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Pest management: Reconciling farming practices and natural regulations

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ABSTRACT

Stimulation of ecological processes of natural pest regulation is a promising avenue for inventing new crop protection models, and reducing the dependence of agricultural systems on pesticides. Here, we review and discuss this emerging approach for the development of agroecological management of insect pests, and necessary bridges between agronomy, ecology, and social sciences. Ecological regulation can be harnessed through better knowledge of the life system of pest populations, interactions with trophic resources and natural enemies in agroecosystems, and incorporation of both cultivated and uncultivated habitats in the landscape as the framework to analyse ecological processes. Harnessing these regulation processes also entails taking into consideration the perception of local stakeholders in a participative approach to collective management of resources and innovation processes. The approach that we propose for improved management of crop pests consists in reconciling (i) action on the environment through biodiversity-friendly farming practices and technical innovations, and (ii) action on the landscape to stimulate the ecological processes involved in natural pest regulation. This approach entails a fundamental shift in the contours of action, from a conventional, often individual and independent approach of systematic or symptomatic interventions at a field scale, to collective organisation and management of ecosystem services at a territory scale, also including ecological, economic and social dimensions.

1. Introduction

Insect crop pests (herein pests) are major constraints on intensification of agricultural production, particularly in tropical areas where they are a constant threat to food security (Chakraborty and Newton, 2011; Maxmen, 2013). While use of pesticides has been able to mitigate this constraint in the most highly-structured value chains or those with the highest added value, it threatens the viability of these production systems through the loss of effectiveness of many insecticides due to the evolution of resistant pest populations, and through a breakdown of biological equilibriums and erosion of biodiversity within the ecosystems (Barzman et al., 2015). Moreover, the simplification of agricultural landscapes and fragmentation or elimination of natural habitats cause new environmental disruptions which contribute to altering the interactions between species, and increase the sensitivity of agricultural systems to pests (Wheeler and von Braun, 2013; Van Ittersum et al., 2016). The simplification of agricultural landscapes often favours pest outbreaks through a concentration of resources around a few cultivated species (Tscharntke et al., 2007), whereas fragmentation of semi-natural habitats has a negative impact on communities of natural enemies and their regulation function (Chaplin-Kramer et al., 2011; Veres et al., 2013).

The challenge is to design sustainable agricultural production systems capable of meeting increased food production and biodiversity conservation (Bommarco et al., 2013). In particular, new models for crop protection are needed to reduce the dependence of agricultural systems on pesticides, that better mobilize ecological processes of natural regulation of crop pests. Mobilizing natural regulations requires better knowledge of the life system of pest populations and spatio-temporal interactions with trophic resources and natural enemies in agroecosystems. This also entails taking into consideration the perception of local stakeholders in a participative approach to collective management of resources and innovation processes ("observing differently"). The approach we propose in the present paper aims at stimulating natural regulations for improved management of crop pests through action (i) on the field with biodiversity-friendly farming practices and (ii) on the agricultural landscape to stimulate the ecological processes involved. This approach entails a fundamental shift in action ("acting differently") from a conventional, often individual and independent approach of symptomatic treatment on a plot scale, to collective organisation of management of ecosystem services and eco-functional landscapes, including ecological, economic and social

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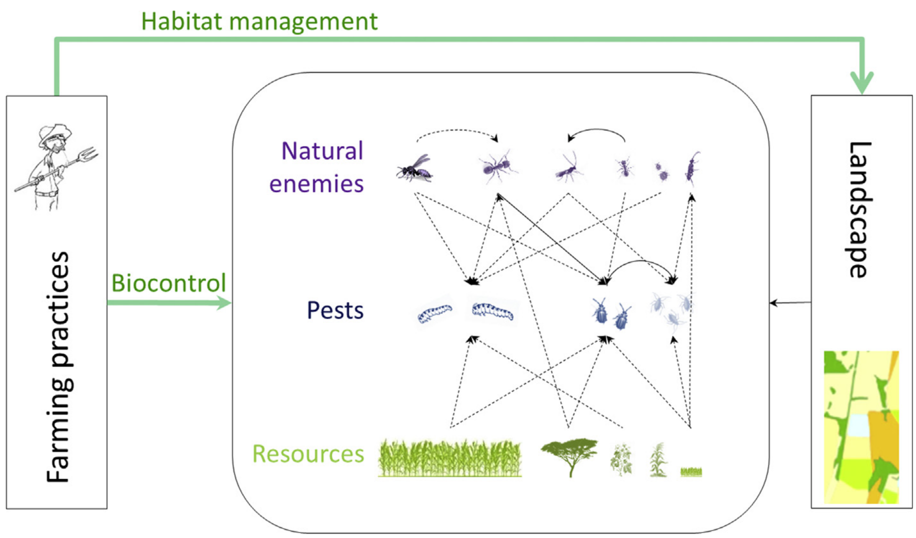

Fig. 1. Ecological control of crop pest populations is one of the ecosystem services (ES) provided by biodiversity. It can be carried out via natural enemies (top-down) or via resources and their availability, according to the landscape composition and structure (bottom-up). Some resources are also used by natural enemies which might find prey or alternative hosts and food there. The approach that we propose for improved management of crop pests consists in reconciling (i) action on the environment through biodiversity-friendly farming practices and technical innovations (e.g., biocontrol), and (ii) action on the landscape to stimulate the ecological processes involved in natural pest regulation (e.g., habitat management).

dimensions (Cong et al., 2014; Zhao et al., 2016). Our vision of success is that farmer communities move from adopting technological packages to adopting locally co-designed eco-friendly practices for the management of ecosystem services integrated into eco-functional landscapes. A case study on the natural regulation of a key pest of millet crops in West Africa illustrates the role of biodiversity and related ecosystem services provided by trees within the agricultural landscape. Future issues include taking into account trade-offs among ecosystem services and concertation among multiple stakeholders for durable management of resources across the explored territories to meet biodiversity conservation and food production.

2. Stimulating ecological regulations

Ecological regulation of crop pest populations is one of the ecosystem services provided by biodiversity (Crowder and Jabbour, 2014). This regulation can be carried out via the resources used by pests in their habitats (bottom-up effects), and via natural enemies (top-down effects) such as predators, parasitoids and pathogens (Fig. 1). At the agricultural landscape scale, the spatial arrangement of crops may delay their colonisation by pests, while non-cultivated areas may be habitats for various natural enemy species and therefore provide support for pest regulation (Rusch et al., 2010). Other factors such as competition between individuals and abiotic components of the environment also contribute to ecological regulation processes (Fig. 1).

The stimulation of ecological processes of pest regulation is a promising avenue for inventing agroecological management models for crop protection systems. They can be harnessed through better knowledge of the life system of pest populations in agroecosystems (Gurr et al., 2003). This entails incorporating the individual's biological traits in the population (demographics, dispersion capacities, etc.), access to resources over time and space (crops, semi-natural vegetation, etc.), intra- and inter-species interactions in the biological system in question (competition, trophic relations, etc.), disruptions caused by cropping practices such as insecticide treatments, and the spatial structures determining the nature and intensity of the ecological processes such as dispersal patterns across habitats. Functional biodiversity including the components and properties of the agricultural landscape supporting natural enemies represents a key factor of ecosystem resistance and resilience against environmental disruptions (Snyder and Tylianakis, 2012). Conserving, stimulating or restoring the ecological regulation function of crop pests is a challenge that needs to be faced in order to reduce the dependence of agriculture on pesticides. This entails "observing" and "acting" differently on a complex system.

3. Observing differently

The term "differently" is used here with reference to a change of posture in the agronomic diagnostic and experimental approaches restricted to the biological model, i.e. the strict interaction between the pest and crop under the effect of cropping practices, or between the pest and one or several natural enemies, to approaches encompassing ecological systems involved in the regulation of pest populations. To address the complexity of such systems, we propose to observe differently the biological models, in particular by adopting the methods and concepts derived from community ecology and landscape ecology. This change requires a systemic approach enabling to (i) characterise multitrophic interactions between and within the communities of the biological system studied, and to (ii) incorporate both cultivated and uncultivated habitats as the framework to analyse ecological processes. Besides biophysical factors influencing survival, development, and evolution of pest populations, observing differently also entails (iii) taking into account the perception of local stakeholders in a participative approach to collective management of resources and innovation processes.

3.1. Relationships between biodiversity and pest regulation

Ecological regulation of pests is a complex ecosystem service generally positively associated with the richness or diversity of natural enemy communities, though not always. Positive effects of species richness are observed when species control pests through complementary action, or when several species facilitate capture of prey by another species, such that the combined effect of several species exceeds the mortality caused by a single species (Crowder and Jabbour, 2014). Positive effects may also occur when a community with higher species richness provides control despite disruptions, with one or more species not affected by this disruption (Tscharntke et al., 2007). Furthermore, natural enemies may provide the plant with protection simply by altering herbivore behaviour (Walzer and Schausberger, 2009). Conversely, increased species richness may have a negative effect on control in the presence of intra-guild predation or behavioural interference between natural enemies (Lang, 2003). In a meta-analysis, Letourneau et al. (2009) demonstrated that 71% of studies involving arthropods revealed positive effects of natural enemy richness on control, with particularly potent effects in agricultural systems. However, this study did not demonstrate to what extent community richness promotes natural pest control through complementarity or facilitation, or through the higher probability (sampling effect) of containing one or