



Management strategies in apple orchards influence earwig community



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HIGHLIGHTS

- The earwig communities were studied in orchards with increasing pesticide use.
- Pesticide use had a stronger impact on earwigs than orchard characteristics.
- Earwig abundance decreased from low-input orchards to organic and IPM orchards.
- *F. pubescens* was more sensitive to insecticides than *F. auricularia*.

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ABSTRACT

Our aim was to assess whether different apple orchard management strategies (low-input, organic, Integrated Pest Management (IPM)) would have an effect on earwigs, which are important natural enemies of apple pests. These commercial orchards were as well compared to abandoned orchards. The density of *Forficula auricularia* and *Forficula pubescens* was studied for three years in 74 orchards around Avignon. The pesticide usage, some orchard characteristics and two small-scale landscape parameters were characterized. Pesticide use was significantly different between low-input, organic and IPM orchards with particularly significant differences in the number of insecticide applications (2.2, 4.9 and 9.2 respectively). Pesticide use had a much stronger impact on earwig community than other characteristics. *F. auricularia* density was significantly lower in IPM orchards (0.47 individuals per tree) compared to organic, low-input and abandoned orchards (3.1, 4.5 and 1.6 individuals per tree, respectively). *F. pubescens* was almost absent from IPM orchards and its abundance was higher in abandoned or low-input orchards compared to organic orchards (1.5 and 2.8 vs 0.8 individuals per tree). The percentage of *F. pubescens* in the earwig community decreased from abandoned (52%) to low-input (40%), organic (15%) and IPM orchards (0.5%). These results were confirmed by LD₅₀ assays showing that for the two pesticides causing mortality close to normal application rates (chlorpyrifos-ethyl and acetamiprid), *F. pubescens* was significantly more sensitive than *F. auricularia*. Since earwigs are also easy to capture and identify, they may be useful to estimate the effects of management strategies and their modification in pome fruit orchards.

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1. Introduction

Pesticides are widely applied worldwide to protect crops (Köhler and Triebkorn, 2013). Since the use of pesticides in agriculture inevitably leads to exposure of non-target organisms,

Abbreviations: IPM, Integrated Pest Management; NAR, normal application rate; TFI, Treatment Frequency Index computed on all pesticides; TFI_{fungicide}, TFI_{insecticide}, TFI_{microbial}, Treatment Frequency Index computed only on fungicides, insecticides and microbial insecticides, respectively.

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undesirable side-effects may affect some species (Denoyelle et al., 2007), communities (Desneux et al., 2007; Pélosi et al., 2013) or the ecosystem as a whole (Hole et al., 2005; Bianchi et al., 2006). In France, apple orchards are among the most intensely agrochemical-treated crops with, on average, more than 30 pesticide applications per year in Provence, South-Eastern France (Sauphanor et al., 2009; Butault et al., 2011). They are thus an interesting case to study the deleterious effects of pesticides on non-target populations. Two pest management strategies are generally identified in commercial apple orchards: Integrated Pest Management (IPM) and organic farming. In France, new protection

methods are being developed to decrease pesticide use such as Alt'carpo nets, i.e. exclusion nets against codling moth (Dib et al., 2010a; Sauphanor et al., 2012). To estimate the impacts of pesticide use and to be able to follow the positive effects of a decrease in pesticide use, we need species that are widespread, easy to collect and able to tolerate sub-lethal effects of contaminants over a wider range.

Studies of the use of terrestrial species to assess pesticide effects are however few in number and present different limitations. In orchards, spiders (epigeal or arboreal) or carabids are often used (Pekar, 1999; Marko et al., 2009; Minarro et al., 2009) but specialist knowledge is required to identify species. Earwigs (Dermaptera: Forficulidae) are arthropods commonly found in apple orchards. In South-Eastern France, they live in the trees from May to October and then in the soil in fall and winter where females build nests to deposit their eggs and nymphs live until the second instar. They are nocturnal and hidden in shelters during the day. Earwigs produce an aggregation pheromone (Sauphanor, 1992) and this characteristic permits easy capture and counting in shelters and traps (Dib et al., 2010b). Earwigs are also omnivorous and in pome fruit and citrus orchards they are considered to be efficient generalist predators (Dib et al., 2011; Romeu-Dalmau et al., 2012).

The effects of pesticides and especially insecticides on predators can be either direct (toxicity) or indirect (through decrease in the abundance of prey) (Sauphanor and Stäubli, 1994; Pekar, 1999). Earwigs are sensitive to organophosphate and pyrethrinoid insecticides (Ffrench-Constant and Vickerman, 1985; Sauphanor and Stäubli, 1994; Epstein et al., 2000; Badji et al., 2004; Nicholas et al., 2005; Logan et al., 2011). More recent insecticides such as thiacloprid or spinosad are toxic or very toxic to *Forficula auricularia* (Shaw and Wallis, 2010). In contrast, it is generally thought that earwigs are not sensitive to fungicides (Hassan et al., 1994; Sterk et al., 1999). Besides pesticides, earwig abundance and diversity can also be influenced by other agricultural practices such as tillage (Sharley et al., 2008; Moerkens et al., 2012) and the presence and quality of hedges (Debras et al., 2007). The characteristics of the bark of apple trees and thus the apple cultivar, offering shelter, can also have an effect (Debras et al., 2007).

In this study, we aimed at assessing whether contrasted management strategies would have impacts on earwig communities inhabiting apple orchards. For this, we studied their presence and diversity in apple orchards under four different management regimes, from abandoned orchards without pesticide use to experimental orchards and commercial orchards with increasing pesticide use (from organic to IPM). To discuss some of our field results, we also determined the impact of the most commonly used pesticides on earwigs through LD₅₀ assays under laboratory conditions.

2. Materials and methods

2.1. Field sites and characterization

This study was carried out in the South-East of France within a radius of 20 km around Avignon. In total, 74 orchards were investigated over a three-year period (2011–2013). Among these 74 orchards, eight were abandoned (for at least five years) and six were classified as low-input regarding pesticide use (experimental INRA orchards). The remaining orchards were commercial: 35 organic and 25 under IPM. Not all orchards were surveyed each year (Appendix 1).

In each surveyed orchard, treatment calendars were recorded and analyzed by computing the global Treatment Frequency Index (TFI) as the total number of pesticide treatments, weighted by the

ratio of the dose used to the recommended dose (Jørgensen, 1999). However, since organic farming uses different kinds of pesticides, the TFI was determined for three classes of pesticides: fungicides, microbiological insecticides (granulosis virus and *Bacillus thuringiensis*), and other insecticides. The insecticides and fungicides authorized for use in organic farming are all natural products (mainly mineral oil, spinosad and pyrethrum as insecticides and sulfur and copper as fungicides) whereas in IPM orchards synthetic pesticides are used as well. Other agricultural practices are different between organic orchards and low-input or IPM orchards. Tillage and organic fertilizers are applied in organic orchards, herbicides and mineral fertilizers to the latter. Thus the possible effect of tillage in early spring through nest destruction (Moerkens et al., 2012) cannot be disentangled from those of management type (organic vs IPM).

Each orchard was briefly described at the beginning of the study (once a year unless major changes were noted). This description included the characterization of the hedgerows, the nature of the land cover surrounding the orchard (i.e. proportion of adjacent orchards), some descriptors of the orchard (surface area, shape) and some tree characteristics (bark roughness). This latter was assessed through a qualitative estimation (using 3 qualitative classes). The landscape around Avignon is characterized by the presence of a dense network of windbreak hedgerows which protects orchards against the prevailing northern winds. We thus created and computed an index (HT for Hedge Type) that merged hedgerow quantity and quality (in terms of floral diversity):

$$HT = \sum (a_i L_i) \sum (L_i) \quad (1)$$

with L_i the length (in m) of each orchard border ($i = 1-4$) and $a_i = 0$ when no hedgerow was present, $a_i = 1$ for the presence of a hedgerow with a very low plant diversity (typically pure *Cypressus* hedgerow) and $a_i = 2$ for the presence of a hedgerow with higher plant diversity (i.e. the dominant species represents less than 80% of the trees). Regarding land cover around each orchard, we computed the linear proportion of orchards (OP, i.e. Orchard Proportion) in the surroundings as follows:

$$OP = \sum (b_i L_i) \sum (L_i) \quad (2)$$

with L_i the length of each orchard border and b_i equal to 1 when this border separated two orchards (otherwise $b_i = 0$). We only considered a 4-connectivity ($i = 1-4$), i.e. the four edges of each orchard (corners were omitted). The shape of each orchard was simply computed by dividing its perimeter by the square root of its surface (the higher this value, the more rectangular the orchard).

2.2. Earwig sampling

Earwig populations were estimated in orchards for two different periods, first every month from May to August and then at one time point in late autumn (October) when earwigs are looking for shelters for overwintering. The first time period corresponds to the activity of earwigs in the trees and to the maximum pesticide use in orchards and the second time period is about 2 months after the last pesticide application. Since the second time period is less time consuming and less risky for the sampler health, it may be preferred. However we have to determine if earwig abundances in late autumn are correlated to those from spring and summer. In both periods, we used 10 cm wide corrugated cardboard band traps wrapped around tree trunks. Thirty band traps per orchard were randomly located and sampled avoiding the first and last rows. The minimum distance between traps was set to 10 m. For each sampling date, the thirty bands were enclosed individually in plastic bags and only opened under laboratory conditions. Each

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