Management implications of earwigs’ overwintering sites in a Mediterranean citrus grove

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\textbf{ABSTRACT}

To promote earwigs as natural enemies of pests, or to control their populations if they damage crops, earwigs can be managed during their overwintering period on the ground. Here, we obtained more than a ton of soil to study earwigs’ overwintering sites in a citrus grove. We found four species of earwigs: \textit{Forficula pubescens}, \textit{Euborellia annulipes}, \textit{Euborellia moesta}, and \textit{Nala lividipes}. Surprisingly, and although the European earwig \textit{Forficula auricularia} is abundant in the citrus canopies the rest of the year, we did not find any \textit{F. auricularia}, indicating that this species spends the winter outside the citrus grove. Therefore, farmers willing to manage European earwig populations in citrus orchards need to consider the possibility that earwigs may spend the winter outside the field. Earwigs that were overwintering in the citrus grove were more abundant at the south side beneath the canopies than at the north side or between rows, indicating that management practices such as soil tillage can impact overwintering earwigs only beneath the canopies, but not between citrus rows. Overall, our results provide insights into how earwig populations can be successfully managed during winter in citrus orchards.

\textbf{1. Introduction}

Earwigs (Insecta: Dermaptera) are common in agroecosystems. As omnivorous insects, earwigs are considered key predators of pests and/or pests in their own right. On the one hand, earwigs are active predators of aphids (Mueller et al. 1988; Nicholas et al. 2005; Dib et al. 2010; Romeu-Dalmau et al. 2012), lepidopteran pests (Romeis and Shanower 1996; Suckling et al. 2006; Frank et al. 2007), and psyllids (Debras et al. 2007; Höhn et al. 2007). On the other hand, earwigs are often perceived as pests since they can damage leaves, flowers, and fruits (Brindley 1918; Fulton 1924; McLeod & Chant 1952; Robertson et al. 1994; Grafton-Cardwell et al. 2003; Romeu-Dalmau et al. 2012).

Farmers might be interested in managing earwig populations either to promote earwigs as key natural enemies of pests, or to control earwig populations if they damage a particular crop. To successfully manage earwig populations, an understanding of their biology is needed. This understanding is required not only for the periods when earwigs are active on the crops, but for their whole lifespan, including winter, when earwigs overwinter either in underground nests or in aggregations on the ground surface (Behura 1956; Lamb & Wellington 1975). However, most previous research on earwigs in crops focused on their active season (Mueller et al. 1988; Helsen et al. 1998; Nicholas et al. 2005; Suckling et al. 2006; Frank et al. 2007; Piñol et al. 2009; Romeu-Dalmau et al. 2012a), and seldom studies focused on studying earwigs during winter (Goodacre 1997; Moerkens et al. 2012; Soszynska-Maj & Jaskula 2013).

The main objective of this study was to determine where earwigs overwinter in a citrus orchard in order to evaluate the potential impact of winter management practices such as soil tillage on their populations. Previous studies that evaluated the impact of soil tillage on overwintering earwigs assessed such impact by monitoring their populations during their active period in trees (Moerkens et al. 2012), but did not monitor earwig populations belowground during winter. In this study, we aimed to obtain earwigs in numbers high enough to conduct sound statistical analyses about earwigs’ preferred overwintering sites, with the final aim to provide insights into how earwig populations can be successfully managed. To do so, we used a small backhoe loader to sample a total surface of 16 m\textsuperscript{2} that rendered more than a ton of soil. To our knowledge, this is the first time that such an effort is made to monitor earwig overwintering populations in the soil. Only seldom studies have reported earwigs in soil samples from farmland, but these studies were not aimed to study earwig populations in particular, and sampled smaller areas: 5.2 m\textsuperscript{2} (Wilson-Rummenie et al. 1999),
Our analysis described earlier rendered some earwigs species, like *Nala lividipes* and *Euborellia* sp., whose biology is much less known than the most common *Forficula* spp., as they spend most of their life on the ground (Albouy & Caussanel 1990; Sauphanor & Sureau 1993; Lordan 2014). Variations in the natural abundance of stable isotopes of C and N can reveal the trophic position of invertebrates (Ponsard & Arditi 2000), and this technique has been used before to study the trophic position of arthropods in agricultural fields (Wise et al. 2006; Duyck et al. 2011; Platner et al. 2012; Mestre et al. 2013). Therefore, as a secondary objective of the study, in order to get a rough idea of the trophic habits of these soil earwigs, we performed C and N stable isotopic analyses on earwigs and on some other typical soil inhabitants obtained in the same sampling.

2. Materials and methods

The study site was an organic plantation of citrus trees located at La Selva del Camp (Tarragona, NE Spain; 41° 13’ 07”N, 1° 8’ 35”E). The climate is Mediterranean, with a rainy spring and autumn and a dry winter and summer. The 0.75 ha grove consisted of about 300 Clementine trees grafted on the hybrid rootstock Carizzo citrange (*Poncirus trifoliata* (L.) Raf. x *Citrus sinensis* (L.) Osb.). The trees were watered during dry periods using micro-spray jets. Soil tillage has not been practised in the grove since 2008.

2.1. Soil sampling of overwintering earwigs

We used a randomized block design with 20 trees to study if the overwintering earwig community varied at different positions in relation to the tree. At each one, we took three soil samples: (1) north side beneath the trees, (2) south side beneath the trees, and (3) halfway between the selected tree and the corresponding tree in the neighbouring row (“between rows”; see supplemental material, Figures S1 and S2). In addition, to monitor overwintering earwigs at the edges of the groove, we selected three different “edges” at the limit between the field and the surrounding terrain (see supplemental material, Figure S1). We took eight samples at “edge 1,” and six samples at both “edge 2” and “edge 3.” In total, we took 80 soil samples to monitor overwintering earwigs.

Each soil sample consisted in a rectangular shallow trench of approximately 1 m long, 20 cm wide, and 8–10 cm deep obtained using a small backhoe loader (see supplemental material, Figure S3). The samples were obtained on 14 February 2011 and stored in sealed fabric bags in a nearby barn. Each sample was examined manually within three weeks of the sampling date. Soil was torn apart in small quantities over a white plastic tray, all earwigs and other macrofauna picked by hand or with tweezers, and immediately stored in 70% ethanol. In the laboratory, earwigs were determined to species using Albouy and Caussanel (1990) key to adult earwigs. As the nymphs, and sometimes even some adults, of *Euborellia annulipes* (Lucas) and *Euborellia moesta* (Gené) were difficult to differentiate at the species level, we mostly refer to them as *Euborellia* sp. Other soil macrofauna was also separated and identified, although these results are not presented here but for some isotopic analyses.

2.2. Stable isotopic analyses

Stable isotopic analyses of N and C were used to compare the trophic position of the different earwig species to other soil fauna. Only specimens sampled beneath the tree canopies (i.e. not from “between rows” or from the “edges” of the field; see earlier) were used for the isotopic analyses. In total, we analysed 32 earwig samples and 32 non-earwig samples. In particular, we made six analyses of *F. pubescens*, eight of *Nala lividipes*, two of *Euborellia moesta*, seven of *E. annulipes*, and nine of individuals identified as *Euborellia* sp. All earwigs were adults but for two samples of *Euborellia* sp. The non-earwig species included eight samples of each of the following groups: *Armadillidium* sp. (*Crustacea, Isopoda, Armadillidiidae*), *Geophilus* sp. (*Myriapoda, Chilopoda, Geophilidae*), *Polydesmus* sp. (*Myriapoda, Diplopoda, Polydesmidae*), and Oligochaeta.

Each sample consisted of 1–1.5 mg of dry material, placed into a tin capsule. For *Euborellia* sp., the head of one individual was used per sample, whereas for *F. pubescens* and *N. lividipes* two or more heads of different individuals were needed per sample to reach the required weight. For non-earwig species, we used per sample one head of *Armadillidium* sp., the proximal half of *Polydesmus* sp. and *Geophilus* sp., and approximately 5 mm of Oligochaeta.

Ratios of $^{13}$C and $^{15}$N were measured by a coupled system consisting of an elemental analyser (Elementar Analysensysteme GmbH, Hanau, Germany) interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, UK) at the UC Davies Stable Isotope Facility (CA, USA). During the analyses, samples were interspersed with several replicates of at least two different laboratory standards selected to be compositionally similar to the samples, and that were previously calibrated against IAEA (International Atomic Energy Agency, Vienna, Austria) standard reference materials. Isotope abundances are expressed as relative differences between samples and a reference in δ values (%). As conventional references, Vienna PeeDee Bellemnite and atmospheric N$_2$ were used for δ$^{13}$C and δ$^{15}$N values, respectively.
2.3. Statistical analyses

To compare the earwig community between the different overwintering sides in relation to the trees (excluding the "edges") we used a mixed model with one fixed factor ("position": N, S, or between rows) and one random factor ("tree"). To compare the earwig community between the citrus grove and the edges only one fixed factor ("site": inside the grove or edges) was included in the Permanova model. The variables considered for both analyses were the number of earwigs of each species at each individual trench. Data were square root transformed and distances were calculated using the Euclidean distance.

Finally, the comparison of the isotopic signature between groups was conducted using a one fixed factor ("taxon") bivariate Permanova. In this case, the δ13C–δ15N distances were also calculated using the Euclidean distance but without any previous data transformation.

All the statistical analyses were conducted with permutational ANOVAs (Permanova) run with the software PERMANOVA+ for PRIMER v.6 (Anderson et al. 2008).

3. Results

3.1. Soil sampling of overwintering earwigs

A total of 267 individuals belonging to four species of Dermaptera were found in the soil sampling of February 2011: Forficula pubescens (24 individuals), Nala lividipes (110 individuals), Euborellia moesta and E. annulipes (133 individuals considering the two species together). These quantities correspond to (mean ± st. error) 1.5 ± 0.1 ind/m² of F. pubescens, 6.9 ± 0.3 ind/m² of N. lividipes, and 8.3 ± 0.5 ind/m² of Euborellia sp.

By far, the highest density of earwigs was at the south side of trees and the lowest between rows (Figure 1). The earwig community significantly varied at different positions in relation to the tree (Pseudo-$F_{2,38} = 25.73; P = 0.0001$). The post-hoc permutational test showed that the earwig community was different at the north and at the south sides of trees ($t = 4.89; P = 0.0003$); in particular, there were many more N. lividipes and Euborellia sp. at the south than at the north side, whereas the density of F. pubescens was similar at both sides. The earwig community in the south side of the trees was also different than the one in the middle of the rows ($t = 5.93; P < 0.0001$), but the community at the north side of trees was similar to the one in the middle of the rows ($t = 1.73; P = 0.06$).

There were only marginal differences on the earwig community between the edges of the field and the field itself (Pseudo-$F_{1,78} = 2.92; P = 0.07$). The earwig community was significantly different between the three different “edges” (Figure 1; Pseudo-$F_{2,17} = 7.77; P < 0.0001$).

3.2. Stable isotopic analyses

To compare the C and N isotopic signature of earwigs and other soil fauna (Figure 2), we first combined E. annulipes, E. moesta, and Euborellia sp. together as Euborellia sp., as there were no differences on the isotopic signature between these three groups (Pseudo-$F_{2,15} = 1.19, P = 0.34$). Second, as Euborellia sp. and N. lividipes were also isotopically indistinguishable ($t = 1.43; P = 0.14$) we combined them in a group of “soil earwigs.” Third, we compared the isotopic signal of these soil earwigs with the signal of F. pubescens and found significant differences between them (Pseudo-$F_{2,29} = 7.41, P = 0.0002$). Finally, the isotopic signal of the earwig species was compared to the isotopic signal of other typical inhabitants from soil habitats. We found that the isotopic signature of F. pubescens was significantly different from that of Oligochaeta, Isopoda (Armadillidium sp.), Chilopoda, and Diplopoda (all four comparisons gave $t$ values above 2.92, and $P$ values below 0.0082). In contrast, the isotopic signature of N. lividipes and Euborellia sp. was no different from that of Oligochaeta ($t = 1.58, P = 0.09$), but differed from that of Armadillidium sp. ($t = 1.92; P = 0.04$) and Myriapoda (Chilopoda: $t = 3.03; P = 0.0007$; Diplopoda: $t = 3.45; P < 0.0001$).

4. Discussion

In this study, 16 m² of ground was dug and around 1250 kg of dry soil was analysed to study overwintering earwigs in a citrus grove. The sampling produced 267 earwig individuals that correspond, approximately, to one earwig in a ground area of 25 cm × 25 cm or to one earwig in 5 kg of soil. These approximate figures give an idea of the effort needed to obtain a representative sample of overwintering earwigs and justifies the
previous scarcity of data. We found that earwigs were more abundant on the south side beneath the citrus canopies than on the north side, indicating that during winter, earwigs prefer the south side probably because it is a bit warmer than the north side. Although we did not measure soil temperatures for this study, Kindermann (2010) did so in July 2010 in the same citrus grove and found that the soil temperature in the south side beneath the canopies was 8°C higher compared to the soil temperature in the north side. Kindermann (2010) measured soil temperatures in summer, but it is likely that these north–south differences, albeit smaller, also occur in winter.

Overwintering earwigs were hardly present in the soil samples taken from “between rows” (halfway between the selected tree and the corresponding tree at the following row). This result indicates that although the area between rows is fully exposed to solar radiation, earwigs avoid overwintering in this site, probably because there is less content of deciduous leaf litter covering the soil (Thomas et al. 1992) and/or because the soil is more compacted as a consequence of the tractor transit between rows. This result has important implications for soil tillage practices in citrus groves. Although soil tillage appeared to impact earwig populations (McCutchan et al. 2003), this result may indicate that Chilopoda have a higher trophic level than Euborellia; in particular, the δ14N signal of ground dwelling earwigs was 2% lower than that of Chilopoda. Considering that there is an enrichment of 2.3 ± 0.2% between trophic positions (McCutchan et al. 2003), this result may indicate that Chilopoda have a higher trophic level than Euborellia and Euborellia sp. In banana fields in Martinique, Duyck et al. (2011) also observed a lower δ14N content of the ground earwig Euborellia caraiba compared to Chilopoda, but the difference on δ14N content was much smaller than the difference found in our study. Taken together these data suggest that N. lividipes and Euborellia sp. are ground dwelling earwigs with a different diet to F. pubescens, an earwig that spends most of its active season on the citrus canopies.

In total, we found four species of earwigs overwintering on the citrus grove: Forficula pubescens, Euborellia annulipes, E. moesta, and Nala lividipes. The main surprise in that list is the absence of the European earwig Forficula auricularia, as we know from previous studies that this species is present in the studied citrus canopies from April to December every year (Romeu-Dalmau et al. 2012a, 2012c). The most parsimonious explanation of the absence of F. auricularia belowground is that it spends the winter outside the field. Previous studies have shown that F. auricularia is capable to migrate short (<30 m; Lamb 1975; Moerkens et al. 2010) to long distances (up to 150 m; Debras et al. 2007). This finding has important implications in terms of management of F. auricularia populations. If European earwigs are to be managed in winter, either to enhance their abundance or to reduce it, farmers need to take into account that European earwigs might not be spending at all the winter in their orchards.

Three of the four species of earwigs found in the ground of the citrus grove (N. lividipes, E. annulipes, and E. moesta) are considered ground dwelling earwigs; that is, they spend their life mainly on the ground (Albouy & Caussanel 1990; Sauphanor & Sureau 1993; Lordan 2014). In contrast, F. pubescens spends most of its active period on the canopies (Romeu-Dalmau et al. 2012a), but it inhabits the ground in winter. These differences in behaviour are detected through the isotopic analyses. We found that the isotopic signature of F. pubescens, δ13C in particular, was different from that of the ground dwelling earwigs Euborellia sp. and N. lividipes, indicating different food sources of carbon (Post 2002). These ground dwelling earwigs were isotopically indistinguishable from each other, and from typical soil inhabitants like Oligochaeta. However, the isotopic signature of N. lividipes and Euborellia sp. was largely different from that of Chilopoda; in particular, the δ14N signal of ground dwelling earwigs was 2% lower than that of Chilopoda. Considering that there is an enrichment of 2.3 ± 0.2% between trophic positions (McCutchan et al. 2003), this result may indicate that Chilopoda have a higher trophic level than N. lividipes and Euborellia sp. In banana fields in Martinique, Duyck et al. (2011) also observed a lower δ14N content of the ground earwig Euborellia caraiba compared to Chilopoda, but the difference on δ14N content was much smaller than the difference found in our study. Taken together these data suggest that N. lividipes and Euborellia sp. are ground dwelling earwigs with a different diet to F. pubescens, an earwig that spends most of its active season on the citrus canopies.
5. Conclusions

Overall, this study shows that (1) earwigs overwinter preferentially at the south side beneath the citrus canopies than at the north side or between rows; (2) European earwigs do not overwinter inside the citrus grove even though from previous studies we know that they are present in the grove the rest of the year; (3) the ground-dwelling earwigs N. lividipes and Euborellia sp. have a similar diet to other soil inhabitants, but different from that of F. pubescens, an earwig that spends the active season on the canopies. These results have practical implications for the management of earwigs in groves. First, our data suggest that soil tillage can negatively impact overwintering earwigs beneath the citrus canopies but not in the area between rows. Second, European earwig populations can hardly be negatively affected by soil tillage during winter on Mediterranean citrus groves as they spend the winter elsewhere. These findings could prove useful to managers either willing to enhance earwigs (if considered natural enemies of pests) or to reduce them (if considered pests). It is difficult to assess the applicability of the reported results to others fruit species or geographical areas until some similar data is “dug up” in other places.

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