



# Impact of Agroecological Infrastructures on the Dynamics of *Dysaphis plantaginea* (Hemiptera: Aphididae) and Its Natural Enemies in Apple Orchards in Northwestern France

Laurence Albert, Pierre Franck, Yann Gilles, Manuel Plantegenest

## ► To cite this version:

Laurence Albert, Pierre Franck, Yann Gilles, Manuel Plantegenest. Impact of Agroecological Infrastructures on the Dynamics of *Dysaphis plantaginea* (Hemiptera: Aphididae) and Its Natural Enemies in Apple Orchards in Northwestern France. *Environmental Entomology*, 2017, 46 (3), pp.528-537. 10.1093/ee/nvx054 . hal-01517228

**HAL Id: hal-01517228**

**<https://hal.science/hal-01517228>**

Submitted on 26 May 2020

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - ShareAlike 4.0 International License

Albert et al.: Agroecological management  
in cider apple orchards

Environmental Entomology  
Biological control – parasitoids and predators

Laurence ALBERT  
Institut Français des Productions Cidricoles  
La Rangées Chesnel  
61500 SEES  
France  
Phone: +33 2.33.27.56.70  
Fax: +33 2.33.27.49.51  
E-mail: [l\\_albert5@yahoo.fr](mailto:l_albert5@yahoo.fr)

# **Impact of Agroecological Infrastructures on the Dynamics of *Dysaphis plantaginea* Passerini (Hemiptera: Aphididae) and its Natural Enemies in Apple Orchards in Northwestern France**

Laurence ALBERT<sup>1</sup>, Pierre FRANCK<sup>3</sup>, Yann GILLES<sup>1</sup>, Manuel PLANTEGENEST<sup>2</sup>

<sup>1</sup> Institut Français des Productions Cidricoles, La Rangée Chesnel, 61500 Sées, FRANCE

<sup>2</sup> UMR1349 IGEPP, INRA/Agrocampus-Ouest/Université Rennes 1, 65 rue de Saint Brieuc, 35042  
Rennes Cedex, FRANCE

<sup>3</sup> INRA Plantes & Systèmes de culture Horticoles, F-84914 AVIGNON Cedex 9, FRANCE

Comment citer ce document :

Albert, L., Franck, P., Gilles, Plantegenest, M. (2017). Impact of Agroecological  
Infrastructures on the Dynamics of *Dysaphis plantaginea* (Hemiptera: Aphididae) and Its Natural Enemies in  
Apple Orchards in Northwestern France. Environmental Entomology, 46 (3), 528-537 . DOI : 10.1093/ee/nvx054

## ABSTRACT

Apple orchard production is facing new environmental and societal challenges, resulting, in particular, in strong pressure to reduce pesticide use. Cider-apple production, for which the perfect visual aspect of fruits is not a marketability imperative, offers good opportunities to study production systems that are developing new agronomic strategies, which could be subsequently extended to all apple-production types. Agroecological infrastructures play an important role in providing shelter, food resources or reproduction habitats to many arthropods. Consequently, setting-up agroecological infrastructures in the vicinity of or within orchards could increase natural enemy presence and thus improve the biological control of pests. In this study, we focused on *Dysaphis plantaginea* (Passerini), one of the major pests in apple orchards in Europe, which causes important economic production losses. During two years (2014 and 2015), we monitored the population dynamics of *Dysaphis plantaginea*, its natural enemies and mutualistic ants in commercial production cider-apple orchards. The influences of the cider-apple cultivar, insecticide use and distance to agroecological infrastructures (hedgerows and flower strips) were assessed. Our results suggest that flower strips favour an increase in natural enemy abundance in the vicinity of the orchards and could thus play an important role in the production system by improving the biological control of *Dysaphis plantaginea*.

## Keywords

Biological control, cider-apple orchard, *Dysaphis plantaginea*, flower strip, hedgerow

In the second half of the 20<sup>th</sup> century, the green revolution allowed an unprecedented increase in agricultural yields in developed countries. This yield increase was achieved by the generalization of agricultural mechanization and the use of synthetic pesticides and fertilizers. The green revolution resulted in agricultural landscape simplification (Robinson and Sutherland 2002, Benton et al. 2003) and produced numerous negative side effects on biodiversity (Krebs et al. 1999), human health (Lee et al. 2004, Simon et al. 2007) and the quality of soil and water (Moss 2008). Consequently, a change in the current agricultural paradigm and the development of more environmentally friendly agricultural practices are strongly required.

Agroecology proposes to primarily base agricultural production on the mobilization of natural processes and the improvement of ecosystem services (e.g. pollination, nutrient cycling, biological control of pests) rather than on chemical inputs. In particular, promoting the natural control of pests would lead to insecticide use reduction. The resulting reduction of economic and environmental costs would contribute to increase farmer benefits and the environmental sustainability of agriculture (Tschumi et al. 2015). Various approaches have been proposed to improve pest biological control, including changes in practices (e.g. pesticide use reduction, accurate choice of cultivars) and establishing agroecological infrastructures within or in the vicinity of the crop (Haenke et al. 2009, Miñarro and Prida 2013). Agroecological infrastructures include hedgerows, flower strips, permanent grasslands and woodlands. They may provide pests and natural enemies with various beneficial functions, including suitable microclimatic conditions and refuge during adverse seasons (Landis et al. 2000). Thus, spiders, beetles and syrphids use them as overwintering areas (Collins et al. 2003, Sarthou et al. 2005, Pfiffner et al. 2013). Agroecological infrastructures also provide pollen and nectar resources that increase the longevity of parasitoids (Wäckers 2001, Berndt and Wratten 2005) and improve the fecundity of other insects (Schmale et al. 2001, Wäckers 2001, Winkler et al. 2006, Hogg et al. 2011, Laubertie et al. 2012, Rijn et al. 2013). Agroecological infrastructures also provide alternative prey for generalist predators when these resources are not available in the crop (Wyss 1996, Denys and Tschamntke 2002, Lavandero et al. 2005).

Northwestern France (i.e. Bretagne, Normandie and Pays de la Loire regions) is the number one cider-apple producing area in Europe. Cider-apple orchard cultivation is thus important in the local economy. The management of apple orchards is based on the intensive use of pesticides to control pests and pathogens (Sauphanor et al. 2009). Currently, farmers are under strong pressure to develop environmentally friendly protection strategies to address the new challenges imposed by society, and environmental laws. Because cider-apples are transformed, their perfect visual aspect is not a prerequisite of their marketability and fewer pesticide treatments are applied in cider-apple orchards than in orchards for fresh fruit production (approximately 15 vs 35 treatments per year). Consequently, cider-apple orchards offer an opportunity to develop and test protection strategies using less pesticide, which could subsequently be generalized.

Approximately 60 phytophagous arthropod species are considered to be apple pests (Jenser et al. 1999). The rosy apple aphid (RAA) *Dysaphis plantaginea* Passerini (Hemiptera: Aphididae), is among

the most detrimental pests, causing significant economic losses by reducing yield (Blommers et al. 2004). The RAA is problematic not only in organic but also in conventional orchards due to its very low abundance threshold for economic damage, resulting in a low treatment threshold (i.e., as soon as the pest is detected) (Cross et al. 2007). As a consequence, an increase in insecticide resistance has been recorded (Delorme et al. 1998). Many recent studies have suggested that improving biological control efficiency could be an alternative to insecticides use to limit RAA populations (Hemptinne et al. 2003, Dib et al. 2010, Miñarro and Prida 2013). RAA is a host-alternating aphid species. Its primary host is the apple tree *Malus domestica* Borkh. (Rosales: Rosaceae), and its secondary hosts are plantain herbs *Plantago* spp, mainly *P. lanceolata* L. (Lamiales: Plantaginaceae) (Blommers, 1999). At the beginning of spring, eggs laid in autumn hatch on apple trees producing parthenogenically reproducing females (Lathrop 1928, Bonnemaïson 1959, Blommers et al. 2004). Migration to a secondary host occurs from mid-June to July in the North of France. The aphids return to apple trees in autumn, where a sexual generation of oviparous females lays fertilized overwintering eggs on the apple trees. The economic losses caused by this leaf-roller aphid, which develops on the lower side of the leaves, are mainly due to the deformations caused to the fruits and growing shoots, decreasing the yield in the year of infestation, as well as in following years (Bonnemaïson 1959, De Berardinis et al. 1994, Wilkaniec and Trzcinski, 1997, Blommers et al. 2004).

Several recent studies have focused on the community of natural enemies, which could play a role in the biological control of *D. plantaginea* during spring. In Europe, this community is mostly composed of syrphids, coccinellids, parasitoids (mainly *Ephedrus* sp – Hymenoptera: Braconidae), earwigs, spiders and *Aphidoletes* sp (Diptera: Cecidomyiidae) (Wyss et al. 1999, Miñarro et al. 2005, Dib et al. 2010, Arnaudov et al. 2013). The abundance of these natural enemies in orchards depends on the abundance of RAA prey (Dib et al. 2016) and on the intra-guild predation pressure (Rosenheim et al. 1993, Rosenheim et al. 1995, Korenko and Pekár 2010). Thus, while an increase in natural enemy abundance is expected to result in a decrease in RAA abundance, this trend may reverse when intra-guild predation is important (Snyder and Ives 2001). RAA population dynamics also depend on the presence of ants in the colony, as *D. plantaginea* is commonly attended by ants (Bonnemaïson 1959, Starý 1970). Interactions between the ants and myrmecophilous aphids are beneficial for both arthropods: ants are supplied with sugar through aphids' honeydew whereas aphids improve their reproductive rate (El-Ziady and Kennedy 1956, Banks and Nixon 1958, Flatt and Weisser 2000) and are protected against natural

enemies (Stadler and Dixon 1999, Yao et al. 2000, Kaneko 2003). Thus, the relationship between ants and *D. plantaginea* enhances the growth of aphid colonies by reducing aphid predation by their natural enemies (Stewart-Jones et al. 2008, Miñarro et al. 2010).

Several recent studies noted the potential of agroecological infrastructures to improve the biological control of *D. plantaginea* by favouring the natural enemy community (Dib et al. 2012, Miñarro and Prida 2013, Pfiffner et al. 2013). Knowledge about the distance at which agroecological infrastructures are operating would help to determine the required density needed to provide an efficient biological control. Indeed, several studies noted that the distance to agroecological infrastructures influenced parasitoids (Corbett and Rosenheim 1996, Lavandero et al. 2005), spiders (Miliczky and Horton 2005) and syrphids (Bowie 1999) abundances. Moreover, the link between the distance to agroecological infrastructures and natural enemy abundance is not systematically linear. For instance, Tylanakis et al. (2004) have shown that the proportion of the aphid *Metopolophium dirhodum* parasitised by *Aphidius rhopalosiphii* decreased exponentially with the distance to flower resources.

The present project aimed to determine the impact of two types of agroecological infrastructures - flower strips and hedgerows - on the abundance of arthropods interacting with *D. plantaginea* (natural enemies and ants) and its consequences on RAA population dynamics. The influence of the distance to these two types of agroecological infrastructures on arthropod dynamics was assessed in 14 cider-apple orchards in northwestern France, which exhibit a range of farming practices (cultivars, insecticide use). For this purpose, the arthropod populations (aphids, their main natural enemies and their mutualistic ants) were monitored in spring during two successive years.

## Materials and Methods

### Monitored Cider-Apple Orchards

Experiments were carried out in the spring and early summer in 2014 and 2015 in cider-apple orchards in seven locations in northwestern France (Fig. 1). The orchards were planted between 2010 and 2012 with three different cider-apple cultivars (three consecutive rows of each cultivar: Douce de l'Avent<sub>cov</sub>, Dabinett and Judor) grafted onto MM106 rootstock. The three cultivars differed in their vigour and precocity: Douce de l'Avent<sub>cov</sub> (DDA) was the most vigorous and precocious cultivar, Dabinett (DAB) was the less precocious cultivar and Judor (JUD) was intermediate.

In each location, two contiguous orchards were studied that differed in regard to insecticide application and in the agroecological infrastructures established (Table 1). Only five out of the seven locations were monitored in 2014 (Fig. 1).

### Monitored Trees

Approximately one-third of the trees were systematically monitored in each orchard (63 to 423 contiguous trees, depending on the considered orchard - Table 1). For each apple tree, the distance to the closest hedgerow (ranging from 5 m to 57 m), the distance to the closest flower strip (ranging from 0 m to 63 m) and the insecticide use were recorded, and the arthropod population dynamics were monitored.

The hedgerows were mainly composed of *Carpinus betulus*, *Cornus* sp, *Corylus avellana*, *Viburnum* sp, *Sambucus nigra* and *Quercus pedunculata*. All flower strips, established specifically for the study, included *Centaurea cyanus*, *Silene vulgaris*, *Silene latifolia alba* and *Achillea millefolium*.

### Assessment of Insecticide Toxicity to Beneficial Arthropods

Calendars of the insecticide treatments in 2014 and 2015 were collected. The Environmental Impact Quotient (EIQ) was used to estimate the toxicity of each insecticide (<https://nysipm.cornell.edu/eiq>) to beneficial arthropods. EIQ assigns to each insecticide ingredient a score ranging from 5 to 125 according to its toxicity to beneficial arthropods (Kovach et al. 1992). We calculated the cumulative impact of the insecticides applied during the period of RAA presence in the apple trees (from March to July) in each orchard using the following formula:

$$EIQ_{field\ use\ rating} = \sum(EIQ_i * RT_i * \%active\ ingredient_i),$$

where  $EIQ_i$  is the EIQ value assigned to the active ingredient contained in the insecticide  $i$  relative to beneficial arthropods,  $RT_i$ , the rate of insecticide  $i$  use and  $\%active\ ingredient_i$  the percentage of active ingredient in the insecticide  $i$ . The  $EIQ_{field\ use\ rating}$  ranged from 0 to 6.61, depending on the year, the orchard and the cultivar (Table 1). The main active ingredients used against RAA in the cider orchard were flonicamid, acetamiprid and lambda cyhalothrin.

### Monitoring of Arthropod Population Dynamics

The monitored trees were visually inspected to record the RAA abundance and the abundance of natural enemies and ants within the RAA colonies. The mean height of the monitored trees was 3.4 m (SD 0.49 m). All terminal shoots of each monitored tree were inspected from the lowest branch up to a height of 1.7 m for practical reasons. In 2014 and 2015, the trees were monitored every week from mid-April to the end of June and every two weeks from mid-March to mid-April and during July (except in the two orchards (4a and 4b) located at location 4, where the RAA populations were recorded every two weeks from April to July).

155

#### *Dysaphis plantaginea*

At each observation date, the total number of RAA individuals was counted on each monitored tree.

158

#### *Natural Enemies and Ants Observed in RAA Colonies*

At each observation date, the number and identity of each natural enemy type and the number of ants found within the RAA colonies were recorded and summed for each monitored tree. We also recorded the developmental stage of all of the observed natural enemies, as not all stages are involved in aphid control. In most cases, natural enemy identification was at the family level. Ants were not identified to the species level. However, we observed only *Lasius niger* and *Formica* sp.

165

### **Data Analysis**

#### *Dysaphis plantaginea*

Three variables were considered to characterize the RAA population dynamics on each monitored tree and for each studied year to assess the different ecological processes:

- (i) The presence/absence variable (*PA*), indicating the RAA colonization process, was set to 0 when no RAA was observed at any date or to 1 when at least one RAA was observed on the monitored tree
- (ii) The logarithm of the area under the curve (*logAUC*) of the tree population abundance, indicating *in situ* RAA population dynamics (survival and reproduction)
- (iii) The presence duration (*PD*), in days (last date at which at least 1 aphid was observed minus the first date at which at least 1 aphid was observed), indicating the RAA emigration process

176

#### *Natural Enemies and Ants*



180 Natural enemy dynamics and ants were only assessed on the monitored trees in which at least one RAA  
 181 was observed (i.e., a monitored tree where the RAA presence/absence was set to 1). The natural enemy  
 182 dynamics were characterized using the same variables as for RAA (*PA*, *logAUC* and *PD*) for each  
 183 considered developmental stage (egg, larva, adult) of each taxon. A global variable (*allNE*) was also  
 184 created by summing the counts of all observed natural enemies for any stage and taxon. The three  
 185 dynamics variables were also calculated for *allNE*. The ant dynamics were characterized in the same  
 186 way as those of RAA and their natural enemies (*PA*, *logAUC* and *PD*).

### 186 Statistical Analyses

187 The main purpose of our study was to assess the influence of agroecological infrastructures on the three  
 188 above variables characterizing RAA population dynamics. First, Generalized Linear Mixed Models  
 189 (GLMM) were used to assess the influence of each considered factor (distance to the closest hedgerow,  
 190 distance to the closest flower strip, *EIQ<sub>field rating use</sub>* and cultivar) on each RAA population dynamics  
 191 variable (*PA*, *logAUC* and *PD*) as well as its significance. Second, to assess in what extent factor effects  
 192 could result from variations in natural enemy and ant population dynamics, the same GLMMs were fitted  
 193 to the population dynamics variables associated to each natural enemy taxon and to ants but including  
 194 as well the rosy apple aphid abundance (*logAUC*) as a supplementary explanatory variable. This allowed  
 195 assessing how the dynamics of natural enemies and ants are impacted by agroecological infrastructures  
 196 and other agricultural variables for a given level of rosy apple aphid abundance. Introducing the *logAUC*  
 197 of RAA as a fixed factor was equivalent to analysing the influence of the factors under study on the  
 198 abundance ratio between the natural enemies and aphids or between the ants and aphids. In all models  
 199 two random factors were added, the orchard location and the studied year. All statistical analyses were  
 200 carried out with the R 3.1.3 software (R core Team 2015) using the tree as the observation unit.  
 201 *PA* were fitted assuming a binomial distribution, *logAUC* were fitted assuming a normal distribution and  
 202 *PD* were fitted using a Gamma distribution, regardless of the arthropod taxon. The mixed linear models  
 203 were fitted using the lme4 package, version 1.1-7 (Bates et al. 2015). A significance threshold of  $p=0.05$   
 204 was considered.

## 206 Results

## **Aphid Abundance and its Variation in Space and Time**

The mean abundance of RAA observed per tree and per sampling date varied widely, depending on the studied year and studied orchard. For instance, in 2014, the mean number of RAA per tree and per sampling date ranged from 0.8 in orchard 3b to 95.5 in orchard 7a (Table 2 and Appendix B). Globally, the pest abundance was higher in 2015 than in 2014 in all orchards, except in orchards 4a and 4b (Appendix B).

## **Community of Natural Enemies and its Variation in Space and Time**

The composition of the natural enemy community remained fairly stable from one year to the next (Table 2). The natural enemy community was dominated by Syrphidae (45% and 32% of the natural enemies observed in 2014 and 2015, respectively) and Coccinellidae (22% and 36% of the natural enemies observed in 2014 and 2015, respectively), followed by Forficulidae (18% and 15% of the natural enemies observed in 2014 and 2015, respectively) and Araneae (9% of the natural enemies observed in both years). Few Chrysopidae, Hemiptera and Cantharidae were observed in both years and were not retained for the subsequent detailed statistical analyses (Table 2). Similarly few mummies were observed and the ratio of the mummy number to the RAA number never exceeded 0.2% whatever the considered year and orchard.

A large variation in the abundance of RAA, natural enemies and ants was observed among the orchards (Appendix B).

The natural enemy community composition varied strongly during the season. The community was dominated by Syrphidae early in the season and then by Coccinellidae and other natural enemies (Fig. 2). In both years, the RAA populations peaked between mid-May and the end of May.

## **Influence of Agricultural Practices and Agroecological Infrastructures on the Main Observed Arthropod Taxa**

Table 3 provides a synthetic overview of the results of the GLMMs. Aphids and ants appeared to be more abundant in the vicinity of the hedgerows. On the contrary, hedgerows had in most cases no effect on the natural enemies. They only have a positive effect on the presence duration of Syrphidae larvae and of Syrphidae eggs and a negative effect on the presence duration of Coccinellidae larvae. On the contrary, aphids and ants were less abundant in the vicinity of the flower strips, while all of the natural

enemies except the Araneae were positively impacted. All arthropods were generally more abundant on the Douce de l'Avent<sub>cov</sub> cultivar, followed by Judor, and were generally negatively impacted by the insecticide use ( $EIQ_{field\ use\ rating}$ ). However, the insecticide effect on the Syrphidae and Coccinellidae was ambiguous. Indeed, the Syrphidae eggs ( $logAUC$  and  $PD$ ) and Coccinellidae larvae ( $PD$ ) were positively impacted by the  $EIQ_{field\ use\ rating}$  but the Syrphidae larvae ( $PA$ ) and the Coccinellidae eggs were negatively impacted by the  $EIQ_{field\ use\ rating}$  ( $PA$ ) (Appendix A). Finally, all natural enemy and ant abundances were positively impacted by aphid abundance. The results were generally consistent regardless of the variables used to describe the arthropod dynamics ( $PA$ ,  $logAUC$  and  $PD$ ) or the considered natural enemy stage (egg, larva, adult). Detailed results by stage and variables are provided in Appendix A.

## Discussion

### Main Findings

This study was carried out under field and farming production conditions. Spatio-temporal variations regarding the abundance of aphids and of their natural enemies have long been reported to depend on farming practices (Marliac et al. 2015) and on climatic conditions (Hemptinne et al. 1994, Roy et al. 2002). Variations among locations and between years in population dynamics of RAA and their natural enemies are not surprising and were modelled as random factors to focus on the effects of farmer practices (insecticide treatment and cultivar choice) and of agroecological infrastructures (distances to the closest hedgerow and to the closest flower strip). All of these factors had an impact on population dynamics of aphids, of natural enemies and of ants. The tested factors appeared to be widely consistent among all natural enemy groups, suggesting that agricultural practices and agroecological infrastructures either favoured or disfavoured the entire community of natural enemies. While the cultivar and insecticide use intensity had a mostly similar influence on all arthropod abundances, the agroecological infrastructures had opposite effects on aphids and ants on the one hand and on natural enemies on the other hand. This result suggests that agroecological infrastructures actually impacted the level of RAA biological control by its natural enemies.

Analyses were carried out using three response variables characterizing arthropod population dynamics: presence probability, logarithm of the area under the curve and presence duration. Our hypothesis was that each variable was related to different ecological processes that could have been differentially influenced by the agricultural practices and agroecological infrastructures. However, in most cases in this study, the three variables were influenced in the same way by the agricultural

practices and agroecological infrastructures, suggesting that environmental and agronomical practices had a similar influence on all of the population dynamics components.

### Structuration of the Arthropod Community

Regardless of the year and orchard, Syrphidae and Coccinellidae were consistently the two most abundant groups of natural enemies, with Syrphidae being generally present earlier than Coccinellidae. These results are consistent with those of previous studies (Miñarro et al. 2005, Dib et al. 2010). However, the synchronization between the RAA and natural enemy dynamics varied between the studied years. The lowest RAA infestation level was observed in 2014, when RAA and natural enemy dynamics appeared to be the most synchronized. Indeed, in 2014, the increase of natural enemy abundance was concomitant to the increase of RAA population whereas in 2015, the natural enemy abundance was at its lowest level when the RAA infestation was highest (Fig. 2).

Hymenoptera parasitoids were very rare in both year and in all orchards. The ratio of the number of mummies to the aphid number was much lower (always less than 0.2% in all years and orchards) than in previous surveys conducted in organic apple orchards (Dib et al. 2010: up to 6.9%; Cruz de Boelpaepe et al. 1987: 3.3%). However, other studies similarly reported the absence or a very low abundance of parasitism in RAA colonies (Miñarro et al. 2005, Brown and Mathews 2007). The low level of parasitism observed in our study could result from the high sensitivity of the hymenoptera parasitoid to insecticides (Theiling and Croft 1988). Another explanation could be an antagonist effect between ants and parasitoids as evidenced in previous studies (Völkl 1992, Stewart-Jones et al. 2008).

As expected, all natural enemies exhibited a positive response to RAA abundance either in their probability of presence (Coccinellidae, Araneae) or in both their probability of presence and abundance (Syrphidae, Forficulidae). This is not surprising, as natural enemies frequently aggregate in places where preys are abundant. In fact, previous studies showed that it is the case for Carabidae and Staphylinidae, (Bryan and Wratten 1984) or for Syrphidae (Tenhumberg and Poehling 1995, Miñarro et al. 2005).

Similarly, the presence probability, logarithm of the area under the curve and presence duration of ants responded positively to RAA abundance, which was expected considering the mutualistic relation between *D. plantaginea* and the two species of ants observed (*Lasius niger* L., *Formica* sp.) (Flatt and Weisser 2000, Stewart-Jones et al. 2008).

This dependence of ant and natural enemy abundances on RAA abundance supported our choice to include RAA abundance as a factor in the models (through the *logAUC* of RAA). In this way, we were able to analyse the direct effects of farmer practices and agroecological infrastructures on natural enemies and ants.

## Practices and Cultivar Influence

### *Impact of Insecticides on RAA and Natural Enemy Population Dynamics*

As expected, we observed a decrease in the probability and duration of RAA presence with an increase of the *EIQ<sub>field use rating</sub>*, but the *EIQ<sub>field use rating</sub>* effect on RAA abundance (*logAUC*) was not significant (Table 3 and Appendix A). Such an effect is especially expected in leaf-curling aphids, such as *D. plantaginea*. Indeed, aphids are more vulnerable to insecticides in the first phase of colonization, resulting in a reduction of the colonization success and hence on the presence probability. The aphid vulnerability further decreases while the colony size increases because the rolling-up of leaves provides them with protection against insecticides (Cross et al. 2007). Moreover, the negative effect of insecticides on natural enemies might further reduce aphid biological control. A negative effect of insecticide treatments was observed on the presence probability of *allNE* and on their abundance (*logAUC*). This negative effect was significant on the presence probability of Syrphidae larvae, of Syrphidae eggs and of Coccinellidae eggs, as well as on the Forficulidae abundance and on Araneae presence duration. Insecticide treatments applied early in the season seem to be the most efficient to control the development of *D. plantaginea* colonies. Insecticide applications after the leaf curling, would impact more strongly the natural enemies than aphids. High *EIQ<sub>field use rating</sub>* also reduced ant abundance in RAA-infested trees, suggesting that insecticide treatments also negatively impact the ant population.

### *Effect of Cultivar on RAA and Natural Enemy Population Dynamics*

A strong impact of the cultivar was observed in our study and its effect varied whether we considered the presence probability and the presence duration of RAA and natural enemies or the abundance of RAA and natural enemies (except for the Dabinett cultivar, which always exhibited the lowest presence probability, abundance and presence duration of RAA and natural enemies). Douce de l'Avent<sub>cov</sub> had the highest presence probability and presence duration of RAA and natural enemies (*allNE*), followed by Judor. For the RAA, this ranking matches cultivars ranked according to precocity. Douce de l'Avent<sub>cov</sub>

was the most precocious cultivar, followed by Judor, with Dabinett being the latest cultivar. Miñarro and Dapena, (2007) still showed that early-leaving apple cultivars were more infested and damaged by RAA than late-leaving ones. We can suppose that the same process operates for natural enemies. However, a different cultivar ranking was obtained when the abundance of RAA and natural enemies was considered, switching between cultivars: Judor had the higher abundance of RAA and of natural enemies (*AI/NE*), followed by Douce de l'Avent<sub>cov</sub>. This apparent inconsistency could result from an interaction between the colonization rate and treatment frequency. In fact, the most heavily colonized cultivar (Douce de l'Avent<sub>cov</sub>) was also the earliest one treated with insecticides, resulting in low abundances of both aphids and natural enemies throughout the season.

### Hedgerows Favour RAA Populations

Unexpectedly, hedgerows appeared to be consistently beneficial to RAA populations. Indeed, hedgerow proximity had a positive impact on all of the RAA population dynamics parameters. This hedgerow effect may result from either direct effects on the RAA population dynamics, from indirect effects through its influence on mutualistic or antagonist arthropods, or both. The vicinity of the hedgerow may influence the flight behaviour of arthropods by modifying the wind speed and turbulences (Pasek 1988), which could result in the accumulation of insects on the leeward side of the hedgerow (Lewis 1965, Grüebler et al. 2008). Such an effect could result in a higher colonization rate by RAA of apple trees situated in the vicinity of hedgerows.

Hedgerows may also indirectly favour aphids by favouring mutualistic ants possibly by providing a suitable nesting habitat. Indeed, the ant presence probability increased with the proximity to the hedgerow in our study. To our knowledge, very few studies have assessed hedgerow influence on ants. Stutz and Entling (2011) found no effect of a woody habitat in the surrounding landscape on ant presence on cherry trees, but Armbrrecht and Perfecto (2003) reported a dramatic decrease of twig-nesting ants with an increase in the distance to forest fragments in coffee plantations in Mexico.

Finally, the proximity of hedgerows may modify the arthropods interaction network. For instance, the presence of a hedgerow could reduce RAA biocontrol by increasing the intra-guild predation between natural enemies (Straub et al. 2008) or by diverting natural enemies from pests by offering them alternative prey (Kozar et al. 1994, Koss and Snyder 2005, Symondson et al. 2006). Moreover, as the presence of ants is higher in the hedgerow vicinity, the protection they provide to RAA against their



natural enemies could be enhanced. Contrary to previous studies (Altieri and Schmidt 1986, Miñarro and Prida 2013), few hedgerow-distance effects on natural enemy occurrence or abundance in aphid colonies were found in our study. The only significant effects were the decrease of the presence probability and of the presence duration of Coccinellidae larvae and the increase of the presence duration of Syrphidae larvae and Syrphidae eggs in the vicinity of the hedgerow.

### **Flower Strips Reduce RAA Populations and Increase Natural Enemy Abundance**

Contrary to hedgerows, flower strips had a negative impact on the RAA populations in our study. Indeed, the presence probability, the abundance and the presence duration of RAA all decreased with flower strips proximity. A direct effect of flower strips on aphids was very unlikely. We then assumed that flower strips exerted an indirect effect through their influence on the natural enemies and/or on ants. Indeed, Wyss, (1995) and Wyss et al. (1995) showed that introducing flower strips in apple orchards resulted in an increase in natural enemy abundance (Chrysopidae, Coccinellidae, Araneae). Similarly, in our study, the abundance (*logAUC*) and presence duration of natural enemies (*allNE*) increased in proximity to flower strips. More specifically, the presence probability and abundance of Syrphidae (eggs and larvae), presence probability of Coccinellidae (eggs and larvae) and abundance of Forficulidae decreased significantly with the distance to flower strips. This increase of presence and/or of abundance of natural enemies could enhance aphid biological control in the vicinity of flower strips. Hogg et al. (2011) showed that floral resources enhanced aphid suppression by the hoverfly *Eupeodes fumipennis* in a California lettuce field. In addition, the negative influence of flower strips on aphid populations could also be amplified by their negative effect on the ant presence probability. Nagy et al. (2013) showed that applying artificial sugar sources in apple orchards resulted in a reduction of the number of ant-attended *D. plantaginea* colonies and in an increase in natural enemy pressure. Similarly, by providing alternative sugar resources, flower strips could distract ants from aphid attendance. Katayama et al. (2013) showed that extrafloral nectar was more attractive to ants than aphid honeydew. In total, our results suggest that flower strips are beneficial to natural enemies and reduce ant attendance that could account for the observed reduction of *D. plantaginea* infestation in cider-apple trees located in the vicinity of flower strips.

### **Conclusion**

Comment citer ce document :

Albert, L., Franck, P., Gilles, Plantegenest, M. (2017). Impact of Agroecological Infrastructures on the Dynamics of *Dysaphis plantaginea* (Hemiptera: Aphididae) and Its Natural Enemies in Apple Orchards in Northwestern France. *Environmental Entomology*, 46 (3), 528-537 . DOI : 10.1093/ee/nvx054

390 This study showed an impact of the distance to agroecological infrastructures on *D. plantaginea*  
 391 dynamics in cider-apple orchards. Hedgerows increased the RAA infestation level. This could result  
 392 from an indirect effect due to modifications in the RAA interactions network with other arthropods.  
 393 Indeed, our results showed an increase in the presence of mutualistic ants and a decrease in RAA  
 394 natural enemy abundance in the vicinity of hedgerow. On the contrary, flower strips appeared  
 395 unfavourable to *D. plantaginea*. Again it could result from indirect effect due to an increase in natural  
 396 enemy abundance and a decrease of ant presence in the RAA colony. Additionally, we confirmed a  
 397 strong influence of cultivars and of insecticide use intensity on *D. plantaginea* dynamics.

398

### 399 **Acknowledgments**

400 We thank A. Taillade and A. Quero for data collection and the farmers who allowed us to access their  
 401 orchards. We thank Sylvaine Simon for her help in the characterization of agroecological infrastructure.  
 402 We thank two anonymous reviewers for their useful comments on a previous version of this manuscript.  
 403 The work was supported by ANRT, UNICID, Région Bretagne, Région Normandie and the Ministère de  
 404 l'Agriculture, de l'agroalimentaire et de la forêt (CASDAR). This project is linked to the PEERLESS  
 405 project (ANR-12-AGRO-0006) and to the "Verger Cidricole de Demain" CASDAR project.

406

407

### 408 **References Cited**

- 409 **Altieri, M. A., and L. L. Schmidt. 1986.** The dynamics of colonizing arthropod communities at the  
 410 interface of abandoned, organic and commercial apple orchards and adjacent woodland habitats. *Agric.*  
 411 *Ecosyst. Environ.*, 16(1): 29-43.
- 412 **Armbrecht, I., and I. Perfecto. 2003.** Litter-twig dwelling ant species richness and predation potential  
 413 within a forest fragment and neighboring coffee plantations of contrasting habitat quality in Mexico. *Agric.*  
 414 *Ecosyst. Environ.*, 97(1): 107-115.
- 415 **Arnaudov, V., S. Raikov, R. Davidova, and H. Hristov. 2013.** Predators of rosy apple aphyd (*Dysaphis*  
 416 *plantaginea*) Pass., (Homoptera, Aphididae) in bulgarian apple orchards. In: Fourth International  
 417 Scientific Symposium "Agrosym 2013": 268-274.



- 418 **Banks, B. Y. C. J., and H. L. Nixon. 1958.** Effects of the ant, *Lasius niger* L., on the feeding and  
419 excretion of the bean aphid, *Aphis fabae* Scop.. J. Exp. Biol., 35(4): 703-711.
- 420 **Barzman, M., and S. Dachbrodt-Saaydeh. 2011.** Comparative analysis of pesticide action plans in five  
421 European countries. Pest management science, 67(12): 1481-1485.
- 422 **Bates, D., M. Mächler, B. Bolker, and S. Walker. 2015.** Fitting linear mixed-effects models using lme4.  
423 Journal of Statistical Software, 67(1), 1-48.
- 424 **Benton, T. G., J. A. Vickery, and J. D. Wilson. 2003.** Farmland biodiversity : is habitat heterogeneity  
425 the key?. Trends Ecol. Evol., 18(4): 182-188.
- 426 **Berndt, L. A., and S. D. Wratten. 2005.** Effects of alyssum flowers on the longevity, fecundity, and sex  
427 ratio of the leafroller parasitoid *Dolichogenidea tasmanica*. Biol. Control, 32(1): 65-69.
- 428 **Biddinger, D. J., T. W. Leslie, and N. K. Joshi. 2014.** Reduced-risk pest management programs for  
429 Eastern US peach orchards: effects on arthropod predators, parasitoids, and select pests. J. Econ.  
430 Entomol., 107(3): 1084-1091.
- 431 **Blommers, L. H. M. 1999.** Probing the natural control of rosy aphid *Dysaphis plantaginea* (Hemiptera:  
432 Aphididae). IOBC-WPRS Bulletin 22(7): 53-56.
- 433 **Blommers, L. H. M., H. H. M. Helsen, and F. W. N. M. Vaal. 2004.** Life history data of the rosy apple  
434 aphid *Dysaphis plantaginea* (Pass.) (Homopt., Aphididae) on plantain and as migrant to apple. J. Pest  
435 Sci., 77(3) : 155-163.
- 436 **Bonnemaïson, L. 1959.** Le puceron cendré du pommier (*Dysaphis plantaginea* Pass.) Morphologie et  
437 biologie – Méthodes de lutte. Annales de l'Institut National de la Recherche Agronomique, Série C,  
438 Epiphyties 3: 257–322.
- 439 **Bowie, M. H. 1999.** Effects of distance from field edge on aphidophagous insects in a wheat crop and  
440 observations on trap design and placement. International Journal of Pest Management, 45(1): 69-73.
- 441 **Brown, M. W., and C. R. Mathews. 2007.** Conservation Biological Control of Rosy Apple Aphid,  
442 *Dysaphis plantaginea* (Passerini), in Eastern North America. Environ. Entomol., 36(5): 1131-1139.
- 443 **Bryan, K. M., and S. D. Wratten. 1984.** The responses of polyphagous predators to prey spatial  
444 heterogeneity: aggregation by carabid and staphylinid beetles to their cereal aphid prey. Ecol. Entomol.,  
445 9(3): 251-259.

- 446 **Collins, K. L., N. D. Boatman, A. Wilcox, and J. M. Holland. 2003.** Effects of different grass treatments  
 447 used to create overwintering habitat for predatory arthropods on arable farmland. *Agric. Ecosyst.*  
 448 *Environ.*, 96(1): 59-67.
- 449 **Corbett, A., and J. A. Rosenheim. 1996.** Impact of a natural enemy overwintering refuge and its  
 450 interaction with the surrounding landscape. *Ecol. Entomol.*, 21(2): 155-164.
- 451 **Cross, J. V., S. Cubison, A. Harris, and R. Harrington. 2007.** Autumn control of rosy apple aphid,  
 452 *Dysaphis plantaginea* (Passerini), with aphicides. *Crop Prot.*, 26(8) : 1140-1149.
- 453 **Cruz de Boelpaepe, M.O., N. M. Filipe, and V. C. Afonso. 1987.** Dynamique des populations  
 454 aphidiennes en verger de pommiers. Leurs fluctuations saisonnières dans la province de Beira-Baixa  
 455 (Portugal) en fonction des facteurs de l'environnement. *Phytoma-La Défense des Végétaux* 246: 5-16.
- 456 **De Berardinis, E., P. Baronio and J. Baumgärtner. 1994.** The effect of aphid (*Dysaphis plantaginea*  
 457 Pass., Hom., Aphididae) feeding on apple fruit growth. *Ecol. Modell.* 72(1-2) : 115–127.
- 458 **Delorme, R., D. Auge, P. Touton, C. Vergnet, and F. Villatte. 1998.** La résistance des pucerons aux  
 459 insecticides. Enquêtes 1997. In: Proceedings of the 1st Colloque Transnational sur les Luittes  
 460 Biologiques, Intégrées et Raisonnées; Lille, France.
- 461 **Denys, C., and T. Tschardtke. 2002.** Plant-insect communities and predator-prey ratios in field margin  
 462 strips, adjacent crop fields, and fallows. *Oecologia*, 130(2): 315-324.
- 463 **Dib, H., S. Simon, B. Sauphanor, and Y. Capowiez. 2010.** The role of natural enemies on the  
 464 population dynamics of the rosy apple aphid, *Dysaphis plantaginea* Passerini (Hemiptera: Aphididae) in  
 465 organic apple orchards in south-eastern France. *Biol. Control*, 55(2): 97-109.
- 466 **Dib, H., G. Libourel, and F. Warlop. 2012.** Entomological and functional role of floral strips in an organic  
 467 apple orchard: Hymenopteran parasitoids as a case study. *J. Insect Conserv.*, 16(2): 315-318.
- 468 **Dib, H., B. Sauphanor, and Y. Capowiez. 2016.** Effect of management strategies on arthropod  
 469 communities in the colonies of rosy apple aphid, *Dysaphis plantaginea* Passerini (Hemiptera: Aphididae)  
 470 in south-eastern France. *Agric. Ecosyst. Environ.*, 216: 203-206.
- 471 **El-Ziady, S., and J. S. Kennedy. 1956.** Beneficial effects of the common garden ant, *Lasius niger* L.,  
 472 on the black bean aphid, *Aphis fabae* Scopoli. *Proc. R. Entomol. Soc. Lond. Ser. A Gen. Entomol.*, 35(1-  
 473 3): 61-65.

- 474 **Flatt, T., and W. W. Weisser. 2000.** The effects of mutualistic ants on aphid life history traits. *Ecology*,  
 475 81(12): 3522-3529.
- 476 **Grüebler, M. U., M. Morand, and B. Naef-Daenzer. 2008.** A predictive model of the density of airborne  
 477 insects in agricultural environments. *Agric. Ecosyst. Environ.*, 123(1): 75-80.
- 478 **Haenke, S., B. Scheid, M. Schaefer, T. Tschardt, and C. Thies. 2009.** Increasing syrphid fly  
 479 diversity and density in sown flower strips within simple vs. complex landscapes. *J. Appl. Ecol.*, 46(5):  
 480 1106-1114.
- 481 **Hemptinne, J. L., P. Guillaume, C. Gaspar, and A. F. G. Dixon. 1994.** Integrated control programme  
 482 for the apple aphid, *Dysaphis plantaginea* Passerini (Homoptera: Aphididae): forecasting seasonal and  
 483 yearly changes in abundance. Mededelingen-Faculteit Landbouwkundige en Toegepaste Biologische  
 484 Wetenschappen Universiteit Gent (Belgique).
- 485 **Hemptinne, J. L., A. F. G. Dixon, and E. Wyss. 2003.** Biological control of the rosy apple aphid,  
 486 *Dysaphis plantaginea* (Passerini) (Homoptera: Aphididae): Learning from the ecology of ladybird  
 487 beetles. *Biology, Ecogology and Behaviour of Aphidophagous Insects Arquipélago - Life and Marine*  
 488 *Sciences S5, Université des Açores, Portugal*: 33-41.
- 489 **Hogg, B. N., E. H. Nelson, N. J. Mills, and K. M. Daane. 2011.** Floral resources enhance aphid  
 490 suppression by a hoverfly. *Entomol. Exp. Appl.*, 141(2): 138-144.
- 491 **Jenser, G., K. Balázs, C. Erdélyi, A. Haltrich, F. Kádár, F. Kozár, V. Marko, V. Racz, and F. Samu.**  
 492 **1999.** Changes in arthropod population composition in IPM apple orchards under continental climatic  
 493 conditions in Hungary. *Agric. Ecosyst. Environ.*, 73(2): 141-154.
- 494 **Kaneko, S. 2003.** Impacts of two ants, *Lasius niger* and *Pristomyrmex pungens* (Hymenoptera:  
 495 Formicidae), attending the brown citrus aphid, *Toxoptera citricidus* (Homoptera: Aphididae), on the  
 496 parasitism of the aphid by primary parasitoid, *Lysiphlebus japonicus* (Hymenoptera). *Appl. Entomol.*  
 497 *Zool.*, 38(3): 347-357.
- 498 **Katayama, N., D. H. Hembry, M. K. Hojo, and N. Suzuki. 2013.** Why do ants shift their foraging from  
 499 extrafloral nectar to aphid honeydew?. *Ecol. Res.*, 28(5): 919-926.
- 500 **Korenko, S., and S. Pekár. 2010.** Is there intraguild predation between winter-active spiders (Araneae)  
 501 on apple tree bark? *Biol. Control*, 54(3): 206-212.

- 502 **Koss, A. M., and W. E. Snyder. 2005.** Alternative prey disrupt biocontrol by a guild of generalist  
503 predators. *Biol. Control*, 32(2): 243-251.
- 504 **Kovach, J., C. Petzoldt, J. Degni, and J. Tette. 1992.** A method to measure the environmental impact  
505 of pesticides. *New York's Food and Life Science Bulletin*, 139: 1-8.
- 506 **Kozar, B. F., M. W. Brown, and G. Lightner. 1994.** Spatial distribution of homopteran pests and  
507 beneficial insects in an orchard and its connection with ecological plant protection. *J. Appl. Entomol.*,  
508 117(1-5): 519-529.
- 509 **Krebs, J. R., J. D. Wilson, R. B. Bradbury, and G. M. Siriwardena. 1999.** The second Silent Spring?.  
510 *Nature*, 400(6745): 611-612.
- 511 **Landis, D. A., S. D. Wratten, and G. M. Gurr. 2000.** Habitat management to conserve natural enemies  
512 of arthropod pests. *Annu. Rev. Entomol.*, 45(1): 175-201.
- 513 **Lathrop, F.H. 1928.** The biology of apple aphids. *The Ohio Journal of Science* 28: 177-204.
- 514 **Laubertie, E. A., S. D. Wratten, and J. L. Hemptinne. 2012.** The contribution of potential beneficial  
515 insectary plant species to adult hoverfly (Diptera: Syrphidae) fitness. *Biol. Control.*, 61(1): 1-6.
- 516 **Lavandero, B., S. Wratten, P. Shishehbor, and S. Worner. 2005.** Enhancing the effectiveness of the  
517 parasitoid *Diadegma semiclausum* (Helen): Movement after use of nectar in the field. *Biol. Control*,  
518 34(2), 152-158.
- 519 **Lee, W. J., J. A. Hoppin, A. Blair, J. H. Lubin, M. Dosemeci, S. Dale, and M. C. R. Alavanja. 2004.**  
520 Cancer Incidence among Pesticide Applicators Exposed to Alachlor in the Agricultural Health Study.  
521 *Am. J. Epidemiol.*, 159(4): 373-380.
- 522 **Lewis, T. 1965.** The effects of an artificial windbreak on the aerial distribution of flying insects. *Ann. of*  
523 *Appl. Biol.*, 55: 503-512.
- 524 **Marliac, G., S. Penvern, J. M. Barbier, F. Lescourret, and Y. Capowiez. 2015.** Impact of crop  
525 protection strategies on natural enemies in organic apple production. *Agron. Sustain. Dev.*, 35(2): 803-  
526 813.
- 527 **Miliczky, E. R., and D. R. Horton. 2005.** Densities of beneficial arthropods within pear and apple  
528 orchards affected by distance from adjacent native habitat and association of natural enemies with extra-  
529 orchard host plants. *Biol. Control*, 33(3): 249-259.

- 530 **Miñarro, M., J.L. Hemptinne, and E. Dapena. 2005.** Colonization of apple orchards by predators of  
 531 *Dysaphis plantaginea*: sequential arrival, response to prey abundance and consequences for biological  
 532 control. *BioControl*, 50(3): 403-414.
- 533 **Miñarro, M., and E. Dapena. 2007.** Resistance of apple cultivars to *Dysaphis plantaginea* (Hemiptera:  
 534 Aphididae): role of tree phenology in infestation avoidance. *Environ. Entomol.*, 36(5): 1206-1211.
- 535 **Miñarro, M., and E. Prida. 2013.** Hedgerows surrounding organic apple orchards in north-west Spain:  
 536 potential to conserve beneficial insects. *Agr. Forest Entomol.*, 15(4): 382-390.
- 537 **Miñarro, M., G. Fernández-Mata, and P. Medina. 2010.** Role of ants in structuring the aphid community  
 538 on apple. *Ecol. Entomol.*, 35(2): 206-215.
- 539 **Moss, B. 2008.** Water pollution by agriculture. *Philos. Trans. R. Soc. Lond. B Biol. Sci.*, 363(1491): 659  
 540 -666.
- 541 **Nagy, C., J. V. Cross, and V. Markó. 2013.** Sugar feeding of the common black ant, *Lasius niger* (L.),  
 542 as a possible indirect method for reducing aphid populations on apple by disturbing ant-aphid mutualism.  
 543 *Biol. Control*, 65(1): 24-36.
- 544 **Pasek, J. E. 1988.** Influence of wind and windbreaks on local dispersal of insects. *Agric. Ecosyst.*  
 545 *Environ.*, 22: 539-554.
- 546 **Pfiffner, L., H. J. Schärer, and H. Luka. 2013.** Functional biodiversity to improve pest control in organic  
 547 cropping systems. *Agric. Ecosyst. Environ.*, 78(3): 215-222.
- 548 **R Core Team 2015.** R: A language and environment for statistical computing. R Foundation for 565  
 549 Statistical Computing, Vienna, Austria. <http://www.R-project.org/>
- 550 **Rijn, C. J. Van, J. Kooijman, and F. L. Wäckers. 2013.** The contribution of floral resources and  
 551 honeydew to the performance of predatory hoverflies (Diptera: Syrphidae). *Biol. Control*, 67(1): 32-38.
- 552 **Robinson, R. A., and W. J. Sutherland. 2002.** Post-war changes in arable farming and biodiversity in  
 553 Great Britain. *J. Appl. Ecol.*, 39(1): 157-176.
- 554 **Rosenheim, J. A., L. R. Wilhoit, and C. A. Armer. 1993.** Influence of intraguild predation among  
 555 generalist insect predators in the suppression of an herbivore population. *Oecologia*, 96(3): 439-449.
- 556 **Rosenheim, J. A., H. K. Kaya, L. E. Ehler, J. J. Marois, and B. A. Jaffret. 1995.** Intraguild predation  
 557 among biological-control Agents: theory and evidence. *Biol. Control*, 5(3): 303-335.

- 558 **Roy, L. E., J. Brodeur, and C. Cloutier. 2002.** Relationship between temperature and developmental  
559 rate of *Stethorus punctillum* (Coleoptera : Coccinellidae) and its prey *Tetranychus mcdanieli* (Acarina:  
560 Tetranychidae). Environ. Entomol., 31(1): 177-187.
- 561 **Sarthou, J. P., A. Ouin, F. Arrignon, G. Barreau, and B. Bouyjou. 2005.** Landscape parameters  
562 explain the distribution and abundance of *Episyrphus balteatus* (Diptera: Syrphidae). Eur. J. Entomol.,  
563 102(3): 539-545.
- 564 **Sauphanor, B., S. Simon, C. Boisneau, Y. Capoview, R. Rieux, J.C. Bouvier, H. Defrance, C.**  
565 **Picard, and J.F. Toubon. 2009.** Protection phytosanitaire et biodiversité en agriculture biologique. Le cas  
566 des vergers de pommiers. Innovations Agronomiques, 4: 217-228.
- 567 **Schmale, I., F. L. Wäckers, C. Cardona, and S. Dorn. 2001.** Control Potential of Three Hymenopteran  
568 Parasitoid Species against the Bean Weevil in Stored Beans: The Effect of Adult Parasitoid Nutrition on  
569 Longevity and Progeny Production. Biol. Control, 21(2): 134-139.
- 570 **Simon, S., H. Defrance, and B. Sauphanor. 2007.** Effect of codling moth management on orchard  
571 arthropods. Agric. Ecosyst. Environ., 122(3): 340-348.
- 572 **Simon, S., L. Brun, J. Guinaudeau, and B. Sauphanor. 2011.** Pesticide use in current and innovative  
573 apple orchard systems. Agron. Sustain. Dev, 31(3): 541-555.
- 574 **Snyder, W. E., and A. R. Ives. 2001.** Generalist Predators Disrupt Biological Control by a Specialist  
575 Parasitoid. Ecology, 82(3): 705.
- 576 **Stadler, B., and A. F. G. Dixon. 1999.** Ant attendance in aphids: why different degrees of  
577 myrmecophily?. Ecol. Entomol., 24(3): 363-369.
- 578 **Stary, P. 1970.** Biology of Aphid Parasites (Hymenoptera: Aphidiidae). Series entomologica Vol. 6.
- 579 **Stewart-Jones, A., T. W. Pope, J. D. Fitzgerald, and G. M. Poppy. 2008.** The effect of ant attendance  
580 on the success of rosy apple aphid populations, natural enemy abundance and apple damage in  
581 orchards. Agr. Forest Entomol., 10(1): 37-43.
- 582 **Straub, C. S., D. L. Finke, and W. E. Snyder. 2008.** Are the conservation of natural enemy biodiversity  
583 and biological control compatible goals?. Biol. Control, 45(2): 225-237.
- 584 **Stutz, S., and M. H. Entling. 2011.** Effects of the landscape context on aphid-ant-predator interactions  
585 on cherry trees. Biol. Control., 57(1): 37-43.



- 586 **Symondson, W. O. C., S. Cesarini, P. W. Dodd, G. L. Harper, M. W. Bruford, D. M. Glen, C. W.**  
 587 **Wiltshire, and J. D. Harwood. 2006.** Biodiversity vs. biocontrol: positive and negative effects of  
 588 alternative prey on control of slugs by carabid beetles. *Bull. Entomol Res.*, 96(6): 637-645.
- 589 **Tenhumberg, B., and H. Poehling. 1995.** Syrphids as natural enemies of cereals aphids in Germany:  
 590 Aspects of their biology and efficacy in different years and regions. *Agric. Ecosyst. Environ.*, 52(1): 39-  
 591 43.
- 592 **Theiling, K. M., and B. A. Croft. 1988.** Pesticide side-effects on arthropod natural enemies: a database  
 593 summary. *Agric. Ecosyst. Environ.*, 21(3-4): 191-218.
- 594 **Tschumi, M., M. Albrecht, M. H. Entling, and K. Jacot. 2015.** High effectiveness of tailored flower  
 595 strips in reducing pests and crop plant damage. *Proc. R. Soc. Lond. B Biol. Sci.*, 282: 20151369.
- 596 **Tylianakis, J. M., R. K. Didham, and S. D. Wratten. 2004.** Improved fitness of aphid parasitoids  
 597 receiving resource subsidies. *Ecology*, 85(3): 658-666.
- 598 **Völkl, W. 1992.** Aphids or their parasitoids: who actually benefits from ant-attendance?. *J. Anim. Ecol.*,  
 599 61: 273-281.
- 600 **Wäckers, F. L. 2001.** A comparison of nectar- and honeydew sugars with respect to their utilization by  
 601 the hymenopteran parasitoid *Cotesia glomerata*. *J. Insect Physiol.*, 47(9): 1077-1084.
- 602 **Wilkaniec, B., and P. Trzcinski. 1997.** Effect of rosy apple aphid, *Dysaphis plantaginea* (Pass.)  
 603 (Homoptera; Aphididae), feeding on fruits of the *Primula* variety. *Progress in Plant Protection* 37: 36-  
 604 39.
- 605 **Winkler, K., F. Wäckers, G. Bukovinskine-Kiss, and J. van Lenteren. 2006.** Sugar resources are  
 606 vital for *Diadegma semiclausum* fecundity under field conditions. *Basic and Applied Ecology*, 7(2): 133  
 607 -140.
- 608 **Wyss, E. 1995.** The effects of weed strips on aphids and aphidophagous predators in an apple orchard.  
 609 *Entomol. Exp. Appl.*, 75(1): 43-49.
- 610 **Wyss, E., U. Niggli, and W. Nentwig. 1995.** The impact of spiders on aphid populations in a strip-  
 611 managed apple orchard. *J. Appl. Entomol.*, 119(1-5): 473-478.
- 612 **Wyss, E. 1996.** The effects of artificial weed strips on diversity and abundance of the arthropod fauna  
 613 in a Swiss experimental apple orchard. *Agric. Ecosyst. Environ.*, 60(1): 47-59.

- 614 **Wyss, E., M. Villiger, J. L. Hemptinne, and H. Müller-Schärer. 1999.** Effects of augmentative releases  
615 of eggs and larvae of the ladybird beetle, *Adalia bipunctata*, on the abundance of the rosy apple aphid,  
616 *Dysaphis plantaginea*, in organic apple orchards. Entomol. Exp. Appl., 90(2): 167-173.
- 617 **Yao, I., H. Shibao, and S. Akimoto. 2000.** Costs and benefits of ant attendance to the drepanosiphid  
618 aphid *Tuberculatus quercicola*. OIKOS, 89(1): 3-10.



## TABLE

**Table 1: Main characteristics of the 14 studied cider-apple orchards.** Two contiguous orchards (referred by *a* or *b*) have been monitored in each location (referred by number). In each orchard, 3 cider-apple cultivars were planted (DDA = Douce de l'Avent<sub>cov</sub> cultivar, DAB = Dabinett cultivar and JUD= Judor cultivar). The Environmental Impact Quotient (EIQ) of each insecticide applied during the RAA presence on the apple trees was used to assess the cumulative toxicity of insecticides used in each orchard each year ( $EIQ_{field\ use\ rating}$ ). \*: only 63 trees monitored in 2014; \*\*:only 425 trees monitored in 2014. NA means Not Applicable.

Location	1		2		3		4		5		6		7		
Orchard	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b	
Year of planting	2010	2010	2012	2012	2011	2011	2012	2012	2011	2011	2011	2011	2010	2010	
Density of planting															
by number of trees/ha	774	774	495	774	774	774	495	774	1000	1000	774	774	774	774	
(planting distance between	(5.5*2.3)	(5.5*2.3)	(6.5*3)	(5.5*2.3)	(5.5*2.3)	(5.5*2.3)	(6.5*3)	(5.5*2.3)	(5.3*2)	(5.3*2)	(5.5*2,3)	(5.5*2.3)	(5.5*2.3)	(5.5*2.3)	
rows*planting distance															
within rows)															
Number of monitored trees	198	198	153	153	162	162	117*	117*	234	234	279	279	270**	270**	
<i>EIQ<sub>field use rating</sub></i> 2014	DDA	0.61	5.58	0	1.20	0.35	0.35	0	0	NA	NA	NA	NA	0	0.29
in (for each apple	DAB	0.61	5.58	0	1.20	0.35	0.35	0	0	NA	NA	NA	NA	0	2.09
cultivar)	JUD	0.61	5.58	0	1.20	0.35	0.35	0	0	NA	NA	NA	NA	0	0
<i>EIQ<sub>field use rating</sub></i> 2015	DDA	0.67	6.61	0	0	0	2.80	0	1.16	0.087	0.33	0	6.81	0	0.24
in (for each apple	DAB	0.67	6.61	0	0	0	1.60	0	1.16	0.087	0.33	0	4.67	0	0.35
cultivar)	JUD	0.67	6.61	0	0	0	2.80	0	1.16	0.087	0.33	0	6.61	0	0.35

Mean distance	2014	0 (0)	34.5	0	38.9	1	43.6	2	24.9	NA	NA	NA	NA	1.5	39.8
(+SD) of orchard			(14.2)	(0)	(11.3)	(0)	(12.0)	(0)	(4.6)					(0)	(13.2)
trees to the closest															
flower strip (in m)	2015	0 (0)	34.5	0	38.9	1	43.6	2	31.8	10.8	27.0	11.9	36.9	1.5	33.4
(according to the			(14.2)	(0)	(11.3)	(0)	(12.0)	(0)	(8.6)	(6.2)	(12.9)	(6.9)	(14.8)	(0)	(11.9)
year)															
Mean distance	2014	16.0	21.3	23.9	20.7	21.3	21.3	15.5	13.8	NA	NA	NA	NA	21.5	28.1
(+SD) of orchard		(7.2)	(11.8)	(12.9)	(10.4)	(11.0)	(11.0)	(6.0)	(4.64)					(11.3)	(12.9)
trees to the closest															
hedgerow (in m)	2015	16.9	21.3	23.9	20.7	21.3	21.3	20.8	18.3	14.3	15.2	27.6	27.6	23.7	23.7
(according to the		(7.2)	(11.8)	(12.9)	(10.4)	(11.0)	(11.0)	(10.4)	(8.2)	(6.6)	(6.5)	(14.1)	(14.1)	(12.7)	(12.7)
year)															

**Table 2: Total number of observed arthropods (and range of the mean number for one monitored tree per observation in one studied orchard) by taxonomic group, life stage and year.**

			Year		Total
			2014	2015	
Number of studied orchards			10	14	
Total number of observations (date*orchard)			35 (from 5 to 10)	57 (from 5 to 11)	103
Order	Family	Life stage			
Diptera	Syrphidae	Eggs	1083 (from 5.6 <sup>-2</sup> to 0.50)	1122 (from 2.9 <sup>-2</sup> to 1.7)	2205
		Larvae	408 (from 1.0 <sup>-2</sup> to 0.47)	429 (from 3.0 <sup>-2</sup> to 0.51)	838
		Adults	9 (from 0 to 1.0 <sup>-2</sup> )	51 (from 0 to 5.3 <sup>-2</sup> )	60
Coleoptera	Coccinellidae	All	1500 (from 6.6 <sup>-2</sup> to 0.71)	1602 (from 6.0 <sup>-2</sup> to 2.3)	3103
		Eggs	533 (from 0 to 4.7 <sup>-1</sup> )	1325 (from 0 to 5.2)	1858
		Larvae	141 (from 0 to 2.7 <sup>-1</sup> )	343 (from 0 to 3.8 <sup>-1</sup> )	484
		Adults	65 (from 6.3 <sup>-3</sup> to 8.8 <sup>-2</sup> )	161 (from 0 to 3.8 <sup>-1</sup> )	226
	Cantharidae	All	739 (6.3 <sup>-3</sup> to 0.79)	1829 (from 0 to 6.4)	2568
		Adults	17 (from 0 to 1.2 <sup>-2</sup> )	68 (from 0 to 4.1 <sup>-2</sup> )	85
		-	34 (from 0 to 4.5 <sup>-2</sup> )	92 (from 0 to 5.0 <sup>-2</sup> )	126
Hemiptera	Anthocoridae	-	37 (from 0 to 1.2 <sup>-2</sup> )	114 (from 0 to 1.7 <sup>-1</sup> )	153
	Nabidae	-	67 (from 0 to 2.4 <sup>-1</sup> )	0 (from 0 to 0)	67

			Year		Total
			2014	2015	
Number of studied orchards			10	14	
Total number of observations (date*orchard)			35	57	
			(from 5 to 10)	(from 5 to 11)	103
Neuroptera	Chrysopidae	Eggs	9	0	9
			(from 0 to 1.2^-2)	(from 0 to 0)	
		Larvae	0	2	2
			(from 0 to 0)	(from 0 to 6.0^-3)	
		Adults	0	3	3
	(from 0 to 0)	(from 0 to 2.3^-3)			
	All	9	5	14	
		(from 0 to 1.2^-2)	(from 0 to 6.0^-3)		
Dermaptera	Forficulidae	Juveniles+adults	582	742	1324
			(from 0 to 0.36)	(from 2.9^-3 to 0.60)	
Hymenoptera		Mummies	33	108	141
			(from 0 to 3.2^-2)	(from 0 5.4^-2)	
		Adults	12	25	37
			(from 0 to 3.2^-2)	(from 0 to 1.9^-2)	
		All	45	133	178
	(from 0 to 6.5^-2)	(from 0 to 5.7^-2)			
Araneae		Juveniles+Adults	296	440	737
			(from 0 to 0.16)	(from 0 to 0.16)	
AIINE			3326	5025	8355
			(from 0.10 to 1.45)	(from 0.30 to 7.4)	
			206195	554230	
Number of RAA			(from 0.77 to 95.5)	(from 21.0 to 182.4)	760425
			0.016	0.009	
Ratio (natural enemies per RAA)			(from 5.0^-4 to 0.18)	(from 2.4^-3 to 0.21)	0.0109
			9279	15578	
Ants			(from 2.4^-2 to 3.8)	(from 4.7^-2 to 7.1)	24857

**Table 3: Synthetic overview of the Generalized Linear Mixed models results:** “+” (resp. “-”) indicates that the factor is favourable (resp. unfavourable) to the considered arthropods. For the distance, a “+” (resp. “-”) indicates that the arthropods are more (resp. less) present in the vicinity of the agroecological infrastructure. For the cultivar factor “\*” means that cultivar has a significant effect on the response variable (*PA*, *logAUC* or *PD*) for at least one arthropod stage. 0 indicates that the factor did not significantly influence the variable. NA: not applicable. See Appendix A for detail.

	RAA	AIINE	Syrphidae	Coccinellidae	Forficulidae	Araneae	Ants
Distance to the							
closest	+	0	+	-	0	0	+
hedgerow							
Distance to the							
closest flower	-	+	+	+	+	0	-
strip							
Cultivar							
( <i>PA</i> / <i>logAUC</i> / <i>PD</i> )	*/*/*	*/*/*	*/0/*	*/*/*	*/0/0	*/0/0	*/0/0
<i>EIQ<sub>field use rating</sub></i>	-	-	-	-	-	-	-
RAA	NA	+	+	+	+	+	+

## FIGURE LEGENDS

**Fig. 1.** Map of the seven studied locations (two orchards per location). Black dots are the locations studied both in 2014 and 2015. Grey dots are the locations studied in 2015.

**Fig. 2.** Mean number (+ SE) of RAA (black dot), of all natural enemies (grey dotted line with circle mark), of Syrphidae (all stages) (grey dotted line with triangle mark) and of Coccinellidae (all stages) (grey dotted line with square mark) per monitored apple tree in aphid colonies in 2014 (A) and 2015 (B).

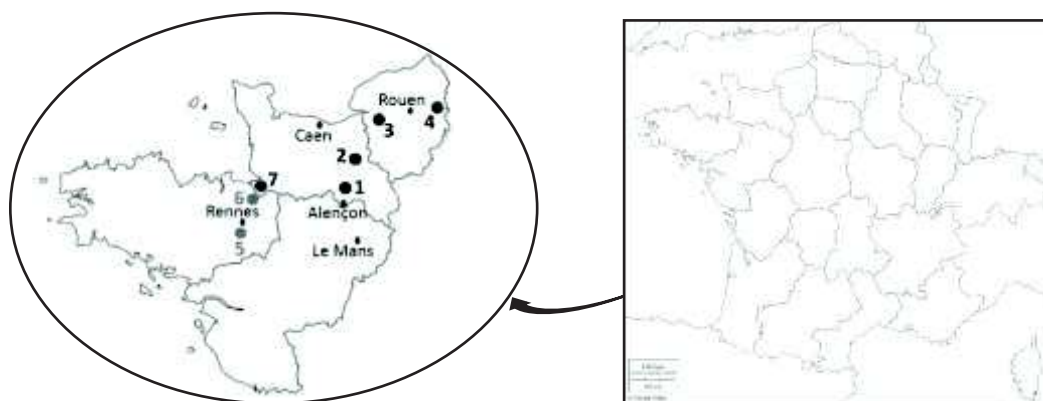


Fig. 1

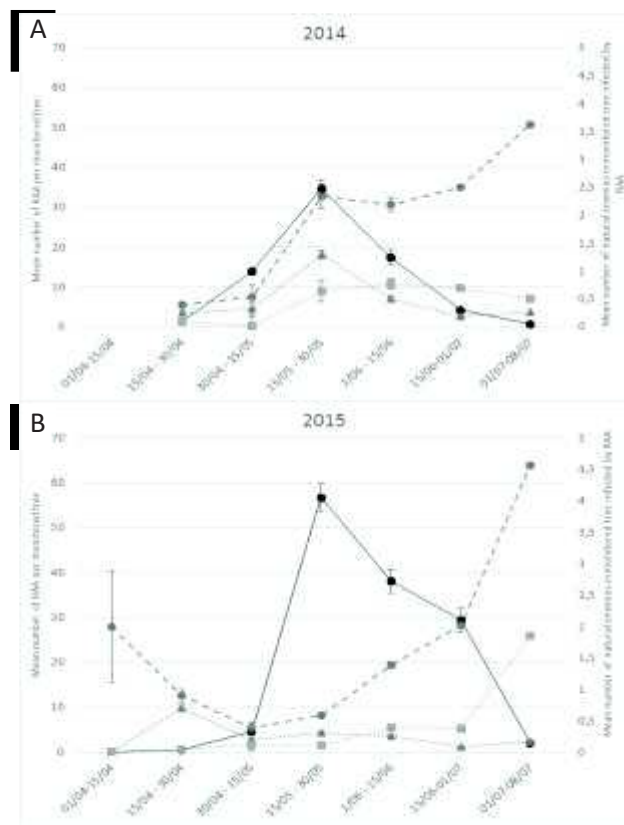


Fig. 2



## Supplementary Material

# Impact of Agroecological Infrastructures on the Dynamics of *Dysaphis plantaginea* Passerini (Hemiptera: Aphididae) and its Natural Enemies in Apple Orchards in Northwestern France

Laurence ALBERT<sup>a</sup>, Pierre FRANCK<sup>c</sup>, Yann GILLES<sup>a</sup>, Manuel PLANTEGENEST<sup>b</sup>

<sup>a</sup> Institut Français des Productions Cidricoles, La Rangée Chesnel, 61500 Sées, FRANCE, [l\\_albert5@yahoo.fr](mailto:l_albert5@yahoo.fr); [yann.gilles@ifpc.eu](mailto:yann.gilles@ifpc.eu)

<sup>b</sup> UMR1349 IGEPP, INRA/Agrocampus-Ouest/Université Rennes 1, 65 rue de Saint Brieuc, 35042 Rennes Cedex, FRANCE, [manuel.plantegenest@agrocampus-ouest.fr](mailto:manuel.plantegenest@agrocampus-ouest.fr)

<sup>c</sup> INRA Plantes & Systèmes de culture Horticoles, F-84914 AVIGNON Cedex 9, FRANCE, [pierre.franck@avignon.inra.fr](mailto:pierre.franck@avignon.inra.fr)

## Contents

Appendix A: Results of Generalized Linear Models obtained for each arthropod (by taxon and stage) and each variable.

Appendix B: Sum of arthropods observed per orchard each studied year (2014 and 2015) and mean number of arthropods per sampling date per tree infected with rosy apple aphid

Appendix A: Results of Generalized Linear Models obtained for each arthropod (by taxon and stage) and each variable. The first line is the pvalue of the variable, when inferior to 0.05, the second line is the coefficient. NS means no-significant. EIQ means Environmental Impact Quotient. AUC mean Area Under the Curve. DAB means cultivar of Dabinett, DDA means cultivar of Douce de l'Avent<sub>COV</sub> and JUD means cultivar of Judor.

		Variables studied				
		Log AUC of <i>D. plantaginea</i>	Distance to the hedgerow	Distance to the flower strips	Cultivar	EIQ <sub>field use rating</sub>
<i>Dysaphis plantaginea</i>	Probability of presence (binomial distribution)		**0.002537 -0.0058	*** < 2.2e-16 0.0111	5.348e-12 DAB<JUD<DDA	*** 7.166e-05 -0.057
	Log(Area Under the Curve) (normal distribution)		*** 0.0001546 -0.0171	*0.03814 0.0063	** 0.003741 DAB<DDA<JUD	NS 0.7999
	Presence duration (Gamma distribution)		*** <2.2^-16 -0.0057	*** 7.867e-16 0.0022	*** < 2.2e-16 DAB<JUD<DDA	*** 8.676e-13 -0.019
Global natural enemies	Probability of presence (binomial distribution)	***< 2.2e-16 0.277	NS 0.3227	NS 0.1266	***1.279e-10 DAB<JUD<DDA	*** 4.617e-05 -0.091
	Log(Area Under the Curve) (normal distribution)	***< 2.2e-16 0.194	NS 0.4274	***3.266e-06 -0.0082	***0.0004949 DAB<DDA<JUD	0.005526 -0.051
	Presence duration (Gamma distribution)	*** 2.894e-11 0.0535	NS 0.1892	**0.001459 -0.0029	** 0.003236 DAB<JUD<DDA	NS 0.2187
Eggs of Syrphidae	Probability of presence (binomial distribution)	*** < 2.2e-16 0.185	NS 0.7486	* 0.0366 -0.0048	*** 2.754e-05 DAB<JUD<DDA	0.01154 -0.0586
	Log(Area Under the Curve) (normal distribution)	*** 7.458e-08 0.122	NS 0.8587	** 0.001588 -0.00787	NS 0.1269	NS 0.1041
	Presence duration (Gamma distribution)	*** 4.961e-06 0.0422	*0.04781 -0.0034	*** 6.688e-05 -0.0044	NS 0.6885	*0.03559 0.0225
Larvae of Syrphidae	Probability of presence (binomial distribution)	***< 2.2e-16 0.286	NS 0.8352	** 0.002112 -0.0078	*** 9.99e-06 DAB<JUD<DDA	*** 0.0008589 -0.090
	Log(Area Under the Curve) (normal distribution)	*** 1.125e-07 0.117	NS 0.8032	* 0.03901 -0.00452	NS 0.08464	NS 0.4199
	Presence duration (Gamma distribution)	*** 0.0009433 0.0376	** 0.00516 -0.00536	NS 0.4155 -0.00091	* 0.02581 DAB<DDA<JUD	NS 0.6054
Eggs of Coccinellidae	Probability of presence (binomial distribution)	*** 8.057e-07 0.219	NS 0.1241	0.02953 -0.010	NS 0.2564	** 0.006066 -0.364
	Log(Area Under the Curve) (normal distribution)	NS 0.6864	NS 0.3697	NS 0.1016	** 0.002943 JUD<DAB<DDA	NS 0.8945
	Presence duration (Gamma distribution)	NS 0.06483	NS 0.4644	NS 0.3969	*0.04445 JUD<DAB<DDA	NS 0.3095
Larvae of Coccinellidae	Probability of presence (binomial distribution)	*** < 2.2e-16 0.285	** 0.005793 0.0162	*** 0.000528 -0.011	**0.00986 DAB<DDA<JUD	NS 0.4914
	Log(Area Under the Curve)	* 0.02581 0.122	NS 0.75	NS 0.4144	NS 0.728	NS 0.294

(normal distribution)						
Adults of Coccinellidae	Presence duration (Gamma distribution)	NS 0.1201	* 0.03643 0.0057	NS 0.7773	* 0.01121 JUD<DAB<DDA	NS 0.07431
	Probability of presence (binomial distribution)	*** 7.437e-15 0.246	NS 0.6654	NS 0.4651	* 0.01922 JUD<DAB<DDA	NS 0.09964
	Log(Area Under the Curve) (normal distribution)	NS 0.491	NS 0.1347	NS 0.895	NS 0.1843	NS 0.5245
	Presence duration (Gamma distribution)	NS 0.8494	NS 0.5724	NS 0.6548	*0.01378 JUD<DAB<DDA	NS 0.4131
Forficulidae (Juveniles and adults)	Probability of presence (binomial distribution)	*** < 2.2e-16 0.223	NS 0.9295	NS 0.8388	*0.01662 DAB<DDA<JUD	NS 0.2327
	Log(Area Under the Curve) (normal distribution)	** 0.001888 0.0892	NS 0.1346	0.04627 -0.005	NS 0.05784	* **0.0006422 -0.097
	Presence duration (Gamma distribution)	*0.03107 0.0304	NS 0.2126	** 0.005847 -0.00534	NS 0.5498	NS 0.9349
Araneae (Juveniles and adults)	Probability of presence (binomial distribution)	*** 4.533e-12 0.146	NS 0.9254	NS 0.1275	*** 1.155e-10 DAB<JUD<DDA	NS 0.08618
	Log(Area Under the Curve) (normal distribution)	NS 0.3479	NS 0.9367	NS 0.3193	NS 0.74	NS 0.1281
	Presence duration (Gamma distribution)	NS 0.1252	NS 0.5216	NS 0.4528	NS 0.1029	** 0.001295 -0.059
Ants	Probability of presence (binomial distribution)	*** < 2.2e-16 0.405	*** 0.000344 -0.0146	0.008168 0.0068	* 0.01761 JUD<DAB<DDA	NS 0.8418
	Log(Area Under the Curve) (normal distribution)	*** < 2.2e-16 0.509	NS 0.5379	NS 0.8873	NS 0.4117	* * 0.006257 -0.049
	Presence duration (Gamma distribution)	*** < 2.2e-16 0.152	NS 0.1676	NS 0.8688	NS 0.6604	NS 0.2145

Appendix B: Sum of arthropods observed per orchard each studied year (2014 and 2015) and mean number of arthropods per sampling date per tree infected with rosy apple aphid

Orchard	Sampling year	Sum of monitored tree per year	Diptera				Coleoptera				Dermaptera	Hymenoptera		Araneae	All NE	Ants	Number of tree with RAA	Number of RAA per tree infected by RAA	Ratio NE/RAA
			Syrphidae				Coccinellidae				Forficulidae	-		-	-	-			
			Eggs	Larvae	Adults	Total	Eggs	Larvae	Adults	Total	Nymph +adults	Mummies	adults	Juvenile +Adults	-	-			
1a	2014	1980	246 0.26	102 0.10	0 0	348 0.37	41 0.04	5 5.3 <sup>-3</sup>	7 7.5 <sup>-3</sup>	53 0.05	337 0.36	3 3.2 <sup>-3</sup>	0 0	105 0.11	850 0.91	3580 3.85	929 46,91%	62291 67.05	0.01
	2015	2574	294 0.43	63 0.09	3 4.4 <sup>-3</sup>	360 0.53	13 0.01	1 1.4 <sup>-3</sup>	4 5.8 <sup>-3</sup>	18 0.02	411 0.60	0 0	0 0	29 0.04	836 1.23	3915 5.77	678 26,34%	123724 182.48	6.7 <sup>-3</sup>
1b	2014	1980	234 0.29	11 0.01	0 0	245 0.31	0 0	0 6.3 <sup>-3</sup>	5 6.3 <sup>-3</sup>	5 6.3 <sup>-3</sup>	156 0.19	0 0	0 0	19 0.02	425 0.54	2461 3.14	783 39,54%	29953 38.25	0.01
	2015	2574	43 0.04	21 0.03	1 1.4 <sup>-3</sup>	65 0.09	0 0	2 2.1 <sup>-3</sup>	8 8.4 <sup>-3</sup>	10 0.01	211 0.22	0 0	2 2.1 <sup>-3</sup>	39 0.04	382 0.40	6712 7.11	943 36,63%	158824 168.4	2.4 <sup>-3</sup>
2a	2014	1377	282 0.50	119 0.21	0 0	401 0.71	260 0.46	43 0.07	9 0.01	312 0.55	18 0.03	1 1.7 <sup>-3</sup>	0 0	46 0.08	821 1.45	342 0.60	564 40,95%	16194 28.71	0.05
	2015	1683	23 0.09	36 0.14	0 0	59 0.23	53 0.21	35 0.13	5 0.01	93 0.37	4 0.01	9 0.03	0 0	12 0.04	212 0.84	12 0.04	251 14,91%	20977 83.5	0.01
2b	2014	1377	148 0.19	84 0.11	0 0	232 0.31	32 0.04	15 0.02	5 6.7 <sup>-3</sup>	52 0.06	8 0.01	2 2.6 <sup>-3</sup>	0 0	81 0.10	403 0.54	245 0.32	743 53,95%	32682 43.98	0.01
	2015	1683	13 0.02	39 0.15	1 3.9 <sup>-3</sup>	53 0.21	126 0.28	125 0.28	7 0.01	258 0.59	4 9.1 <sup>-3</sup>	5 0.01	3 6.8 <sup>-3</sup>	14 0.03	382 0.87	528 1.21	436 25,90%	57232 131.2	6.6 <sup>-3</sup>
3a	2014	810	19 0.06	3 0.01	0 0	22 0.08	15 0.05	1 3.6 <sup>-3</sup>	6 0.02	22 0.08	3 0.10	0 0	0 0	0 0	48 0.17	20 0.07	274 33,82%	263 0.95	0.18
	2015	972	235 1.79	67 0.51	7 0.05	309 2.35	221 1.68	51 0.38	37 0.28	309 2.35	24 0.18	0 0	2 0.01	0 0	691 5.27	239 1.82	131 13,47%	22047 168.2	0.03
3b	2014	810	16 0.05	3 0.01	0 0	19 0.06	0 0	0 0	5 0.01	5 0.01	5 0.01	0 0	0 0	2 7.0 <sup>-3</sup>	31 0.10	7 0.02	285 35,18%	222 0.77	0.13
	2015	972	21 0.13	23 0.17	0 0	44 0.33	0 0	0 0	4 0.02	4 0.02	31 0.19	0 0	0 0	3 0.01	89 0.55	57 0.35	161 16,56%	8388 52.0	0.01

4a	2014	378	6 0.07	9 0.11	0 0	15 0.18	19 0.24	21 0.26	4 0.05	44 0.55	0 0	1 0.01	0 0	13 0.16	92 1.16	80 1.01	79 20,89%	2411 30.51	0.03
	2015	819	34 0.65	2 0.03	1 0.01	37 0.71	247 4.75	15 0.28	20 0.38	282 5.43	1 0.01	0 0	1 0.01	1 0.01	354 6.80	0 0	52 6.34%	1629 31.3	0.21
4b	2014	378	11 0.16	2 0.02	0 0	13 0.19	32 0.47	16 0.23	6 0.088	54 0.79	7 0.10	0 0	0 0	6 0.08	92 1.35	3 0.04	68 17,98%	1309 19.25	0.07
	2015	819	28 0.35	5 0.09	1 0.019	34 0.65	441 5.58	35 0.44	31 0.39	507 6.41	0 0	1 0.01	0 0	1 0.01	587 7.43	2 0.02	79 9.64%	1661 21.02	0.35
5a	2015	2574	109 0.10	52 0.04	4 3.8 <sup>-3</sup>	165 0.15	27 0.025	2 1.9 <sup>-3</sup>	6 5.7 <sup>-3</sup>	33 0.03	13 0.01	57 0.05	3 2.8 <sup>-3</sup>	117 0.11	368 0.35	570 0.54	1044 40,55%	23252 22.27	0.01
5b	2015	2574	206 0.19	66 0.06	7 6.7 <sup>-3</sup>	279 0.26	108 0.10	72 0.06	27 0.024	136 0.12	9 8.5 <sup>-3</sup>	24 0.02	5 4.7 <sup>-3</sup>	99 0.09	651 0.62	1251 1.19	1048 40,71%	61721 58.89	0.01
6a	2015	2790	24 0.05	13 0.03	3 6.9 <sup>-3</sup>	40 0.09	89 0.20	4 9.3 <sup>-3</sup>	11 0.025	104 0.24	1 2.3 <sup>-3</sup>	1 2.3 <sup>-3</sup>	0 0	70 0.16	245 0.57	641 1.49	429 15,37%	20844 48.58	0.01
6b	2015	2790	8 0.03	0 0	6 0.01	14 0.03	0 0	1 3.9 <sup>-3</sup>	1 3.9 <sup>-3</sup>	2 7.8 <sup>-3</sup>	1 3.9 <sup>-3</sup>	0 0	3 0.01	41 0.16	79 0.30	845 3.13	255 9.13%	16913 66.32	4.6 <sup>-3</sup>
7a	2014	1875	8 0.12	42 0.45	1 0.10	51 0.54	24 0.25	26 0.27	4 0.04	54 0.58	1 0.10	3 0.03	3 0.03	3 0.03	115 1.23	262 2.81	93 4,96%	8889 95.5	0.01
	2015	2700	26 0.12	18 0.08	6 0.02	50 0.24	0 0	0 0	0 0	0 0	15 0.07	0 0	3 0.01	7 0.03	76 0.36	187 0.90	207 7.66%	10105 48.81	7.5 <sup>-3</sup>
7b	2014	1875	47 0.17	33 0.09	1 2.8 <sup>-3</sup>	81 0.22	85 0.24	12 0.03	8 0.02	105 0.29	43 0.12	20 0.05	3 8.4 <sup>-3</sup>	5 0.01	267 0.75	733 2.07	353 18,82%	17173 48.64	0.01
	2015	2700	58 0.17	24 0.11	11 0.05	93 0.44	0 0	0 0	0 0	0 0	17 0.05	11 0.03	3 9.1 <sup>-3</sup>	7 0.02	122 0.37	619 1.88	329 12,18%	26913 81.80	4.5 <sup>-3</sup>