



**HAL**  
open science

## Management diversity within organic production influences epigeal spider communities in apple orchards

Gaëlle Marliac, Christophe Mazzia, Alain Pasquet, Jean-Francois Cornic, Mickael Hedde, Yvan Capowiez

### ► To cite this version:

Gaëlle Marliac, Christophe Mazzia, Alain Pasquet, Jean-Francois Cornic, Mickael Hedde, et al.. Management diversity within organic production influences epigeal spider communities in apple orchards. *Agriculture, Ecosystems & Environment*, 2016, 216, pp.73-81. 10.1016/j.agee.2015.09.026 . hal-01444058

**HAL Id: hal-01444058**

**<https://hal.science/hal-01444058>**

Submitted on 4 Apr 2023

**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 - NonCommercial - NoDerivatives 4.0 International License

# Management diversity within organic production influences epigeal spider communities in apple orchards

Gaëlle Marliac <sup>a</sup>, Christophe Mazzia <sup>b</sup>, Alain Pasquet <sup>c</sup>, Jean-François Cornic <sup>d</sup>, Mickaël Hedde <sup>e</sup>, Yvan Capowiez <sup>a</sup>.

**a** : INRA, UR 1115 Plantes et Systèmes de cultures Horticoles, Site Agroparc, 84914 Avignon cedex 09, France

**b** : UAPV, UMR 7263 CNRS-IRD, Institut Méditerranéen de Biodiversité et Ecologie, 301 rue Baruch de Spinoza, BP 21239, 84916 Avignon cedex 09, France

**c** : CNRS, University of Lorraine, Faculté des Sciences et Technologies, UR AFPA, B.P. 239, 54504 Vandoeuvre les Nancy cedex, France

**d** : 5, allée des Violettes, 84610 Caumont, France

**e** : INRA, UMR 1402 Ecosys, 78026 Thiverval Grignon, France

*Published in Agriculture, Ecosystems and Environment. Available online: <http://dx.doi.org/10.1016/j.agee.2015.09.026>*

## Keywords

Organic pesticides, trait-based approach, biodynamics, insect-proof nets.

## Abstract

When compared to conventional production, organic production often has positive effects on the biodiversity of non-pest arthropods. However, organic production is only defined by the ban of synthetic pesticides and fertilizers and each farmer can still apply a wide variety of management practices that may also directly and indirectly influence arthropod biodiversity. Taking epigeal spiders inhabiting apple orchards as a case study, we first characterised the main agricultural practices applied in 20 selected organic orchards around Avignon in the South-East of France. Using ordination (PCA) and classification (HAC) methods, we identify three groups within these organic apple orchards: (i) the Biodynamics group, (ii) the Net group and (iii) the Classic group. The growers from the Biodynamics group used significantly less insecticides (40% less than those from the Classic group) and had more favourable habitat management practices (hedge and ground cover). We then sampled spider communities in each orchard in spring (April) and summer (June) using pitfall traps and showed that the spider communities in the Biodynamics and Net groups were significantly more abundant (+4% on average), species rich (+60% on average) and diverse (+70% on average) than those in the Classic group. GLM analysis showed that these differences were mainly due to reduced insecticide use but also the hedge quality of these orchards. A trait-based approach was further used to differentiate the spiders found in the three groups of orchards. The most striking finding was that spiders that use webs to forage (Linyphiidae, Ageniidae and Titanoecidae) were favoured in the Net group. This is probably because these nets protect the orchards from the major pest, allowing reduced pesticide use but also because the nets protect orchards from the windy conditions frequently observed around Avignon.

## 1. Introduction

---

In theory, organic production follows four principles: health, care, fairness and ecology (IFOAM, 2006). The principle of ecology is the basis for plant protection and states that “organic agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them”. In practice, organic production is defined mainly

based on the ban of chemical pesticides, chemical fertilizers, growth hormones, antibiotics, and genetically modified organisms. Besides this, other practices are recommended or encouraged such as habitat management to increase biodiversity and especially the abundance and diversity of natural enemies. Thus, farmers who adopt organic production

can still use a large set of different practices (Wyss et al., 2005; Zehnder et al., 2007). In addition, in the last two decades and with regulatory harmonisation at the European scale in 1991, the proportion of organic farms has increased in Europe to reach 2.23% (Willer et al., 2013). This increase has resulted in an additional diversity of practices due to either new alternatives or recent conversion to organic production for economical rather than ecological/ethical reasons (Lamine and Bellon, 2008). It is thus difficult to consider organic production as a homogeneous system, completely distinct from conventional production (Vasseur et al., 2013; Puech et al., 2014). Several authors suggested that diversity within the system could explain why meta-analyses comparing biodiversity in organic and conventional production did not detect significant differences for some taxa (Hole et al., 2005; Bengtsson et al., 2005). However this diversity of practices was rarely described in such studies. Furthermore, to our knowledge, its potential consequences on natural enemy communities have not yet been investigated.

To test this idea, we chose apple orchards in Provence (South-East of France) as an agronomic case study and the epigeal spiders inhabiting these orchards as a target community. Commercial organic apple orchards in the South-East of France are a highly sprayed crop with, on average, 25 pesticides applied each year (Sauphanor et al., 2009; Marliac

et al., 2015). An additional advantage of orchards is their perennial and multi-strata status (soil surface, grass and trees) in which habitat management is thought to have greater effects (Landis et al., 2000; Simon et al., 2010). This means that the effects observed on natural enemies may be increased and/or stabilised by the repeated application of the same agricultural practices over years. In orchards, communities of epigeal spiders are mainly influenced by pesticide applications (Pekar, 2012; Mazzia et al., 2015) and by habitat management within (ground cover) or around (hedges) orchards (Horton et al., 2002; Minarro et al., 2009; Marko and Keresztes, 2014). In this study we also benefited from the recent introduction of exclusion netting, also called Alt'carpo, a new alternative for controlling codling moth (*Cydia pomonella*), the main apple pest (Dib et al., 2010; Sauphanor et al., 2012). When these nets cover every single row in the orchards, the number of insecticides applied is significantly reduced and the microclimate is slightly modified (Capowiez et al., 2014).

The aim of this study was to define groups of practices in organic apple orchards based on differences in pesticide use and habitat management. We then used taxonomic and functional approaches to examine how these groups of practices influence spider community characteristics. In particular, we wanted to determine whether any effects on spider communities were due to differences in pesticide use.

## 2. Material and Methods

### 2.1. Characterisation of the orchards and crop management practices used therein

The study was carried out in the South-East of France, where 24% of French apple orchards are concentrated (Agreste, 2007), with 4% under organic farming (Agence Bio, 2012). We surveyed 24 organic apple farmers identified by the technical advisors of the region to represent the widest diversity of crop protection strategies in organic apple orchards in the South-East of France. Based on the results of these interviews, a set of 20 orchards (belonging to 12 farmers) was chosen in a 20 km circular region around Avignon (43°57'00"N and 4°49'01"E, Appendix A).

A set of characteristics was selected to describe the diversity of practices within these orchards. Due to the limited number of orchards studied, this number of characteristics was kept as low as possible and care was taken to ensure that these were not well correlated with each other (all correlation coefficients were <0.7). Some basic orchard characteristics (area and shape) were assessed but not included in the analysis of the farmer practices since, at least in the short-term, farmers cannot easily modify these characteristics. The shape of each orchard was computed by dividing its perimeter by the square root of its surface (this value increases as the orchard becomes more rectangular). The six selected characteristics focused on orchard vicinity (proportion of orchards: OP), habitat management (grass cover height and hedge quality: HQ) and pesticide use (TFI for fungicides, microbial and classical insecticides).

The linear proportion of orchards (OP) in close proximity to other orchards was computed as follows:

$$OP = \frac{\sum_{i=1}^4 b_i \times L_i}{\sum_{i=1}^4 L_i}$$

with *i* as the indice for each orchard border, *L<sub>i</sub>* the length of each orchard border and *b<sub>i</sub>* equal to 1 when this border separated two orchards (otherwise *b<sub>i</sub>* = 0). We only considered a 4-connectivity, i.e. the four edges of each orchard (corners were neglected). As no crops or woods were found around the 20 selected orchards, the proportion of orchards was also the inverse proportion of natural habitats (gardens, fallows or meadow) around each orchard.

The landscape around Avignon is characterised by the presence of a dense network of windbreak hedgerows protecting orchards against the prevailing northern winds. We thus computed an index (HQ) that merged hedgerow quantity and quality (in terms of floral diversity):

$$HQ = \frac{\sum_{i=1}^4 a_i \times L_i}{\sum_{i=1}^4 L_i}$$

with *i* as the indice for each orchard border, *L<sub>i</sub>* the length of each orchard border and *a<sub>i</sub>* = 0 when no hedgerow was present, *a<sub>i</sub>* = 1 for the presence of a hedgerow with a very low plant diversity (typically pure Cypressus hedgerow) and *a<sub>i</sub>* = 2 for the presence of a hedgerow with higher plant diversity (i.e.

the dominant species represents less than 80% of the trees). Some farmers under organic management chose to decrease the frequency of mowing to promote the abundance and diversity of natural enemies within orchards (Marliac et al., 2015). Since the ground cover density did not vary (natural grass species) and was very dense in all the orchards, we only characterised its mean height based on the measurements made at the two spider sampling dates. For this, ten measurements were carried out at randomly chosen locations in the rows of each orchard.

Only natural pesticides are authorised in organic orchards. The main pesticides used in apple production are: copper and sulphur (fungicides), mineral oils, Pyrethrum and spinosad (insecticides), which target aphids and codling moth and some microbial insecticides targeting codling moth (granulovirus and *Bacillus thuringiensis*). In each orchard, treatment calendars were recorded and analysed to compute the overall treatment frequency index (TFI) as the total number of treatments per hectare with commercial products, weighted by the ratio of the dose used to the recommended dose (Jørgensen, 1999). The TFI was determined for three classes of pesticides: fungicides, microbiological insecticides, and other insecticides and computed following the formula:

$$TFI = \sum_{i=1}^n \frac{AD_i}{HD}$$

where n is the total number of pesticides applied in one year in an orchard, AD<sub>i</sub> is the amount of each pesticide applied and HD is the recommended amount per hectare.

To study the variability within these 20 organic orchards, a PCA was applied to the six orchard characteristics (OP, ground cover height, HQ and TFI for the three classes of pesticides) and followed by a Hierarchical Ascending Classification (HAC) using Ward's algorithm of aggregation by variance applied on Euclidean distances. After visual inspection of this classification, three well-separated groups of orchards were defined (Appendix B).

The significance of these groups was then tested using a between-class analysis based on a permutation test and applied on the PCA coordinates on the two first axes (Chessel et al., 2004). The difference between these groups for each characteristic was tested either using a one way-ANOVA after log-transformation when necessary or a Kruskal-Wallis test when the requirements for ANOVA were not met.

## 2.2. Spider sampling

Spiders were collected using pitfall traps (diameter = 11 cm, depth = 8 cm) partially filled with a solution of diluted (1:5) ethylene glycol mixed with a few ml of detergent. The sampling dates were chosen (April and June of 2012) to correspond to periods of pesticide application in orchards. In each orchard at each date, six pitfall traps were placed in the centre of three different inter-rows of the orchard separated from each other by at least one row to limit spatial autocorrelation. The rows were chosen to be the furthest possible from the borders. In the selected rows, the first and the last pitfall traps were located at least 20 m from the row extremities. Pitfall traps were always placed at least 10 m from each other and more

than 20 m away from any hedges or orchard borders. Their contents were collected after one week and preserved in 70% alcohol for further identification. Adult spiders were identified to the species level and juveniles to the genus level (Roberts, 1996; Nentwig, 2003). Platnick (2012) was used as a standard for taxonomy.

## 2.3. Characterisation of the spider communities in each organic group

### 2.3.1. Taxonomic and functional characteristics

To assess whether epigeal spider communities were different in the three organic groups, we first characterised the taxonomic composition of the spider communities. An ordination method (PCA) was then used after Hellinger transformation of the data to study the species distribution and proportion between groups and dates. The means of the number of species (species richness SR), the Shannon-Wiener diversity index (H') and the Pielou's equitability index (J') of the communities were also computed. Then ecological traits defined for each species were used to assess community functional characteristics. All these analyses were performed at the species level thus excluding juveniles. However, to take into account these juvenile spiders, the mean abundance of each spider family was also computed. To avoid the effect of rare species in analyses of compositional and functional diversity, spider species for which the abundance was less than 0.5% of the total spider abundance were discarded.

For the functional trait-based approach, six functional traits of each spider species were chosen and so again only adults were considered. Body size (five attributes: 0–2.5, 2.5–5, 5–7.5, 7.5–10 and >10 mm) was derived from Roberts (1996) and Nentwig (2003). Maternal care (binary attributes) and prey types (three attributes: walking, flying or jumping prey) were derived from the review on hunting and reproductive strategies in Foelix (2011) and Nentwig (2013). Ballooning, which is the propensity to aerial dispersion of juveniles and adults was taken from the data of Greenstone et al. (1987) and the review of Bell et al. (2005). The period of activity for adults and stage for survival during winter (overwintering) was detailed by LePeru (2006). All ecological and morphological traits were stored in a database called BETSI, "Biological & Ecological functional Traits of Soil Invertebrates" (Pey et al., 2014). To take into account all the information gathered on each species, we did not consider traits as exclusive values instead we used the fuzzy coding method (Chevenet et al., 1994), the percentage of affinity of each species to a class of a trait was thus coded by a procedure adapted to terrestrial invertebrates (Hedde et al., 2012, 2013). This means that a species is not "forced" to feed on only one type of prey (walking or flying or jumping) but that depending on the information found in the scientific literature, a species can have, for example, a diet of 50, 30 and 20% of flying, walking and jumping prey, respectively. Community-weighted mean trait values (CWM; Lavorel et al., 2008) were computed using the 'FD package in the R environment (Laliberté and Shipley, 2011). CWM for one trait is simply the mean affinity of the spider community for this attribute taking into account (i) the attribute affinity of each species composing this community and (ii) the species relative abundance. CWM trait values were then used to analyse functional profiles (i.e. distribution of affinities between the attributes of a trait) in response to each group of orchards.



### 2.3.2. Statistical analysis of the spider communities

The mean abundance of each spider family in each organic group was compared using Kruskal–Wallis tests with two factors (orchard group and date) followed by a post-hoc comparison test (Zar, 1984). For the PCA, the difference between organic groups (and dates) was tested using a between-class analysis based on a permutation test and applied on the PCA coordinates on the two first axes (Chessel et al., 2004). To determine whether orchard group, date or their interaction influenced the community characteristics (abundance, species richness, diversity, evenness), we used a linear mixed-effect (LME) regression model. Using the ‘nlme’ library for R (Pinheiro et al., 2011), we created LME regression models with an intercept-only fixed-effect term and a random effect term that included the sampled orchard. Post-hoc comparisons were made using the ‘multcomp’ library for R. The same approach (LME) was applied to identify the effect of the studied factors on CWM. Post-hoc comparisons were made using the ‘multcomp’ library for R.

### 2.4. Exploring the link between pesticide use and spider communities

If spider communities differed between organic groups, we wanted to know whether these differences were mainly due to differences in pesticide use or to another management practice. However, to define the orchard groups, the overall TFI values computed for the whole year were used. Thus, to correlate spider communities at both sampling dates to the pesticides applied recently, we computed partial TFI values for each two-month period before the spider sampling distinguishing again between insecticides, fungicides and

microbial insecticides. Indeed, we assume that the effects of pesticides in each orchard are due to those applied prior to sampling. Ground cover height was measured at each date but it should be noted that for each orchard, values for HQ and OP were the same for the two dates.

TFI only indicates the intensity of pesticide use. To estimate the toxicity related to the active ingredients applied in each orchard, we used the database of pesticide toxicity on natural enemies developed by the International Organization for Biological and Integrated Control (IOBC. <http://www.iobc-wprs.org/>). In this database, a toxicity class has been assigned to each pesticide on a scale of 1–4 from lowest to highest mortality. We calculated cumulative IOBC toxicity indices for each orchard, using the following formula:  $S$  (TFI<sub>pesticide</sub> X toxicity) where TFI<sub>pesticide</sub> was the TFI of one pesticide and toxicity the toxicity class of this pesticide (Thomson and Hoffmann, 2006). Differences in mean toxicity between groups were then tested using a one-way ANOVA after log-transformation.

To determine which factor influenced the characteristics of the spider communities, we used LME, as described previously, to identify the respective effects of the six previously defined orchard characteristics. An information-theoretic approach including all the candidate models (based on the fit of all possible variable combinations) was used. The best model was selected using Akaike information criterion (AIC) (Zuur et al., 2012). Computations were carried out using the ‘MuMIn’ package for R.

## 3. Results

### 3.1. Identification and characterisation of three groups of orchards

The three groups of orchards defined by the HAC were well separated on the two first axes of the PCA, representing approximately 70% of the variability (Fig. 1). The between class analysis indicated that the difference between these groups was significant ( $p < 0.01$ ). The first axis was defined by the TFI for fungicides and insecticides (positive coordinates) and the hedge quality and proportion of non-cultivated areas around each orchard (negative coordinates). This axis opposed a first group (negative coordinates) to two other groups (Fig. 1). This first group included all the farmers that followed the guidelines of biodynamic principles (here Demeter1 guidelines) and two additional organic farmers. This group was further named ‘Biodynamic’. The second axis opposed the two remaining groups. The TFI for microbial insecticide and to a lesser extent the insecticide TFI (positive scores) were mainly responsible for the contrasts on this second axis (Fig. 1). The group with negative coordinates on the second axis included farmers that mainly (five out of six) used a new alternative (Alt’carpo nets) against codling moth and it was named ‘Net’. The third group was named by default ‘Classic’. None of the orchards in this last group followed biodynamic principles but one orchard (out of eight) was covered with Alt’carpo nets.

The Biodynamic group differed significantly from the two other groups due to less fungicide use (only 3.42 fungicides were applied per year) and taller groundcover (on average >35 cm) (Table 1). In addition this group is significantly different to the Classic group because of less insecticide use (40% less), higher hedge quality and a lower proportion of nearby orchards. Overall the Biodynamic group used the least pesticides (if microbial insecticides are not included due to their a priori low toxicity) and relied the most on habitat management. The differences between the two other groups are mainly driven by lower insecticide and microbial insecticide use in the Net group with 4.33 and 6 applications respectively per year compared to 6.4 and 13.65 for orchards from the Classic group (Table 1). Of note for some growers, when one orchard but not a second one was covered with nets, the two orchards were not assigned to the same group.

### 3.2. Differences between spider communities in the orchards groups

A total of 4804 spiders were caught including 4126 adults which were identified to the species level. However, after exclusion of 49 rare species, only 3949 adults and 30 species were considered (Table 2). The most common spider families were Lycosidae (58.8%), Linyphiidae (21.9%), Gnaphosidae (5.7%) and Tetragnathidae (4.3%). Three species were the most abundant (*Pardosa hortensis*, *Pardosa proxima* and

*Oedothorax apicatus*) and accounted for 57% of the total number of spiders caught. About 94% of the *O. apicatus* were found in the Classic group whereas only 29 and 16% of *P. hortensis* and *P. proxima* respectively, were caught in this Classic group.

The PCA did not clearly separate the spider communities based on the three orchard groups, even when the analysis was carried out with each date separately, since the three orchard groups greatly overlapped. (Appendix C). The analysis only showed that the sampling date had a strong effect on the composition of the spider communities since the first axis (representing 16.4% of the variability) separated the April and June communities. The date had a significant effect on mean abundance and species richness, with higher values in June compared to April, but no effect on the diversity ( $H'$ ) or equitability ( $J'$ ).

Regarding the effect of the orchard groups, the mean abundance of adult spiders per trap was significantly lower in the Classic group compared to the Biodiversity and Net groups with a mean decrease of 60% (Fig. 2). The same results were observed for abundance when juveniles were included (results not shown). The mean species richness and the Shannon–Wiener diversity also decreased significantly by 37 and 28% respectively in the Classic group compared to the mean values observed in the Biodiversity or Net groups. No significant difference was observed for equitability (Fig. 2).

At the family level (thus including juveniles), we only observed significant differences for Linyphiidae, which were more abundant in the Net groups (with on average 6.67 linyphiid spiders per pitfall) compared to the two other groups (with 2.05 and 2.03 linyphiid spiders in the Classic and Biodiversity groups respectively).

### 3.3. Effects on spider functional diversity

## 4. Discussion

### 4.1. Diversity of agronomical practices within organic apple production

In our case study of apple orchards in the South-East of France, even with a limited set of orchards and producers, we were able to define three distinctive groups. These three groups were defined by both their reliance on pesticide use and the characteristics of the natural habitats within (ground cover) or around (hedges) the orchards. The Biodiversity group was characterised by a lower fungicide and insecticide use and a greater reliance on microbial insecticides, which are more specific and thus less toxic to non-target organisms. These orchards also had the taller ground cover (thus low mowing frequency), higher values for hedge quality and fewest nearby orchards. The Net group mainly included orchards covered by nets (but not only) and thus that relied less on microbial insecticides since the net is a physical and efficient way of controlling the main apple main pest, *C. pomonella* (Sauphanor et al., 2012). For most of the parameters, these orchards had intermediate values between the Biodiversity group and the Classic group, except for the ground cover height that was similar to that observed for the Classic group.

The three groups of orchards had significantly different CWM for many functional traits. In contrast, sampling date rarely had an effect on CWM (Table 3) and no significant interaction was found between the two factors for any traits.

Two sets of functional attributes had different CWM responses in the three orchard groups. For the first set, a significant difference was observed between the Biodiversity group and the Net group with intermediate values for the Classic group. The relative percentage of spiders with the ability to disperse as aeronauts (at both the juvenile and adult stages) and whose diet consisted of non-walking prey was significantly lower in the Biodiversity group compared to the Net group. The percentage of spiders showing maternal care and having an active foraging strategy (no web) was significantly lower in the Biodiversity group compared to the Net group (Table 3). For the second set of traits, a significant difference was revealed between the Biodiversity and the Classic and Net groups. The percentage of spiders overwintering as juveniles was higher in Biodiversity orchards than in Classic and Net orchards. The percentage of spiders with a body size within the 5.0–7.5 mm range was significantly higher in the Biodiversity compared to the Classic and Net groups. For the body size interval of 2.5–5.0 mm, the opposite trend was observed.

### 3.4. Pesticide toxicity and factors influencing spider communities

The IOBC toxicity indexes differed for the defined groups of orchards. The pesticides applied in the Biodiversity group had a significantly lower estimated toxic effect than those applied in the Classic group, with Net orchards having intermediate values (Table 1).

Model selection indicated that only insecticide use (negatively) influenced spider abundance. Insecticide use also had a negative effect on species richness and diversity ( $H'$ ) whereas these were positively influenced by the index for hedge quality (Table 4).

This Classic group relies heavily on the use of fungicides and insecticides (including microbial). In addition, these orchards had lower ground cover heights, lower values for hedge quality and are surrounded by a higher percentage of orchards. The two axes of de-intensification, through (i) reduced pesticide use and (ii) proportion or quality of the natural habitats were oriented in opposite directions in the first axis of the PCA. Thus, from these results it is difficult to disentangle the relative influence of these two main factors on spider communities.

Overall, using apple production to identify and characterise the diversity of practices within organic production was an appropriate choice. Indeed, pome fruit production is characterised by high levels of pesticide use (with TFI values between 12 and 40) and, as a perennial crop, the stability of its natural habitats. The high level of pesticides is linked to the economical importance of damages due to codling moth and apple-scab. The diversity of pesticide use in our region depends on ethical choices and the tolerance for lower yields (Biodiversity group) as well as the emergence of a new alternative for controlling codling moth (Net group).

## 4.2. Effects of management diversity within organic production on spider communities

Using a meta-analysis approach, Garratt et al. (2011) showed that organic agrosystems had an overall significantly positive effect on spider abundance even if most of the case-studies found a neutral effect (among these studies, 36, 24 and 8 were neutral, positive or negative respectively). These global positive effects are thought to be associated with a decrease in use of synthetic pesticides but also other cultural practices (fertilizers, habitat management). Indeed, for epigeal or ground spiders, several studies found that spider communities were more abundant (Pfiffner and Luka, 2003; Cardenas et al., 2006; Prieto-Benitez and Mendez, 2011) or more species-rich in organic systems (Pekar and Koucourek, 2004). In orchards, it is known that communities of epigeal spiders are sensitive to pesticides (Pekar, 2012) and mowing frequency (Horton et al., 2002). In addition, an increasing number of reports have shown that some landscape characteristics such as landscape heterogeneity or the presence of hedges influence spider communities (Schmidt et al., 2008; Garratt et al., 2011).

We were able to reveal differences in the characteristics of the spider communities within organic production. However, despite clear differences in the total abundance for some species (including *O. apicatus*), no clear separation of the communities found in the three production strategies was found with PCA. This suggests that no spider species (or group of species) abundance or proportion was obviously preferentially associated with any of the organic production group. Thus, the spider communities may assemble from a habitat species pool, selected at a regional scale rather than a local scale. In contrast, date and thus species phenology had a much greater effect with some clear-cut effects (seven out of 30 species were only present at one of the two dates; Table 2). The community characteristics did enable a clear separation of the Biodynamy and Net groups from the Classic group, in which the spider communities had lower abundance, species richness and diversity. The Biodynamy and Classic groups differed strongly in fungicide and insecticide use but also in ground cover height, hedge quality and the proportion of surrounding orchards. The only difference between the Net and Classic groups is the higher use of insecticides (microbial or not) in the Classic orchards. The estimate of the pesticide application toxicity, which was significantly higher in the Classic group than in the Biodynamy group, corroborated these results. Further, linear regression analysis indicated that the intensity of insecticide use (and not fungicides or microbial insecticides) and the hedge quality (not the ground cover) has the most influence on the characteristics of the spider communities.

Our main findings, increased spider abundance and diversity in the Biodynamy group, were not completely unexpected since within organic production biodynamic production represents a special approach characterised, for example, by the use of herbal teas for general crop health (Chalker-Scott, 2013). Thus, this type of organic production is actually characterised by low pesticide use, an avoidance of the most toxic insecticides (no spinosad or Pyrethrum were used in these orchards) and an increased focus on habitat quality (hedge and groundcover choice and management). Surprisingly, the differences between classical organic and

biodynamic production on invertebrate diversity have not yet been widely assessed with the noticeable exception of Pfiffner and Niggli (1996) and Birkhofer et al. (2008). However, both these wheat studies reported no significant differences for epigeal spiders.

## 4.3. Trait-based approach

The CWM estimates revealed two sets of traits with different responses to the orchard groups. The first set separated the Biodynamy group from the two other groups. Spider communities in the Biodynamy group had a different overwintering strategy (with a greater proportion of spiders overwintering as juveniles) and size distribution (with a greater proportion of larger species). Individuals overwintering as juveniles reproduce in early summer, a period of intense pesticide spraying in apple orchards and this may explain their higher proportion in the Biodynamy group where pesticide applications are the lowest. The difference in size distribution may be indirectly linked to the significantly lower abundance of Linyphiidae spiders in the Biodynamy group.

The second set of functional traits opposed Net to Biodynamy, with the Classic group having intermediate values. These traits described spider diet, hunting strategy, dispersion ability and parental care. The main striking difference lies in the much higher proportion of web building spiders (hunting strategy) in the Net group. Indeed, in these orchards we observed higher mean abundances of Linyphiidae, Agelenidae and Titanoecidae (albeit the difference was significant only for the first family), i.e. the only three spider families identified in this study which build webs. This in turn explains the difference in prey with a much higher proportion of spiders which feed on flying and jumping prey, prey that are classically caught in webs, in the Net group. The big difference in spiders which are able to disperse through the air is linked to the higher proportion of Linyphiidae spiders (one abundant family) that are known to be good aeronauts. In turn this may explain the relative lower proportion of spiders exhibiting maternal care (most are Lycosidae and none are Linyphiidae). Nets are not only an effective way to decrease pesticide use but are also a physical barrier for controlling codling moth. As such, they modify the micro-climate in and around the apple trees. Specifically this kind of physical protection is known to reduce the air ventilation rate and thus the wind speed (Fatnassi et al., 2013; Tanny, 2013). Wind, depending on its speed, can be a strong constraint for web-building spiders. Indeed, wind influences orb-web spider behaviour (Turner et al., 2011), the location and the geometry of the web (Ramirez et al., 2003; Wu et al., 2013) as well as spider abundance (Stokmane and Spungis, 2014). In our case, orchards in which each row is covered by a small meshed net represent a better environment for web-building spiders, especially in a very windy region such as Avignon (for example 76 days with maximal wind speed higher than 50 km h<sup>-1</sup> were recorded in 2012).

A striking finding of our study is that although classical ordination methods, based on species abundance, did not separate the three groups of organic orchards, the trait-based approach, based on the functional traits of these species, did. This reinforces the postulate that trait-based approaches best reflect the link between biodiversity and environment since they rely on causal relationships between individual features and stresses/constraints (Pey et al., 2014).

## 5. Conclusion

---

Organic production is not a simple and homogeneous production system. Its technical definition (ban of synthetic pesticides and fertilizers) hides a wide variety of agricultural practices. Within apple production in the South-East of France, it was thus possible to define three well-separated types of orchards based on pesticide use and habitat management. We further demonstrated that these groups had a significant impact on epigeal spider communities which responded negatively in abundance and diversity to pesticide use and positively to the hedge presence and quality (floral diversity). Thus, if this variability in practices, which has an impact on beneficial

organisms, is ignored this could explain why sometimes in meta-analysis the benefits of organic production compared to conventional production are not clearly identified. It also shows that organic production, depending on the agricultural practices applied and especially the type of pesticides used, can even have detrimental effects on beneficials such as epigeal spiders. Finally, our study highlighted that in intensively sprayed crops, some alternative methods, such as nets as a physical control tool, can also be efficient and environmentally friendly. Their complete sustainability however remains to be fully assessed.



**Table 1. Means (+SE) values for the main characteristics of the three groups of organic apple orchards. Only the first six characteristics were used for the PCA and HAC analysis. For each line, values bearing the same letters are not significantly different at the 5% level.**

<b>Empty Cell</b>	<b>Biodynamy group</b>	<b>Nets group</b>	<b>Classic group</b>
<b>% of orchards in the vicinity (OP)</b>	51.69 <sup>b</sup> (9.34)	71.38 <sup>ab</sup> (9.49)	82.30 <sup>a</sup> (8.91)
<b>Groundcover height (cm)</b>	35.62 <sup>a</sup> (0.28)	23.67 <sup>b</sup> (0.39)	20.12 <sup>b</sup> (0.35)
<b>Index for hedge quality (HQ)</b>	1.32 <sup>a</sup> (0.12)	1.00 <sup>ab</sup> (0.12)	0.67 <sup>b</sup> (0.15)
<b>TFI fungicide</b>	3.42 <sup>a</sup> (1.07)	11.83 <sup>b</sup> (2.96)	16.69 <sup>b</sup> (1.02)
<b>TFI insecticide</b>	2.58 <sup>b</sup> (0.30)	4.33 <sup>b</sup> (0.74)	6.40 <sup>a</sup> (0.54)
<b>TFI fungicide</b>	3.42 <sup>a</sup> (1.07)	11.83 <sup>b</sup> (2.96)	16.69 <sup>b</sup> (1.02)
<b>Area (ha)</b>	0.70 (0.13)	0.68 (0.14)	0.66 (0.19)
<b>Shape</b>	4.86 (0.26)	4.43 (0.17)	5.05 (0.43)
<b>IOBC toxicity index (whole calendar)</b>	31.92 <sup>b</sup>	50.67 <sup>ab</sup>	76.52 <sup>a</sup>

**Table 2. Abundance of adult spiders for each species depending on the orchard groups and sampling dates. The family is only given for the first species of each family.**

Abundance of adult spiders for each species depending on the orchard groups and sampling dates. The family is only given for the first species of each family.

Species names (and family)	Biodynamy group	Net group	Classic group	April	June
<i>Tegenaria hasperi</i> (Agelinidae)	4	16	2	0	22
<i>Phrurolithus festivus</i> (Phrurolithidae)	13	15	28	14	42
<i>Drassylus praeficus</i> (Gnaphosidae)	7	6	2	0	15
<i>Gnaphosa alacris</i>	3	14	3	0	20
<i>Gnaphosa lucifuga</i>	14	5	5	2	22
<i>Haplodrassus signifer</i>	12	11	6	29	0
<i>Trachyzelotes barbatus</i>	9	3	3	1	14
<i>Civuelotes civicus</i>	12	2	5	3	16
<i>Zelotes nilicola</i>	7	13	15	0	35
<i>Zelotes tenuis</i>	9	48	20	0	77
<i>Agyneta rurestris</i> (Linyphiidae)	22	5	9	2	34
<i>Diplocephalus cristatus</i>	5	19	4	17	11
<i>Diplostyla concolor</i>	40	58	63	74	87
<i>Erigone dentipalpis</i>	6	8	27	29	12
<i>Mermessus trilobatus</i>	7	7	0	5	9
<i>Oedothorax apicatus</i>	25	6	447	138	340
<i>Pelecopsis parallela</i>	6	3	2	10	1
<i>Alopecosa pulverulenta</i> (Lycosidae)	16	11	2	27	2
<i>Pardosa agrestis</i>	135	62	15	118	94
<i>Pardosa agricola</i>	2	4	4	4	6
<i>Pardosa hortensis</i>	272	370	260	135	767
<i>Pardosa proxima</i>	488	324	160	314	658
<i>Trochosa hispanica</i>	24	59	21	67	37
<i>Trochosa ruricola</i>	3	54	22	64	15
<i>Xerolycosa miniata</i>	35	4	54	16	77
<i>Thanatus atratus</i> (Philodromidae)	8	2	3	0	13
<i>Pisaura mirabilis</i> (Pisauridae)	8	6	5	17	2
<i>Pachygnata degeeri</i> (Tetragnathidae)	29	126	15	34	136
<i>Nurscia albomaculata</i> (Titanoeidae)	17	108	8	0	133
<i>Zodarion italicum</i> (Zodariidae)	64	12	46	71	51

**Table 3. Effects of the apple orchard group on the community-weighted means trait values (mean percentages of the spider community sharing an ecological trait). Only traits for which a significant difference between orchard groups was observed are presented. p-Values for orchard groups and season are given. Values bearing a same letter are not different at the 5% level.**

Trait (attribute)	Biodynamy	Net	Classic	p-Values (group)	p-Values (season)
Dispersion (yes)	12.01b	34.17a	22.68ab	0.034	0.35
Diet (walking prey)	34.11a	23.11b	29.33ab	0.018	0.42
Foraging mode (web)	13.42a	38.25b	23.14ab	0.016	0.48
Parental care (yes)	66.99a	41.97b	52.60ab	0.006	0.20
Overwintering (juveniles)	43.76a	31.36b	38.73b	0.027	0.31
Body size (2.5–5 mm)	21.29b	33.49a	29.67a	0.031	0.78
Body size (5–7.5 mm)	61.33a	34.18b	18.56b	<0.01	0.01

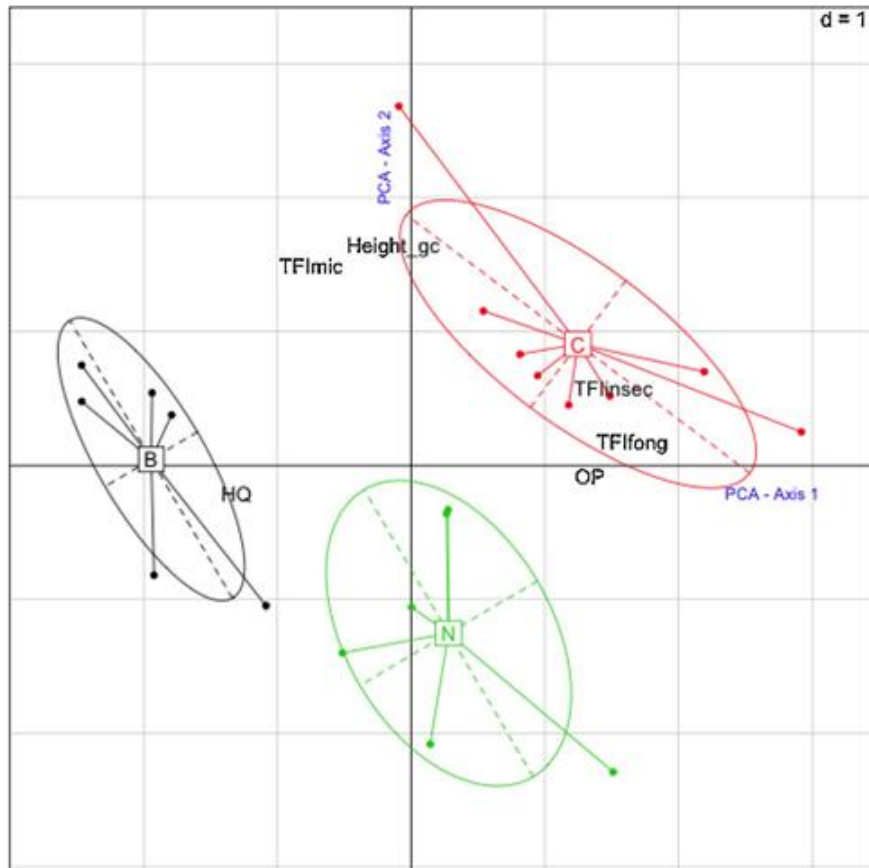
**Table 4. Summary of the linear mixed-effect model (LME) and model selection testing the effects of the orchard characteristics on the spider communities. For each response variable, the significant explanatory variables of the**

best model according to the Akaike information criterion, their standardised effect and standard error (SE) are shown as well as the R2 value of the selected model. TFI: treatment frequency index.

Response variable	Explanatory variables <sup>a</sup>	Standardised effect	SE	Estimated R2
Abundance (excluding juveniles)	TFlinsecticide	-0.284	0.07	0.40
Species richness	TFlinsecticide	-0.731	0.16	0.53
	HQ <sup>b</sup>	+1.909	0.68	
Shannon-Wiener diversity index (H')	TFlinsecticide	-0.089	0.02	0.35
	HQ	+0.420	0.15	
Pielou evenness (J')	None			

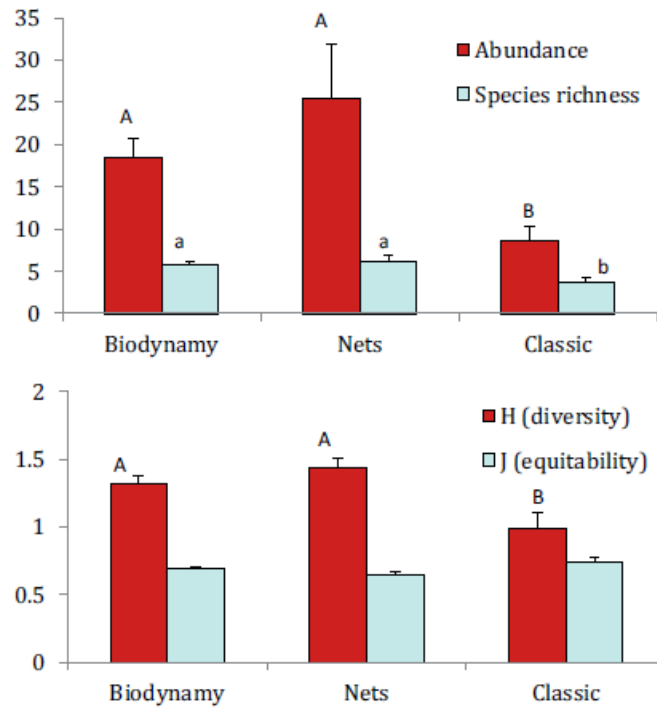
a Kept after model selection.

b Synthetic index of hedge quality.



**Figure 1**

Projection of the orchards on the two first axes of the principal component analysis of agricultural practices (these two axes explained more than 70% of the variability). Each practice ('Height\_gc' for height of the ground cover, 'TFIfong', 'TFImic' and 'TFlinsec' for treatment frequency index for fungicides, microbial insecticides and other insecticides respectively, 'OP' for orchard proportion in the vicinity and 'HQ' for hedge quality) is indicated at its barycentre (coordinates were multiplied by two for the sake of readability). Ellipses are drawn around orchards belonging to the same group defined after HAC ('C' for Classic, 'N' for Nets and 'B' for Biodynamy).



**Figure 2**

Means values (+SE) for the spider characteristics of the epigeal spider communities in the three groups of orchards: abundance and species richness, Shannon-Wiener diversity index ( $H'$ ) and Pielou equitability ( $J'$ ). Bars sharing a letter are not statistically different (capital letters were used for abundance and diversity).

## 6. References

- Agence Bio, 2012. <http://www.agencebio.org/la-bio-en-France>
- Agreste, 2007. <http://agreste.agriculture.gouv.fr/page-d-accueil/article/donnees-en-ligne>
- Bell, J.R., Bohan, D.A., Shaw, E.M., Weyman, G.S., 2005. Ballooning dispersal using silk: world fauna, phylogenies, genetics and models. *Bull. Entomol. Res.* 95, 69–114.
- Bengtsson, J., Ahnström, J., Weibull, A.-C., 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. *J. Appl. Ecol.* 42, 261–269.
- Birkhofer, K., Bezemer, T.M., Bloem, J., Bonkowski, M., Christensen, S., Dubois, D., Ekelund, F., Fliessbach, A., Gunst, L., Hedlund, K., Mäder, P., Mikola, J., Robin, C., Setälä, H., Tatin-Froux, F., Van der Putten, W.H., Scheu, S., 2008. Long-term organic farming foster below and aboveground biota: implications for soil quality, biological control and productivity. *Soil Biol. Biochem.* 40, 2297–2308.
- Capowiez, Y., Severac, G., Alaphilippe, A., Gros, C., Parisi, L., Simon, S., Franck, P., Lavigne, C., Plénet, D., Siegwart, M., Angevin, F., Mazzia, C., Rault, M., 2014. Impacts Agronomiques Et Environnementaux D'une Méthode De Lutte Permettant De Réduire Fortement L'usage Des Pesticides: Les Filets Alt'carpo En Arboriculture. Rapport D'activité. Ministère de l'Ecologie et du Développement Durable, Paris.
- Cardenas, M., Ruano, F., Garcia, P., Pascual, F., Campos, M., 2006. Impact of agricultural management on spider populations in the canopy of olive tress. *Biol. Control* 38, 188–195.
- Chalker-Scott, L., 2013. The science behind biodynamic preparations: a literature review. *HortTechnology* 23, 814–819.
- Chessel, D., Dufour, A.-B., Thioulouse, J., 2004. The ade4 package-I-one-table methods. *R. News* 4, 5–10.
- Chevenet, F., Doledec, S., Chessel, D., 1994. A fuzzy coding approach for the analysis of long-term ecological data. *Freshwater Biol.* 31, 295–309.
- Dib, H., Sauphanor, B., Capowiez, Y., 2010. Effect of codling moth exclusion nets on the rosy apple aphid, *Dysaphis plantaginea*, and its control by natural enemies. *Crop Prot.* 29, 1502–1513.
- Fatnassi, H., Boulard, T., Bouriden, L., 2013. Development, validation and use of a dynamic model for simulate the climate conditions in a large greenhouse equipped with insect-proof nets. *Comput. Electron. Agric.* 98, 54–61.
- Foelix, R.F., 2011. *Biology of Spiders*. Oxford University press, New York.
- Garratt, M.P.D., Wright, D.J., Leather, S.R., 2011. The effects of farming system and fertilisers on pests and natural enemies: a synthesis of current research. *Agric. Ecosyst. Environ.* 141, 261–270.
- Greenstone, M.H., Morgan, C.E., Hultsh, A.-L., 1987. Ballooning spiders in Missouri, USA, and New South Wales, Australia: family and mass distributions. *J. Arachnol.* 15, 163–170.
- Hedde, M., van Oort, F., Lamy, I., 2012. Functional traits of soil invertebrates as indicators for exposure to soil disturbance. *Environ. Pollut.* 164, 59–65.
- Hedde, M., van Oort, F., Renouf, E., Thénard, J., Lamy, I., 2013. Dynamics of soil fauna after plantation of perennial energy crops on polluted soils. *Appl. Soil Ecol.* 66, 29–39.
- Hole, D.G., Perkins, A.J., Wilson, J.D., Alexander, I.H., Grice, F., Evans, A.D., 2005. Does organic farming benefit biodiversity? *Biol. Conserv.* 122, 113–130.
- Horton, D.R., Broers, D.A., Lewis, R.R., Granatstein, D., Zack, R.S., Unruh, T.R., Moldenke, A.R., Brown, J.J., 2002. Effects of mowing frequency on densities of natural enemies in three Pacific Northwest pear orchards. *Entomol. Exp. Appl.* 106, 135–145.
- IFOAM, 2006. The principles of organic agriculture. International Federation of Organic Movements [http://www.ifoam.bio/sites/default/files/ifoam\\_poa.pdf](http://www.ifoam.bio/sites/default/files/ifoam_poa.pdf).
- Jørgensen, L.N., 1999. Denmark's action plans for pesticides: status and role of research. *Nordisk Jordbrugsforskning* 81, 201–202.
- Laliberté E., Shipley B., 2011. FD: measuring functional diversity from multiple traits, and other tools for functional ecology, R package version 1. 0–11.
- Lamine, C., Bellon, S., 2008. Conversion to organic farming: a multidimensional research at the cross roads of agricultural and social science. A review. *Agron. Sustain. Dev.* 29, 97–112.
- Landis, D.A., Wratten, S.D., Gurr, G.M., 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annu. Rev. Entomol.* 45, 175–201.
- Lavorel, S., Grigulis, K., McIntyre, S., Williams, N.S.G., Garden, D., Dorrough, J., Berman, S., Quetier, F., Thebault, A., Bonis, A., 2008. Assessing functional diversity in the field—methodology matters!. *Funct. Ecol.* 22, 134–147.
- LePeru, B., 2006. Catalogue et répartition des araignées de France. *Rev. Arachnol.* 16, 1–468.
- Marko, M., Keresztes, B., 2014. Flowers for better pest control? Ground cover plants enhance orchard spiders (Araneae) but not necessarily their impacts on pests. *Biocontrol Sci. Technol.* 24, 574–596.
- Marliac, G., Penvern, S., Barbier, J.-M., Lescourret, F., Capowiez, Y., 2015. Impacts of crop protection strategies in organic apple production. *Agron. Sustain. Dev.* 35, 803–813.
- Mazzia, C., Pasquet, A., Caro, G., Thénard, J., Cornic, J.-F., Hedde, M., Capowiez, Y., 2015. The impact of management strategies in apple orchards on the structural and functional diversity of epigeal spiders. *Ecotoxicology* 24, 616–625.
- Minarro, M., Espadaler, X., Melero, V.X., Suarez-Alvarez, V., 2009. Organic versus conventional management in an apple orchard: effects of fertilization and tree-row management on ground-dwelling predaceous arthropods. *Agric. For. Entomol.* 11, 133–142.
- Nentwig, W., 2003. Management of biodiversity in agroecosystems. *Basic Appl. Ecol.* 4, 105–106.
- Nentwig, W., 2013. *Ecophysiology of Spiders*. Springer-Verlag, Berlin.
- Pekar, S., Koucourek, F., 2004. Spider (Araneae) in the biological and integrated pest management of apple in Czech Republic. *J. Appl. Entomol.* 128, 561–566.
- Pekar, S., 2012. Spiders in the pesticide world: an ecotoxicological review. *Pest Manag. Sci.* 68, 1438–1446.
- Pey, P., Nahmani, J., Auclerc, A., Capowiez, Y., Cluzeau, D., Cortet, J., Decaëns, T., Deharveng, L., Dubs, F., Joimel, S., Briard, C., Grumiaux, F., Laporte, M.A., Pasquet, A., Pelosi, C., Pernin, C., Ponge, J.-F., Salmon, S., Santorufu, L., Heede, M., 2014. Current use of and future needs for soil invertebrate functional traits in community ecology. *Basic Appl. Ecol.* 15, 194–206.
- Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., the R Development Core Team, 2011. Nlme: linear and nonlinear mixed effects models. R package version 3. 1–113.
- Pfiffner, L., Luka, H., 2003. Effects of low-input farming systems on carabids and epigeal spiders—a paired farm approach. *Basic Appl. Ecol.* 4, 117–127.
- Pfiffner, L., Niggli, U., 1996. Effects of bio-dynamic, organic and conventional farming on ground beetles (Col. Carabidae) and other epigeal arthropods in winter wheat. *Biol. Agric. Hortic.* 12, 353–364.
- Platnick, N., 2012. *The World Spider Catalog V 13.0*. American Museum of Natural History.
- Prieto-Benitez, S., Mendez, M., 2011. Effect of land management on the abundance and richness of spiders (Aranea): a meta-analysis. *Biol. Conserv.* 144, 683–691.
- Puech, C., Baudry, J., Joannon, A., Poggi Aviron, S.S., 2014. Organic vs. conventional farming dichotomy: does it make sense for natural enemies? *Agric. Ecosyst. Environ.* 194, 48–57.
- Ramirez, M.G., Wall, E.A., Medina, M., 2003. Web orientation of the banded garden spider *Argiope trifasciata* (Araneae, Araneidae) in a California coastal population. *J. Arachnol.* 31, 405–411.
- Roberts, M.J., 1996. *Spiders of Britain and Northern Europe*. Harper Collins, London.
- Sauphanor B., Dirwimmer C., Boutin S., Chaussabel A., Dupont N., Fauriel J., Gallia V., Lambert N., Navarro E., Parisi L., Plénet D., Ricaud V., Sagnes J.-L., Sauvaitre D., Simon S., Speich P., Zavagli F., 2009. Analyse comparative de différents systèmes en arboriculture fruitière. INRA (Ed.) *Ecophyto R&D: vers des systèmes de culture économes en produits phytosanitaires. Rapport d'Expertise Collective INRA. Tome I*.
- Sauphanor, B., Severac, G., Maugin, S., Toubon, J.-F., Capowiez, Y., 2012. Exclusion netting may alter reproduction of the codling moth (*Cydia pomonella*) and prevent associated fruit damage to apple orchards. *Entomol. Exp. Appl.* 145, 134–142.
- Schmidt, M.H., Thies, C., Nentwig, W., Scharnke, T., 2008. Contrasting responses of arable spiders to the landscape matrix at different spatial scales. *J. Biogeogr.* 35, 155–166.
- Simon, S., Bouvier, J.-C., Debras, J.-F., Sauphanor, B., 2010. Biodiversity and pest management in orchard systems. A review. *Agron. Sustain. Dev.* 30, 139–152.
- Stokmane, M., Spungis, V., 2014. Diversity of grass-dwelling spiders (Arachnida, Araneae) in a calcareous fens of the Coastal Lowlands, Latvia. *J. Insect Conserv.* 18, 757–769.
- Tanny, J., 2013. Microclimate and evapotranspiration of crops covered by agricultural screens. *Biosyst. Eng.* 114, 26–43.
- Thomson, L.J., Hoffmann, A.A., 2006. Field validation of laboratory-derived IOBC toxicity ratings for natural enemies in commercial vineyards. *Biol. Control* 39, 507–515.
- Turner, J., Vollrath, F., Hesselberg, T., 2011. Wind speed affects prey-catching behaviour in an orb web spider. *Naturwissenschaften* 98, 1063–1067.
- Vasseur, C., Joannon, A., Aviron, S., Burel, F., Menard, J.-M., Baudry, J., 2013. The cropping system mosaic: how does the hidden heterogeneity of agricultural landscapes drive arthropod populations? *Agric. Ecosyst. Environ.* 166, 3–14.
- Willer, H., Lernoud, J., Kilcher, L., 2013. *The World of Organic Agriculture: Statistics and Emerging Trends 2013*. Frick: Research Institute of Organic Agriculture (FiBL) & Bonn: International Federation of Organic Agriculture Movements (IFOAM).
- Wu, C.C., Blamires, S.J., Wu, C.L., Tso, I.M., 2013. Wind induces variations in spider web geometry and sticky spiral droplet volume. *J. Exp. Biol.* 216, 3342–3349.
- Wyss, E., Luka, H., Pfiffner, L., Schlatter, C., Gabriela, U., Daniel, C., 2005. Approaches to pest management in organic agriculture: a case study in European apple orchards. *Organic Research.com*. Cab International, Wallingford, UK, pp. 33N–36N.
- Zar, J.H., 1984. *Biostatistical Analysis*. Prentice-Hall, Englewood Cliffs NJ.
- Zehnder, G., Gurr, G.M., Kuhne, S., Wade, M.R., Wratten, S.D., Wyss, E., 2007. Arthropod pest management in organic crops. *Annu. Rev. Entomol.* 52, 57–80.
- Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., Smith, G.M., 2012. *Mixed Effects Models and Extensions in Ecology with R*. Springer, Berlin.

## 7. Acknowledgements

The study was funded by PURE project, supported by the European Commission through the Seventh Framework Programme under grant agreement number: FP7-

265865. The PhD fellowship of G. Marliac was jointly financed by the DynRurABio program and the Smach metaprogram.