Science of the Total Environment 621 (2018) 600–611

Contents lists available at ScienceDirect

Science of the Total Environment

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

Spatial diversification of agroecosystems to enhance biological control and other regulating services: An agroecological perspective

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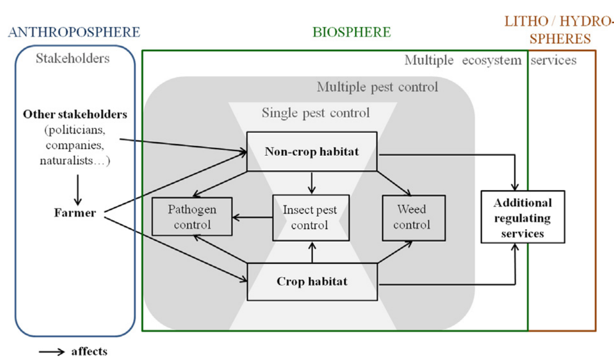
HIGHLIGHTS

- Pest control in agroecosystems depends on composition, design and management of crop and non-crop habitats.
- Habitats should be composed, designed and managed towards the delivery of multiple ecosystem services.
- Considering farmer needs and perspectives through participatory approaches may allow triggering a change in fields.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 7 July 2017
Received in revised form 20 November 2017
Accepted 26 November 2017
Available online xxxx

Editor: Yolanda Picó

Keywords:
Agroecology
Ecosystem services
Conservation biological control
Crop diversity
Interdisciplinarity
Transition

ABSTRACT

Spatial diversification of crop and non-crop habitats in farming systems is promising for enhancing natural regulation of insect pests. Nevertheless, results from recent syntheses show variable effects. One explanation is that the abundance and diversity of pests and natural enemies are affected by the composition, design and management of crop and non-crop habitats. Moreover, interactions between both local and landscape elements and practices carried out at different spatial scales may affect the regulation of insect pests. Hence, research is being conducted to understand these interdependencies. However, insects are not the only pests and pests are not the only elements to regulate in agroecosystems. Broadening the scope could allow addressing multiple issues simultaneously, but also solving them together by enhancing synergies. Indeed, spatial diversification of crop and non-crop habitats can allow addressing the issues of weeds and pathogens, along with being beneficial to several other regulating services like pollination, soil conservation and nutrient cycling. Although calls rise to develop multifunctional landscapes that optimize the delivery of multiple ecosystem services, it still represents a scientific challenge today. Enhancing interdisciplinarity in research institutions and building interrelations between scientists and stakeholders may help reach this goal. Despite obstacles, positive results from research based on such innovative approaches are encouraging for engaging science in this path. Hence, the aim of the present paper is to offer an update on these issues by exploring the most recent findings and discussing these results to highlight needs for future research.

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https://doi.org/10.1016/j.scitotenv.2017.11.296
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1. Introduction

Increasing the environmental sustainability of farming through a reduction of external input uses is a main challenge for today's agriculture. The concept of agroecology proposes to mobilise ecological processes towards the delivery of ecosystem services (Hatt et al., 2016), i.e. the benefits ecosystems can provide to human well-being (Reid et al., 2005). Pesticides are among these external inputs, for which there is evidence of their harmful effects on human health (Mostafalou and Abdollahi, 2013) and the environment (Annett et al., 2014; Devine and Furlong, 2007). Moreover, their efficiency faces pest resistance (Heap, 2014; Thieme et al., 2010) and consumers call for healthier food (Howard and Allen, 2010). This is leading to ever tighter regulations on their use (Skevas et al., 2013). Hence, programs have been set by governments of countries to reduce pesticide uses (DEFRA, 2013; MAP, 2008). Nevertheless, applying pesticides remains the most common way to protect crops (Hossard et al., 2017), inviting strengthening of efforts at various levels.

One of the propositions put forward by agroecology hinges on the conception of making farming systems less sensitive to pest pressure by mobilising biological regulations in agroecosystems (Malézieux, 2012; Nicholls and Altieri, 2004). *Functional agrobiodiversity* is 'those elements of biodiversity on the scale of agricultural fields or landscapes, which provide ecosystem services that support sustainable agricultural production and can also deliver benefits to the regional and global environment and the public at large' (ELN-FAB, 2012). Functional agrobiodiversity, through ecological processes and functions (e.g. predation, flower visits, mineralisation), allows the provision of regulating services (e.g. pest control, pollination, nutrient cycling), on which provisioning (production of biomass for food, fibre and energy) and cultural services (e.g. landscape sight, recreation sources) depend (Zhang et al., 2007). Nevertheless, enhancing agrobiodiversity may also induce disservices (e.g. plant competition, crop herbivory). Intensive agriculture optimizes the provision of biomass while limiting the occurrence of these disservices by simplifying and artificializing agroecosystems with the use of external inputs. These external inputs also decrease the flow of regulating services (e.g. pest control, pollination, water flow regulation, carbon storage) (Foley et al., 2005; Robinson and Sutherland, 2002). The challenge remains in mobilising functional agrobiodiversity able to provide regulating services for producing resources with fewer external inputs and with a limited provision of disservices (Power, 2010; Zhang et al., 2007). However, there is a debate whether functional agrobiodiversity enhances the delivery of ecosystem services through high species richness, or the presence of some key species, or even the involvement of functional traits of individuals (in the case of insects: e.g. Cardinale et al., 2003; Jonsson et al., 2017; in the case of plants: e.g. Hatt et al., 2017c; Uyttenbroeck et al., 2017; for a review: Perović et al., 2017).

Biological pest control is a regulating service delivered by functional agrobiodiversity (Zhang et al., 2007). Predators and parasitoids can be mobilised to control insect herbivores (top-down control, Gurr et al., 2003). These natural enemies find in non-crop habitats a shelter against adverse conditions, overwintering sites, floral resources, prey and hosts (Gurr et al., 2017). Favouring their presence towards pest control relates to *conservation biological control* (Barbosa, 1998). Plants on which pests feed can moreover be managed (bottom-up control, Gurr et al., 2003). The tactic consists in complicating the ability of pests to locate and develop on their host plant. Because development of specialised herbivores is facilitated in homogeneous fields (i.e. *resource concentration hypothesis* of Root, 1973), diversifying cropping areas by mixing crops (i.e. intercropping), crop with non-crop plants (i.e. cover cropping) or trees (i.e. agroforestry) has been proposed (Altieri and Nicholls, 2004). Enhancing both a bottom-up and a top-down control of insect pests, i.e. considering tritrophic interactions as trophic levels are highly overlapping (Wilkinson and Sherratt, 2016), by spatially diversifying crop and non-crop habitats represents the first two phases proposed by Zehnder et al. (2007) for managing arthropod pests without chemical pesticides in a context of organic farming and is the main component of agroecological crop protection described by Deguine et al. (2016). Although they can be implemented at the farm level, they together induce a diversification at the landscape scale, influencing insects (both pests and natural enemies) that are highly mobile, easily crossing farm borders. Hence, considering the landscape scale, in addition to smaller scales, is essential to understand the pest regulation processes and to design pest control strategies (Tscharntke et al., 2005; Zhao et al., 2016).

These last 10 years, studies highlighted how spatial diversification of agroecosystems can lead to the regulation of insect pests. Efforts have been made in reviewing and synthesising through meta-analyses the numerous studies assessing the effect of spatial diversification at the local and landscape scales on the control of insect pests. In addition, research has continued addressing specific issues, i.e. how to compose, manage and design crop and non-crop habitats at the local scale, and how managements at the local and landscape scales interact. Hence, the first aim of the present paper is to summarize our current knowledge by discussing these recent findings, to highlight gaps and propose issues for future research.

In addition, insects are not the only pests that trouble farmers, and pests are not the only biotic or abiotic elements of the agroecosystem that need to be regulated. Indeed, weeds and pathogens but also soil erosion or nutrient run-off lead to crop losses (Oerke, 2006). Moreover, pollination determines yield and quality of many crops (Bommarco et al., 2012; Holzschuh et al., 2012). Therefore, regulating multiple pests along with favouring the provision of other regulating services is needed. Previous papers addressed this need to develop multifunctional systems (Fiedler et al., 2008; Gurr et al., 2003; Kremen and Miles, 2012; Marshall and Moonen, 2002). Recently, Landis (2017) approached the issue by focusing on levers to trigger at the landscape scale. As studies generally focus on a single regulation (as is discussed in the first part of the present paper), our second aim is to address the issue of multifunctional farming systems, in exploring the possible ways to compose, manage and design crop and non-crop habitats towards the provision of multiple regulating ecosystem services. After Landis (2017), it is proposed here to address the issues at a more local scale, i.e. habitat composition and management as well as field/farm design.

Finally, such an investment of scientific research is only meaningful if it aims at participating in the development of a more sustainable agriculture. Therefore, our third aim is to discuss ways to trigger change so that the existing knowledge on ecological processes can be translated into practice in farmers' fields.

Because conditions of crop and non-crop habitat diversification are very different between temperate and tropical regions, the present perspectives focus on agricultural systems under a temperate climate.

2. Spatial diversification towards biological control of insect pests

2.1. Does spatial diversification at local and landscape scales enhance insect pest regulation?

2.1.1. At the local scale

Diversifying plants in space is possible by cultivating several crops (i.e. intercropping), crop with non-crop plants (i.e. cover cropping), or crop with trees (i.e. agroforestry) simultaneously in the same field, and by implementing non-crop habitats. In a meta-analysis, Letourneau et al. (2011) showed that spatial diversification of both crop and non-crop habitats at the local scale allows reducing insect pests and damages to crops while increasing natural enemies. More specifically, increasing plant diversity tends to enhance abundance of generalist predators, while not affecting abundance of specialist pests (Dassou and Tixier, 2016). Nevertheless, when focusing on specific practices (summarized in Table 1), the effect of diversification may vary. For example in their review, Lopes et al. (2016) showed that diversifying crop habitat solely through intercropping allows significantly

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