, Markus.Kelderer@provinz.bz.it (corresponding author)
[2] University of applied sciences Weihenstephan-Triesdorf (Student), 91746 Weidenbach, Deutschland, rene_schuetz@web.de

deemed necessary, because these products can hardly be applied during the period of vegetative growth because of phytotoxicity issues.

Material and Methods

Late autumn and early spring applications of plant protection products: the products tested in the 3 trials conducted from 2013 to 2015 were slaked lime and Polithiol, an emulsifiable suspension (SE) containing 400 g/L paraffin oil (CAS N. 97862-82-3) as active substance and 5-10 % w/w sulphur according to the Material Safety Data Sheet (UPL, 2014). Polithiol is produced by Cerexagri (France) and distributed in Italy by UPL Italia. In all trials, treatments were applied in late autumn and/or in early spring, and tested in comparison to an untreated control. Those treatments consisting of 2 applications, 1 in late autumn and 1 in early spring, aimed at increasing the efficacy of the product(s). A summary of the different treatments tested from 2013 to 2015 in the 3 trials is provided in Table 1.

Pruning methods & hail netting: to evaluate the effect of vegetative growth on *E. lanigerum* infestations, different pruning methods, used in combination with and without hail netting, were compared (see Table 2 for summary). An untreated control was not included in the trials, but intensive pruning (without hail netting) was considered as standard reference treatment.

Rootstocks: finally, also the effect on *E. lanigerum* infestations of different rootstocks was evaluated in order to identify rootstocks potentially resistant or tolerant to *E. lanigerum*. A summary of the investigated rootstocks is provided in Table 3. M9 T337 can be considered as standard reference rootstock.

Late autumn- and early spring-applications of plant protection products

N. trials: 3

Study period: 2013 - 2015

Study site: open field, Research Centre Laimburg

Variety / Rootstock: Fuji / M9

Year of planting: 2003

Distance between rows x distance between plants: 3.5 x 1.0 m

Study design: randomized complete block design, 4 replicates of 7 trees each per treatment, assessments on the 5 central trees per plot; untreated control: included.

Application equipment: air blast plot sprayer and spraying gun for applications onto tree trunks

Spray volume: 2,000 l/ha

Assessments: woolly apple aphid-infested area per tree (cm^2) in 2013 and 2014; percentage of shoot length infested by woolly apple aphid in 2015

Pruning methods & hail netting

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Year of planting: 2003

Distance between rows x distance between plants: 3.5 x 1.0 m

Study design: randomized complete block design, 4 replicates of 7 trees each per treatment, assessments on 5 central trees per plot; untreated control: not included.
Assessments: percentage of shoot length infested by woolly apple aphid in all trials

Rootstocks
N. trials: 2
Study period: 2014 - 2015
Study site: greenhouse, Research Centre Laimburg
Rootstocks tested: M9 T337, G11, G41, M9 Pajam2, Supporter 4, BUD 9
Year of planting: not applicable (cuttings)
Distance between plants: 1 cutting per pot (pot length x width x height: 10x10x14 cm)
Study design: cuttings were grown in the greenhouse, uniformed to 2-3 shoots per cutting, disposed in a randomized block design, artificially infested with the target pest by using 1 approx. 3 cm-long piece of shoot infested with woolly apple aphid per cutting, and individually covered with insect-proof and anti-hail net immediately after artificial infestation; untreated control: not included.
Assessments: woolly apple aphid-infested area per cutting (cm^2) in all trials

Statistical analysis
Extreme Studentized deviate (ESD) test was used to detect outliers in the data sets. If deemed necessary, outliers were removed from data sets. The data assessed in the different trials were then compared across treatments using 1-way ANOVAs, followed by Tukey's test for post-hoc comparisons of means. All analyses were performed using IBM SPSS Statistics 20.

Table 1: Late autumn and/or early spring applications of plant protection products (active substance, trade name, manufacturer, applied rate in l/hl, date of application) tested in the 3 trials conducted from 2013 to 2015.

Trial no.	**Year**	**Treatment** (active substance & timing)	**Trade name**	**Producer**	**Applied rate (l/hl)**	**Date of application**
1	2013	paraffin oil (autumn+spring)	Polithiol	Cerexagri	4.5 l	17.12.2012 27.02.2013
		paraffin oil (spring)	Polithiol	Cerexagri	4.5 l	27.02.2013
		Untreated control	-	-	-	-
2	2014	paraffin oil (autumn+spring)	Polithiol	Cerexagri	4.5 l	13.12.2013 04.03.2014
		paraffin oil (spring)	Polithiol	Cerexagri	4.5 l	04.03.2014
		Untreated control	-	-	-	-
3	2015	paraffin oil (autumn) + slaked lime (spring)			4.5 l + 7.5 kg	05.12.2014 13.03.2015
		slaked lime (autumn) + paraffin oil (spring)			7.5 kg + 4.5 l	05.12.2014 13.03.2015
		slaked lime (autumn)			7.5 kg	05.12.2014
		paraffin oil (spring)	Polithiol	Cerexagri	4.5 l	13.03.2015
		Untreated control	-	-	-	-

Table 2: Pruning methods tested from 2013 to 2015 (date of pruning and date of hail netting deployment, where applicable)

Trial no.	Year	Treatment (pruning method ± anti-hail net)	Date of pruning and hail netting deployment	Remarks
1	2013	intensive pruning + anti-hail net	15.02. 2013 17.05.2013	long shoots and longer fruiting branches were cut, strong stimulation of growth
		long pruning	15.02.2013	as few cuts as possible, weak stimulation of growth
2	2014	intensive pruning + anti-hail net	04.04. 2014 05.05.2014	long shoots and longer fruiting branches were cut, strong stimulation of growth
		long pruning	04.04.2014	as few cuts as possible, weak stimulation of growth
3	2015	intensive pruning + anti-hail net	11.03. 2015 05.05.2015	long shoots and longer fruiting branches were cut, strong stimulation of growth
		long pruning	11.03.2015	as few cuts as possible, weak stimulation of growth
		root pruning	25.03.2015	distance to trunk: 30-40 cm, depth into soil: 30-40 cm, applied two both sides

Table 3: Root stocks tested in 2014 and 2015 (date of planting, artificial infestation, and evaluation).

Year	Tested root stocks	Planting	Infestation	Evaluation	Remarks
2014	M9 T337 G11	20.05.2014	17.06.2014	07.07.2014	pots were set up in a randomized block design, and covered with insect-proof and anti-hail net after artificial infestation
2015	M9 T337 G11, G41, M9 Pajam 2 Supporter 4 BUD 9	28.04.2015	10.06.2015	10.07.2015	pots were set up in a randomized block design, and covered with insect-proof and anti-hail net after artificial infestation

Results

Late autumn and/or early spring applications of plant protection products

In both 2013 and 2014 a clear effect of Polithiol on woolly apple aphid infestations emerged, with 2 applications (1 in late autumn and 1 in early spring) being significantly more effective in reducing the *E. lanigerum*-infested area per tree than 1 single application of the product in spring (Fig. 1). One early spring application only significantly reduced the infestation level in comparison to the untreated control in 2014, but not in 2013.

Applications of slaked lime were tested in the trial conducted in 2015, but the product was not effective in controlling the pest (Fig. 2). In the treatment consisting of 1 autumn application of slaked lime + 1 spring application of Polithiol, the observed reduction of percent shoot length infested by woolly apple aphid in comparison to the untreated control

was only due to the activity of Polithiol. In fact, also 1 spring application of Polithiol only resulted in a significant reduction of the infestation in comparison to the untreated control, while 1 autumn application of slaked lime failed to do so (Fig. 2).

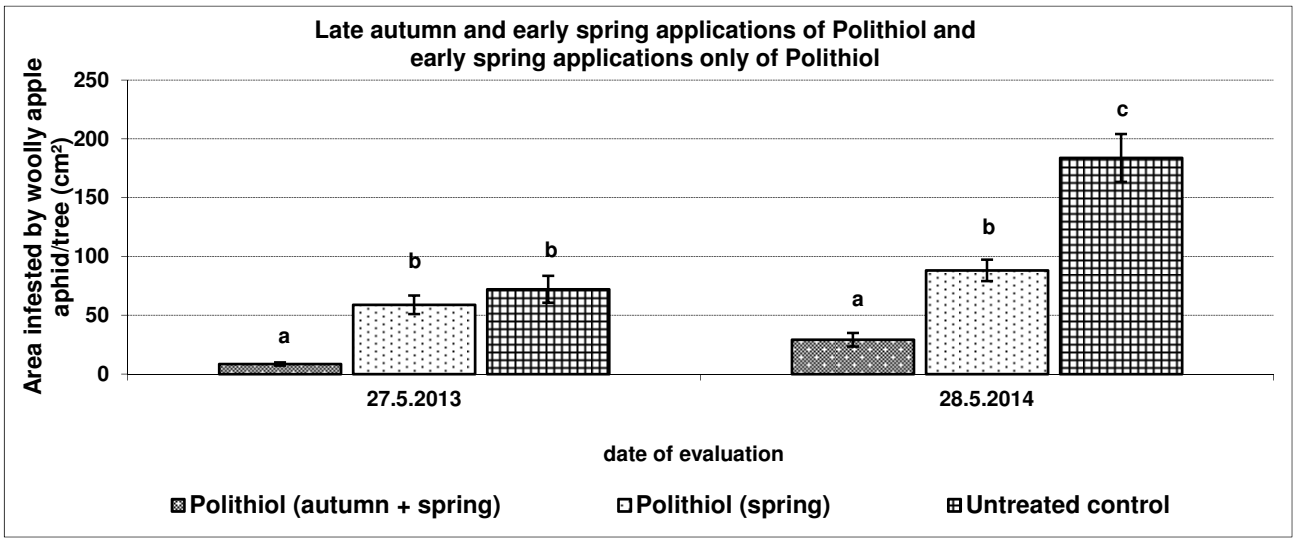

Figure 1: area (mean±s.d.) infested by woolly apple aphid/tree (cm²) in 2013 and 2014; comparison among autumn and spring applications of Polithiol, spring applications only of Polithiol, and an untreated control.

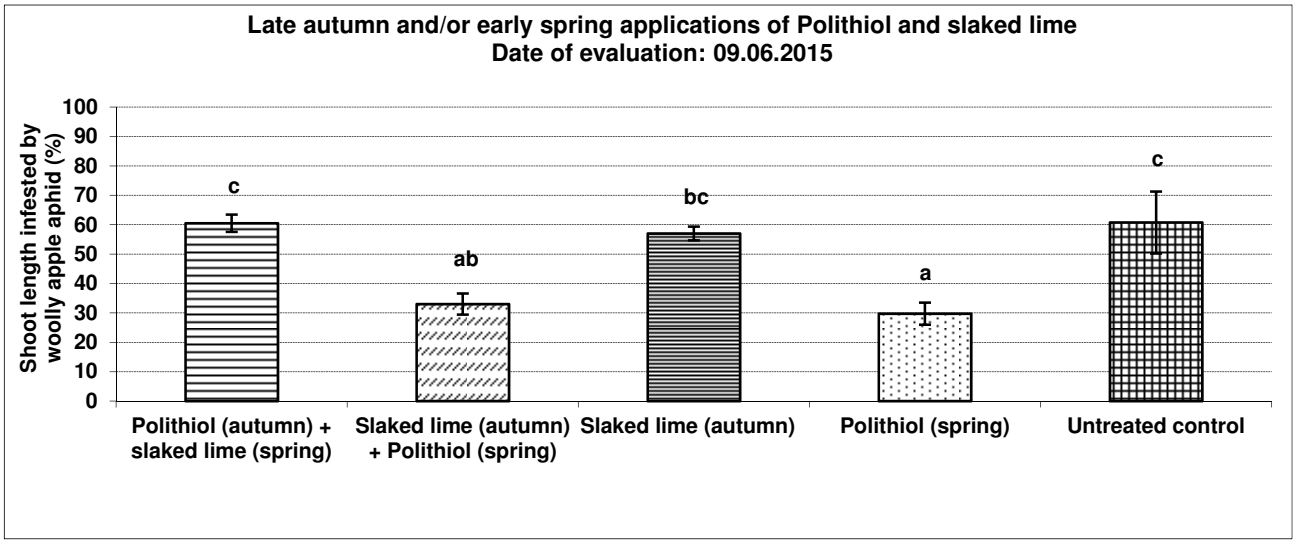

Figure 2: percent shoot length (m±s.d.) infested by woolly apple aphid in the different treatments in 2015; comparison among combinations of autumn + spring applications of Polithiol and slaked lime, of slaked lime (autumn) and Polithiol (spring) applications only, and an untreated control.

Pruning methods & hail netting

In all trials, hail netting in addition to intensive pruning resulted in a significant increase of woolly apple aphid infestations (Figure 3). Long pruning showed generally lower infestation values than intensive pruning (significantly lower in 1 out of 3 trials; Fig. 3), but percent infested shoot length values remained high. Root pruning, tested only in 2015, did not seem to be an effective method for improving *E. lanigerum* control.

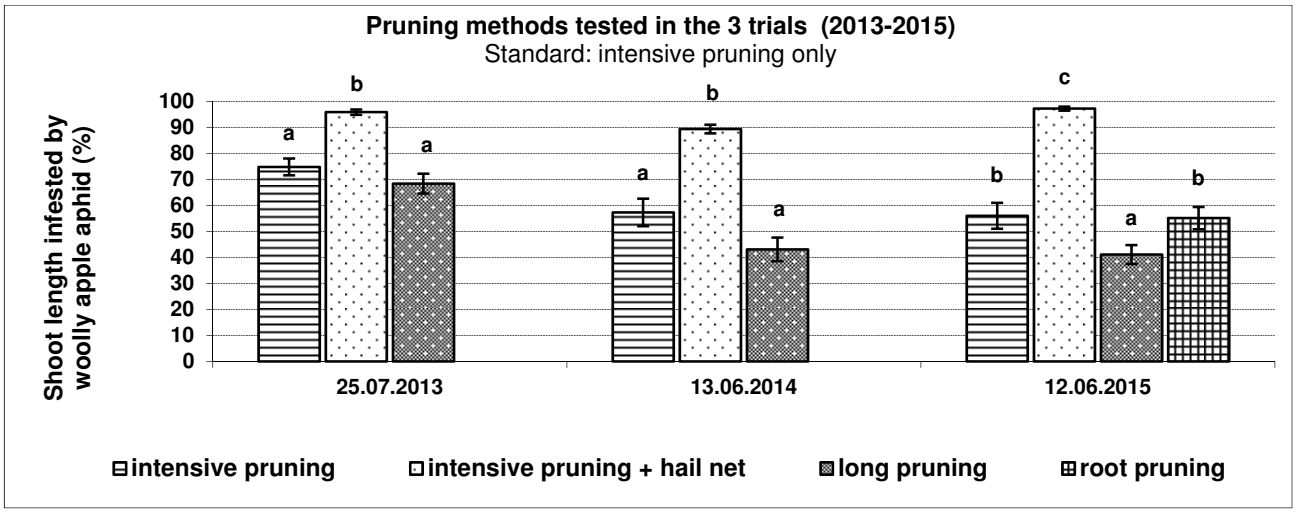

Figure 3: percent shoot length (m±s.d.) infested by woolly apple aphid in the different treatments tested in the 3 trials from 2013 to 2015; comparison among intensive pruning (standard treatment), intensive pruning + hail net, long pruning, and root pruning.

Rootstocks

Clear differences among rootstocks in the area infested by woolly apple aphid per cutting emerged (Fig. 4), with infestation levels being lowest for the Geneva® rootstocks G11 und G41. Reduced infestation levels in comparison the standard rootstock M9 T337 were observed also for M9 Pajam 2, while no reduction in the infestation was observed for the other rootstocks tested. Potential rootstock resistance or tolerance to woolly apple aphid may thus be excluded for Supporter 4, BUD 9, and M9 T337.

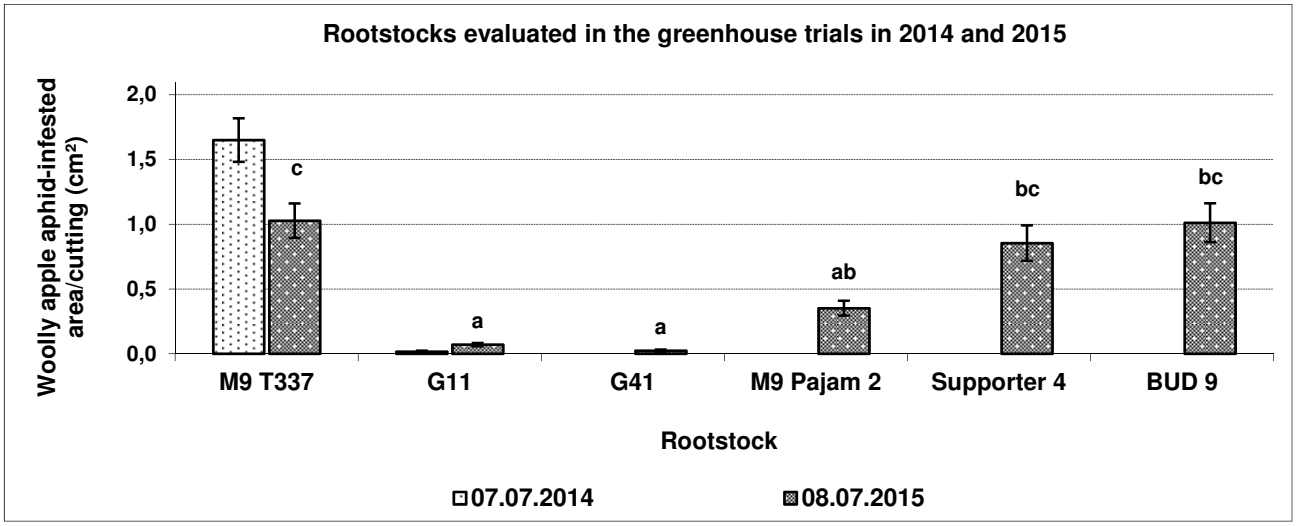

Figure 4: area (mean±s.d.) infested by woolly apple aphid per cutting (cm²) on the rootstocks M9 T337, G11, G41, M9 Pajam 2, Supporter 4 und BUD 9; in 2014, only M9 T337 and G11 were tested, and therefore no statistical analysis was performed, while in 2015 six rootstocks were evaluated.

Discussion

Late autumn and early spring applications of plant protection products

Two applications of Polithiol, one in late autumn and one in early spring, provided very promising results in reducing woolly apple aphid infestations, and were more effective than one single application of Polithiol in spring only. In addition, no risk of phytotoxic effects, such as necrotic spots on leaves and fruit russetting, which are very likely to occur extensively in case of summer applications, exists. The overall conclusion from the evaluation concerning the inclusion of paraffin oils in Annex I to Directive 91/414/EEC was that it may be expected that plant protection products containing paraffin oils (CAS No 97862-82-3, and thus Polithiol, included) will fulfil the safety requirements laid down in Article 5(1) (a) and (b) of Directive 91/414/EEC (SANCO, 2012). According to the Draft Assessment Report (DAR) submitted by the notifier to the Rapporteur Member State (RMS) Greece, paraffin oils have a relatively high log K_{OW}[3] value of 3.9 to 6; due to their high hydrophobicity, they are adsorbed by the soil, and no risk of ground water contamination and to aquatic organisms is expected (DAR, 2008). However, concern regarding the environmental impact of paraffin oils was raised by EFSA[4] (2008), and risk mitigation measures, such as the establishment of no-spray buffer zones, were recommended to protect natural waterbodies. According to EFSA (2008) there is no concern for birds and mammals arising from oral intoxication with paraffin oil, but data gaps exist concerning not only the risk to aquatic organisms, but also to other non-target organisms, such as honeybees, other Arthropod species, and earthworms, because the tests submitted in the DAR were not considered reliable. Furthermore, the information concerning environmental fate and behaviour provided with the exception of ready biodegradability data, was not considered sufficient (EFSA, 2008). The product Polithiol is listed as safe to humans and the environment by the Italian *Sistema Informativo Agricolo Nazionale*[5]. Therefore, if spray applications of paraffin oils are conducted just once or twice a year, as it has been done up to now, no long-term risk to the environment is expected.

Pruning methods & hail netting

In our trials we clearly demonstrated that hail netting strongly contributes to increased infestation levels of woolly apple aphid. However, it must be pointed out that in our trials single-row netting structures were used, and that the impact of these structures may be higher than that of conventional netting structures.

Long pruning by itself was not sufficient to effectively control *E. lanigerum*, but may constitute a valuable, complementary measure to other treatments.

Root pruning, tested only in 2015, was not effective, but further studies will be conducted to evaluate the effect of root pruning at a closer distance to the trunk than in 2015, in order to further reduce the vegetative growth of the trees.

Rootstocks

Woolly apple aphid infestation levels differed considerably among the tested rootstocks. Notwithstanding the extremely high initial artificial infestation and conditions being favourable to pest development, the Geneva® rootstock showed almost no infestation. Further investigations are warranted to evaluate the field performance of these rootstock

[3] K_{OW} = Octanol / Water Partition Coefficient
[4] European Food Safety Authority
[5] Compare: http://www.sian.it/biofito/mimfRicerca.do (choose Polithiol as product)

as well as the influence of different rootstock-variety combinations on woolly apple aphid infestations in the open field.

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