Agriculture, Ecosystems and Environment 227 (2016) 1–10

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Local landscape heterogeneity affects crop colonization by natural enemies of pests in protected horticultural cropping systems

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ARTICLE INFO

Article history:
Received 19 November 2015
Received in revised form 18 April 2016
Accepted 20 April 2016
Available online 11 May 2016

Keywords:
Conservation biological control
Tomato colonization
Landscape context
Miridae
Macrolophus spp.
Dicyphus spp.

ABSTRACT

Conservation biological control of crop pests is considered a promising strategy in protected horticultural cropping systems. In Mediterranean regions, crop colonization by native predatory mirid bugs is frequent but highly heterogeneous among crop production sites. The contribution of landscape heterogeneity to the variability in colonization levels remains little explored, although it is a major driver of the abundance of natural enemies of pests in open field cropping systems. The goal of our study was to assess whether landscape heterogeneity (land-cover diversity, percent cover, and spatial configuration) at a local scale (up to 300 m) affects colonization of protected crops by *Macrolophus* and *Dicyphus* mirids, and whether these effects are significantly greater or lower than those of crop management practices. In southern France (Roussillon) in 2010 and 2011, we collected data on mirid populations, pest infestation levels, crop management practices, and landscape heterogeneity within 300 m buffers. We investigated relationships between natural enemies, farming practices, and landscape metrics using an algorithm for random forests combined with GLM analyses. Tomato crops were colonized the most by *Macrolophus* mirids in landscapes with fallow, suggesting that these semi-natural habitats contribute to mirid movements between protected crops and the surrounding landscape. In contrast, crop colonization by mirids was reduced by nearby orchard, which reflected either sink effects due to intensive management practices or dilution effects linked to herbaceous resources. Landscape composition and configuration had similar effects on mirid populations. *Macrolophus* and *Dicyphus* mirids responded the most to lanscape heterogeneity at different spatial scales (200–300 and 100 m scales, respectively), possibly reflecting different dispersal abilities. However, effects of landscape heterogeneity on mirids were lower than those of crop management practices. Our study suggests that maintaining large areas of semi-natural habitats with ruderal vegetation typical of fallow is important to ensure colonization of protected crops by natural enemies of pests. Our findings emphasize that converting farms from conventional to organic production systems and adopting integrated plant management practices remain the most promising strategies to enhance populations of natural enemies in protected horticultural crops in Mediterranean regions.

1. Introduction

Conservation biological control of crop pests is considered a promising strategy to reduce pesticide use and to increase the sustainability of agricultural production systems (Pickett and Bugg, 1998; Gurr et al., 2000; Landis et al., 2000). Much is known about the drivers of natural biological control in open field cropping systems. The diversity of natural enemies and pest regulation processes are enhanced in organic farming systems compared to conventional ones (Östman et al., 2003; Bengtsson et al., 2005; Zehnder et al., 2007; Letourneau and Bothwell, 2008), mainly due to the prohibition of chemical pesticides and inorganic fertilizers (Hole et al., 2005). Landscape heterogeneity or complexity has been shown to be a major driver of natural pest control processes (Schmidt et al., 2004, 2005; Tschnartke et al., 2005; Tscharntke et al., 2007), and can sometimes be even more important than the type of farming system (Bengtsson et al., 2005). Landscape heterogeneity related to semi-natural elements increases the diversity and abundance of natural enemies, and the rates of

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http://dx.doi.org/10.1016/j.agee.2016.04.013
0167-8809/

predation or parasitism of pests (Thies et al., 2003; Bianchi et al., 2006; Gardiner et al., 2009; Rusch et al., 2011).

In protected horticultural cropping systems, little is known about potential drivers of conservation biological control. Protection strategies based on the use of biological control agents mainly rely on augmentative methods (i.e., periodical release of commercialized organisms (van Lenteren, 2000, 2012)). However, these methods have important socio-technical and economic limits (Nicot, 2008; Brismontier et al., 2009; Nicot, 2011; van Lenteren, 2012). Because greenhouses without insect-proof screens have been found to be spontaneously colonized by indigenous natural enemies from surrounding agro-ecosystems (van Lenteren, 1992; Albajes and Alomar, 1999), conservation biological control is increasingly considered a complementary or even alternative strategy to commercial augmentative methods (Messelink et al., 2014).

In southern Europe, natural colonization of protected horticultural systems has been frequently reported; greenhouses are mainly unheated plastic structures with openings that facilitate insect exchanges with the surrounding landscape (Castañe et al., 1989; Castañe et al., 1997; Gabarra et al., 2004). Among the native beneficial fauna in protected crops in this region, polyphageous predatory mirid bugs (Heteroptera: Miridae) of the genera *Macrolophus*, *Dicyphus,* and *Nesidiocoris* have been recorded in several Mediterranean countries (Alomar et al., 2002; Gabarra et al., 2004; Ingegno et al., 2009; Lambion, 2011). These insects, some species of which are used in augmentative strategies (e.g., *Macrolophus pygmaeus* (Rambur) and *Nesidiocoris tenuis* (Reuter)) (Perdikis et al., 2008; Molla and Gonzalez-Cabrera, 2011; Trottin-Caudal et al., 2011), are considered major biological control agents against various Solanaceous crop pests, which include whiteflies, aphids, thrips, leafminers, and mites (Perdikis et al., 2008; Trottin-Caudal et al., 2011; Calvo et al., 2012).

The success of pest control by indigenous mirid bugs depends on early colonization and population establishment in protected crops (Smith et al., 1997). These processes can, however, vary among crop production sites and even among different crops in a given site (Ingegno et al., 2009). Smaller populations of mirids in certain crops can be partly explained by the use of specific cultural practices, including spraying chemical or natural insecticides (Tedeschi et al., 2002; Arnó and Gabarra, 2011; Biondi et al., 2012), and frequent deleafing and disbudding (Bonato and Ridray, 2007). Minimum pest densities are needed to allow the reproduction and population establishment of mirids in crops (Alomar et al., 2002). Alternative plants can be placed inside greenhouses to improve crop colonization by mirids and the development of their populations, since they provide refuges, oviposition or alternative food resources (Sanchez et al., 2003; Perdikis et al., 2011; Messelink et al., 2014; Biondi et al., 2016). The use of such alternative plants can also allow the reduction of damages on crops due to the phytophageous behavior of mirids (Biondi et al., 2016). Crop colonization by mirids has also been shown to be enhanced by the proximity (up to 75 m) of agricultural and uncultivated host-plants, which act as sources of mirids and as refuges during winter (Alomar et al., 2002; Gabarra et al., 2004; Lykouressis et al., 2008; Lambion, 2011). Therefore, the link between landscape heterogeneity and host-plant availability at larger spatial scales has been assumed to explain differences in mirid colonization and population establishment success among crop production sites (Ingegno et al., 2009). However, this assumption relies on comparisons between a few locations without explicit analysis of the effects of the availability, diversity, and spatial configuration of potential habitats or refuges within a landscape context. Knowledge gaps about the ecology of mirids persist, especially regarding their dispersal ability and crop colonization processes (Perdikis et al., 2011). The potential contribution of landscape heterogeneity to mirid populations in protected crops remains unclear, especially regarding local crop management practices. Filling these knowledge gaps is crucial in determining whether conservation measures should focus on changes in crop management practices or on the design of the surrounding landscape. Identifying the spatial scale(s) at which mirid bugs respond to landscape heterogeneity should also demonstrate whether landscape management measures can be implemented at the scale of a single production farm.

The main aim of this study was to assess whether local landscape heterogeneity can explain the variability in colonization of protected vegetable crops by indigenous mirid bugs. We addressed this question for tomato crops under organic and conventional cropping systems in southern France, where the dominant mirid bugs in crops belong to the genera *Macrolophus* and *Dicyphus*. We focused on the local scale of the landscape within buffers of 300 m around crops. This spatial extent encompasses the range of sizes of production farms in this region, and is consistent with the maximum dispersal distance expected for mirid bugs during their active period (Alomar et al., 2002). We first analyzed the effects of the percent cover, diversity, and spatial configuration of cultivated and semi-natural landscape elements at different spatial scales (50, 100, 200, and 300 m) on mirid populations in crops. Secondly, we analyzed the effects of landscape heterogeneity relative to those of local crop management practices and conditions (pest infestation levels).

2. Material and methods

2.1. Study area and site selection

We conducted our study on the Roussillon plain (Eastern Pyrenees region) in southern France. In this region, landscapes are mosaics of various annual (cereal, horticultural) and perennial (mainly orchard, and vineyard) crops, semi-natural elements (hedges, herbaceous elements, fallow), and urban areas. We sampled 34 tomato crops distributed among 22 production sites in 2010 and 2011. We selected crops to maximize the variability in the area covered by semi-natural elements in the surrounding landscape (Mean = 42%, SD = 12%, range from 18% to 65%), and the diversity of crop protection strategies against pests in protected tomato cropping systems. Twenty six crops under organic management and eight crops under conventional management were selected. Because of inter-annual changes in tomato cropping in the study area, some sampled fields and crop production sites differed between sampling years but were located in the same study area. The average distance between fields sampled in subsequent years was 12.6 km (SD = 6.4 km). Tomato crops were planted from mid-March to mid-April in tunnels or plastic greenhouses without insect-proof nets, or in soil.

2.2. Mirid and pest sampling

We estimated mirid abundance and pest infestation levels in crops by non-destructive weekly sampling from early March just after tomato planting until late July. Depending on the planting date, the duration of sampling varied between 12 and 17 weeks. In each crop, we counted adults of *Macrolophus* spp. and *Dicyphus* spp. on 6 leaves on each of 24 tomato plants that were evenly distributed in the crop for a total of 144 leaves per crop. A dozen individuals of each genus were removed from each crop in June for taxonomic identification in the laboratory to confirm visual identification of mirids in the field.

We assessed levels of infestation of the main potential prey of the mirids (crop pests) comprising aphids (mainly *Macrosiphum euphorbiae* (Thomas) and *Myzus persicae* (Sulzer)), whiteflies (adult