API-Tree oucomes: Pesticide-free methods to control apple pests, experimentation and performance.

Aude Alaphilippe, Georgina Alins, Nicolas Borowiec, Enrique Dapena de La Fuente, Tarek Dardouri, Teun Dekker, Louise Ferrais, Pierre P. Franck, Hélène Gautier, Pauline Gardin, et al.

API-Tree

Outcomes

Pesticide-free methods to control apple pests

Experimentation and performance

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Contacts:

Coordinator: Aude Alaphilippe, INRAE, France, aude.alaphilippe@inrae.fr

Partners: INRAE, France; University of Copenhagen, Denmark; GRAB, France; Université Catholique de Louvain and CRA-W, Belgium; Swedish University of Agricultural Science, Sweden; Institut de Recerca i Tecnologia Agroalimentaries and Servicio Regional de Investigación y Desarrollo Agroalimentario, Spain.

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For more information: www.smach.inra.fr/en c-ipm.org/

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Credits:

Project coordination: Aude Alaphilippe, Sylvaine Simon

Booklet design and creation: Aude Alaphilippe, Blandine Rozies

Leaflet editing: Aude Alaphilippe, Caroline Goutines and leaflet authors (see leaflets)

Legends and credits for cover photographs: apple sawfly caught on a blue sticky trap, GRAB; blue tit feeding nesting box, Marcos Miñarro, SERIDA; cardboard tube for the release of aphid parasitoids, UCLouvain; earwig shelter, IRTA; *Mastrus ridens* release, INRAE.

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The API-Tree Project

Developing apple pest control strategies through an integrated agro-ecosystem approach towards an insecticide-free orchard

The aim of the project was to design and assess the efficiency and sustainability of combinations of practices offering an alternative to chemicals for pest control in apple orchards.

Context

Apple trees are the most common fruit trees in Europe, covering an area of 450,000 ha and 35% of Europe's total orchard surface area (Eurostat, 2014). As current apple orchards rely on heavy pesticide use (MAAF, 2012), their sustainability has been questioned. However, the control of insect pests such as codling moth (*Cydia pomonella*) and aphids (mainly the rosy apple aphid, *Dysaphis plantaginea*) is critical for apple production. The woolly apple aphid (*Eriosoma lanigerum*), oriental fruit moth (*Grapholita molesta*), apple blossom weevil (*Anthonomus pomorum*), European apple sawfly (*Hoplocampa testudinea*) and tortricid leafrollers can also cause severe or even total fruit loss depending on the country and cropping practices.

Alternative methods to chemicals have been made available to growers (e.g. mating disruption) but they target single pests and/or lack an overall evaluation of their advantages and limits (Heijne *et al*., 2015). Some researchers (Brown 1999; Malézieux 2012; Ratnadass *& al*., 2012) have proposed new insights for the design of agroecological cropping systems (i.e. relying on ecology-based processes rather than external inputs), but such an approach requires further knowledge. There is a need to gather skills, experiences and knowledge from researchers and other stakeholders (e.g. growers and advisers) in various regions and contexts to account for the complexity of agroecosystems and to consider within-space and -time interactions (Le Bellec *et al*., 2012).

Objective

The API-Tree project suggested that we design a pest-suppressive agroecosystem. This entails making it difficult for pests to be in the same space and time-frame as pest-susceptible tree organs and creating conditions that promote pests' natural enemies.

Both a holistic approach taking into account the whole orchard-pest complex and a focus on aphids in apple trees were used. The project's integrated approach took into account agroecosystem management, orchard design and practices, as well as economic constraints.

This European project involved scientists from eight different research institutions in France, Denmark, Belgium, Sweden and Spain. This means a broad range of geographic and climatic conditions was covered by the consortium, which included countries from Northern to Mediterranean Europe (see the consortium description on the next page). This also made it possible to exchange knowledge and suggestions for innovative context-adapted solutions across a wide variety of growing conditions.

How can we design a pest-suppressive agroecosystem?

Such an innovative design is built by selecting practices related to the enhancement of plant diversity (mixed cultivars, cover crops, introduction of companion plants etc.), to soil and tree management (cultural practices) and to the design of agroecological infrastructure (habitat management to provide pests' natural enemies with food resources and shelter, push-pull plant assemblages etc.).

The practices targeted are designed to build consistent and resilient systems that reduce both pest attacks and damage to attacked plants. We have developed a conceptual framework to present all the levers for action to be considered, the processes behind them and their interactions (see page 6).

A consortium bringing together scientists from all over Europe

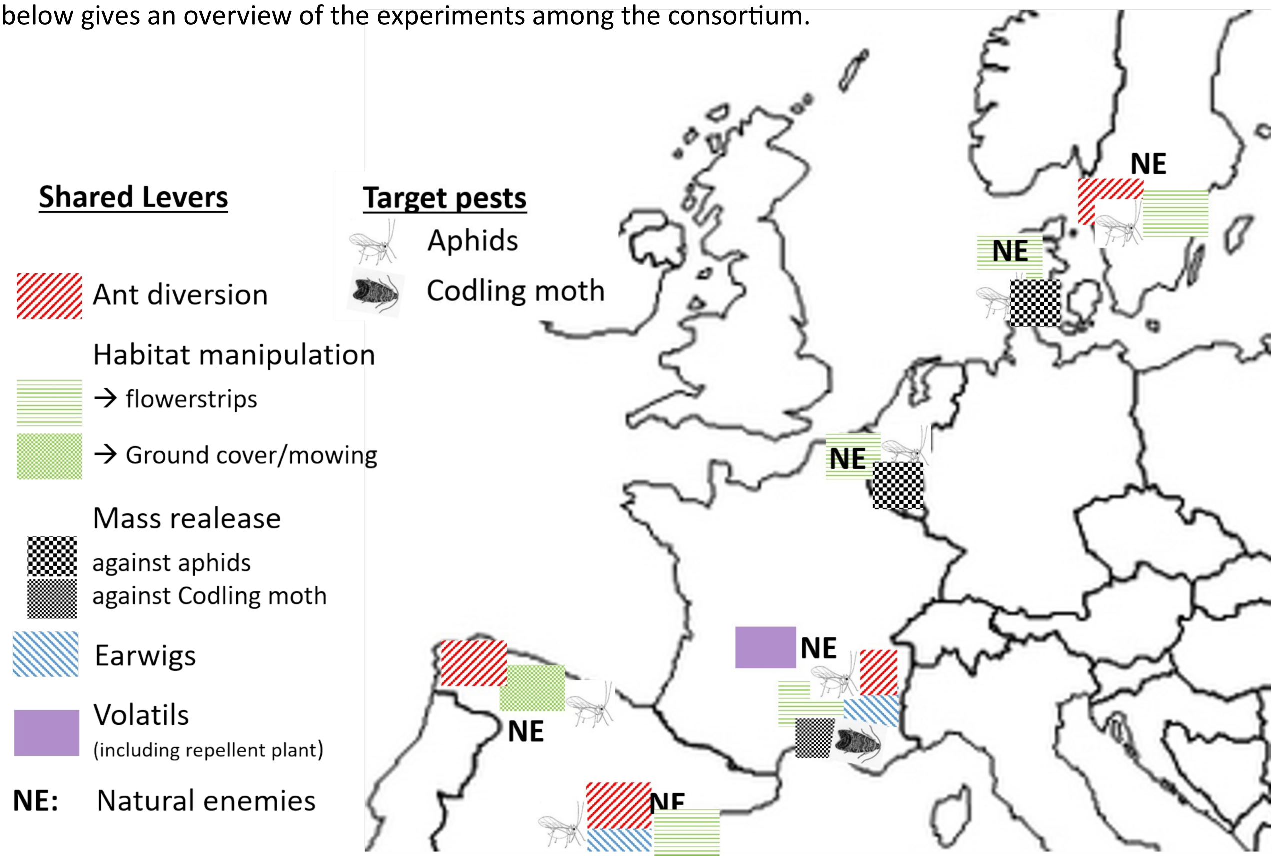
This European project involved scientists from eight different research institutions in France, Denmark, Belgium, Sweden and Spain. All the partners have skills in ecology and agronomy and expertise in methods that foster apple tree defences against pest attacks and promote the control of apple pests by their natural enemies.

Sweden:	Marco Tasin and Teun Dekker (SLU)
Denmark:	Lene Sigsgaard and Stine Kramer (UCPH)
Belgium:	Marc Lateur (CRA-W)
	Thierry Hance and Louise Ferrais (UCLouvain)
Spain:	Enrique Dapena and Marcos Miñarro (Serida), Daniel García (University of Oviedo)
	Georgina Alins (IRTA)
France:	Sylvaine Simon, Tarek Dardouri and Aude Alaphilippe (INRAE UERI Gotheron)
	Claire Lavigne, Marie-Odile Jordan, Pierre Franck, Myriam Siegwart, Hélène Gautier and Laurent Gomez (INRAE PSH)
	Nicolas Borowiec and Elodie Vercken (INRAE ISA)
	Claude-Eric Parveaud and Maxime Jacquot (GRAB)

Each partner is testing one or a combination of levers for action based on one or several ecological processes as described in the common framework. These levers are:

- Effect of apple tree phenology on rosy apple aphid (RAA) return flight and infestation dynamic (common experiment conducted by all partners)
- Evaluation of cultivar susceptibility
- Effect of bud phenology on blossom weevil/parasitism rate
- Effect of cropping system on RAA
- Alternate mowing
- Natural control of RAA with flower strips or plants
- Nest boxes
- Codling moth light trapping systems
- Mass release of parasitoids
- Inoculative release of *Mastrus ridens* against codling moth
- Monitoring aphid, ant and natural enemy dynamics at spring infestation on apple
- Ant diversion

The map below gives an overview of the experiments among the consortium.

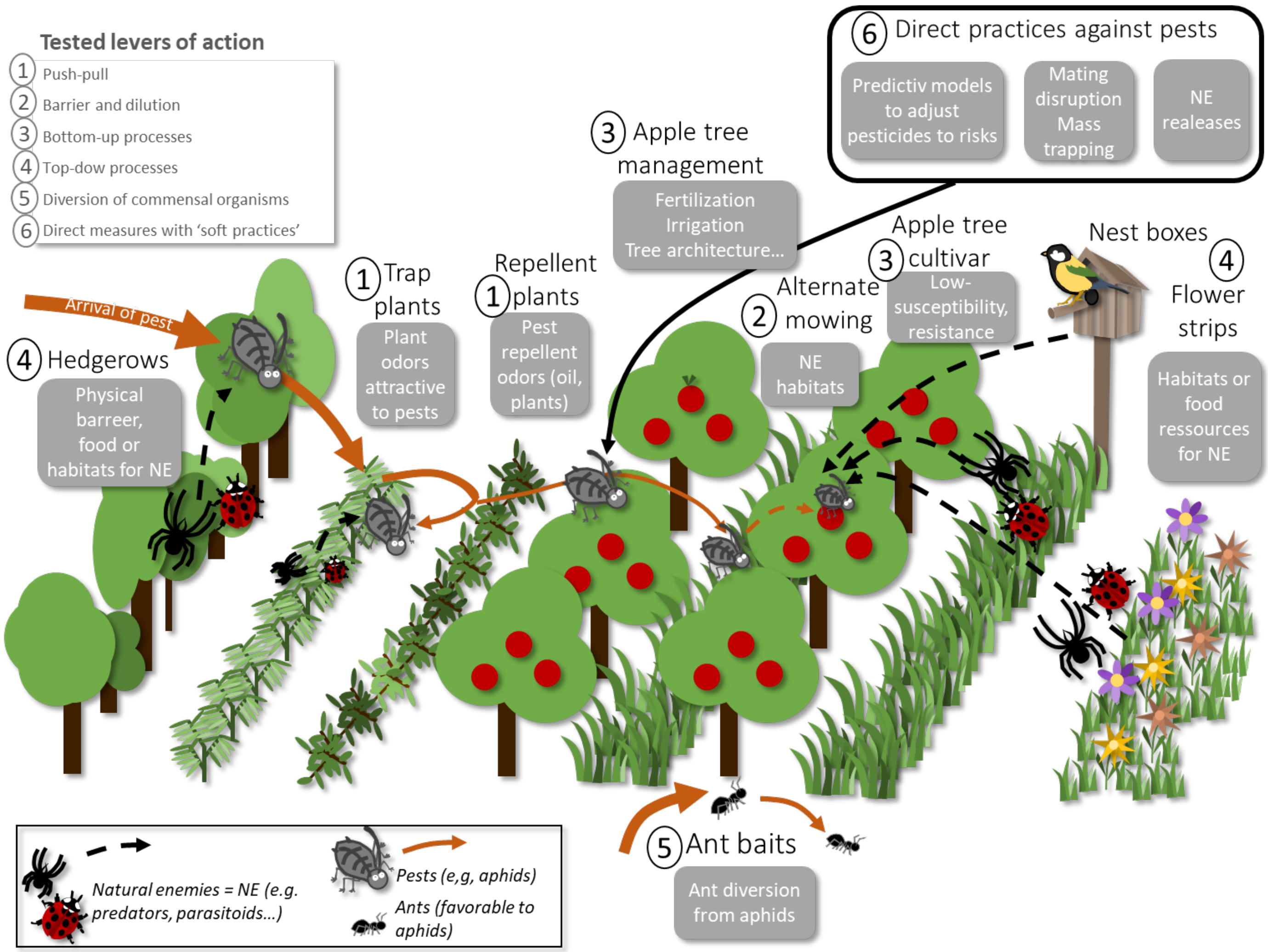


The API-Tree common framework to design a pest-suppressive agroecosystem

We have developed a conceptual framework representing the orchard agroecosystem, pests and natural enemies, and studied ecological processes to integrate our results and use it as a tool to discuss orchard redesign with stakeholders.

This framework provides support to the design of orchards combining the diverse levers for action against pests tested by the partners. In the figure below, both the lever for action and the process behind it (e.g push-pull, bottom-up processes etc.) are presented.

All the leaflets produced indicate to which lever for action the practice described is related to.



Lever 1. Push & push-pull using trap and/or repulsive plants emitting plant volatiles.

Lever 2. Barrier and dilution effects by increasing plant diversity within the orchard.

Lever 3. Bottom-up processes through cultivar, tree nutrition and manipulation of tree architecture.

Lever 4. Top-down processes mediated by naturally occurring beneficials (aerial and aboveground), through provision of food resources and/or habitat within the orchard and surroundings.

Lever 5. Diversion of commensal organisms.

Lever 6. Direct measures by soft practices, using predictive models to assess damage risk, including release of indigenous or exotic natural enemies.

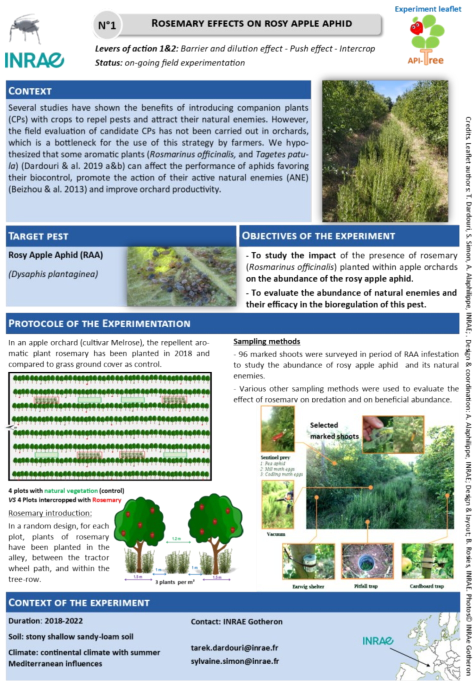
Booklet content and API-Tree outputs

Field experiments conducted in the API-Tree project allowed us to assess, in real field conditions, the effect of different levers for action including management practices and combinations of levers. Experimental systems provided data information to guide what to test in more realistic on-farm trials. In on-farm trials, cropping system performances can be assessed.

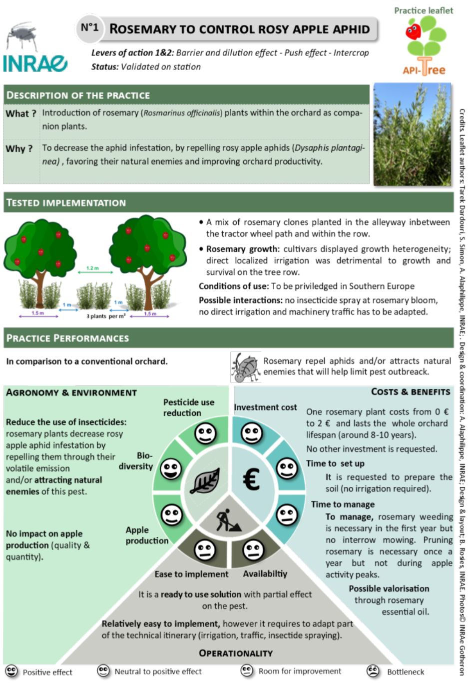
Results from experimental fields and on-farm experiments provided a basis for developing management practices and testing novel field designs: this is what we provide in this booklet. **For each technical solution undergoing experimentation in the project, standalone leaflets** (i.e. a 2-page summary) **dedicated to farmers has been produced.**

Experiment leaflet

The experiment leaflets are a summary of each experimentation conducted with a description of contexts, methods and major results with limitations, perspectives and conditions for success.



Performance leaflet



Where practical solutions have been trialled at the farm scale, a performance leaflet has been produced presenting the main performance details.

These second leaflets describe the practice, the conditions for its implementation and its performance, and provide some extra information to understand the mode of action.

Our goal with this compilation of leaflets is to provide summarised and sufficiently relevant information to share the knowledge produced regarding all the alternatives to pesticide use, some of which are ready to be implemented and others which require further experimentation. To reach satisfactory pest control in apple orchards, it is necessary to combine various levers and methods in order to supress some insecticide applications. For example, the introduction of flower strips and/or companion plants promotes the presence of natural enemies and, depending on its composition, can also have a repellent effect against aphids. It can be combined with ant diversion and the release of beneficials such as parasitoids or predators such as earwigs in order to optimise aphid control (see levers 1, 2, 5 and 3).

Leaflets on experiments

Each leaflet presents a description of the experimentation and the major results. The list below mentions the number of the lever for action it is related to (as described in the common framework) and also which insect pest(s) is/are concerned.

Practice combination

Leaflets on application of levers for action (performance leaflets)

Each leaflet presents the practice, the way to implement it and its performance. The list below mentions the number of the lever for action it is related to (as described in the common framework) and also which insect pest(s) it concerns.

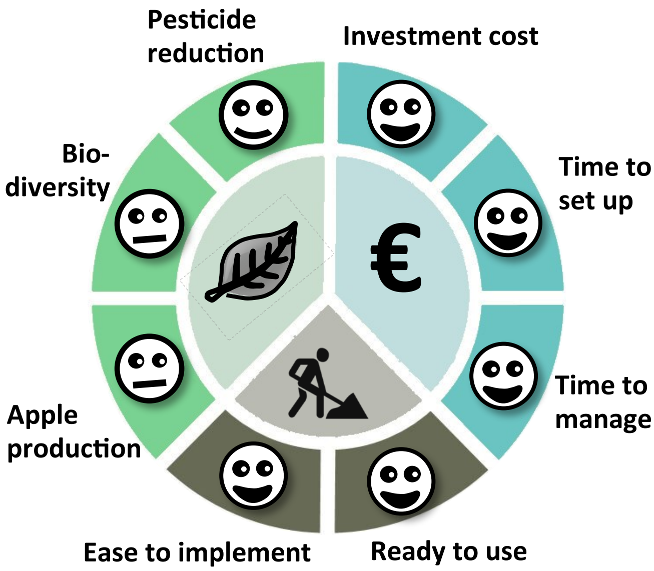
How to read a performance leaflet

Practice performance evaluation

To describe the performance **three axes are considered**: agronomy & environment, costs & benefits, and operationality, with two to three indicators for each. Each indicator is qualitatively evaluated on a **four-level scale, in comparison to a reference system described at the top of the section**:

Positive effect, Neutral to positive effect, Room for improvement, Bottleneck.

For each indicator, a short explanation is given and for each axis a summary on the strengths and weaknesses of the practice is provided.



Example of performance wheel

Agronomy & environment

INDICATORS				
Pesticide reduction	All pesticides eliminated	Some pesticides eliminated	No pesticide reduction but risk of pullulation of pests is limited	Not currently known
Biodiversity	Increase in both richness AND abundance	Increase in richness OR abundance	No effect	Reduction in biodiversity or not currently known
Apple production	Increase in fruit production quantity AND quality	Increase in fruit production quantity OR quality	No effect on quantity and quality	Reduced fruit production quantity and/or quality

Costs & benefits

INDICATORS				
Investment cost	No extra cost	Low or possible to build	Investment needed	Large investment needed
Time to set up	None	Low	Labour intensive	Labour intensive and at a peak period
Time to manage	None	Low	Labour intensive	Labour intensive and at a peak period

Operationality

INDICATORS				
Ease to implement	No specific knowledge or skills needed OR easy to implement	Training course needed for implementation	Complex to implement	Not ready for implementation
Ready to use	Available and widespread practice	Practice being disseminated	Validated on station	Ongoing experimentation

Experiment leaflet

N°1 ROSEMARY EFFECTS ON ROSY APPLE APHID

Levers of action 1&2: *Barrier and dilution effect - Push effect - Intercrop*

Status: *Ongoing field experimentation*

BACKGROUND

Several studies have shown the benefits of introducing companion plants (CPs) in crops to repel pests and attract their natural enemies. However, the field evaluation of candidate CPs has not been carried out in orchards, which is a bottleneck for the use of this strategy by farmers. We hypothesised that some aromatic plants (*Rosmarinus officinalis* and *Tagetes patula*) (Dardouri *et al*. 2019 a&b) can affect the performance of aphids, favouring their bio-control, promoting the action of their active natural enemies (ANE) (Beizhou *et al*. 2013) and improving orchard productivity.

TARGET PEST

Rosy apple aphid (RAA)

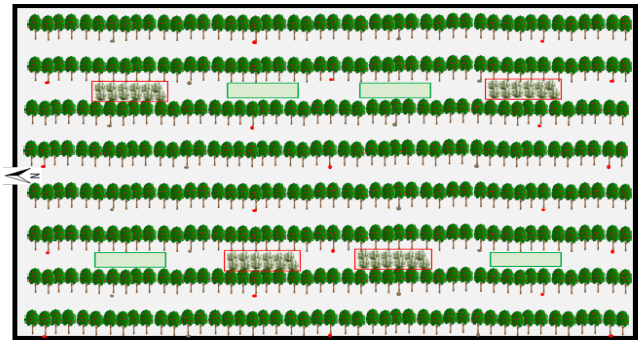
(Dysaphis plantaginea)

EXPERIMENT OBJECTIVES

- **To study the impact** of the presence of rosemary (*Rosmarinus officinalis*) planted within apple orchards **on the abundance of rosy apple aphid.**
- **To evaluate the abundance of natural enemies and their efficacy in the bioregulation of this pest.**

EXPERIMENT PROTOCOL

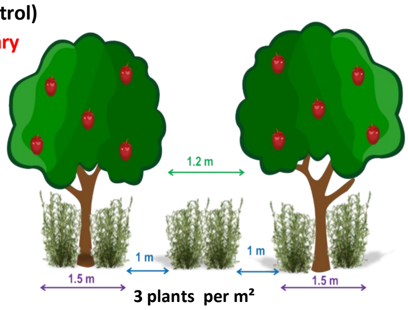
In an apple orchard (cultivar Melrose), the repellent aromatic plant rosemary was planted in 2018 and compared to grass ground cover as a control.



4 plots with natural vegetation (control)
vs 4 plots intercropped with rosemary

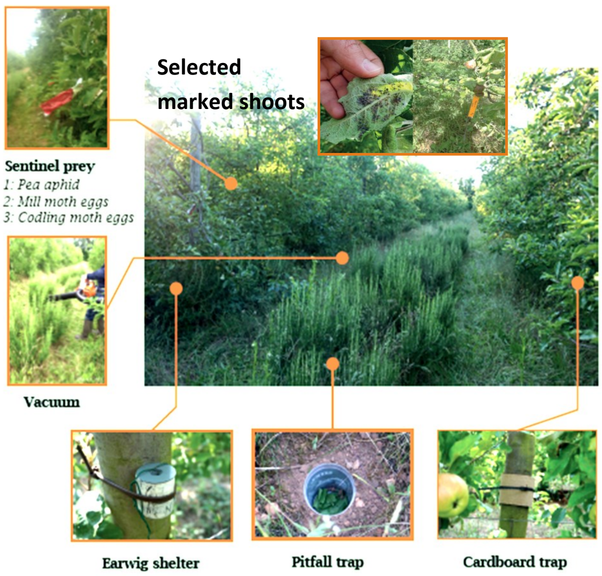
<u>Rosemary introduction:</u>

In a random design, for each plot, rosemary plants were planted in the alley, between the tractor wheel path, and within the tree-row.



<u>Sampling methods</u>

- 96 marked shoots were surveyed in a period of RAA infestation to study the abundance of rosy apple aphid and its natural enemies.
- Various other sampling methods were used to evaluate the effect of rosemary on predation and on beneficial abundance.



EXPERIMENT OVERVIEW

Duration: **2018-2022**

Soil: Stony shallow sandy-loam soil

Climate: Continental climate with summer Mediterranean influences

Contacts: INRAE Gotheron

tarek.dardouri@inrae.fr

sylvaine.simon@inrae.fr

Leaflet authors: T. Dardouri, S. Simon, A. Alaphilippe, INRAE; . Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, INRAE. Photos© INRAE Gotheron

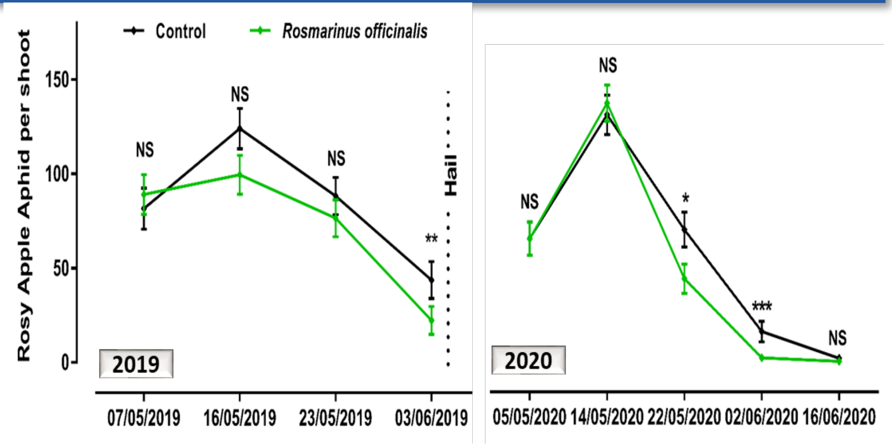
N°1 ROSEMARY EFFECTS ON ROSY APPLE APHID

Levers of action 1 & 2: *Barrier and dilution effect - Push effect - Intercrop*

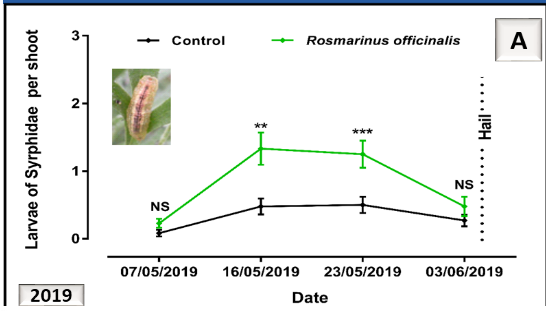
Status: *Ongoing field experimentation*

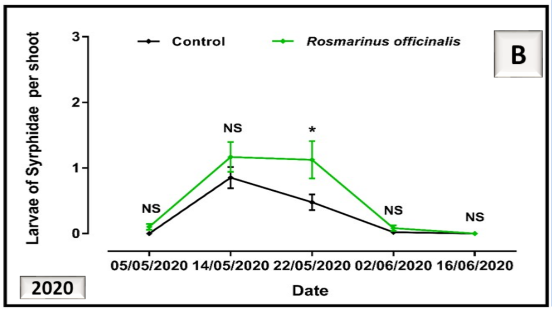
ROSEMARY TENDS TO REDUCE THE NUMBER OF ROSY APPLE APHIDS

At the first date of observation, aphid abundance measured by the mean number of RAA individuals per apple shoot is similar in both modes. Later in the season, aphid abundance tends to be lower in the presence of rosemary compared to the control and is significantly different after the infestation peak on 3 June 2019, 22 May 2020 and 2 June 2020.



GLOBAL INCREASE IN NATURAL ENEMIES





In general, plots with companion plants have higher numbers of beneficials than control plots. The most abundant active natural enemies were hoverflies. A significant increase in the number of hoverfly larvae (active stage) was observed in the rosemary plots compared to the control at the time of peak infestation on 16 May 2019, 23 May 2019 and 22 May 2020.

The reduction in the number of aphids after mid-May is probably due to predators and parasitoids alongside the migration of aphids to their secondary host plant. Furthermore, most of the predator surveys performed (data not shown) showed a significant increase in the main aphid predators and parasitoids in the rosemary plots.

In line with Beizhou *et al*. (2012), the higher abundance of predators in the apple-rosemary plots is likely to have favoured pest predation compared to the control plots.

CONCLUSION AND PERSPECTIVES

Our experiment did not allow us to disentangle a possible direct repellent effect of rosemary against RAA from an important indirect effect mediated by natural enemies. This underlines the difficulty of showing the repellent effect of plants shown to be promising under controlled conditions (Dardouri *et al*. 2019b) in natural conditions. A longer study (> 2 years) could provide further information about the attraction of predators and aphid regulation.

Measures of the abundance of other pests (*Hoplocampa testudinea*, *Cydia pomonella* and *Aphis* spp.) were also completed in the orchard and deserve to be further studied.

FOR MORE INFORMATION

Performance leaflet N°1.

References:

Beizhou S, Tang G, Sang X, Zhang J, Yao Y, Wiggins N. Intercropping with aromatic plants hindered the occurrence of *Aphis citricola* in an apple orchard system by shifting predator–prey abundances. Biocontrol Science and Technology; 23 (4): 381- 395 (2013).

Dardouri T, Gautier H, Ben Issa R, Costagliola G and Gomez L. Repellence of *Myzus persicae* (Sulzer): evidence of two modes of action of volatiles from selected living aromatic plants. Pest Manag Sci; 75(6): 1571-1584 (2019a).

Dardouri T, Gomez L, Schoeny A, Costagliola G and Gautier H. Behavioural response of green peach aphid *Myzus persicae* (Sulzer) to volatiles from different rosemary (*Rosmarinus officinalis* L.) clones. Agricultural and Forest Entomology; 21(3): 336-345 (2019b).

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Leaflet authors: T. Dardouri, S. Simon, INRAE; . Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, INRAE. Photos© T. Dardouri, INRAe Gotheron

Experiment leaflet

N°2 Repellent effect of essential oils to control apple sawfly

Lever of action 1: *Barrier and dilution effect - Push effect*
Status: *Further lab experiment needed before field trials*

Background

The apple sawfly (*Hoplocampa testudinea*) is a major pest in organic apple orchards and is also becoming more threatening in IPM. The efficiency of white sticky traps used to control apple sawfly is not high enough to keep the damage below an economically tolerable threshold (Vincent *et al.*, 2019). The use of volatile compounds as a repellent is promising: apple sawfly damage occurs exactly at bloom, i.e. when the application of insecticide is the most problematic. De Almeida *et al.* (2017) showed a significant repellent effect in yarrow (*Achillea millefolium*), either planted in flower strips or sprayed as an essential oil (EO) on apple blossoms (4% concentration).

Target pest

Apple sawfly

(Hoplocampa testudinea)

Experiment Objectives

- **To assess the repellent effect of three essential oils** (yarrow, ylang-ylang and tarragon) and an organic volatile compound mixture (α-farnesene and β-ocimene) on apple sawfly.
- **To assess potential effect of these volatiles on beneficials and pollinators.**

Experiment protocol

Year 1 The trial was set up in different plots planted with the Juliet cultivar. One white sticky trap with a disperser was hung for each essential oil (yarrow, ylang-ylang and tarragon) and one as a reference without a disperser, totalling four treatments.

5 to 8 sticky traps per treatment, 10m away from each other.
Dispensers: Eppendorf® tube with 4 openings of 2 mm diameter.

The repellent effect of EO was assessed by the **abundance of apple sawfly adults** caught on traps at four dates in April.

Year 2 The trial was set up in two different plots planted with the Juliet cultivar. Yarrow EO and a 50:50 mixture of α-farnesene and β-ocimene were assessed and compared to a reference without dispensers.

Dispensers consisted of a base matrix paste put in a plastic cup (SPLAT paste, ISCA Technologies), easier to install.

The repellent effect was assessed by the **abundance of apple sawfly damage on fruits** at two dates in April and May.

Experiment overview

Duration: 2018-2019

Soil: Clay-loam

Climate: Continental climate with summer Mediterranean influences

Contact: GRAB Avignon
claudeeric.parveaud@grab.fr

Leaflet authors: Claude-Eric Parveaud, GRAB. Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosiès, Caroline Goutines, INRAE. Photos: ©GRAB

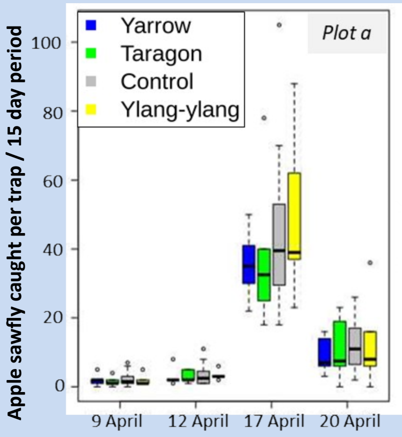
N°2 Repellent effect of essential oils to control apple sawfly

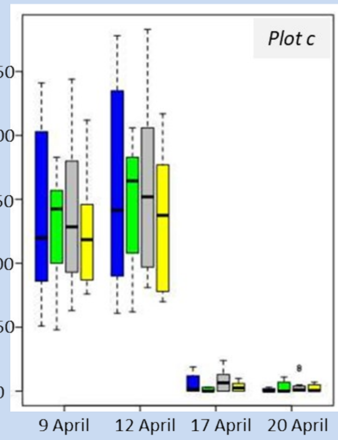
Lever of action 1: *Barrier and dilution effect - Push effect*
Status: *Further lab experiment needed before field trials*

Effect of essential oils (EO) and volatiles against apple sawfly

In year 1, no significant effect of yarrow, ylang-ylang and tarragon EO was observed on the abundance of apple sawfly in the tree plots (see examples right), regardless of the apple sawfly pressure in the plots (10, 57 and 155 insects caught per trap over a 15-day period in plots A, B and C respectively).

In year 2, no significant effect of yarrow EO and the 50:50 mixture of α-farnesene and β-ocimene was observed on the abundance of damage on fruits (results not shown). The mean percentage of infected fruits at the end of May ranged from 17% to 46% according to the plot.





Effect of essential oils on natural enemy and pollinator selectivity

In year 1, the mean number of pollinators (wild bees and honey bees) and natural enemies (hoverfly, spiders, lacewing, Coccinellidae and Hemerobiidae) caught per trap over a 15-day period ranged from 1 to 3. For predators, a significant difference was observed at one date in two plots. However, the difference between treatments, although statistically significant in some cases, is limited to a difference of 1 predator per trap: its agronomic impact is therefore probably insignificant. No significant effect was observed on the other dates or plots.

Conclusion and perspectives

Under our experimental conditions, no significant repellent effect of essential oils and a mixture of α-farnesene and β-ocimene was found, regardless of the method used to diffuse these volatile compounds. The two diffusion devices used could not reproduce the effect of the concentration of EO sprayed directly on flowers (every morning over five days) displayed in the study of De Almeida *et al.* (2017).

Laboratory trials to screen the repellent effects of different essential oils at different concentrations before field trials would be useful. However, apple sawfly rearing has not been developed, which strongly limits applied research on this pest.

For more information

Experiment leaflet N°7 and performance leaflet N°5.

References:

Boevé JL, Lengwiller U, Tollsten L, Dorn S, Turlings T. (1996). Volatiles emitted by apple fruitlets infested by larvae of the European apple sawfly. Phytochemistry 42(2): 373-381.

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Roitberg BD, Prokopy RJ. (1984). Host discrimination by adult and larval European apple sawflies *Hoplocampa testudinea* (Klug) (Hymenoptera: Tenthredinidae). Environ Entomol 13: 1000-1003.

Vincent C & al. (2019). A review of the apple sawfly, *Hoplocampa testudinea* (Hymenoptera Tenthredinidae). Bulletin of Insectology 72(1): 35-54.

Leaflet authors: Claude-Eric Parveaud, GRAB. Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, Caroline Goutines, INRAE. Photos: ©GRAB

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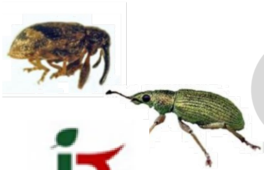
Experiment leaflet



N°3

Planting late-blooming cultivars to reduce blossom weevil attack

Lever of action 3: *Bottom-up processes*

Status: *Ready to use solution*

Background

Pest damage can be modulated by cultivar choice. Besides genetic susceptibility to pests, a lack of synchronisation is also known to protect plants from pest infestation. In apple trees, late-leafing cultivars can avoid infestation and damage by rosy apple aphid, simply because egg hatching occurs before bud burst and neonate larvae cannot feed on these late cultivars and die (Miñarro and Dapena, 2007). We hypothesised that a similar phenological mismatch between blooming period and weevil time for egg-laying could also protect apple trees from weevil pest infestation. Accordingly, cultivars blooming the latest could partially avoid weevil damage.

Target pests

Apple blossom weevil (*Anthonomus pomorum*) and **green weevil** (*Polydrusus formosus*) —>

Experiment Objectives

- **To assess if weevil abundance and damage depends on cultivar** and particularly if both are lower in late-blooming ones.
- **To determine the rate of parasitism and if this level is related to cultivar phenology.**

Experiment Protocol

The experiment has been conducted in one orchard with 22 cultivars (2 blocks of three trees per cultivar randomly distributed).

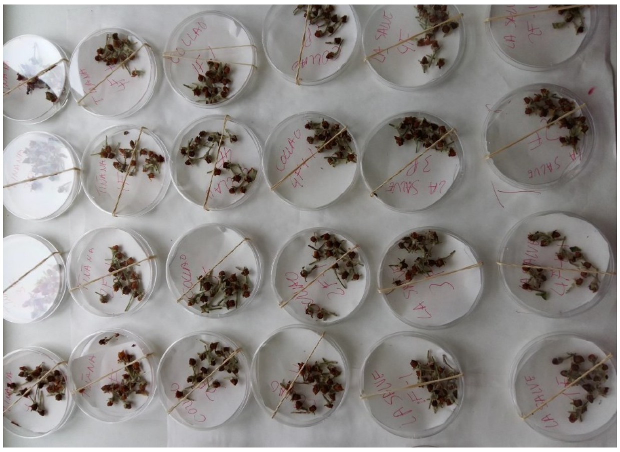
Blossom weevil damage to flowers

Green weevil damage to leaves

Monitoring

Three parameters were recorded:

- Tree blooming phenology
- Adult weevil phenology (beating)
- Blossom weevil parasitism



Monitoring emergence of weevil parasitoids

Experiment overview

Duration: 2018-2019

Climate: Temperate oceanic climate with abundant rainfall spread evenly across the year and mild temperatures even in winter.

Contact: SERIDA, Spain

mminarro@serida.org

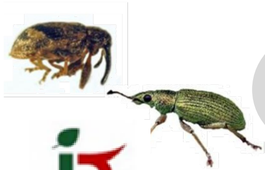
Leaflet author: M. Miñarro, SERIDA; . Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, C. Goutines. INRAE. Photos M. Miñarro ©

N°3

Planting late-blooming cultivars to reduce blossom weevil attack

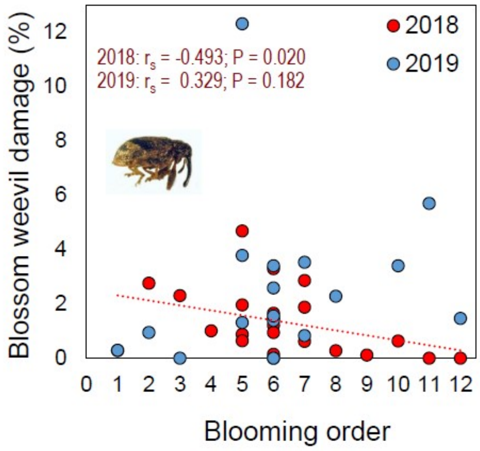
Lever of action 3: *Bottom-up processes*

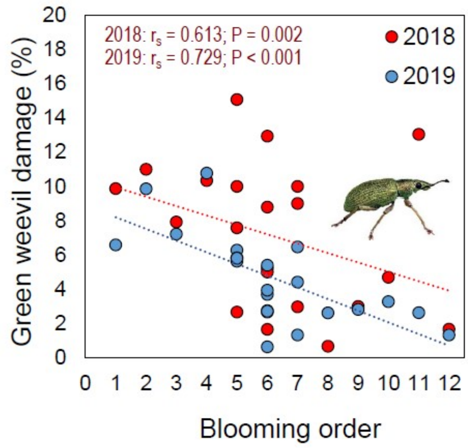
Status: *Ready to use solution*



A phenological mismatch partially explains differences in cultivar damage by weevils

Blossom weevil and green weevil damage varied according to cultivars. The abundance and damage from green weevils and the damage by blossom weevils (one year) related negatively with the blooming order of the cultivars, i.e. late-blooming cultivars suffered lower infestation and damage. Sprouting late decreases the time window in which the blossom weevil can lay eggs in blossoms or the green weevil can feed on leaves.

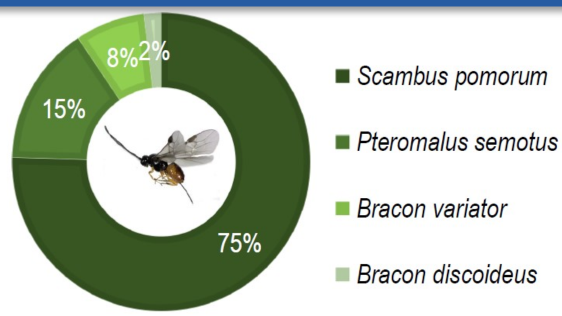


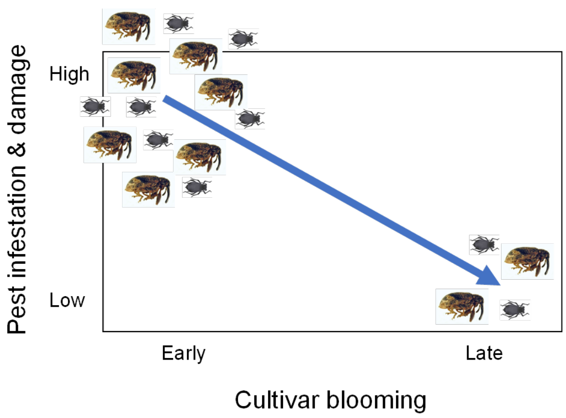


Parasitoids contribute to reducing blossom weevil populations

Four parasitoid species (*Scambus pomorum, Pteromalus semotus, Bracon variator* and *Bracon discoideus*) contibuted to reducing apple blossom weevil populations by 15.2%.

The level is in the range of parasitism found in the region (6-81%; Miñarro and García, 2018). The level of parasitism was not affected by cultivar phenology.





Conclusion

The experiment demonstrated that cultivar phenology can be a way to reduce pest infestation and damage. In particular, we showed that using cultivars that bloom relatively late can help to decrease damage by weevils apart from that by the rosy apple aphid (Miñarro and Dapena, 2007).

For more information

Performance leaflet N° 2.

References:

Miñarro, M., Dapena, E. (2007). Resistance of apple cultivars to *Dysaphis plantaginea* (Hemiptera: Aphididae): role of tree phenology in infestation avoidance. Environmental Entomology 36(5): 1206-1211.

Miñarro, M., García, D. (2018). Unravelling pest infestation and biological control in low-input orchards: the case of apple blossom weevil. Journal of Pest Science 91 (3): 1047-1061.

API-Tree (2017-2021) is an ERA-Net C-IPM project coordinated by INRAE with funding from the European Union.

Leaflet author: M. Miñarro, SERIDA; . Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, C. Goutines, INRAE. Photos M. Miñarro ©

Experiment leaflet

N°4

Predation of the rosy apple aphid investigated by molecular gut content analysis

Lever of action 4: *Top-down processes*

Status: *Ongoing experimentation requiring additional trials*

Leaflet authors: S. Kramer Jacobsen, L. Sigsgaard, UCPH; P. Franck, INRAE. Design & coordination: A. Alaphilippe, & layout; B. Rosies, INRAE. Photos Lars Skipper, Natural History Museum, Aarhus, INRAE ©

Background

Diverse plant habitats surrounding cropping areas can benefit the natural regulation of pests in orchards by promoting the occurrence of predators (Landis *et al.*, 2005). Promoting and conserving natural enemies by providing them with undisturbed and plant-diverse habitats, will benefit the predator population and thereby benefit the control of the rosy apple aphid, a major pest in apple orchards (Simon *et al.*, 2011; Herz *et al.*, 2019). This study investigated the influence of hedgerows and flower strips on the most abundant insect predators in apple orchards and predation of the rosy apple aphid, in two distances from each plant-diverse vegetational structure. Predation was assessed by predator gut content analysis for the most abundant groups of insect predators in apple trees.

Target pest

Rosy apple aphid (RAA)

(Dysaphis plantaginea)

Experiment Objectives

- To identify **which predator species** contribute to **the natural regulation of the rosy apple aphid.**
- To investigate **the impact of hedgerows and flower strips for the predation of the rosy apple aphid.**

Experiment Protocol

Experimental design

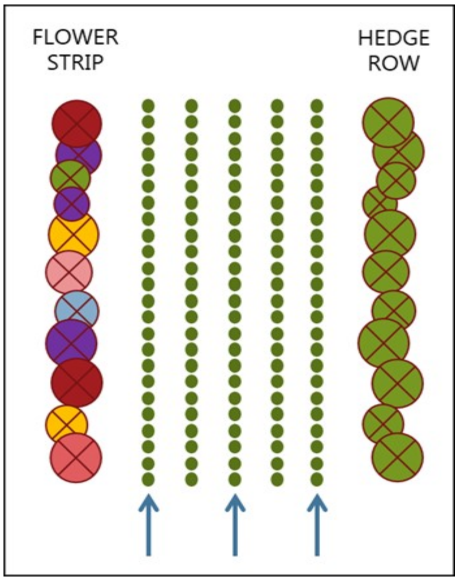
Sampling of predators for gut content analysis was done in two organic apple orchards in Zealand, Denmark. The flower strips were established in 2015 and consist of 36 perennial plant species native to Denmark.

Sampling method

Sampling was conducted before flowering, after flowering and at the second fruit fall (June drop), in the first row (2 m) and in the third row (10 m) from either a hedgerow or a flower strip (Figure 1).

The most abundant **insect predators** were sampled.

- Predators were collected from apple trees individually in tubes with ethanol (70%) and further processed by DNA extraction and PCR in the lab (Lefevbre *et al.*, 2017).
- Abundance of the rosy apple aphid was assessed visually in the orchard.
- The abundance of predators was assessed by beating samples.



Experiment overview

Duration: 2018

Soil: Sandy clay to clay soil

Climate: Temperate climate

Contacts: UCPH (University of Copenhagen); INRAE PSH

stikra@plen.ku.dk; les@plen.ku.dk; pierre.franck@inrae.fr

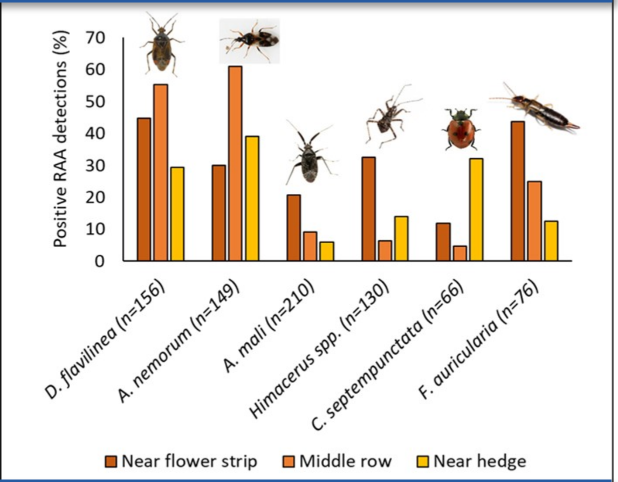
N°4 Predation of the rosy apple aphid investigated by molecular gut content analysis

Lever of action 4: Top-down processes
Status: Ongoing experimentation requiring additional trials

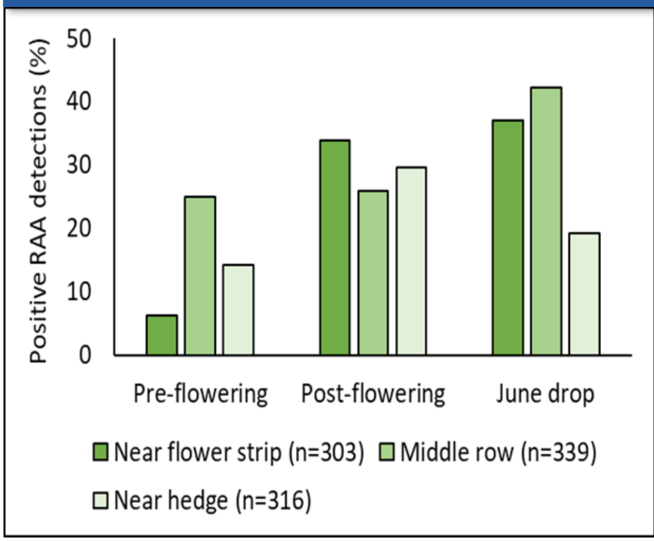
Predator species contribute differently to control of rosy apple aphids

The predators sampled from the apple trees were flower bugs (*Deraeocoris flavilinea* and *Atractotomus mali*), anthocorids (*Anthocoris nemorum*), nabids (*Himacerus apterus*), coccinellids (*Coccinella septempunctata*), and earwigs (*Forficula auricularia*).

The highest proportion screening positive for rosy apple aphid DNA was *D. flavilinea* and *A. nemorum,* followed by *F. auricularia* (see figure right). *A. mali* had RAA in their gut content at lower proportions compared to *A. nemorum* and *D. flavilinea*.



Detection of RAA in predator gut content



Preliminary results show that positive detection of RAA in the gut content of the sampled predators increased during the season in the row near the flower strip and in the middle row, while there was a drop in the proportion of positive detections by June in the apple row near the hedge (see figure left).

After flowering, the level of positive detection of RAA in gut content was most evenly distributed across the apple rows. The abundance of RAA increased during the sampling period, except in the apple row near the hedge. *A. nemorum* was most abundant near the hedge, while *A. mali* and *F. auricularia* were most abundant in the middle row and near the flower strip. Considering the abundance of *A. nemorum* near the hedge and the proportion of positive DNA detections in its gut content, *A. nemorum* likely contributed to the reduction of RAA near the hedgerow, with hedgerows likely to be the main source of this predator.

Conclusion and perspectives

Pest control in an orchard can benefit from both hedgerows and flower strips for increasing the natural enemy community. This study shows that different species benefit differently from these two types of conservational habitats. Molecular tools have been used to identify the predator species, linking them directly to the control of the rosy apple aphid and have shown that they are influenced by distance to semi-natural habitat. Orchard planning and design should integrate the value of proximity to non-crop habitats for increased pest control.

This study did not consider all natural enemy groups occurring in apple orchards, notably analysis of spiders is still ongoing. Similarly, it was not possible within the framework of this study to include other herbivores. A more complete knowledge of predator diet would be very useful in understanding the full contribution to pest regulation by predators in apple orchards. A study of early-season predator species would complement the present study in understanding the dynamics of predator-prey interactions and how predators can limit risks of early-season pest outbreaks.

References:

Herz, A., Cahenzli, F., Penvern, S., Pfiffner, L., Tasin, M., Sigsgaard, L. (2019). Managing Floral Resources in Apple Orchards for Pest Control: Ideas, Experiences and Future Directions. Insects. 10, 247.

Landis, D.A., Menalled, F.D., Costamagna, A.C., Wilkinson, T.K. (2005). Manipulating plant resources to enhance beneficial arthropods in agricultural landscapes. Weed Sci. 53, 902-908.

Simon, S., Bouvier, J.C., Debras, J.F., Sauphanor, B. (2011). Biodiversity and pest management in orchard systems. A review. Agron. Sustain. Dev. 30, 139-52.

Lefebvre, M., Franck, P., Olivares, J., Ricard, J.-M., Mandrin, J.-F., Lavigne, C. (2017). Spider predation on rosy apple aphid in conventional, organic and insecticide-free orchards and its impact on aphid populations. Biological Control 104, 57–65.

Leaflet authors: S. Kramer Jacobsen, L. Sigsgaard, UCPH; P. Franck, INRAE. Design & coordination: A. Alaphilippe, & layout: B. Rosiès, INRAE. Photos: L. Skipper, Natural History Museum, Aarhus ©

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Universidad de Oviedo

SERIDA

N°5 Nest boxes to increase pest control by birds

Experiment leaflet

API-Tree

Lever of action 4: *Top down processes*

Status: *Ready to use solution*

Background

Apple crops are subject to intensification with negative effects for bird communities. For example, cavity-nester birds have more problems in establishing themselves in modern orchards because trees are grown on dwarfing rootstock and they are cavity-poor habitats compared to traditional orchards (Grüebler *et al*., 2013). The provision of nest boxes is one of the strategies in the ecological restoration of these agroecosystems (Lindell *et al*., 2018).

We hypothesised that providing nest boxes for insectivorous birds can increase the biological control of arthropod pests by birds (García *et al*., 2021).

Target pests

Many apple pests:

Aphids, weevil, codling moth, tortricids etc.

Experiment Objectives

- To assess **nest box occupation by insectivorous birds.**
- To assess **the effect of occupied nest boxes on insectivory** and, particularly, pest predation.
- To assess if the various occupying **bird species differ in their role as natural enemies** of apple pests.

Experiment Protocol

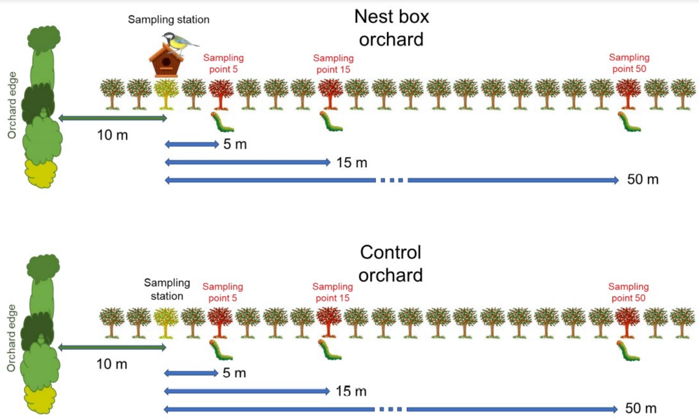
Experimental design

24 cider apple orchards were divided into two groups of 12 orchards each: the nest box group, with 10 nest boxes each, and the control group, without nest boxes.

Each nest box occupied by breeding birds was considered a sampling station, that had in turn three sampling points that were single trees at 5, 15 and 50 m from the occupied nest box.

Nest boxes were made of wood, measured 21.5 × 14.5 × 15.0 cm, and had a 2.6 or 3.2 cm radius entrance hole.

For each nest box orchard, an equivalent sampling design was replicated in its paired control orchard.



Sampling method

We estimated the effects of insectivorous birds in each sampling point through two complementary methods:

1) Estimates of bird insectivory based on bird attack on a sentinel pest, mimicked by plasticine green caterpillars
2) Measurements of the abundance (biomass and number) of arthropods, and particularly of apple pests, in beating samples from apple trees.

Complementary to the experiments, we took pictures of adult birds to identify the arthropod prey captured for feeding nestlings.

All nest boxes were checked for occupation of breeding birds at the end of April.

Experiment overview

Duration: 2018-2020

Soil: Several types (24 orchards)

Climate: Temperate oceanic

Contact: SERIDA - Universidad de Oviedo

mminarro@serida.org

Leaflet authors: M. Miñarro, SERIDA; D. García, University of Oviedo. Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, C. Goutines. INRAE. Photos M. Miñarro ©

N°5 **Nest boxes to increase pest control by birds**

Lever of action 4: *Top-down processes*

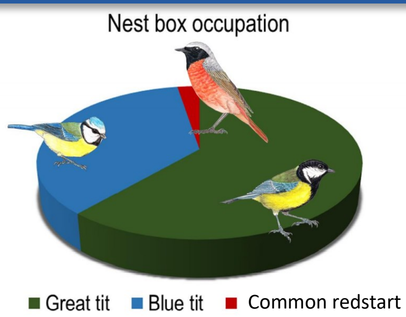
Status: *Ready to use solution*

Leaflet authors: M. Miñarro, SERIDA; D. García, University of Oviedo. Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, C. Goutines, INRAE. Photos M. Miñarro ©

Birds occupy nestboxes

Birds occupied for breeding 25.0%, 29.8% and 33.3% of nest boxes in 2018, 2019 and 2020 respectively. The percentage of occupied boxes per orchard and year ranged from 10 to 80%.

Great tit (*Parus major)* was the dominant species in every year (61.4% in total), followed by Eurasian blue tit (*Cyanistes caeruleus*; 36.0%). The occurrence of the common redstart (*Phoenicurus phoenicurus)* was somewhat secondary (2.6%).



Breeding birds increase insectivory reducing pest populations

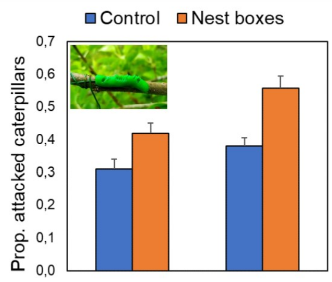
The proportion of replica caterpillars attacked by birds was 35-41% higher in orchards with nest boxes than in control orchards (see first graph right).

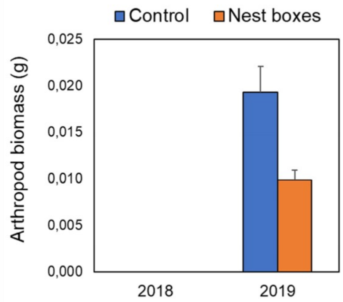
In the beating samples, we found that the total biomass of arthropods on the trees was reduced by 51.7% in the nest box orchards in comparison to the control without nest boxes (see second graph). In particular, the probability of the occurrence of apple pests on trees significantly decreased from 60% in the control orchard to 43% in nest box orchards.

No effect of distance in bird insectivory was detected, which means that insectivory was maintained at least up to 50 m from the nest box.

Photos revealed that great tits, blue tits and redstarts caught both herbivores and natural enemies to feed nestlings.

Blue tits had the higher proportion of apple pests in the nestling diet (28.4%), such as woolly, rosy and green aphids and the larvae of blossom weevils.





Conclusion and perspectives

We demonstrated the efficacy of installing nest boxes for insectivorous birds as a method of ecological restoration for pest control ecosystem services. We showed that nest boxes placed on apple trees are occupied by birds for breeding and that these breeding birds have an insectivory effect leading to the reduction of arthropods in general, including pest populations.

Here we demonstrated that installing nest boxes produces higher predation activity of natural enemies and a reduced abundance of crop pests, but we did not test a reduction in crop damage. However, we have previously shown, in the same agroecosystem, reductions in foliar damage by aphids associated with predation by birds (García *et al.,* 2018).

For more information

Performance leaflet N°3.

References:

García, D., Miñarro, M., Martínez-Sastre, R. (2021). Enhancing ecosystem services in apple orchards: nest boxes increase pest control by insectivorous birds. Journal of Applied Ecology 58(3): 465-475.

García, D., Miñarro, M., Martínez-Sastre, R. (2018). Birds as suppliers of pest control in cider apple orchards: Avian biodiversity drivers and insectivory effect. Agriculture, Ecosystems and Environment 254: 233-243.

Grüebler, M. U., Schaller, S., Keil, H., & Naef-Daenzer, B. (2013). The occurrence of cavities in fruit trees: effects of tree age and management on biodiversity in traditional European orchards. Biodiversity and conservation, 22(13-14), 3233-3246.

Lindell, C., Eaton, R. A., Howard, P. H., Roels, S. M., & Shave, M. E. (2018). Enhancing agricultural landscapes to increase crop pest reduction by vertebrates. Agriculture, Ecosystems & Environment, 257, 1-11.

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Experiment leaflet

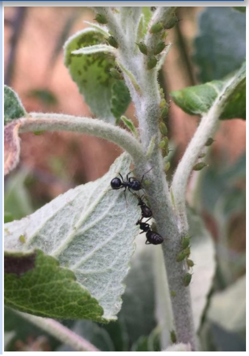
N°6

Diversion of Commensal Organisms

Levers of action 4 & 5: *Top-down processes mediated by beneficials*
Diversion of commensal organisms.
Status: *Ongoing experimentation.*

Background

Many studies have shown that flowerstrips can enrich biodiversity and increase beneficials in cropping systems. However, the effects on ecosystem services, such as pollination and biocontrol, is diverse. In apple, as well as in many other perennial crops, flowerstrips have had little effect on the biocontrol of aphids. We hypothesized that this is due to two factors: ants protect aphids and natural enemies do not sufficiently move into the crop to render ecosystem services. We therefore assessed whether diversion of ants (using sugar baits) and attraction of natural enemies (using odor lures) could harness the increased biodiversity in biocontrol of aphids.



Target pest

Rosy apple aphid (RAA)

(Dysaphis plantaginea)

Experiment Objectives

- **To assess the impact of diversion of ants on the occurrence of natural enemies in colonies** of RAA and green apple aphid (GAA), and the fate of these aphid species
- **To assess the effect of lures** for lacewings and hoverflies on biocontrol of RAA and GAA

Experiment Protocol

Diversion of ants (picture 1):

Twenty ml plastic tubes with sucrose and amino acids in specific ratios and capped with a cotton plug. Each tree has one tube placed horizontally at the base of the tree trunk. Tubes were replaced weekly for 5 consecutive weeks.

Attraction of predators (in particular syrphid, picture 2**):**

Each of three odour lures embedded at 5% AI in SPLAT (ISCA Tehcnologies, BioInnovate) were placed 2 gr each in each treatment tree.

Lures were replaced weekly.

Sampling method

Each colony in each tree was individually marked and followed weekly.

The number of aphids in the colony, the number of tending ants, and the number of resident predators, were scored visually.

Experiment overview

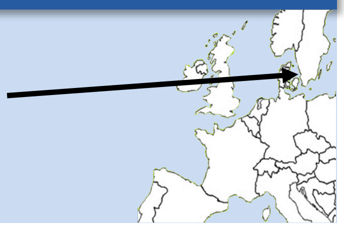
Duration: 2018 - 2021

Soil: clay-sand- silt

Climate: temperate continental

Contact: SLU

Teun.dekker@slu.se



Leaflet author: Teun Dekker, SLU; . Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, C. Goutines. INRAE. Photos T. Dekker©

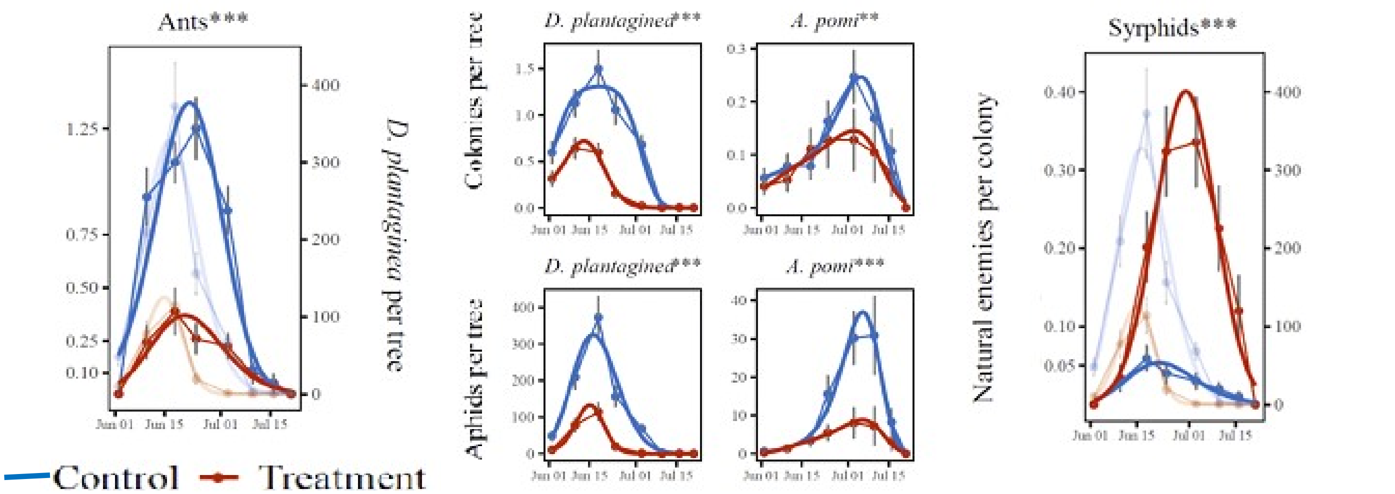
N°6

Diversion of commensal organisms

***Levers of action 4 & 5:** Top-down processes mediated by beneficials*
Diversion of commensal organisms.
***Status:** Ongoing experimentation.*

Ecological intensification for biocontrol of aphids requires severing myrmecophily

Close monitoring of food-web interactions in thousands of aphid colonies show that tending ants dominated functional responses, while those of natural enemies being weak or absent. Application of artificial honeydew diverted ants from tending aphids and flipped the myrmecophily-dominated state into favouring functional responses of a guild of natural enemies. Responses were swift and controlled both *Aphis pomi* and *Dysaphis plantaginea*, provided intervention was synced with aphid and predator phenology.



Baits that attract natural enemies can significantly enhance biocontrol

Whereas three different lure types for different aphid predators. Whereas lacewing lures attracted selectively lacewings and increased oviposition in other studies, in our studies in 2018 and 2921, lacewing lures did not enhance the presence of larvae in aphid colonies.

In contrast, two lures, aimed at attracting syrphid fly adults, did increase oviposition and presence of syrphid fly larvae in rosy apple aphid colonies, and reduced aphid colony size and number.

Conclusion and perspectives

Main results: 1. To unlock 'nature's own' aphid-control potential provided through ecological intensification, myrmecophily needs disruption. This may be particularly true for perennial cropping systems in which ants

2. Biocontrol in a diversified cropping system can be significantly enhanced by lures that attract natural enemies into the crop.

Limits and conditions for success: 1. Formulation pf baits and lures need further development. Registration or exemption from registration needs to be addressed.

2. The combination of ant diversion and natural enemy attraction needs further assessment in terms of the ability to suppress aphid populations below economic thresholds.

3. The effectiveness of the combination of bait and lure needs to be tested in other climate zones in Europe

Limits and conditions for success: Tests in other climate zones are needed. Furthermore, attractants for other natural enemies need to be tested including for ladybird beetles, as well as parasitoids. Parasitoids of aphids were rarely seen in the Swedish apple orchards, but may be more important in other zones.

For more information

Performance leaflet N°4.

References:

Our results have not been published yet. Diversion of ants have been tested before (1, below).
Lures for attraction and biocontrol of aphids in barley and apple were studied under 2 below

1.C. Nagy, J. V. Cross, V. Markó, Biol. Control 65, 24–36 (2013). and C. Nagy, J. V. Cross, V. Marko, Crop Prot. 77, 127–138 (2015).

2. Pålsson J, Thöming G, Silva R, Porcel M, Dekker T, Tasin M. 2019. Insects 10: E6. doi: 10.3390/insects10010006 and.Pålsson, J., Porcel, M., Dekker, T. et al. J Pest Sci (2021). https://doi.org/10.1007/s10340-021-01410-2

Leaflet author: Teun Dekker, SLU; . Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, C. Goutines. INRAE. Photos T. Dekker©

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N°7

Effect of the colour of sticky traps to catch apple sawfly

Experiment leaflet

Lever of action 6: *Direct measures with 'soft practices'*

Status: *Ongoing field experimentation*

Background

The apple sawfly is a major concern in organic apple orchards where it can cause severe damage to production. The larvae develop on flowers and young fruit. While white sticky traps are the usual method for monitoring and controlling apple sawfly (Vincent *et al.*, 2019), some advisers in the Avignon area use blue traps.

Target pest

Apple sawfly

(Hoplocampa testudinea)

Experiment Objectives

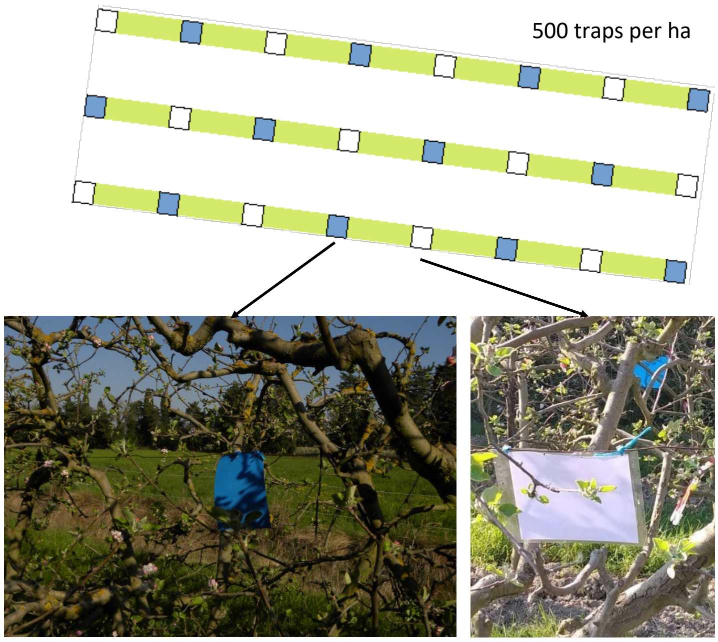
To compare the effectiveness of blue and white sticky traps.

An effective coloured trap would capture a lot of apple sawflies and few beneficials.

Experiment Protocol

Experimental design:

The trial was set up in an orchard containing the Akane cultivar. Coloured sticky traps were placed in April, at the beginning of blossom, in a plot of three rows : 12 traps per colour and 8 traps per row.



Traps:

Commercial blue traps were used (Horiver® KOPPERT). White traps were handcrafted: two sheets of paper were put in plastic coated with Soveurode® glue. The size of both traps was 20 x 25 cm and they were placed on the trellis of the orchards at a height of 1.5 m.

Sampling method:

The total number of apple sawfly caught was assessed between April 6 and 17. Unintentional catches were also counted and identified.

Experiment overview

Duration: 2020

Soil: Sandy-loam

Climate: Mediterranean

Contact:

GRAB Auvergne-Rhône-Alpes

maxime.jacquot@grab.fr

Leaflet authors: Maxime Jacquot, GRAB. Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, Caroline Goutines, INRAE. Photos: ©GRAB

N°7

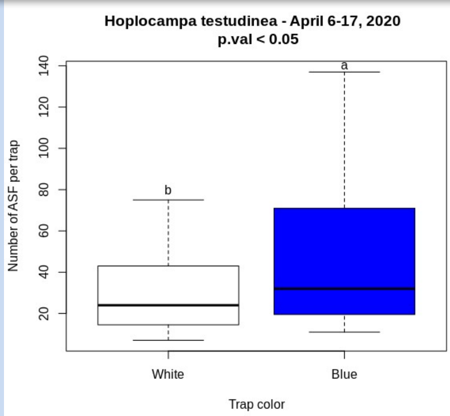
Effect of the colour of sticky traps to catch apple sawfly

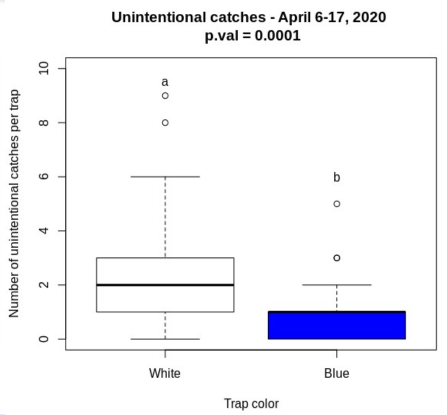
Lever of action 6: *Direct measures with 'soft practices'*

Status: *Ongoing field experimentation*

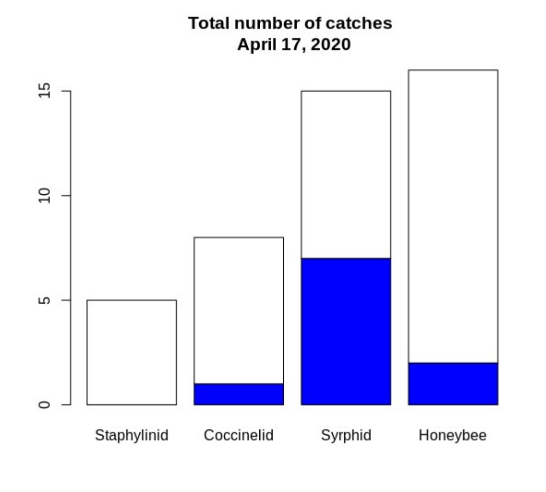
Captures by coloured sticky traps

Blue traps caught significantly more apple sawfly than our hand-crafted white traps. The mean number of apple sawfly caught by the white and blue traps was 30.5 and 48.8 respectively.





Unintentional catches by blue sticky traps



Regarding unintentional catches, blue traps caught significantly fewer beneficials than white traps. This trend was particularly pronounced for honeybees, Staphylinidae and Coccinellidae, while the two types of traps caught the same number of Syrphidae. The mean number per trap of unintentional captures was 1.4 for the white traps and 0.5 for the blue traps.

Conclusion and perspectives

Blue traps seem to be very useful for catching apple sawflies while limiting the impact on beneficials.

To confirm these results, this experimentation needs to be replicated in other orchards for several more years. The results would have to be confirmed with other types of white sticky traps. The type of white used and UV reflection has an effect on the capture rate of apple sawflies (Helsen *et al.*, 2020).

For more information

Performance leaflet N°5.

References:

Helsen HHM., Jansonius P.J., Brouwer G.W., van der Sluis B.J., van Tol R.W.H.M., de Groot A.V., van Kats R.J.M. , M.P. van der Maas M.P. (2020). Mass trapping of the apple sawfly *Hoplocampa testudinea*. Conference on Organic Fruit Growing.

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Leaflet authors: Maxime Jacquot, GRAB. Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, Caroline Goutines, INRAE. Photos: ©GRAB

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Experiment leaflet

N°8 Woolly apple aphid control by earwigs

IRTA

Lever of action 6: *Direct measures with 'soft practices'*
Status: *Experimentation validated on station*

Background

Woolly apple aphid (WAA) affects apple trees and causes damage to branches, trunks and roots. Previous studies indicate that earwigs can play an important role in the control of this pest as predators (Lordan *et al.*, 2015, Mueller *et al.*, 1988). However, even though earwigs are naturally present in apple orchards, they are not always able to prevent outbreaks (Happe *et al.*, 2018). For this reason, a trial was conducted to evaluate the effect of earwig (*Forficula auricularia*) release on the biological control of woolly apple aphid.

Earwig shelter

Target pest

Woolly apple aphid

(Eriosoma lanigerum)

Experiment Objectives

To evaluate the effect of earwig release on the biological control of woolly apple aphid.

Experiment Protocol

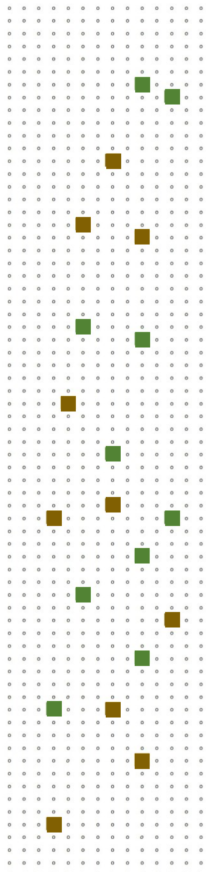
Experimental design

The trial was conducted in two organic apple orchards located in Lleida (north-east Spain) over two consecutive years.

The earwigs (*Forficula auricularia)* were released by means of a shelter that consisted of a corrugated cardboard cylinder (9 cm in diameter x 12 cm in height) inserted in a PVC tube.
The shelters were placed next to a WAA colony that was used for sampling. The trial was conducted in a completely randomised design with 10 replicates; each replicate was formed by one tree.
Each year, a single release of 30 earwigs per tree was performed in spring and compared to a control treatment.

Earwig release

Control treatment



Sampling method

The effect of earwig release on WAA infestation was assessed by measuring the **length of the WAA colony** next to the shelter (weekly) and the **number of WAA colonies per tree** (fortnightly).

Experiment overview

Duration: 2017-2020

Soil: Loamy soils

Climate: Mediterranean with continental influences

Contact: IRTA

georgina.alins@irta.cat

IRTA Institute of Agrifood Research and Technology

Leaflet authors: Georgina Alins, IRTA. Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, Caroline Goutines, INRAE. Photos: ©IRTA

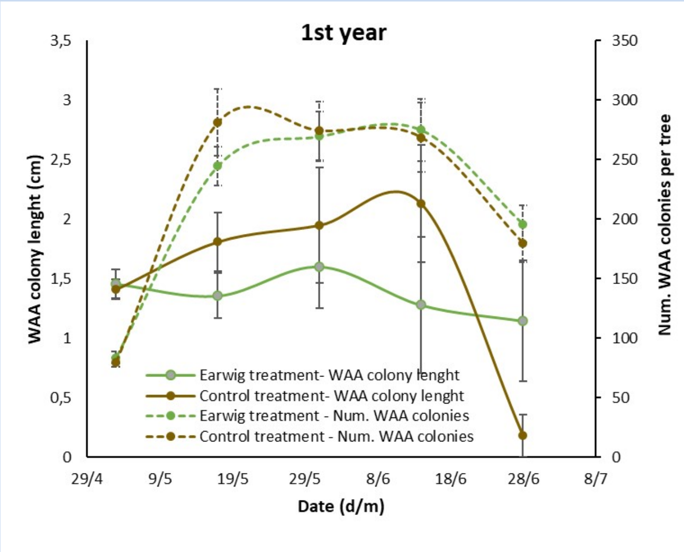
N°8 Woolly apple aphid control by earwigs

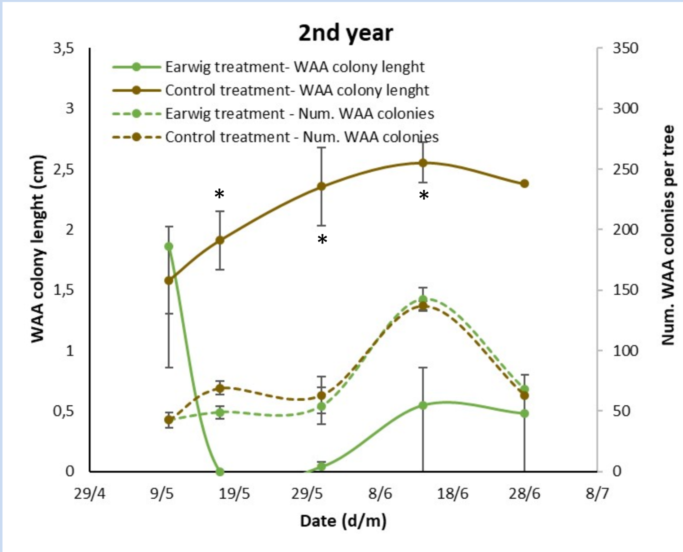
***Lever of action 6:** Direct measures with 'soft practices'*
***Status:** Experimentation validated on station*

Two consecutive years of earwig release are needed to get WAA biological control

The first year that earwigs were released, no effect on biological control of the WAA was observed in any of the orchards. However, **in the second year the length of the WAA colonies decreased between 30 and 100% in both orchards compared to the control treatment**. However, earwigs were not able to reduce the number of colonies per tree.

These results suggest that earwig release takes time to be an effective means of biological control, in this case two years.





**Significant results*

Conclusion

Our results show that augmentative biological control of WAA using earwigs is effective over short distances and that two consecutive years of earwig releases are needed to achieve this effect. Therefore, more research should be carried out to adjust the number of shelters per tree needed to produce satisfactory WAA control.

For more information

Experiment leaflet N°11 and performance leaflet N° 6.

References:

Happe A.K., Roquer-Beni L., Bosch J., Alins G., Mody K. (2018). Earwigs and woolly apple aphids in integrated and organic apple orchards: responses of a generalist predator and a pest prey to local and landscape factors. Agriculture, Ecosystems & Environment: 44-51.

Lordan J., Alegre S., Gatius F., Sarasua M.J., Alins G. (2015). Woolly apple aphid *Eriosoma lanigerum* Hausmann ecology and its relationship with climatic variables and natural enemies in Mediterranean areas. Bulletin of Entomological Research 105:60-69.

Mueller T.F., Blommers L.H.M., Mols P.J.M. (1988). Earwig (*Forficula auricularia*) predation on the woolly apple aphid, *Eriosoma lanigerum*. Entomologia Experimentalis et Applicata 47:145-152.

Leaflet authors: G. Alins, IRTA. Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, Caroline Goutines, INRAE. Photos: ©IRTA

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Experiment leaflet

N°9

Improvement of parasitoid release frequency for better control of rosy apple aphid

Lever of action 6: *Direct measures with soft practices*

Status: *Validated on experimental station*

Background

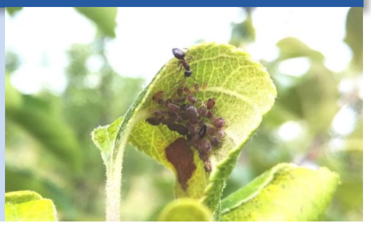
The use of parasitoids to control aphids has already been studied and has led to an optimal usage of parasitoid releases in greenhouses (Hågvar and Hofsvang, 1991; Hance *et al.*, 2017). However, this practice has been poorly developed for aphid control in open crops such as orchards, even though it could be useful for apple producers. We hypothesised that a longer time between mass releases could be more effective to spread the control of rosy apple aphid (RAA) over a longer period and could avoid interspecific competition phenomena.

Cardboard tube for the release of parasitoïds

Target pest

Rosy apple aphid (RAA)

(Dysaphis plantaginea)



Experiment Objectives

To test and compare the **impact of two parasitoids release frequencies on the growth of rosy apple aphid populations** under field conditions.

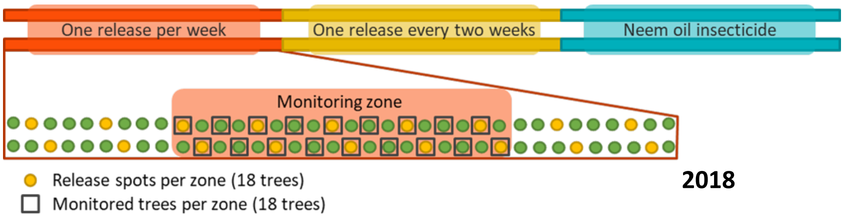
Experiment Protocol

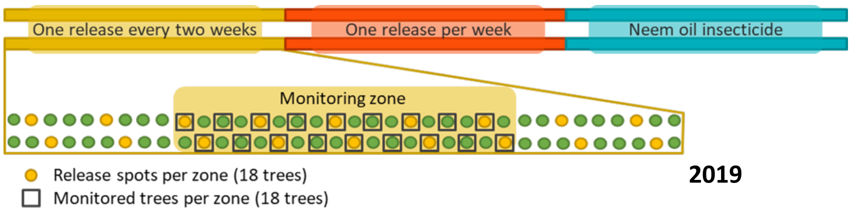
Experiment design

In two apple rows of the Natyra variety from a commercial orchard (Toubio, Fleurus), three consecutive releases of two parasitoid species (*A. matricariae* and *E. cerasicola*) were carried out on one tree out of four.

Three zones have been delimited with different frequency releases in each zone.

In 2018: zone 1 received one release per week, zone 2 one release every two weeks and zone 3 was treated with neem oil in 2018.





Rosy apple aphid colonies on 18 trees per zone and **aphid number per colony** for 10 colonies per zone were monitored weekly. The total number of aphids per tree was then calculated.

Experiment overview

Duration: 2018-2019

Soil: Loamy soils

Climate: Oceanic climate with lukewarm summers and mild winters

Contacts:

UCLouvain - Earth and Life Institue Biodiversity

pauline.gardin@uclouvain.be

louise.ferrais@uclouvain.be

thierry.hance@uclouvain.be

Leaflet authors: Louise Ferrais, Pauline Gardin, Thierry Hance, UCLouvain. Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, C. Goutines, INRAE. Photos: @UCLouvain

N°9 Improvement of parasitoid release frequency for better control of rosy apple aphid

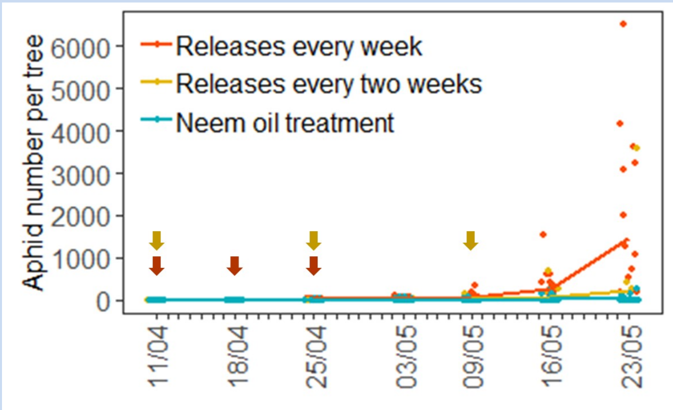
Lever of action 6: *Direct measures with soft practices*

Status: *Validated on experimental station*

Field trial in 2018

The survey was conducted between April 11 and May 23.

The initial infestation of *Dysaphis plantaginea* was weak, with almost no aphids per tree. During the season, the aphid number per tree increased.



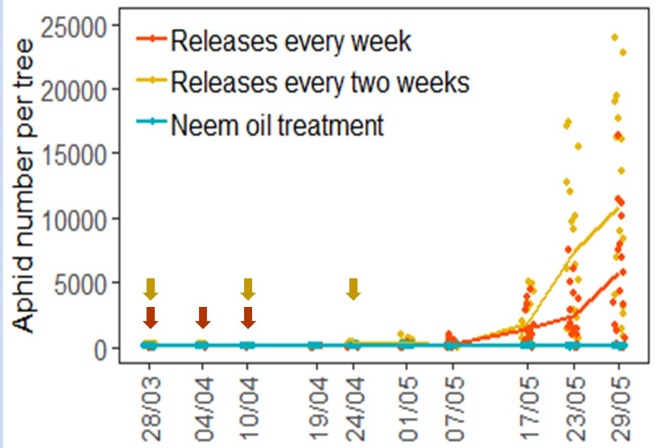
There was a difference in aphid quantity per tree according to the three zones.

The first zone with parasitoid releases every week was significantly different from the other two with a higher mean of aphids per tree (265.04 ± 874.25) compared to the second zone (44.44 ± 325.61) with aphid releases every two weeks and to the third zone treated with neem oil (12.36 ± 37.64). This difference increased through the season.

Field trial in 2019

The survey was conducted between March 28 and May 29.

The initial infestation of *D. plantaginea* was higher than in 2018.



As in 2018, we observed the same tendency with the first zone having a higher aphid quantity per tree than the other zones even if the parasitoid release frequency was changed: 18.23 ± 22.05 for the first zone with releases every two weeks, 8.94 ± 11.92 for the second zone with releases every week and 5.60 ± 4.36 for the neem oil treated zone.

At the very beginning of the monitoring, the first zone already had a significantly higher number of aphids per tree than the two other zones but at the end of the survey, all three zones were equivalent.

Conclusion and perspectives

Main results: We have not observed any effect of the two frequencies of parasitoid releases (every week or every two weeks). We hypothesised that the orchard zone had a strong influence on the presence and growth of rosy apple aphid colonies. However, over the two years, the treatment, no matter which, showed the same efficacy as that of the neem oil treatment.

Limits and conditions for success: Presently, this method is still too expensive to be used by producers because of the cost of parasitoids and the time required for the setting up of the parasitoid tubes. The protocol could be adapted towards a lower quantity of parasitoids released. Moreover, it could be interesting to replicate the experimentation to limit the effect of the initial infestation of rosy apple aphid.

For more information

Experiment leaflet N°12 and performance leaflet N°7.

References:

Hågvar EB, & Hofsvang T. (1991). Aphid parasitoids (Hymenoptera, Aphidiidae): biology, host selection and use in biological control. Biocontrol news and Information, 12(1):13-42.

Hance T, Kohandani-Trafresh F & Munaut F. (2017). Biological control. In: van Emden, H.F. and Harrington, R. (eds) Aphids as Crop Pests, 2nd edn. CABI, Wallingford, 448-493.

Leaflet authors: L. Ferrais, P. Gardin, T. Hance, UCLouvain. Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, C. Goutines, INRAE. Photos: ©UCLouvain

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Experiment leaflet

N°10 RELEASE OF PARASITOID *MASTRUS RIDENS* TO CONTROL CODLING MOTH

Lever of action 6: *Direct measures with 'soft practices'*

Status: *Ongoing experimentation*

BACKGROUND

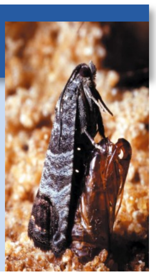
Mastrus ridens

Classical biological control (ClBC) is a sustainable and promising tool to induce long-term pest control by introducing exotic and co-evolved natural enemies (Borowiec and Sforza, 2020; Fauvergue *et al.*, 2012). *Mastrus ridens*, a specific parasitoid native to Asia, has been released in several countries (Argentina, Australia, Chile, USA and New Zealand) to reduce codling moth populations (Charles *et al.*, 2019; Mills, 2007; Tortosa *et al.*, 2014) but few data were collected in the field on the establishment and efficacy of this biological control agent.

TARGET PEST

Codling moth

(Cydia pomonella)



EXPERIMENT OBJECTIVES

- **To release *M. ridens* in apple orchards and assess its establishment ability** in different agrosystems (apple and cider orchards) and in different pedoclimatic conditions**.**
- **To study the dispersal and the efficacy of *M. ridens* on codling moth** populations in relation with habitat complexity.

EXPERIMENT PROTOCOL

Mastrus ridens **rearing**

Rearing of *M. ridens* was conducted in the quarantine laboratory of Sophia Antipolis (ISA, INRAE PACA) using overwintering codling moths. To produce the moths, eggs of codling moths were produced in Avignon (PSH, INRAE PACA) and sent to Sophia Antipolis every week, where larvae were reared on artificial diets under a short photoperiod and low temperature (8/16, 18°C). At the end of the development, overwintering larvae were put in PCR plastic plates (100 larvae per plate) and stored in the same conditions until their use for *M. ridens* production.

Mastrus ridens release

Releases

Releases were made in organic orchards with a minimal distance of 10km between two release sites. On each site, a single release of 200 females and 100 males was conducted, except on one site (2018) where we used a mass release of 3,000 females.

Sampling method

Pre- and post-release surveys were conducted using 10 cm wide corrugated cardboard wrapped around the trunks of the trees, with 30 to 50 bands per orchard. To provide better detection of *M. ridens*, the exposition of sentinel larvae of codling moths was employed using 2 cm wide corrugated cardboard bands fixed to the trunk. 1,137 cardboard bands were put in the field: 595 in 2019 (on 20 sites) and 542 in 2020 (on 17 sites).

Corrugated cardboard bands

EXPERIMENT OVERVIEW

Duration: 2018 - 2022

Soil: Stony shallow sandy-loam soil

Climate: Mediterranean and oceanic

Contact: INRAE ISA - INRAE PSH

nicolas.borowiec@inrae.fr

Leaflet authors: Nicolas Borowiec, Benoit Sauphanor; Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, Caroline Goutines, INRAE. Photos: ©INRAE

N°10 Release of parasitoid *Mastrus ridens* to control codling moth

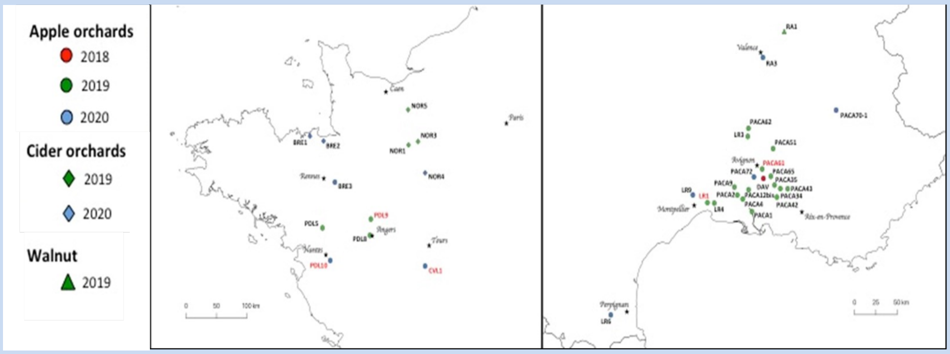
***Lever of action 6 :** Direct measures with 'soft practices'*

***Status:** Ongoing experimentation*

Release of *Mastrus ridens*

35 sites were selected for releasing *M. ridens.* To better assess the ability of establishment of *M. ridens*, the sites were located in different pedoclimatic and agronomic conditions.

So, 12 sites were located in north-west France and 23 sites in the south-east. Among these sites, 28 are apple orchards, 6 are cider orchards and 1 is for walnuts (see figure right).



Releases were distributed as follows: 1 release in 2018, 23 releases in 2019 and 11 releases in 2020, for a total of 14,700 *M. ridens* introduced in the field (9,800 females and 4,900 males).

Establishement of *Mastrus ridens*

The mean number of codling moth per band was 2.81 in 2019 and 2.96 in 2020 but different trends are observed according to the type of orchards. In apple orchards, the mean number of codling moth per band decreased from 3.03 in 2019 to 1.90 in 2020, whereas in cider orchards, an increase of the population levels was observed, from 1.57 in 2019 to 6.38 in 2020.

Year	Total number of sites with releases	Number of sites sampled (number of sites with *Mastrus ridens*)	Total number of *Mastrus ridens*	Total number of native parasitoids
2018	1	1 (0)	0	0
2019	24	2 (1)	2	1
2020	35	9 (4)	10	30

The first post-release surveys have allowed us to recapture *M. ridens* from 5 sites among the 10 sites sampled. A total of 2 individuals were collected in 2019 and 10 individuals in 2020. Native parasitoids were also collected, comprising a total of 30 specimens such as *Pristomerus vulnerator* (Ichneumonidae), *Ascogaster quadridentata* (Braconidae) and *Perilampus tristis* (Perilampidae).

Conclusion and perspectives

Three years after the first release in France (and Europe), *M. ridens* was recaptured on 50% of the sampled sites. Even though few specimens were collected, data showed that *M. ridens* is able to survive in different pedoclimatic and agronomic conditions. Further post-release surveys will be necessary to (i) better assess the establishment and dispersal ability of *M. ridens* as well as (ii) characterising the level of control of codling moth populations induced by this exotic parasitoid.

The next steps of this experiment will also need to allow for the integration of this method in technical itineraries, and in particular to identify practices that may negatively impact the presence of *M. ridens* in orchards. For example, laboratory experiments have shown that Spinosad is very toxic to *M. ridens* either by contact or by ingestion (Marie Perrin, unpublished data). Similarly, and since *M. ridens* develops on overwintering larvae of codling moth, the use of cardboard to trap and kill overwintering larvae should be used with caution or adaptation (i.e. augmentorium). Data collected in the coming years should make it possible to produce technical recommendations for growers.

References:

Borowiec N. & Sforza R. (2020). Lutte biologique par acclimatation (Chapitre 3). In: Fauvergue X, Rusch A, Barret M, Bardin M, Jacquin-Joly E, Malausa T, Lannou C. Biocontrôle: éléments pour une protection agroécologique des cultures, Quae Editions, 49-61.

Charles JG *et al.* (2019). Establishment and seasonal activity in New Zealand of *Mastrus ridens*, a gregarious ectoparasitoid of codling moth *Cydia pomonella.* Biocontrol 64: 291-301.

Fauvergue X., Vercken E., Malausa T., Hufbauer R.A. (2012). The biology of small, introduced populations, with special reference to biological control. Evolutionary Applications 5, 424-443.

Mills N. (2007). Classical biological control of codling moth: the California experience. Proceedings of the 2nd International Symposium on Biological Control of Arthropods, 12-16 September, Davos, Switzerland.

Tortosa O.E., Carmona A., Martinez E., Manzano P., Giardina M. (2014). Liberacion y establecimiento de *Mastrus ridens* (Hym., Ichneumonidae) para el control de *Cydia pomonella* (Lep., Tortricidae) en Mendoza, Argentina. Revista de la Sociedad Entomologica Argentina 73: 109-118.

Leaflet authors: Nicolas Borowiec. Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, Caroline Goutines, INRAE. Photos: ©INRAE

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Experiment leaflet

N°11

Earwig release combined with companion plants to control rosy apple aphid

Levers of action 1, 2 & 6: *Barrier and dilution effect - Push effect - Intercrop*
Status: *Ongoing experimentation*

Background

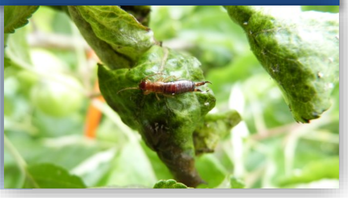
Forficula pubescens

The release of beneficials (Dib *et al.*, 2016) and the use of service plants (Dardouri *et al.*, 2019 a&b) combined with crops are techniques commonly explored to control aphid pests in arboriculture. However, the combination of these two techniques has never been tested. We therefore investigated whether the combination of the release of two earwig species (*Forficula auricularia* and *Forficula pubescens*) with the introduction of tagetes (*Tagetes patula*) in apple orchards had synergistic or antagonistic effects for the control of rosy apple aphid.

Target pest

Rosy apple aphid (RAA)

(Dysaphis plantaginae)

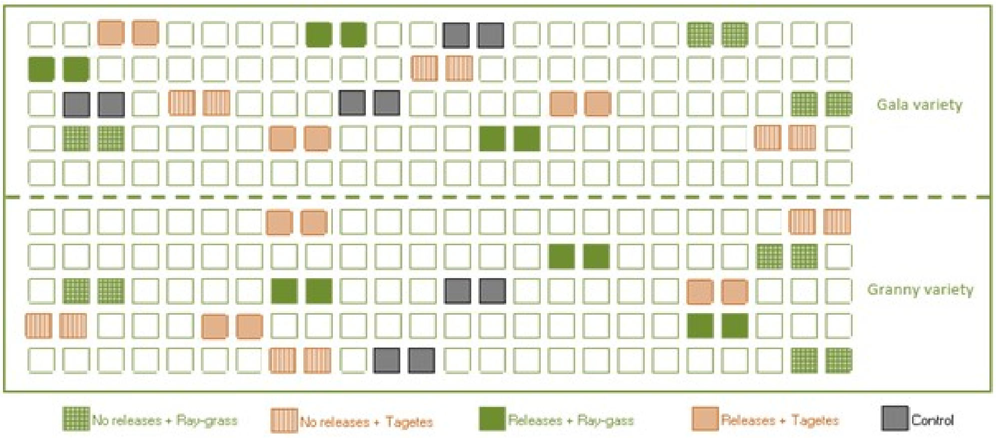


Experiment Objectives

- Studying the effect of **combining two soft techniques to control rosy apple aphids (RAA).**
- To **compare the efficacy of this combination with each single method.**

Experiment Protocol

The experiment was conducted in two experimental orchards, one planted with the Royal Gala cultivar and the second with Granny Smith.



Monitoring

4 parameters were recorded :

- Earwig presence in apples
- Aphid dynamics
- Natural enemy populations in RAA colonies and tagetes
- Ant presence in RAA colonies

Earwig shelter

In each orchard, **five treatments were evaluated:**

1. No earwig release with ray-grass; 2. No release with tagetes;
3. Earwig release with ray-grass; 4. Earwig release with tagetes;
5. Control

Three replicates per orchard and per mode corresponding to an elementary plot of 2 trees side by side.

The earwig release comprised 2 shelters per tree installed within the canopy near aphid-infested twigs, containing 16 Forficula earwigs: 14 *F. pubescens* + 2 *F. auricularia* in the adult stage.

Experiment overview

Duration: **1 season (2018)**

Soil: Silty-clay

Climate: Mediterranean climate

Contact: INRAE PSH

myriam.siegwart@inrae.fr

Leaflet authors: Myriam Siegwart, INRAE. Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies & C. Goutines, INRAE. Photos: A. Dempsey ©

EARWIG RELEASE COMBINED WITH COMPANION PLANTS TO CONTROL ROSY APPLE APHID

N°11

INRAE

Levers of action 1, 2 & 6: *Barrier and dilution effect - Push effect - Intercrop*
Status: *Ongoing experimentation*

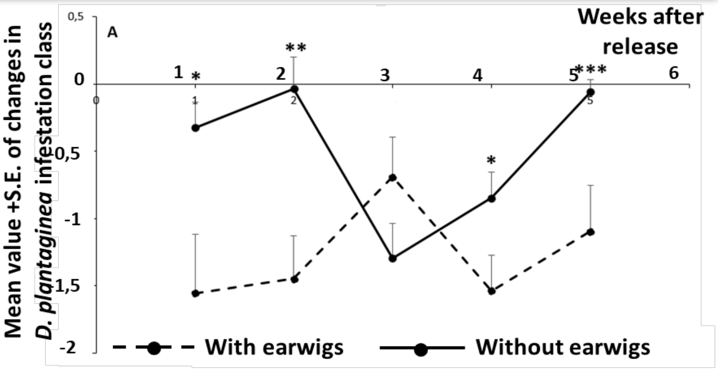
Experiment API-Tree

EARWIGS SIGNIFICANTLY AFFECT ROSY APPLE APHID DYNAMICS

The presence of Forficula earwigs had a significant effect on aphid dynamics at all recording dates except for the third week after release. In contrast, other natural enemies had an impact on aphid dynamics only during weeks 4 and 5.

The presence or absence of earwigs was examined at the first of two sampling weeks. Asterisks indicate significant differences between the 2 treatments.

Mann-Whitney test at the 5% significance level (*: 0.005 < P ≤ 0.05, **: 0.0005 < P ≤ 0.005, ***: P ≤ 0.0005).



NO EFFECT OF TAGETES ON APHID POPULATION

No significant effect was observed in the treatment with tagetes. Tagetes seems to have no effect on this aphid species. Forficula earwigs, mostly young, were found under the pots of the plants. The earwigs were using the pots as a refuge to protect themselves from light during the day. This may be an advantage in keeping the forficulae in the trees near the aphid foci. As for natural predators other than forficula, these were not found on the flowers, in the soil or even in the pot. Some spiders were present but in low numbers.

CONCLUSION AND PERSPECTIVES

Our experiment has confirmed the interest of earwig releases in apple orchards to control RAA, but not tagetes. Tagetes seems to have no side effect on beneficials naturally present in apple orchards and could be combined with beneficial releases in peach orchards to control *M. persicae,* which is susceptible to organic volatiles of this plant.

Limits and conditions for success: For forficulidae release to be sufficiently successful, it must be done early in the season (just after flowering). The use of impregnated shelters was favourable to the installation of forficulidae in the canopy.

Adaptation needed: The release of very large numbers of forficulae may provide better results for early control of rosy apple aphid.

FOR MORE INFORMATION

Experiment leaflet N°8 and performance leaflet N°6.

References:

Dardouri T, Gautier H, Ben Issa R, Costagliola G and Gomez L. Repellence of *Myzus persicae* (Sulzer): evidence of two modes of action of volatiles from selected living aromatic plants. Pest Manag Sci; 75(6): 1571-1584 (2019a).

Dardouri T, Gomez L, Schoeny A, Costagliola G and Gautier H. Behavioural response of green peach aphid *Myzus persicae* (Sulzer) to volatiles from different rosemary (*Rosmarinus officinalis* L.) clones. Agricultural and Forest Entomology; 21(3): 336-345 (2019b).

Dib, H., Jamont, M., Sauphanor, B., Capowiez, Y. The feasibility and efficacy of early-season releases of a generalist predator (*Forficula auricularia* L.) to control populations of the rosy apple aphid (*Dysaphis plantaginea* Passerini) in south-eastern France. Bulletin of Entomological Research, 106: 233–241 (2016a).

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API-Tree (2017-2021) is an ERA-Net C-IPM project coordinated by INRAE with funding from the European Union.

N°12 Influence of flower strips on the control of rosy apple aphid populations by parasitoid release

Experiment leaflet

API-Tree

UCLouvain

Levers of action 4 & 6: *Direct measures with soft practices - Top-down processes*

Status: *Validated on experimental station*

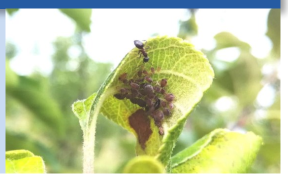
Background

The use of parasitoids to control aphids has already been studied and has led to the optimal usage of parasitoid releases in greenhouses (Hågvar and Hofsvang, 1991; Hance *et al.*, 2017). However, this practice has been poorly developed for aphid control in open crops such as orchards. Furthermore, flower strips are usually recommended to improve biodiversity and play an important role in the nutrition of arthropods such as the natural enemies of aphids (Campbell *et al.*, 2017). We assume that flower strips would allow released parasitoids to be maintained within the plots and thereby provide a better regulation of rosy apple aphids (RAA). Furthermore, since parasitoids have difficulties flying from one tree to another when temperatures are low, we assume that the further the RAA colonies are from the release point, the less effective is their regulation.

Target pest

Rosy apple aphid (RAA)

(Dysaphis plantaginea)



Experiment Objectives

- To test **the influence of flower strips** planted between apple tree rows **on the regulation of RAA colonies by parasitoid release.**
- To test the **effect of distance from the release point on the regulation of RAA by parasitoids.**

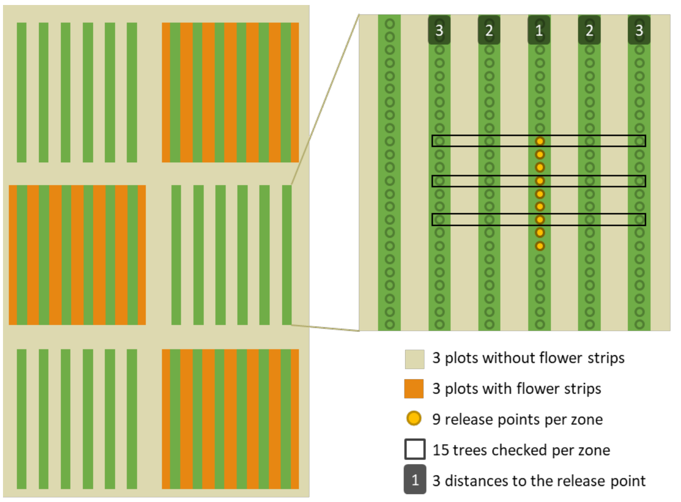
Experiment Protocol

Experimental design

The trial was set up in an experimental organic apple orchard in Gembloux. The orchard was divided into six plots, with three of them planted with flower strips and three others with no flower strips as a control.

Within each plot, three distances where tested:

- Parasitoid release row (distance 1)
- The two adjacent rows of the release row (distance 2)
- The two adjacent rows of distance 2 (distance 3)



Parasitoid releases

Three consecutive releases of two parasitoid species (*Aphidius matricariae* and *Ephedrus cerasicola*) were made every 10 days, on the nine control trees at distance 1.

Sampling method

Transects of 2 rows were drawn on either side of the parasitoid release spots.

RAA colonies were counted on the five trees of three transects by plot every 10 days as well as the **aphid number per colony for two colonies at each distance.** The **total number of aphids per tree** was then calculated.

Experiment overview

Duration: 2018-2019

Soil: Loamy soils

Climate: Oceanic climate with lukewarm summers and mild winters

Contacts:
UCLouvain - Earth and Life Institute -Biodiversity
pauline.gardin@uclouvain.be
louise.ferrais@uclouvain.be
thierry.hance@uclouvain.be

Leaflet authors: Louise Ferrais, Pauline Gardin, Thierry Hance, UCLouvain. Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, C. Goutines, INRAE. Photos: ©UCLouvain

N°12 Influence of flower strips on the control of rosy apple aphid populations by parasitoid release

UCLouvain

Levers of action 4 & 6: *Direct measures with soft practices - Top-down processes*

Status: *Validated on experimental station*

Experiment API-Tree

Infestation of rosy apple aphid (RAA)

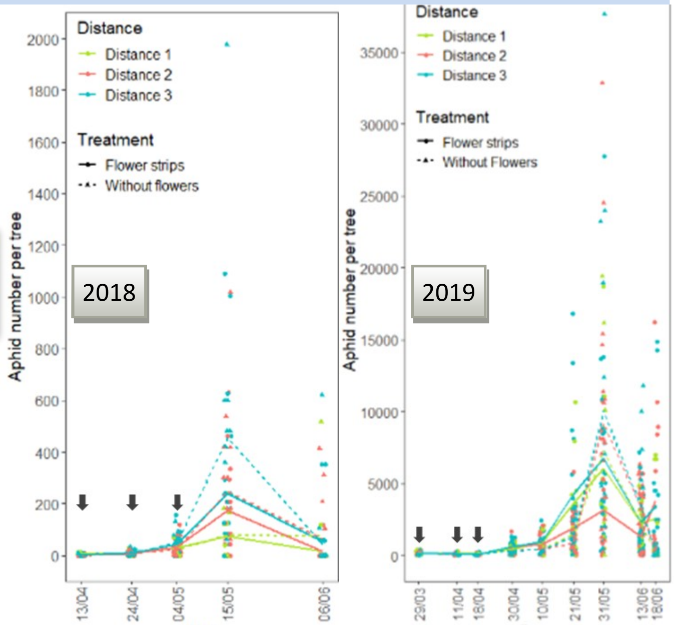
In 2018, the survey was conducted from April 13 to June 6. The initial RAA infestation was weak with less than 15 aphids per tree. Then the infestation reached a peak with an average of 230 aphids per tree.

In 2019, the survey was conducted from March 29 to June 18. The initial RAA infestation was higher than in 2018 with an average of 105 aphids per tree for the three first dates and peaked with an average of 7,133 aphids per tree.

Effect of flower strips on aphid regulation by parasitoid release

The presence of flower strips influenced the number of aphids per tree at the infestation peak in both years. In 2018, there were 69% more aphids (marginally non-significant) in the treatment without flowers (336.65 ± 349.77) than for the flower strip treatment (199.15 ± 251.92).

In 2019, there were 56% more aphids in the treatment without flowers (10,707.56 ± 8,996.01) than for the flower strip treatment (6,852.43 ± 5,918.45).



Effect of the distance from parasitoid release spot on aphid quantity

In 2018, the distance from the parasitoid release point influenced aphid numbers per tree at the infestation peak. The further the distance to the release point was, the higher the number of rosy apple aphids, with **366.83 (± 386.85) aphids in the furthest rows from the release row (distance 3)**, **222.74 (± 235.22) in the adjacent rows of the release row (distance 2)** and **125.80 (± 129.79) in the release row (distance 1)**, but only distance 1 and 3 are significantly different (P = 0.003).

Conclusion and Perpectives

Main results: Although the result depends on the year (weather conditions, initial aphid infestation etc.), the proximity of flower strips seems to have favoured the action of the parasitoids and their presence seems to have helped maintain or even reduce the number of rosy apple aphids early in the season. Aphid populations always increased by the end of the study period but the presence of parasitoids has helped reduce the peak of rosy apple aphids.

Limits and conditions for success: The combination of flower strips and parasitoid release provides better control of the aphid population. However, this method is presently too expensive and time-consuming for producers. Aphid control using parasitoids should be more efficient with releases from the very beginning of aphid infestation, when the first females (stem mothers) appear on trees. Moreover, the protocol could be adapted towards the release of a lower number of parasitoids.

For more information

Experiment leaflet N°9 and performance leaflet N°7.

References:

Campbell AJ, Wilby A, Sutton P & Wäckers F (2017). Getting more power from your flowers: Multi-functional flower strips enhance pollinators and pest control agents in apple orchards. Insects, 8(3): 101.

Hågvar EB & Hofsvang T (1991). Aphid parasitoids (Hymenoptera, Aphidiidae): biology, host selection and use in biological control. Biocontrol news and Information, 12(1):13-42.

Hance T, Kohandani-Trafresh F & Munaut F (2017). Biological control. In: van Emden, H.F. and Harrington, R. (eds) Aphids as Crop Pests, 2nd edn. CABI, Wallingford, 448-493.

Leaflet authors: L.Ferrais, P. Gardin, T. Hance, UCLouvain. Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, C. Goutines, INRAE. Photos: ©UCLouvain

INRAE

C-IPM Coordinated Integrated Pest Management in Europe

API-Tree (2017-2021) is an ERA-Net C-IPM project coordinated by INRAE with funding from the European Union.

N°1 Rosemary to control rosy apple aphid

Performance leaflet

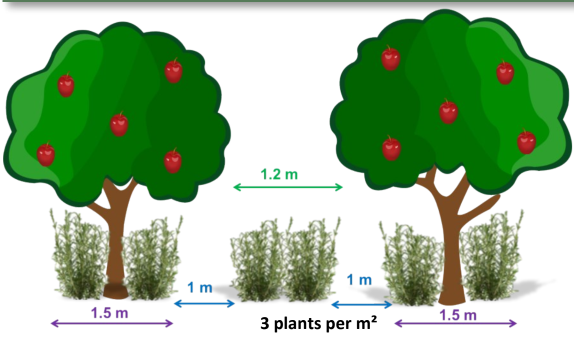
Levers of action 1 & 2: *Barrier and dilution effect - Push effect - Intercrop*
Status: *Validated on station*

Description of the practice

What? Introduction of rosemary (*Rosmarinus officinalis*) plants within the orchard as companion plants.

Why? To reduce aphid infestation by repelling rosy apple aphids (*Dysaphis plantaginea)*, favouring their natural enemies and improving orchard productivity.

Implementation tested



- A mix of rosemary clones planted in the alleyway between the tractor wheel path and within the row.
- **Rosemary growth:** Cultivars displayed growth heterogeneity; direct localised irrigation was detrimental to growth and survival in the tree row.

Conditions for use: To be favoured in southern Europe

Possible interactions: No insecticide spray at rosemary bloom, no direct irrigation and machinery traffic has to be adapted.

Practice performance

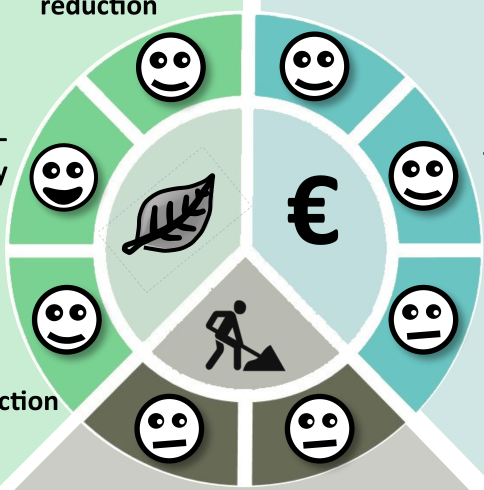
In comparison to a conventional orchard.

Rosemary repels aphids and/or attracts natural enemies that will help limit pest outbreaks.

Agronomy & environment

Reducing insecticide use:
Rosemary plants decrease rosy apple aphid infestation by repelling them through their volatile emissions and/or **attracting natural enemies** of this pest.

No impact on apple production (quality and quantity).



Costs & benefits

One rosemary plant costs from €0 to €2 and lasts the whole orchard lifespan (around 8-10 years).

No other investment is required.

Time to set up

Soil preparation is required (no irrigation required).

Time to manage

Rosemary weeding is necessary in the first year but no interrow mowing. Pruning rosemary is necessary once a year but not during peaks in apple activity.

Possible added-value through rosemary essential oil.

Operationality

It is a **ready to use solution** with partial effects on the pest.

Relatively easy to implement, however it requires partial adaptation of the technical itinerary (irrigation, traffic, insecticide spraying).

Positive effect — Neutral to positive effect — Room for improvement — Bottleneck

Leaflet authors: Tarek Dardouri, S. Simon, A. Alaphilippe, INRAE; . Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, INRAE. Photos© INRAe Gotheron

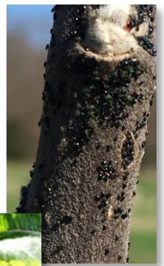
N°1 Rosemary to control rosy apple aphid

Information about target pests

Aphids overwinter on apple trees as eggs laid on twigs, bud axils or in bark crevices. After egg hatching, they reproduce on apple until migration towards their secondary hosts (plantain) in late spring.

One aim of this practice is to interfere with the return flight of aphids through rosemary plants, which might emit volatiles that repel the aphids and/or increase predation by attracting natural enemies.

Aphid eggs



Rosy apple aphid on apple leaf

Larvae of Coccinellidae

Larva of Syrphidae

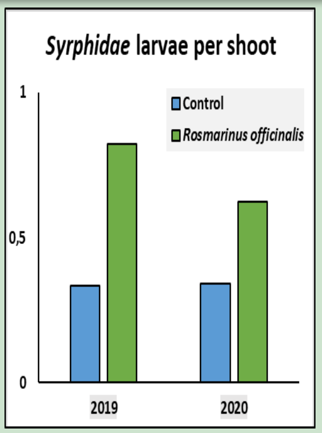
Aphid mummy

Information about natural enemies

- Many groups of insects can predate aphids and have been found on rosemary planted close to apple trees.
- One aim of this practice is to provide aphid natural enemies with food and habitat, to favour predation.
- The most important predators of rosy apple aphid are Syrphidae larvae.

Results of the experiments

- Rosemary had a negative effect on rosy apple aphid abundance.
- Rosemary had a positive effect on hoverfly abundance.
- The predation rate is higher in the presence of rosemary.
- The number of natural enemies was higher in rosemary plots, but non-significant, except for Syrphidae larvae and spiders.



Experiment conditions

Scale:

Validity:

Duration: 2 years

No. of repetitions: 2

For more information

Beizhou S, *et al*. Intercropping with aromatic plants hindered the occurrence of *Aphis citricola* in an apple orchard system by shifting predator-prey abundances. Biocontrol Science and Technology; 23 (4): 381- 395 (2013).

Dardouri T *et al*. Repellence of *Myzus persicae* (Sulzer): evidence of two modes of action of volatiles from selected living aromatic plants. Pest Manag Sci; 75(6): 1571-1584 (2019a).

Dardouri T *et al.* Behavioural response of green peach aphid *Myzus persicae* (Sulzer) to volatiles from different rosemary (*Rosmarinus officinalis* L.) clones. Agricultural and Forest Entomology; 21(3): 336-345 (2019b).

Contacts:

tarek.dardouri@inrae.fr

sylvaine.simon@inrae.fr

Experiment leaflet N°1.

Leaflet authors: T. Dardouri, S. Simon, INRAE;. Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, INRAE. Photos© T. Dardouri, INRAe Gotheron

API-Tree (2017-2021) is an ERA-Net C-IPM project coordinated by INRAE with funding from the European Union.

Performance leaflet

N°2 Planting late blooming cultivars to reduce apple pest

SERIDA

Lever of action 3: *Bottom-up processes*
Status: *Ready to use solution*

API-Tree

Description of the practice

What? Planting late-blooming cultivars to reduce pest attack.

Why? Late-blooming cultivars could partially avoid infestation and damage by early-occurring pests, such as apple blossom weevil (*Anthonomus pomorum*), green weevil (*Polydrusus formosus*) and rosy apple aphid (*Dysaphis pantaginea*).

Implementation tested

Experimental orchard planted with **22 cultivars** presenting different blooming phenology

Possible interactions:

Theoretically these cultivars could partially avoid infestation by other early pests, such as leafrollers.

Practice performance

In comparison with commonly planted early blooming cultivars

In addition to partially avoiding infestation by weevils and rosy apple aphid, late-blooming cultivars can also avoid damage from late frost and potentially better pollination since the weather tends to be better as spring progresses.

Agronomy & environment

Pesticide reduction

Some insecticide applications suppressed, since infestation by early pests could **partially** be **avoided.**

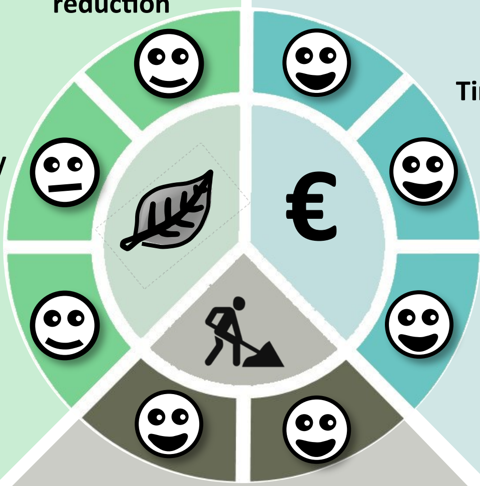
Biodiversity

No impact on biodiversity.

Apple production

Late blooming could **improve pollination or lower risks from late frost** and so increase apple production.

No environmental or agronomical impact.



Costs & benefits

Investment cost

Time to set up

No difference compared to planting other cultivars.

Time to manage

Each cultivar has specific requirements for training, pruning and thinning.

Operationality

Ease to implement

Availability

No specific skills are needed and it is an available and widespread practice.

It is a ready to use solution with a partial effect on pests threatening apple trees in early spring.

Positive effect | Neutral to positive effect | Room for improvement | Bottleneck

Leaflet author: Marcos Miñarro, SERIDA; . Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, C. Goutines. INRAE. Photos M. Miñarro ©

N°2 Planting late blooming cultivars to reduce apple pests

Information about target pests

Many pests attack apple trees in early spring, as soon as the trees go into bud burst. Apple blossom weevils attack blossoms before they are open, rosy apple aphid eggs hatch very early and neonate larvae attack shoots as soon as they burst. Green weevils fed on leaves early in the spring, too. The aim of planting late-blooming cultivars is to create a phenological mismatch between plant and pest to reduce infestation and damage.

Blossom weevil on apple

Green weevil on apple leaves

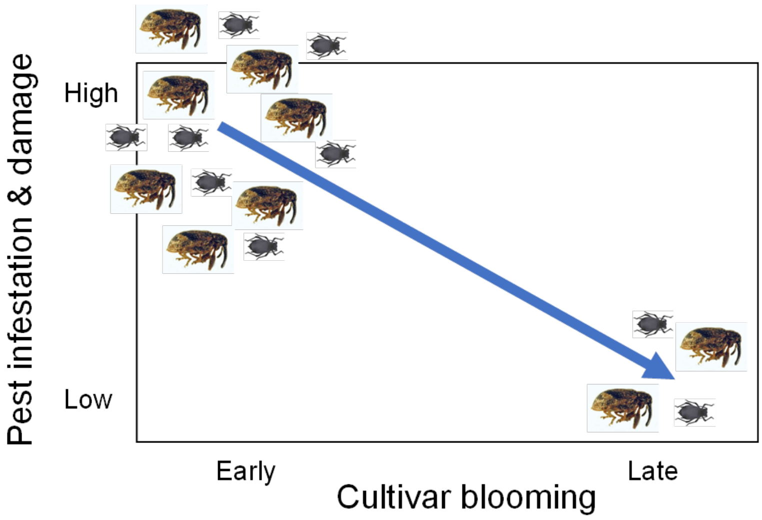
Scambus pomorum

Information about the mode of Action

Apple trees have evolved in part to regulate their development with climatic conditions. However, there are strong differences in tree phenology among cultivars, including the chilling and heat requirements to bud break. We have reported four weeks of difference in the flowering phenology among local cultivars.

Results of the experiments

Cultivar phenology can be a tool for reducing pest infestation and damage. In particular, planting cultivars that bloom relatively late can help to decrease damage by weevils and rosy apple aphids, avoiding infestation. In this study, damage significantly decreased with the blooming delay over the two years of the experimentation for green weevils and in the first year for blossom weevils (p value <0.05).



For more information

Contact: mminarro@serida.org

Experiment leaflet N°3.

References:

Miñarro, M., Dapena, E. (2007). Resistance of apple cultivars to *Dysaphis plantaginea* (Hemiptera: Aphididae): role of tree phenology in infestation avoidance. Environmental Entomology 36(5): 1206-1211.

Miñarro, M., García, D. (2018). Unravelling pest infestation and biological control in low-input orchards: the case of apple blossom weevil. Journal of Pest Science 91 (3): 1047-1061.

Experiment conditions

Scale: Field

Validity:

Duration: 2018 –2020

No. of repetitions: 2

API-Tree (2017-2021) is an ERA-Net C-IPM project coordinated by INRAE with funding from the European Union.

Leaflet author: M. Miñarro, SERIDA; . Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, C. Goutines. INRAE. Photos M. Miñarro ©

Universidad de Oviedo

SERIDA

Performance leaflet

API-Tree

N°3 Nest boxes to increase apple pest control by birds

***Lever of action 4**: Top-Down processes*

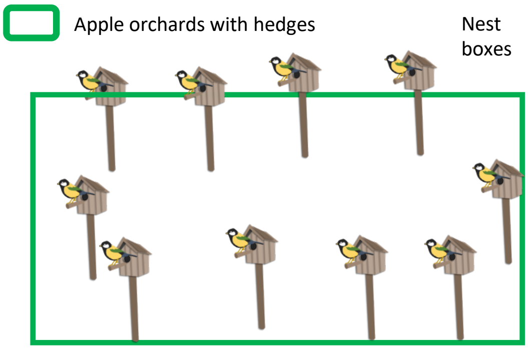
***Status:** Ready-to-use solution*

Description of the practice

What? Installation of nest boxes for insectivorous birds within the orchard.

Why? To increase the abundance of breeding birds in the orchard and to enhance bird insectivory in the orchard in spring to reduce apple pest populations.

Implementation tested



Nest boxes were placed:

- At a distance of 10 m from the orchard edge (in order to facilitate occupation by forest-dwelling birds)
- On trees separated 15 m from each other.

Conditions for use: All climatic zones.

Possible interactions: Broad-spectrum pesticides could have a toxic effect on birds. Birds also prey on natural enemies, but the overall effect is of pest reduction. The use of smaller entrance holes (2.6 cm radius) selected blue tits.

Practice performance

In comparison with low-input orchards without nest boxes.

Pest regulation level: Birds breeding in nest boxes make it possible to reduce arthropod numbers in general and pest populations in particular (blossom weevils and aphids).

Agronomy & environment

No pesticide reduction but limits the risk of pest pullulation. Breeding birds reduce abundance of spring crop pests such as aphids and weevils.

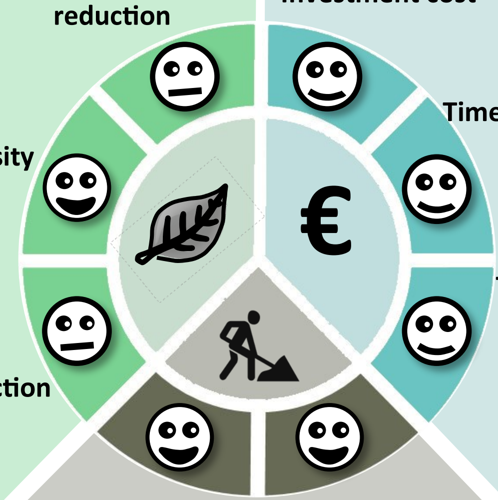
Increased biodiversity in terms of both richness and abundance. Birds also prey on natural enemies, but the overall effect is on pest reduction.

No effect on yield and fruit quality. There is no risk of fruit attacks by birds since fruits are not ripe during the breeding season. Reduction in crop damage not tested.

Pesticide reduction

Biodiversity

Apple production



Costs & benefits

Investment cost Nest boxes are easily built or cost around €15-20 each with 10 nest boxes per hectare. They can last 10 years.

Time to set up Installation of nest boxes is done just once and does not require any special skill.

Time to manage Annual cleaning during winter to remove old nests and parasites is recommended (less than 2 hours per year).

Other value Contributes to preserving bird diversity by facilitating nesting in the orchard for cavity-nesters.

Operationality

Ease to implement **Ready to use**

No specific skills are needed and it is an available and widespread practice.

It is a ready to use solution with a partial effect on several pests attacking apple trees in spring.

Positive outcome | Neutral to positive outcome | Room for improvement | Critical points

Leaflet authors: Marcos Miñarro, SERIDA; D. García, University of Oviedo. Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, C. Goutines. INRAE. Photos M. Miñarro ©

N°3 Nest Boxes to increase apple pest control by birds

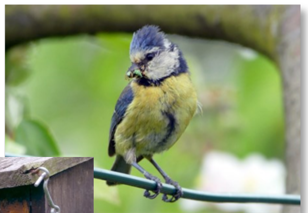
Universidad de Oviedo

SERIDA

Information about target pests

Numerous pest arthropods are eaten by tits. Many apple pests attack different apple tree parts in spring. Apple blossom weevils and some lepidopteran pests attack blossoms. Aphids (rosy aphids and green aphids) and leafrollers feed on growing shoots. Woolly apple aphids and codling moth cocoons can be found in bark crevices.

Breeding birds particularly reduce the abundance of spring crop pests such as aphids and weevils.



Blue tit

Great tit

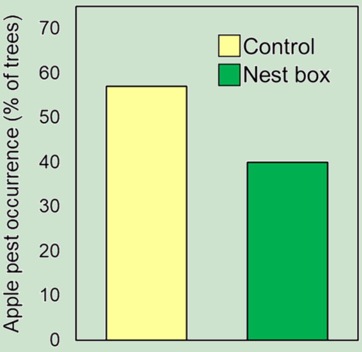
Common redstart

Information about natural enemies

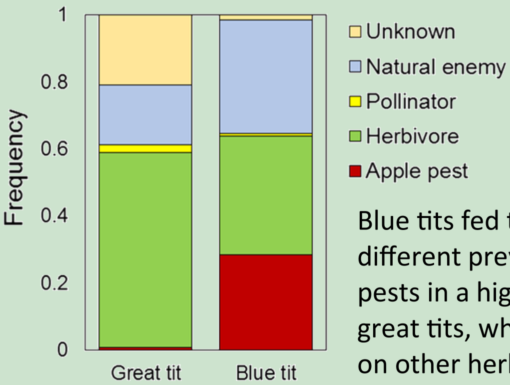
Insectivorous birds using nest boxes for breeding are present in the orchard throughout the year. But during the spring, the breeding season, their lives are frenetic as they feed their nestlings with arthropods. A couple of blue tits can visit the nest box more than 70 times per hour, carrying more than one prey in 30% of the visits. The aim of the practice is to provide nesting sites for these birds within the orchard in order to increase their population.

- Nest boxes are mainly used by great and blue tits.
- Blue tits are the authentic apple pest killers (great tits seem to eat more other insects in the surrounding landscape).
- Nest boxes with smaller holes encourage blue tits.

Results of the experiments



Placing nest boxes in orchards increases biological control of pests by birds. For example, the proportion of apple trees attacked by pests was lower in orchards with nest boxes.



Blue tits fed their nestlings with different prey, including apple pests in a higher proportion than great tits, which mostly preyed on other herbivores.

For more information

Contact: mminarro@serida.org

Experiment leaflet N°5.

Reference:

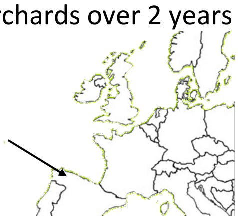
García, D., Miñarro, M., Martínez-Sastre, R. (2021). Enhancing ecosystem services in apple orchards: nest boxes increase pest control by insectivorous birds. Journal of Applied Ecology 58(3): 465-475.

Experiment conditions

Scale: **Validity:**

Duration: 2018 –2020

No. of repetitions: 24 orchards over 2 years



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API-Tree (2017-2021) is an ERA-Net C-IPM project coordinated by INRAE with funding from the European Union.

Leaflet authors: M. Miñarro, SERIDA; D. García, University of Oviedo . Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, C.Goutines. INRAE. Photos M. Miñarro ©

Performance leaflet

N°4 Divert ants to allow natural enemies

***Levers of action* 4 & 5:** *Top-down processes mediated by beneficials - Diversion of commensal organisms.*
Status: *Ongoing experimentation.*

Description of the practice

What? Flower strips to enhance biocontrol and sugar baits to divert ants from protecting aphids.

Why? To decrease rosy apple aphid (*Dysaphis plantaginea*) infestation, flower strips are used to increase the biological control potential. This is combined with sugar baits to divert ants from protecting aphids and allow natural enemies to attack rosy apple aphid (RAA) colonies.

Implementation tested

A flower strip mix in each interrow combined with sugar-baited vials at the base of each tree to divert ants.
Artificial honeydew placement (1 per tree) during peak activity from blooming until 4 weeks in.
Flower strips can be sown in spring or autumn.

Adapted climate zone:

Flower strips may not be suitable in dry climates. Myrmecophily, the positive association of ants and RAA in this case, is important in any climate zone.

Possible interactions:

Diversion does not affect the importance of ants in other roles (e.g. as predators). For flower strips, the composition should be adapted, in particular where voles are a problem.

Practice performance

In comparison with an organic orchard.

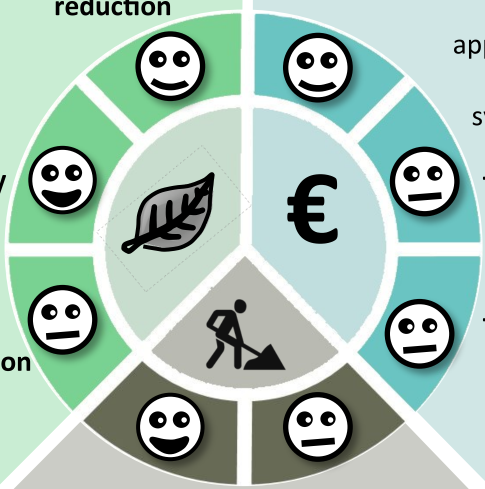
Ant diversion restores numerical responses of natural enemies to aphid colonies and causes early collapse of the colonies.

Agronomy & environment

The combination of both ant diversion and flower strips reduces pesticide use against RAA by harnessing natural enemies in the system.

Ants are diverted from tending aphids, but otherwise continue to fulfil ecosystem services as predators of pests.

There are no negative impacts on apple production. However, effects of low level of RAA colonies earlier in the season on production needs to be assessed.



Costs & benefits

Artificial honeydew is **cheap**, but the application method needs development (persistence over time, slow release system). It **requires time** and at a peak period (blooming).

Flower strip establishment and management can be costly and requires time for maintenance. Moreover, strips need to be resown after several years.

Operationality

No specific skills are needed but further experiments are required.

Artificial honeydew has been tested in both organic experimental orchards and commercial orchards. The practise is not yet adopted at a commercial scale. Flower strips have been adopted at a low rate and are a well established practice.

Positive effect — Neutral to positive effect — Room for improvement — Bottleneck

Leaflet author: Teun Dekker, SLU; . Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, C. Goutines. INRAE. Photos T. Dekker©

N°4 Divert ants to allow natural enemies

Information about target pests

The rosy apple aphid (RAA) is a primary concern in apple production throughout Europe. RAA colonies are characterised by explosive growth in early spring, which causes direct and indirect losses through deformation of shoots and fruits. During summer, adult RAA migrate to plantain, while in autumn, females migrate back to apple for overwintering.

Syrphid attacking aphid

Information about the mode of Action

Numerical responses of natural enemies are inhibited by myrmecophily. Conversely, natural enemies are abundant in colonies where ants are not present. Disrupting myrmecophily (diversion of ants using artificial honeydew), while favouring natural enemy populations (flower strips) synergistically increases the biocontrol potential.

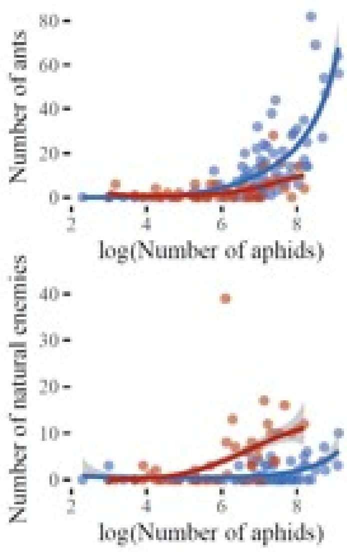
Ant protecting aphids

Results of the experiments

Take-home message: Aphids are attacked by many natural enemies if ants are not there to protect them. Diverting ants and simultaneously increasing the natural enemy population synergises biocontrol of rosy apple aphids.

Right: Number of ants *Lasius niger* (top) and natural enemies (bottom) plotted against the logarithm of the number of *D. plantaginea* using polynomial models (lines). Control colonies (blue lines) display a strong functional response of ants to aphids and no functional responses of natural enemies. The diversion of ants reverses this and restores functional responses of natural enemies (red lines).

Control — Treatment with ant diversion



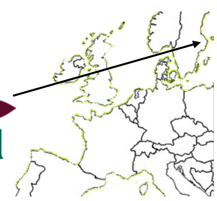
Experiment conditions

Scale:

Validity:

Duration: 2018-2021

No. of repetitions: 20



For more information

Contact: teun.dekker@slu.se

Experiment leaflet N°6

API-Tree (2017-2021) is an ERA-Net C-IPM project coordinated by INRAE with funding from the European Union.

Leaflet author: T. Dekker, SLU; . Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, C. Goutines. INRAE. Photos T. Dekker ©

N°5 Blue sticky traps to control apple sawfly

Lever of action 6: *Direct measures with 'soft practices'*
Status: *Ongoing experimentation*

Description of the practice

What? Installation of blue sticky traps within the orchard.

Why? To catch adult apple sawflies (*Hoplocampa testudinea*) before they lay their eggs on apple blossoms, while minimising the capture of beneficial insects in orchards.

Implementation tested

Blue sticky traps were placed on the trellis of orchards at a height of 1.5 metres.

Trap size: 20 x 25 cm. Recommended density: 200-500 traps per hectare. Horiver® blue traps and Rebell® white traps had already been tested and approved.

Set-up during flowering:

- 2 days of work per season per hectare
- 1 day for set up and 1 for removal.

Further experimentation and years of sampling are needed to better define the effective trap density.

Practice performance

In comparison to an organic orchard without sticky traps.

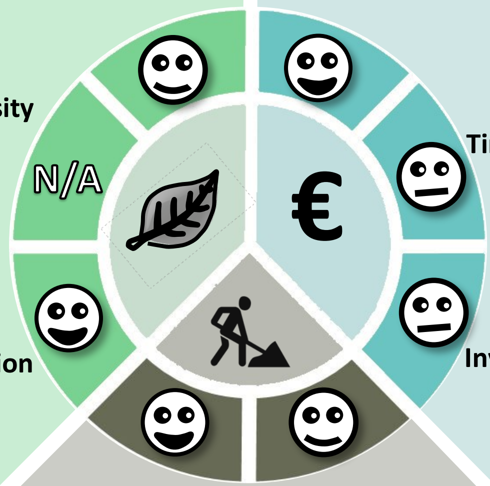
Level of pest regulation: sticky traps reduce populations of apple sawfly and its impacts on fruit production.

Agronomy & environment

Pesticide reduction: pesticides used against apple sawfly can be avoided.

Impact on functional biodiversity: not yet known but this practice could limit negative effects.

Impact on apple production: this practice will increase fruit production quantity and quality (fewer fruits with scars)



Costs & benefits

No time required for management: once traps are set up, no other action is needed.

Setting the traps takes time, there is no management needed until the traps are removed after flowering.

The unit price varies between €0.50 for single-use traps and €4 for reusable traps.

Operationality

No skills are needed for this practice.

Traps are available on the market and ready to use but new experiments are needed to establish the effective trap density in order to be a ready-to-use practice.

Positive effect | Neutral to positive effect | Room for improvement | Bottleneck

Leaflet authors: Maxime Jacquot, GRAB. Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, C.Goutines, INRAE. Photos: ©GRAB

N°5 Blue sticky traps to control apple sawfly

Information about target pests

Apple sawflies (*Hoplocampa testudinea*) are univoltine and adults emerge in spring according to soil temperature sums (usually in BBCH 57). Eggs are laid on the side of the receptacles of apple flowers. Damage is caused on the fruitlets by early stage larvae after hatching on the calyx, until 5th instar larvae enter the soil in June. Descending larvae form cocoons to protect them during their prolonged diapause until pupation the following spring. Mass trapping targets adults before they lay eggs on flowers.

Apple sawfly on blue sticky trap

Tested sticky traps

Information about natural enemies

Female apple sawfly are attracted by the white colour of flowers (Vincent *et al.*, 2019). Sticky traps with a non-UV reflective white colour and some blue traps can attract and catch them.

Results of the experiments

During this experiment the effectiveness of white traps for catching apple sawfly was validated but blue traps caught significantly more individuals. In addition, blue traps caught significantly fewer beneficials than white ones.

Blue sticky traps are an effective choice to reduce apple sawfly populations and fruit damage while minimising the negative impact on beneficials.

Further experimentation and years of sampling are needed to first confirm the effectiveness of blue and white sticky traps and to establish the effective trap density.

Experiment conditions

Scale:

Validity:

Duration: 2020

No. of repetitions: 1

For more information

Helsen HHM., Jansonius P.J., Brouwer G.W., van der Sluis B.J., van Tol R.W.H.M., de Groot A.V., van Kats R.J.M. , M.P. van der Maas M.P. (2020). Mass trapping of the apple sawfly *Hoplocampa testudinea*. Conference on Organic Fruit Growing.

Vincent C., Babendreier D , Swiergiel W., Helsen H., Blommers L.H. M. (2019). A review of the apple sawfly, *Hoplocampa testudinea* (Hymenoptera Tenthredinidae). Bulletin of Insectology 72 (1): 35-54.

Contact:

maxime.jacquot@grab.fr

Experiment leaflet N°7

Leaflet authors: Maxime Jacquot, GRAB. Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, C. Goutines, INRAE. Photos: ©GRAB

API-Tree (2017-2021) is an ERA-Net C-IPM project coordinated by INRAE with funding from the European Union.

Performance leaflet

N°6 Woolly apple aphid control by earwigs

Lever of action 6: *Direct measures with 'soft practices'*
Status: *Validated on station*

Description of the practice

What? Release of earwigs in apple orchards through shelters set up next to woolly apple aphid (WAA) colonies.

Why? To control woolly apple aphid infestation by increasing the resident populations of earwigs and offering alternative shelters.

Implementation tested

In this experiment corrugated cardboard shelters with 30 earwigs were set on the tree canopy near to WAA colonies (see photo).

Earwigs shelters should be set up at the beginning of WAA infestation. This practice offers satisfying control of the colonies near the shelter but more research is needed to adjust the number of shelters per tree.

Conditions of use: Earwigs occur naturally across Europe.

Possible interactions: Since earwigs are nocturnal, insecticide spraying should not be performed at night.

Practice performance

In comparison to an organic orchard where the usual practice is cutting infested branches and spraying soap.

Level of pest regulation: Earwigs predate many pests including woolly apple aphids.

Agronomy & environment

Pesticide reduction

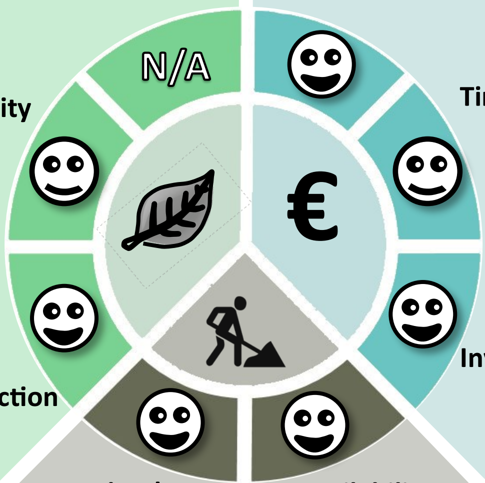
Pesticide reduction: not yet known, but tends to reduce woolly apple aphid numbers.

Biodiversity

Impact on functional biodiversity: increases richness or abundance.

Apple production

Impact on apple production: Prevents reduction of future yield (indirect and positive effect) since it can limit flower bud damage by WAA.



Costs & benefits

Time to manage

No time required for management: once the shelter is set up, no other action is needed.

Time to set up

To set up, the working time is mainly due to making shelters and earwig trapping from other orchards. Little work is needed to tie the shelter to the trees.

Investment cost

The raw material needed for making the shelters costs €0.50 -1.50 (approximately) and lasts the whole orchard lifespan. No other investment is requested.

Ease to implement

Availability

It is a ready to use practice, with a partial effect on the pest.

It is **easy to implement**, earwigs are naturally present in orchards.

This data comes from an experimental orchard and needs to be validated in commercial orchards.

Operationality

Positive effect   Neutral to positive effect   Room for improvement   Bottleneck

Leaflet authors: Georgina Alins, IRTA. Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, C.Goutines, INRAE. Photos: ©IRTA

N°6 Woolly apple aphid control by earwigs

Information about target pests

The woolly apple aphid (WAA) is a native of North America, where the American elm is its primary host and apple the secondary one. In Europe, where the American elm is absent, it develops on apple trees throughout the year. The main activity can be observed from the end of spring until summer.

Woolly apple aphid with the 'wool' partially removed.

Woolly apple aphid on an apple twig.

European earwig *(Forficula auricularia)*

Aphelinus mali adult and a parasitised woolly apple aphid (black).

Information about natural enemies

Even though the woolly apple aphid has many natural enemies, earwigs and the parasitoid *Aphelinus mali* are cited as the most important (Asante, 1997; Gontijo *et al.*, 2012).

Results of the experiments

Earwig releases control the WAA colonies that are present next to the shelter. However, they are not able to control other colonies.

WAA far from the shelter.

WAA next to the shelter, predated by earwigs.

Experiment conditions

Scale:

Validity:

Duration: 2017-2020

No. of repetitions: 10 per year and per orchard

IRTA Institute of Agrifood Research and Technology

For more information

Experiment leaflets N°8 and N°11.

Contact: georgina.alins@irta.cat

Lordan, J., Alegre, S., Gatius, F., Sarasua, M. J. & Alins, G. (2015). Woolly apple aphid *Eriosoma lanigerum* Hausmann ecology and its relationship with climatic variables and natural enemies in Mediterranean areas. Bulletin of Entomological Research 105 (1): 60-69.

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C-IPM Coordinated Integrated Pest Management in Europe

API-Tree (2017-2021) is an ERA-Net C-IPM project coordinated by INRAE with funding from the European Union.

Leaflet authors: Georgina Alins, IRTA. Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, C. Goutines, INRAE. Photos: ©IRTA

Performance leaflet

N°7 Parasitoid mass releases to control rosy apple

Lever of action 6: *Direct measures with 'soft practices'*

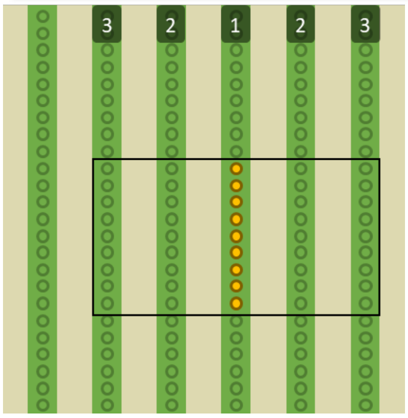
Status: *Promising but needs to be confirmed*

Description of the practice

What? Introduction of two parasitoid species.

Why? To reduce rosy apple aphid populations by the mass release of parasitoids, natural enemies of this pest, at the beginning of the season in the orchard.

Implementation tested



Release points: In an orchard divided into 6 plots (little orchards), three releases of parasitoids every 10 days in 9 apple trees at the centre of the plot.

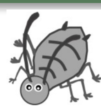
- 9 release points per zone
- Apple trees considered as protected by parasitoïd releases
- 1 3 distances to the release point

Conditions for use: All Europe, except the north where springs are too cold.

Possible interactions: No insecticides when parasitoids are present. Implementation of flower strips to maintain parasitoids within the orchard.

Practice Performances

In comparison to a standard organic orchard.



Pest regulation level: Parasitoids help to reduce aphid populations in the early spring if aphid populations are low and may help to control other aphid species.

Agronomy & environment

Pesticide reduction

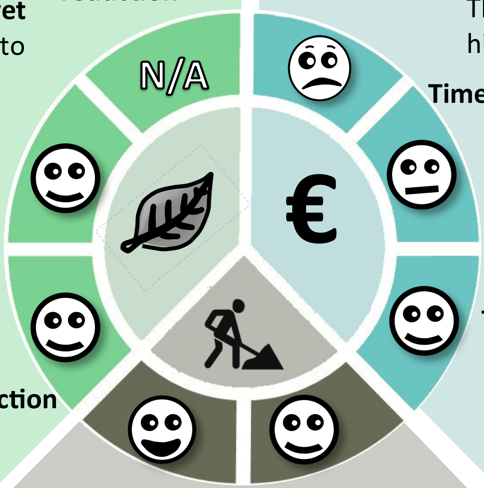
The pesticide reduction is **not yet known** but the practice could help to reduce the number of applications.

Biodiversity

Mass releases help to increase the abundance of natural enemies.

Apple production

Mass releases show no direct impact on apple production.



Costs & benefits

Investment cost

The cost of parasitoids is presently too high to be used in field conditions.

Time to set up

Working time is due to the application of parasitoid tubes on apple trees, several times during the season.

Time to manage

No work is needed for management except in the case of a high presence of ants that can remove parasitoids from the tubes.

Operationality

Ease to implement **Availability**

No specific skills are needed and it is an available and widespread practice.

It is a ready to use solution already tried and tested in greenhouses, but yet **to be proven under field conditions**

Positive effect | Neutral to positive effect | Room for improvement | Bottleneck

Leaflet authors: Louise Ferrais, Pauline Gardin, Thierry Hance, UCLouvain. Design & coordination: A. Alaphilippe, INRAE; Design & layout; B. Rosies, C. Goutines, INRAE. Photos: ©UCLouvain

N°7 Parasitoid mass releases to control rosy apple aphid

UCLouvain

Performance API-Tree

Information about target pests

The rosy apple aphid, *Dysaphis plantaginea*, causes leaf-rolling, fruit deformation and significant yield losses when uncontrolled. Spring individuals are responsible for most of the damage. The aim of this practice is to reduce the population growth of these aphids. In summer, they migrate to their second host plant, plantain.

Aphidius matricariae

Ephedrus cerasicola

Information about natural enemies

Parasitoid wasps are natural enemies that lay eggs in aphids, leading to their death. The two species used in this practice, *Aphidius matricariae* and *Ephedrus cerasicola*, are known to parasitize the rosy apple aphid and potentially other aphid species, though not the woolly aphid.

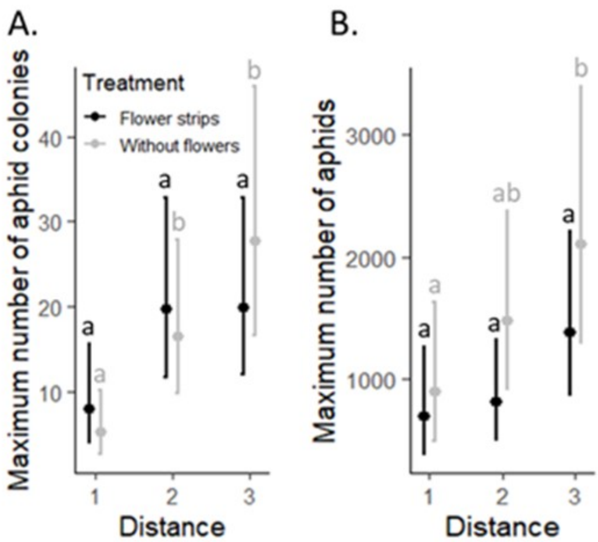
The aim of the practice is to highly increase the presence of aphid natural enemies in the orchard by releasing parasitoids.

Results of the experiments

Although the result is dependent on the year (weather conditions, initial infestation of aphids etc.) the presence of parasitoids combined with the proximity of flower strips seems to have helped reduce the peak of rosy apple aphids.

Graph legend: Predicted values of the effects of the treatment (flower strips vs. without flower strips), and the distance (1, 2, and 3)* on (a) the maximum number of aphid colonies per tree and (b) the maximum number of aphids per tree, for combined peak data of 2018 and 2019.
Different lowercase letters indicate differences among distance classes within each treatment (flower strip vs. without flower strips).

**Distance 1 = release row; distance 2 = adjacent row to the release row; distance 3 = adjacent rows of distance 2 rows.*



For more information

Contacts: louise.ferrais@uclouvain.be; pauline.gardin@uclouvain.be
thierry.hance@uclouvain.be

Experiment leaflets N°9 & 12.

References:

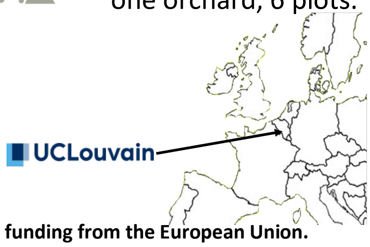
Hance, T., Kohandani-Trafresh, F. & Munaut F. (2017). Biological control. In: van Emden, H.F. and Harrington, R. (eds) Aphids as Crop Pests, 2nd edn. CABI, Wallingford, 448-493.

Levie, A., Legrand, M. A., Dogot, P., Pels, C., Baret, P. V., & Hance, T. (2005). Mass releases of *Aphidius rhopalosiphi* (Hymenoptera: Aphidiinae), and strip management to control of wheat aphids. Agriculture, ecosystems & environment, 105(1-2), 17-21.

Experiment conditions

Scale: **Validity:** **Duration:** 2018 –2019

No. of repetitions: one orchard, 6 plots.



Leaflet authors: L. Ferrais, P. Gardin, T. Hance, UCLouvain. Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies, C. Goutines, INRAE. Photos: ©UCLouvain

C-IPM Coordinated Integrated Pest Management in Europe API-Tree (2017-2021) is an ERA-Net C-IPM project coordinated by INRAE with funding from the European Union.

Contacts :

Coordinator: Aude Alaphilippe, INRAE, France, aude.alaphilippe@inrae.fr

Partners: INRAE, France; University of Copenhagen, Denmark; GRAB, France; Université catholique de Louvain and CRA-W, Belgium; Swedish University of Agricultural Science, Sweden; Institut de Recerca i Tecnologia Agroalimentaries and Servicio Regional de Investigación y Desarrollo Agroalimentario, Spain.

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For more information: www.smach.inra.fr/en c-ipm.org/

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Credits:

Project coordination: Aude Alaphilippe, Sylvaine Simon

Booklet design and creation: Aude Alaphilippe, Blandine Rozies

Leaflet editing: Aude Alaphilippe, Caroline Goutines and leaflet authors (see leaflets)

API-Tree (2017-2021) is an ERA-Net C-IPM project coordinated by INRAE with funding from the European Union.

Summary

The API-Tree project started in 2017 with a consortium of 10 partners across Europe. Its main objective was to design and assess the efficiency and sustainability of combinations of practices as alternatives to the chemical control of apple pests.

Many levers for action that reduce both pest attacks and damage to attacked plants have been tested, with a focus on aphids, for which chemical control solutions are missing due to regulatory pesticide withdrawal. Over four years, 44 experiments were conducted, among which 12 are summarised in the experiment leaflets of this booklet: repellent plants (INRAE Gotheron and INRAE PSH), diffusion of repellent essential oil (GRAB) and ant diversion (SLU), cultivar susceptibility to insect damage (SERIDA and CRA-W) and the effect of bud phenology on apple blossom weevil (SERIDA); predation of rosy apple aphid (predator gut content analysis, UCPH and INRAE PSH); nest boxes (University of Oviedo, SERIDA); mass release of parasitoids (UCL and INRAE ISA) and predators (INRAE PSH), mass trapping (GRAB and CRA-W). Others levers have been tested in the API-Tree project but are not included here, such as the effect of cropping systems on rosy apple aphid (common experimentation) or its predation by *Adalia bipunctata* on summer and winter hosts (UCPH and SLU).

The novelty of this booklet is that, in addition to the summaries of experiments, it offers an integrated approach of the practice undergoing experimentation that takes into account agroecosystem management, orchard design and practices, as well as economic constraints. These aspects are presented in the performance leaflets.

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