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Organic cropping practice decreases pest abundance and positively influences predator-prey interactions

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Abstract: Cropping practice influence arthropod species abundance and diversity in agroecosystems, thus impacting populations of insect pests and their natural enemies. A field study was conducted to investigate whether pest and natural enemy abundance was higher in organic compared with conventional strawberry fields, and whether the non-managed vegetation surrounding the field impacted natural enemy abundance and diversity in and around the field sites. The two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), and predatory mites were sampled from strawberry leaflets and the leaves of wild herbaceous plants from the surrounding vegetation. Insect predators, hymenopteran parasitoids, spiders and herbivores were collected from the same habitats. Abundance of *T. urticae* was ten-fold higher in conventional compared to organic strawberry fields, whereas the ratio of spider mite to predatory mites was 9.5 times lower in organic compared with conventional strawberry fields. The 14 species of predatory mites identified were all from the family Phytoseiidae, and predominantly found on stinging nettle, *Urtica dioica* L. (Rosales: Urticaceae) (> 80% of individuals), in the surrounding vegetation. There was no significant effect of cropping practice on the density of insect predators and spiders, while the density of insect parasitoids and insect herbivores was higher in the organic compared to the conventional sites. Total species richness at the edge of organic fields and in the surrounding vegetation of both organic and conventional sites was higher than in the other sampling sites. This study demonstrates the major impact of cropping practice on *T. urticae* abundance and on the prey to predator ratio, whilst also emphasizing the importance of the surrounding vegetation as a source of natural enemies of phytophagous arthropods.

Keywords: *Tetranychus urticae*, Phytoseiidae, biological control, diversity, strawberry, *Urtica dioica*

1. Introduction

Agricultural intensification has led to crops grown increasingly as monocultures over large areas with few non-crop habitats, which contributes to biodiversity loss and reduced biological control of pests (Tscharntke et al., 2005; Krauss et al., 2011). As a result, attention has focused on conserving and enhancing arthropod natural enemies. Non-crop habitats are crucial for the conservation and promotion of natural enemies, and their benefits for natural enemy diversity increase as does landscape heterogeneity (Cohen and Crowder, 2017; Schellhorn et al., 2015). Conservation strategies are based on manipulating cropping practices and the non-crop habitats in the surrounding landscape (Gonthier et al., 2014). Meta-analyses show that, in general, organic cropping practices are more effective for conserving natural enemies, and are thought to encourage a lower prey to predator ratio, than conventional cropping practices (Attwood et al., 2008; Bengtsson et al., 2005), resulting in more efficient biological control of pests (Krauss et al., 2011).

Strawberry is a high value crop produced throughout temperate and subtropical regions worldwide (FAOSTAT, 2013; Solomon et al., 2001). In northern Europe, strawberries are primarily grown in open fields (Davik et al., 2000; Hancock et al., 2008). One of the economically most important pest species is the two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) (Solomon et al., 2001; Wysoki, 1985). In non-managed ecosystems, tetranychid mites are generally distributed in small scattered populations in equilibrium with their natural enemies (Kennedy and Smitley, 1985). Conversely, in managed agroecosystems the population densities of *T. urticae* can reach high levels within short periods (Funayama, 2015; Kennedy and Smitley, 1985; van de Vrie et al., 1972). An undisturbed environment allows natural enemies to establish and reproduce in prey-rich areas, reducing the likelihood of pest population outbreaks (Landis et al., 2000). *Tetranychus urticae* is a good source of nutrition, not only for generalist predatory mites, but also for generalist insect predators (Bayoumy et al., 2014; Sabelis, 1985;

Shimoda et al., 2015). Predatory mites are known to play a variable role in the natural regulation of *T. urticae* in agroecosystems, depending on characteristics of the habitat, which are affected by management practices (Dabrovski and Garnis, 2012). In Danish strawberry grown in open fields, application of synthetic acaricides is the most common strategy used to control *T. urticae*. Their efficiency can be unsatisfactory, often declining over time due to the development of resistance. In addition, continuous use of acaricides can reduce natural enemy populations (Dermauw et al., 2012; van de Vrie et al., 1972; Van Leeuwen et al., 2014). The arthropod communities in conventional cropping systems are often more disturbed than in organic cropping systems, because synthetic acaricides can remove unwanted herbivores, but also many natural enemies (Landis et al., 2000; van de Vrie et al., 1972). Cropping practices can significantly influence abundance of *T. urticae* (Kennedy and Storer, 2000; Roy et al., 1999) and organic production can enhance both the abundance of generalist predators and the availability of alternative prey (Gomiero et al., 2011; Kovanci et al., 2007; Kromp, 1999). Parasitoids are often found in smaller numbers, but at a higher diversity, in organic systems when compared with conventional systems (Macfadyen et al., 2011; Sigsgaard et al., 2014).

In this study, we examined populations of pest mites and their natural enemies in strawberry crops and their surrounding vegetation. Specifically, we tested the hypotheses that; i) the abundance of *T. urticae* was higher and the natural enemies fewer in conventional compared to organic strawberry fields; ii) non-crop plant habitats surrounding crop fields was a potential source of natural enemies, expecting to find higher predator abundance in the surrounding vegetation; iii) the diversity of natural enemies was higher in the non-crop habitat than in the crop itself.

2. Material and Methods

2.1 Sampling sites

Samples were collected from sites in and around five conventionally-managed and five organically-managed commercial strawberry fields in Zealand, Denmark. The organic sites are managed under standard procedures according to EU and Danish legislation (EU Regulative 2018/848/EU, Danish Consolidation Act 2015/1675 and 2017/1773). Sites were only sampled if they had wild herbaceous plants in the non-crop area surrounding the field. All fields were in their second year of strawberry production, except one conventional field in its third year. At each site, samples were taken in three regions: field centre, field edge (up to 1m from the margin of field edge), and surrounding vegetation (up to 6m away from the field edge). Field sizes (0.5-50 ha), distances between surrounding vegetation and field edges (0-6 m), and rate of application of synthetic pesticides varied across sites (Table 1). Topping of plants, a common management practice after harvest in July, also varied between sites. This practice removes foliage, reducing plant height to ca 10 cm, and consequently reduces *T. urticae* populations. Information on pesticide treatments was provided by the farmer (Table 1).

2.2 Botanical survey

To estimate plant diversity in the vegetation surrounding each field, a survey was conducted between the second and third arthropod sampling occasions, in six plots of 0.5 x 2 m distributed evenly in the vegetation border. One of each plant species found in each plot was collected and identified using taxonomic keys (Hansen, 2002; Mossberg and Stenberg, 2003). Abundance of each plant species was not recorded.

2.3 Sampling of T. urticae *and predatory mites*

Samples were collected in 2013, in June at strawberry flower set, in July at harvest time, and in August at postharvest time On each occasion, 15 plots were selected at random in the field centre and 15 plots at the field edge. The plots in the field centre were at least 3 m from the field edge and separated from each other by at least 1m. Each plot consisted of a 1m long section of crop row, usually three strawberry plants. Twenty fully-grown strawberry leaflets were randomly collected from each plot by conducting the sampling across all rows within the sampling area, at each sampling date. Five herbaceous plant species were sampled from the surrounding vegetation: stinging nettle, *Urtica dioica* L.; mugwort, *Artemisia vulgaris* L.; thistle, *Cirsium arvense* (L.) Scop.; cow parsley, *Anthriscus sylvestris* (L.) Hoffm.; and dandelion, *Taraxacum officinale* F.H. Wigg. These species were chosen because they were likely to be present at all sites. Ten leaves of each plant species were sampled from each of five plots (1 x 0.3 m), and randomly chosen from the area of surrounding vegetation, by ensuring a gradient of distance between samples. Leaves and leaflets from each plot or plant species were collected in paper bags and transported to the laboratory in a cool box.

Samples were stored at 5°C for up to two days. *Tetranychus urticae* adults, mobile immatures and eggs were counted separately on each leaflet or leaf, under a stereo microscope. Predatory mites were also counted and stored in 70% ethanol, mounted in Hoyer's medium (Walter and Krantz, 2009) and identified to genera with the help of the unpublished keys used in the Acarology Summer Workshop, Ohio State University, and to species based on the original descriptions or redescriptions of each species (Demite et al., 2015).

2.4 Sampling of predatory insects, spiders and parasitoids

Predatory insects and spiders were sampled by sweep netting on the same day and in the same fields as leaf sampling occurred. In each area (field centre, field edge and surrounding vegetation) 10 sweep samples were taken; walking at a moderate pace along one crop row, equivalent to 30 strawberry plants. A sweep was two strokes through the upper foliage of the plants. Specimens obtained in each sweep sample were bagged, transferred to the laboratory in a cool box, stored at -20°C, and identified under a stereomicroscope. Predatory insects and spiders, omnivores, and herbivores, were subsequently identified to family and, when possible, to species (Danmarks Fauna; Lissner, 2011; Roberts, 1985; Skipper, 2013; Southwood and Leston, 2005).

2.5 Statistical analysis

Data were analyzed using the statistical software package R, version 3.5.1 (R Development Core Team, 2018). Analyses investigated differences between cropping systems (conventional and organic), location at each site (centre, edge and surrounding vegetation) and sampling time (June, July and August); the number of pesticide treatments was included as a covariate. All groups of data were analyzed using a Linear Mixed Effects Model with data log-transformed and field as a random effect. Due to low abundances, predatory mites were analyzed by logistic regression with random field effect, and the linear mixed effects model applied to positive counts only. In all cases, model terms were selected based on the Akaikes Information Criterion (AIC) and the linear mixed effects models were validated by inspection of residuals. Reported estimates and p-values are from the models selected by AIC. Geographic location (pairing of fields) and topping of plants were not included in the analysis since it was difficult to distinguish variation in these factors from the overall field effect, and because topping could only have an effect in August. The plant species (likelihood of presence per plot) recorded in the botanical survey of the surrounding vegetation was analyzed using a paired Wilcoxon test.

2.6 Arthropod species richness

Species diversity of predators, parasitoids and herbivores in the strawberry field and in the surrounding vegetation was analyzed by a rarefaction method assessing species richness using the Vegan package, version 2.4-2) in R (Oksanen et al., 2017). The rarefaction analysis was based on abundance and the number of species obtained from the sweep net samples.

The rarefaction analysis provides a measure of species richness based on the number of individuals sampled, accounting for unequal numbers of samples (Cayuela et al., 2015; Chao et al., 2014). The analysis compared species richness of herbivores and predators in the field centre, field edge and surrounding vegetation, between the two cropping systems. Predatory mite species richness was compared between field and surrounding vegetation. At the maximum sample size for each location, a comparison was made with the remaining locations. The number of arthropods was pooled across months, i.e. only location in the field/surrounding vegetation and cropping practice was compared. 95% confidence limits were calculated by doubling the standard errors provided by the analysis of rarefaction in R and confidence limits were compared amongst all locations. If confidence limits did not overlap the difference was considered to be significant at a $p \approx 0.01$ level (Cumming et al., 2007).

3. Results

3.1 Spatial effects of cropping practice on the arthropod community

3.1.1 Overall impact of cropping practice

The number of *T. urticae* per leaflet was significantly higher in conventional fields than in organic fields on the three sampling occasions (June, July and August) (p=0.004) (Fig. 1). When the three sampling occasions were pooled, the median number of *T. urticae* per leaflet was 10.8-fold higher in conventional fields than in organic fields (95% CI 2.5-45.1).

The likelihood of the presence of predatory mites occurring on leaflets in the field was similar between cropping systems (Fig. 2a). The ratio of spider mites to predatory mites was significantly higher (9.5-fold, 95% CI 1.6-55.8) in conventional fields than in organic fields (Fig. 2b). There was no significant difference between conventional and organic strawberry fields on the number of non-phytoseiid natural enemies (insect predators, spiders and parasitoids), though numbers in August were twice as high in the organic fields than in the conventional fields and the difference in abundance of predatory hemipterans even larger (Table 2). Variation between fields with the same cropping practice was high which may have concealed any effects of cropping practice. For parasitoids, a significant interaction between time and cropping practice (p=0.03) was found, i.e. the increases in numbers of parasitoids from June to August was dependent on the type of cropping practice, where the increase was more pronounced in the organic cropping system. In August, the number of parasitoids was 2.3 times larger in the organic field and its surrounding vegetation compared with the conventional strawberry field and the respective surrounding vegetation (95% CI 1.0-5.1) (Table 2).

Overall, herbivore abundance was significantly higher (1.8-fold, 95% CI 1.0-3.1) in organic compared with conventional fields and surrounding vegetation combined (p=0.04) (Appendix A).

The number of omnivores found in the sweep net samples was low prohibiting statistical comparisons.

3.1.2 Centre versus edge of field

No significant differences were found between densities of *T. urticae* in the field centre and field edge at any time. The likelihood of presence of predatory mites occurring on leaflets was similar in the center and edge of the fields, while the ratio of spider mites to predatory mites was significantly affected by location, with lower values in the field edge than in the field centre ($p=0.02$) (Fig. 2b). The ratio of spider mites to predatory mites corresponded to approximately 200:1 in the conventional field centre and edge, to 40:1 in the organic strawberry field centre, and 15:1 in the organic strawberry field edge (extracted from Fig. 2b). There was no difference between the number of non-phytoseiid natural enemies at the edge and centre of the fields. Also, comparisons of herbivore abundance within the field (center and edge) showed no differences between organic and conventional fields ($p=0.05$).

3.1.3 Surrounding vegetation

No *T. urticae* were found in the vegetation surrounding fields. In the surrounding vegetation of organic and conventional fields combined, there were significantly more predatory mites per leaflet than on leaflets in the strawberry field ($p<0.0001$) (Fig. 2a). The estimated median was 10.1 times higher in the surrounding vegetation compared to the field (95% CI 6.4-15.9). There was no difference in the number of predatory mites per leaf in the vegetation surrounding organic and conventional fields.

Most phytoseiids collected in this study belong to type III (generalist predators). The exceptions were three species of *Neoseiulus* (type II, selective predators of tetranychid mites) and *Euseius finlandicus* (Oudemans) (type IV, pollen-feeding generalist predator), the latter represented by a single specimen (Table 3) (McMurtry et al., 2013). Of the five most numerous phytoseiid species collected, *Neoseiulus cucumeris* (Oudemans), one of the predatory phytoseiids most extensively used for periodic releases to control spider mites and thrips, was found in comparable numbers on strawberry and plants of the surrounding vegetation of both conventional and organic fields. The other four species, *Neoseiulus reductus* Wainstein, *Neoseiulus umbraticus* (Chant), *Typhlodromus pyri* Scheuten and *Phytoseius juvenis* Wainstein & Arutunjan, were found in this study only on plants of the surrounding vegetation, in fields of both cultivation systems, except *T. pyri*, found only on plants of the surrounding vegetation of organic fields (Table 3).

More than 80% of the predatory mites found on plants in the surrounding vegetation were collected from *U. dioica* throughout the season. This plant was present in the surrounding vegetation in three of four conventional sites and in two of five organic sites. Fewer predatory mites were found on *A. sylvestris* and *C. arvense* than on *U. dioica*, though their numbers increased over time (2.4-4.9% of the total number of predatory mites sampled in June compared with 7.1-9.9% in August; an average including both plant species). *Artemisia vulgaris* and *T. officinale* were of minor importance as habitats for predatory mites (0-1.8% of predatory mites was found on these plants combined).

More non-phytoseiid natural enemies were found in the surrounding vegetation (55.3%) than in the field centre (22.4%) and edge (22.2%) ($p<0.0001$) (Fig. 3a,b). Considering all samples, the resulting median of the number of non-phytoseiid natural enemies was 2.6 times higher in the vegetation surrounding fields than in the field edge (95% CI 2.0-3.5), and 2.8 times higher in the vegetation surrounding fields than in the field centre (95% CI 2.1-3.8). Also the number of parasitoids was greater in the surrounding vegetation than in the centre and edge of the strawberry fields (p<0.0001) (Fig. 3b).

Significantly more herbivores were found in the surrounding vegetation compared to the centre and edge of the field regardless of cropping practice (p<0.0001) (Appendix A). Abundance of herbivores in the surrounding vegetation was 5.8 times higher than in the centre of fields (95% CI 4.2-8.2) and 4.2 times higher than at the edge of the fields (95% CI 3.0-5.9).

3.2 Seasonal influence on arthropod abundance

Abundance of *T. urticae* changed significantly over time (p=0.005) and peaked in July (Fig. 1). Presence of predatory mites in all sites combined differed over time (p=0.011), with a lower likelihood of presence of predatory mites per leaf/leaflet in June compared to July and August. The number of predatory mites in the fields also differed over time (p=0.008). Pairwise comparisons of sampling occasions showed fewer predatory mites on leaflets in June compared with July and August (June vs. July: p=0.006, June vs. August: p=0.001, July vs. August: p=0.55) (Fig. 2a). There was no difference in the number of spider mites to predatory mites over time. Overall, the abundance of non-phytoseiid natural enemies was higher in June compared with July (p<0.0001) and August (p=0.01), while no significant difference in abundance was found between July and August (p=0.08). The abundance of herbivores increased over time (p<0.0001); numbers were 2.7 times larger in July than in June (95% CI 1.9-3.8) and 1.7 times larger in August than in July (95% CI 0.2-0.9). There were no significant interactions between abundance, time and location of the herbivores.

3.3 The influence of chemical pesticides on arthropod natural enemies

Overall, two arthropod groups were affected by the application of chemical pesticides (average of 4.4 pesticide applications per site). The presence of predatory mites per leaflet was negatively affected by the number of applications of chemical pesticides (p=0.048), i.e. pesticide applications resulted in fewer predatory mites, with an estimated odds ratio of 0.78. On the contrary, the application of chemical pesticides resulted in minor increases in the numbers of parasitoids (p=0.02), with an estimated increase in the median number of parasitoids by a factor of 1.1 following every application (95% CI 1.0-1.2). Other than that, pesticide applications did not directly influence the abundance of arthropods.

3.4 Species richness

3.4.1 Phytoseiid predators

All predatory mites sampled from fields and surrounding vegetation, and identified to species, belonged to the family Phytoseiidae (Acari: Mesostigmata); we identified 581 adults of 14 species (Table 3). Ten of the species is classified as type III predators and accounted for approximately 82% of the adults identified. Three species were classified as type II predators and accounted for approximately 18% of the adults identified. Only one species (one individual) was classified as a type IV predator (Table 3).

Phytoseiid species richness was higher in the vegetation surrounding the conventional fields (185 individuals: CI 9.5-10.4) than in the vegetation surrounding the organic fields (CI 5.6-7.7) (p≈0.01). No differences in species richness were found amongst the remaining sampling areas.

3.4.2. Predatory insects, spiders and parasitoids

The largest number of predatory insects and spiders (625 individuals) collected was obtained from the vegetation surrounding organic fields while the smallest number (154 individuals) collected was obtained from the conventional field centre. The species richness in the conventional field centre (at its lowest abundance) was not significantly different to the organic field centre, but significantly lower than from all other areas sampled ($p \approx 0.01$) (Table 4). The species richness was higher in the organic field edge, than in the conventional field edge ($p \approx 0.01$). There was no difference in species richness in the surrounding vegetation of conventional fields and organic fields (when abundance was greatest in the vegetation surrounding organic fields) (Table 4). Coccinellid larvae and spiderlings were not included in the richness analysis.

Parasitoids were identified to three families and one group that represented all the ‘others’. Because of few groupings, an analysis of species richness was not possible, while a combined analysis of predatory insects, spiders and parasitoids was done. The combined analysis including parasitoids showed the same results as for analysis of predatory insects and spiders alone, i.e. a lower species richness in the conventional field centre compared to all other areas sampled (at 414 individuals: CI 18.8-19.2).

3.4.3 Herbivores

The largest number of herbivores (4845 individuals) was found in the surrounding vegetation of organic fields, while the smallest number (532 individuals) was obtained from the conventional field centre. The species richness in the conventional field centre was similar to all sampled areas (Table 5). Herbivore species richness in the organic field centre was significantly lower than in the surrounding vegetation of both conventional and organic fields ($p \approx 0.01$). Likewise, species richness in the organic field edge was significantly lower than in the vegetation surrounding both conventional and organic fields (p≈0.01). Finally, species richness was significantly higher in the vegetation surrounding organic fields compared to the vegetation surrounding conventional fields (p≈0.01; Table 5). Key strawberry pest densities in sweep net samples were low, and no significant differences were found amongst sample areas (Appendix A).

3.5 Botanical survey

In total, 42 plant species were identified in the vegetation surrounding strawberry fields. The botanical survey of the surrounding vegetation showed no significant difference in plant species diversity around conventional and organic fields (p=0.6) (likelihood of presence per plot). Plant diversity inside the fields was not assessed but consisted predominantly of the crop.

4. Discussion

Our findings confirmed our hypothesis that *T. urticae* infestation is greater in conventional than in organic strawberry fields, where *T. urticae* abundance were 10-fold higher in conventional fields. Infestation levels on strawberry in both cropping systems could still be considered as low.

Synthetic pesticides are not used in Danish fields of organic production (Danish Consolidation Act 2015/1657 and 2017/1773) which may account for the better conservation of natural enemy populations in those than in conventional systems (Bengtsson et al., 2005). However, predator abundance is not only dependent on the level of exposure to harmful chemicals, but also upon other factors including food availability. The abundance of both phytoseiid and non-phytoseiid natural enemies was the same between the two cropping systems, and most species were only found in the surrounding vegetation. Phytoseiids in the field was mainly *N. cucumeris*, a generalist predator also feeding on other pest species such as thrips. The abundance of predatory mites was though negatively affected by chemical pesticide applications in the conventional fields over time, which has also been found in other studies (Fountain and Medd, 2015; Pozzebon et al., 2015).

For phytoseiid mites, there was a much lower prey to predator ratio in organic strawberry fields than in conventional fields, implying that there was greater availability of alternative food resources in organic fields, ultimately leading to more effective control of *T. urticae* (Fraulo and Liburd, 2007). From previous studies the maximal ratio of *T. urticae* to predatory mite for biological control to be successful is between 10:1 and 15:1 (Greco et al., 2005; Fraulo and Liburd, 2007). In this study, the ratio recorded in the centre and edge of conventional strawberry fields was 200:1, which is far from the recommended optimal ratio; in contrast the ratio found at the edge of organic strawberry fields was 15:1, i.e. within the tolerable range.

The reductions in *T. urticae* populations in August in the present study could be a consequence of higher occurrence of natural enemies, decreasing plant quality or plant topping. In Spain, naturally occurring predacious arthropods were able to maintain *T. urticae* population densities below damaging levels in organically managed fields (García-Mari and González-Zamora, 1999). Furthermore, in our study, the lower ratio of *T. urticae* to predatory mites found in organic strawberry fields was not significantly affected by sampling time, indicating the potential for natural enemies to keep *T. urticae* populations low throughout the production season. The higher abundance of predatory mites found at the edge of the strawberry fields compared with the centre of fields confirms many other studies emphasizing the importance of non-crop vegetation bordering crop fields for maintaining sufficient numbers of natural enemies within the field (Dabrovski and Garnis, 2012; Dennis and Fry, 1992; Zehnder et al., 2007). Another study also found *U. dioica* particularly important for predatory mite diversity (Dabrovski and Garnis, 2012); this plant species often supports large numbers of many arthropods, alternative prey such as mites and aphids, and predatory bugs such as *Anthocoris nemorum* L. (Davis, 1991; Sigsgaard, 2010). Predatory mite abundance and species richness have never before been studied in Danish strawberry fields and surrounding vegetation; our results are the first to show that *U. dioica* is an important wild host plant for sustaining an abundant and diverse predator complex in the Danish strawberry field environment.

As expected, a higher abundance of predaceous insects and spiders was found in the surrounding vegetation compared with the field environment, reflecting the higher plant and herbivore diversity found in the surrounding vegetation. The vegetation surrounding fields usually contains a high diversity of plant species and alternative prey that together provide a favorable habitat and food source for predators (Denys and Tscharntke, 2002). In our study, we found no differences in non-phytoseiid predator abundance between organic and conventional sites. Spiders and coleopteran predators were abundant throughout the season in both cropping systems, while the hemipteran predators in particular seemed to occur in high abundances in the organic cropping system. Hemipteran predators such as *Anthocoris*, *Orius* and *Nabis* species can be important contributors to the control of *T. urticae* (Huffaker et al., 1969; Torres and Boyd, 2009). Even though predator abundance was almost twice as high in the organic sites than in the conventional sites, these differences were not significant, most likely due to the high variation amongst individual cropping systems. Heterogeneity amongst replicate fields can mask the effect of covariables, and more controlled designs are needed to assess their possible influence (Sigsgaard et al., 2014). Two other studies investigating the effect of organic versus conventional cropping practice on the predator community in strawberry, also found no significant differences in predator abundance (Tuovinen and Tolenen, 2002; Caballero-López et al., 2012).

Our results on parasitoid abundance are similar to those of other studies that also found higher abundance of parasitoids in organic compared with conventional cropping systems (Inclán et al., 2015; Puech et al., 2015), while parasitism rates on particular herbivore species did not vary according to cropping system (Macfadyen et al., 2009; Sigsgaard et al., 2014). The parasitoids found in the present study cannot be directly related to control of *T. urticae*, and higher parasitoid abundance may simply reflect the much higher host abundance in organic fields (Inclán et al., 2015; Moreira et al., 2016). A minor but positive influence of chemical pesticide applications (sum of insecticides, fungicides and acaricides) on parasitoid occurrence is counterintuitive, but could partially be explained by the fact that some studies find pyrethroids to have only minor impact on parasitoid depletion (D'Ávila et al., 2018).

The conventional production sites were not subjected to the same level of applications of plant protection, and in one site no chemical pesticides application was done in that year. However, applications of previous years may have impacted the arthropod communities of the following years; hence even that site was included in the analysis. Data indicates that exclusion of this site would only emphasize our hypotheses, but the variation in treatments among conventional growers does exist and thereby provides a more general picture of the varied practices applied.

Organic cropping practice has been shown to promote biodiversity of plants, predatory arthropods and non-predatory arthropods, independent of spatial scale (Letourneau and Bothwell, 2008). We did not assess within-field plant diversity, but, we found no difference in plant species diversity between the vegetation surrounding conventional and organic strawberry fields. Thus, the higher phytoseiid species richness in the surrounding vegetation of conventional strawberry fields in the present study could be attributed to the occurrence of *U. dioica* (Dabrovski and Garnis, 2012), rather than to increased plant diversity. Although not significant, *U. dioica* was recorded more frequently in the vegetation surrounding conventional fields than in the vegetation surrounding organic fields, and *U. dioica* responds well to high N levels (Wagner and Beck, 1993). Generalist insect predators and spiders are considered particularly important as pest control agents in the early stage of pest incidence, preventing possible pest outbreaks (Symondson et al., 2002). A similar reasoning can be adopted for the generalist phytoseiids (type III and IV) (McMurtry et al., 2013, 2015), and they were the predominant predators in this study.

Neoseiulus cucumeris and *T. pyri*, the most numerous in this study, have also been reported as abundant in similar studies elsewhere in Europe. In the UK, *N. cucumeris*, *Neoseiulus californicus* (McGregor) and *T. pyri* were the phytoseiids most often found colonizing strawberry fields (Fitzgerald et al., 2008). However, in a study conducted in Norway, *Typhlodromus rhenanus* (Oudemans) and *E. finlandicus* were the main phytoseiids found in open-field strawberry production (Castilho et al., 2015); these two species were also found in the present study, but only a single mite of each species. Most of the species found in this study were generalist predators, and of the five most numerous, only two (*N. cucumeris* and *T. pyri*) are widely considered important biological control agents on crops.

Like our own work, most studies investigating biodiversity of predatory insects and spiders report a higher diversity in organically-managed fields than in conventionally-managed fields (Hole et al., 2005; Puech et al., 2015). Despite this, there was no significant difference in herbivore abundance between conventional and organic strawberry fields in our study, suggesting that there would be no effect on yield. Though yield was not assessed in the present study, a previous study comparing organic and conventional strawberry cropping practice found no significant difference in yield (Sigsgaard et al., 2014).

We found higher abundance and species richness of herbivores in the vegetation surrounding organic fields compared with the vegetation surrounding conventional fields. These herbivores may be of importance as alternative prey or hosts for natural enemies of *T. urticae*. The results of the present study confirm our three hypotheses, because i) more predators were found in the surrounding vegetation than in strawberry fields, and the level of *T*. *urticae* were significantly affected by cropping practice with the pest to predator ratio being almost ten times higher in conventional than in organic fields, ii) most herbivores were found in the surrounding vegetation, but also more than half of all predators sampled were found in the surrounding vegetation, emphasizing the importance of non-crop habitats as a reservoir of natural enemies, where herbivores are present as alternative prey, iii) a higher predator species richness was found in the surrounding vegetation, and the lowest predator species richness was found in the field centre.

5. Conclusions

This study demonstrates that cropping practice significantly influences *T*. *urticae* abundance; densities of *T*. *urticae* were ten times lower in organic compared with conventional strawberry fields. Chemical pesticide applications negatively influenced phytoseiid predator abundance. A lower pest to predator ratio was found in organic strawberry fields what could explain the lower *T*. *urticae* abundance in those fields. Phytoseiid, insect predator and spider abundances were higher in the vegetation surrounding fields. The higher predator species richness at the edges of organic fields may have been due to the high abundance and species richness found in the surrounding vegetation, the consequence of which would be better conservation of species in the organic cropping system. Predatory phytoseiid mites were predominantly found on the herbaceous *U*. *dioica*, emphasizing the potential of a more direct use of this plant species as a source of beneficial arthropods in the agricultural environment.

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Figure Legends

Figure 1: Number of *T*. *urticae* per strawberry leaflet. Mean number (±SEM) of *T*. *urticae* per leaflet in conventional (conv) and organic (org) center and edge of field, in June, July and August.

Figure 2: Number of predatory mites. **a)** Mean number (±SEM) of predatory mites per leaflet in the conventional (conv) and organic (org) field and surrounding vegetation (surr), in June, July and August. **b)** Mean number (±SEM) of predatory mites per *T*. *urticae* in conventional and organic center and edge of field, in June, July and August.

Figure 3: Number of predators and parasitoids. **a)** Mean number (±SEM) of predators per 100 sweeps, in the conventional (conv) and organic (org) field and surrounding vegetation (surr), in June, July and August. **b)** Mean number (±SEM) of parasitoids per 100 sweeps, in the conventional and organic field and surrounding vegetation, in June, July and August.

Table Legends

Table 1: Location, area and management parameters of five conventional (1-5) and five organic (6-10) strawberry fields that where sampled. All fields are located in Zealand, Denmark. The number of applications of synthetic insecticide, fungicide and acaricide were recorded for the year of the study and were used in all the conventional fields. Synthetic insecticides, fungicides and acaricides were not used in the organic fields.

Table 2: Relative abundance (%) of species/families of predators and parasitoids sampled by sweep netting in conventional and organic strawberry fields and the vegetation surrounding them on three sampling dates. On each sampling occasion, the proportion of each taxon was calculated based on either 'all non-phytoseiid predators' or 'all parasitoids'. The number of individuals per 100 sweeps is the cumulative number of predators or parasitoids in each cropping system during the production season.

Table 3: Adult phytoseiid mites from conventional and organic strawberry fields and surrounding vegetation, with their respective lifestyles (based on McMurtry et al., 2013) and host plant. Lifestyles are defined as II: selective predators of tetranychid mites, III: generalist predators with a wide range of prey, IV: pollen feeding generalist predators. *Specific species type unknown, type is based on knowledge of closely related species, **FA: strawberry, *Fragaria* x *ananassa*; AS: cow parsley, *Anthriscus sylvestris*; AV: mugwort, *Artemisia vulgaris*; CA: thistle, *Cirsium arvense*; TO: dandelion, *Taraxacum officinale*; UD: stinging nettle, *Urtica dioica*.

Table 4: Species richness of predatory insects and spiders. Figures in the same column that are followed by a different lower-case letter are significantly different to each other ($p \approx 0.01$). Significance is determined at each maximum sample count for each location, represented by the levels of significances in the table ±CI.

Table 5: Species richness of herbivores. Figures in the same column that are followed by a different lower-case letter are significantly different to each other ($p \approx 0.01$). Significance is determined at each maximum sample count for each location, represented by the levels of significances in the table ±CI.

Tables
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Table 1

	Latitude	Longitude	Production area (ha)	Topping of plants*	Distance: centre to edge (m)	Distance: edge to surrounding veg. (m)	Insecticides (treatments per season)	Fungicides (treatments per season)	Acaricides (treatments per season)
1	55,6049	12,2655	5	Yes	40	0	2	5	2
2	55,5391	11,9211	50	Yes	60	6	2	4	0
3	55,4762	11,8316	1	No	50	5	0	2	0
4	55,3582	12,3131	2.3	No	25	4	0	0	0
5	55,2838	11,3346	21	Yes	50	4	2	3	0
6	55,5199	12,1359	12	No	15	2	0	0	0
7	55,6112	12,0250	0.5	No	35	0	0	0	0
8	55,4782	11,6822	2	Yes	50	0	0	0	0
9	55,3646	12,3143	1.5	Yes	40	4	0	0	0
10	55,2921	11,3676	1	Yes	40	4	0	0	0

*Topping of plants was done between July and August sampling.

Table 2

	Order	Family/genus/species	Conventional June	Conventional July	Conventional August	Organic June	Organic July	Organic August
Predators	**Araneae**		**44.2**	**51.6**	**39.9**	**44.4**	**49.5**	**24.3**
		Araneidae	16.8	21.9	20.2	10.5	24.4	9.5
		Linyphiidae	5.3	6.7	1.7	3.4	5.7	2.1
		Thomisidae	2.9	0.2	2.9	1.9	1.1	0.9
		Philidromidae	0.5	1.4	0	1.1	0.3	1.2
		Theridiidae	0	0.5	0.4	0	0	0
		Tetragnathidae	3.4	3.7	3.4	2.3	4.6	1.4
		Lycosidae	0.5	0.5	4.2	0	0.5	1.4
		Clubionidae	0.5	0.2	0.8	1.9	0.5	0.9
		Salticidae	1.0	0.5	0.4	0	0.5	0
		Spiderling	8.1	4.4	1.3	1.9	4.1	0.9
	Opiliones		5.3	11.6	4.6	21.4	11.4	6.0
	Hemiptera		**3.9**	**10.9**	**14.3**	**9.8**	**24.5**	**31.6**
		Anthocoris nemorum	0.5	7.0	4.2	3.8	10.3	6.7
		Anthocoris nemoralis	0	0	0	0	0.5	0.4
		Anthocoris confusus	0	0	0	0	0.3	0.2
		Anthocoris nymphs	0.5	0.2	0	0.4	0.8	4.4
		Orius majusculus	0	0.2	0	0	0	2.1
		Orius niger	0	0	0	0.4	0	0.9
		Orius laevigatus	0	0.2	0	0	0	3.5
		Orius minutus	0	0.2	4.2	0.4	0.3	2.5
		Deraeocoris scutellaris	0.5	0.9	0	0	0	0.2
		Deraeocoris ruber	0	0	0.8	0	0	0
		Blepharidopterus angulatus	0	0	0.4	0	0	0.2
		Heterotoma planicornis	0	0	1.3	0	0	1.1
		Nabis ferus	2.4	1.9	3.4	1.5	11.4	8.6
		Himacerus mirimicoides	0	0.2	0	3.4	2.7	1.1
	Coleoptera		**9.6**	**14.9**	**27.3**	**6.4**	**10.4**	**28.3**
		Adalia bipunctata	0	0	0	0	0	1.9
		Propylea quatuordecimpunctata	0.5	0.4	8.4	1.1	0.8	5.5
		Coccinella septempunctata	0.5	0.2	14.7	0	0.3	16.0
		Coccinellid larvae	2.9	9.8	3.4	0.8	5.2	2.8
		Staphylinidae	5.8	4.4	0.8	4.5	4.9	2.1
	Diptera		**40.4**	**21.2**	**3.8**	**34.6**	**14.7**	**3.9**
		Feltiella acarisuga	23.6	4.9	3.8	21.1	7.3	1.4
		Empididae	16.8	16.3	0	13.5	8.4	2.5
	Neuroptera	*Chrysoperla carnea*	**1.9**	**1.4**	**14.7**	**4.9**	**1.1**	**12.0**
Predators	**Individuals per 100 sweeps**		**13.9**	**28.7**	**19.8**	**18.5**	**27.5**	**41.4**
Parasitoids	**Hymenoptera**							
		Ichneumonidae	13.1	10.6	39.3	9.9	13.0	17.2
		Braconidae	12.0	6.2	15.2	19.1	14.7	6.2
		Chrysididae	19.7	5.6	15.0	12.2	30.8	15.6
		Parasitoid sp.	55.2	77.6	30.6	58.8	41.5	61.0

Parasitoids	**Individuals per 100 sweeps**	**29.5**	**42.8**	**35.7**	**30.8**	**28.8**	**103.3**

Table 3

Genus	Species	Conventional: Strawberry	Conventional: Surrounding Vegetation	Organic: Strawberry	Organic: Surrounding Vegetation	Lifestyle	Host plant**
Neoseiulus	*cucumeris*	49	44	62	34	III	FA, UD, AS, CA, AV
	reductus	0	48	0	47	II*	UD
	umbraticus	0	43	0	15	III	UD, AS
	fallacis	5	0	7	0	II	FA
	californicus	1	0	0	0	II	FA
Amblyseius	*andersoni*	6	2	4	0	III	FA, CA
	bryophilus	0	11	0	0	III*	UD, CA
	obtusus	0	1	0	0	III*	CA
Proprioseiopsis	*okanagensis*	5	1	2	1	III*	FA, CA
Typhlodromus	*pyri*	0	1	1	138	III	FA, UD, AS
	rhenanus	1	0	0	0	III*	FA
Paraseiulus	*triporus*	0	1	0	0	III*	UD
Phytoseius	*juvenis*	0	35	0	15	III*	UD, AS, CA
Euseius	*finlandicus*	0	0	1	0	IV	FA

Table 4

Management	Location	Expected species richness at: Minimum sample count (154 individuals)	Next level of significance (188 individuals)	Maximum sample count (437 individuals)
Conventional	field centre	15.0 ±0.3[a]	-	-
	field edge	18.4 ±1.5[b]	19.0±0.4[a]	-
	surrounding vegetation	20.3 ±2.9[b]	21.2±2.8[a]	25.0±0.3[a]
Organic	field centre	16.8 ±2.3[a]	17.5±2.1[a]	-
	field edge	21.2 ±2.3[b]	22.1±1.7[b]	-
	surrounding vegetation	23.0 ±2.8[b]	23.8±2.8[b]	26.7±1.9[a]

Table 5

Management	Location	Expected species richness at: Minimum sample count (532 individuals)	Next level of significance (1056 individuals)	Next level of significance (1470 individuals)	Maximum sample count (2755 individuals)
Conventional	field centre	19.0±0.3[a]	-	-	-
	field edge	23.0±1.6[a]	-	-	-
	surrounding vegetation	24.8±2.8[a]	30.2±2.1[a]	31.0±1.7[a]	32.0±0.04[a]
Organic	field centre	23.0±2.7[a]	27.0±0.1[b]	-	-
	field edge	26.0±3.3[a]	27.5±2.2[a]	29.0±2.3[b]	-
	surrounding vegetation	26.8±3.4[a]	30.7±2.8[a]	31.9±2.4[a]	33.5±1.3[b]

Figure 1
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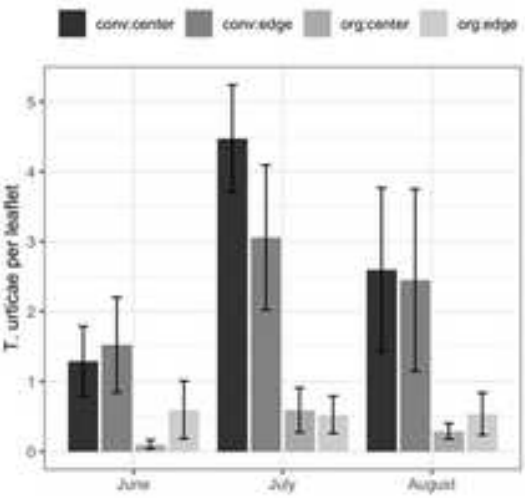

Figure 2
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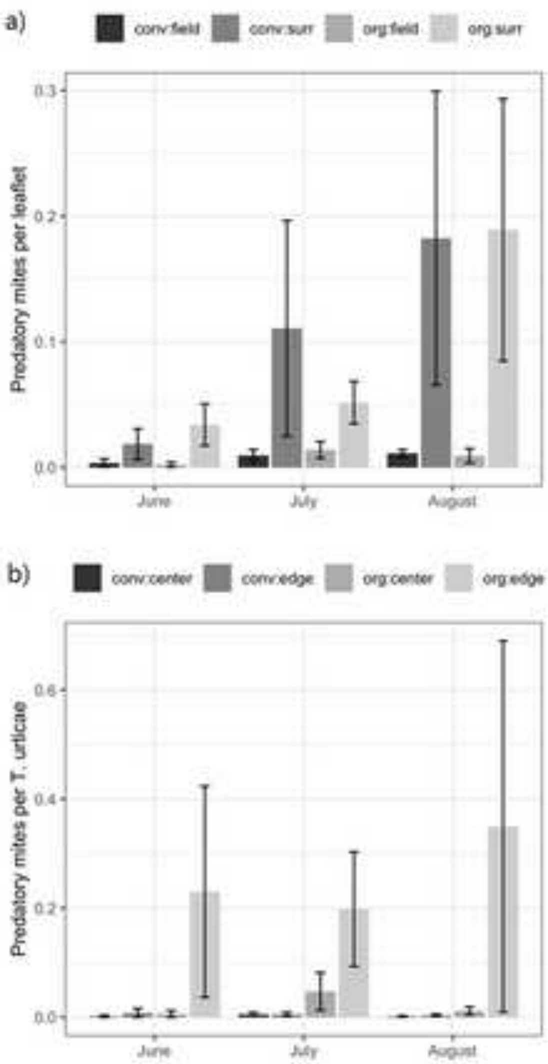

Figure 3

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