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Cropping systems alter the biodiversity of ground- and soil-dwelling herbivorous and predatory arthropods in a desert agroecosystem: Implications for pest biocontrol

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ABSTRACT

In irrigation-maintained desert agroecosystems in northwestern China, cereal crop production occurs mainly as maize (*Zea mays* L.) monoculture (MM), along with wheat (*Triticum aestivum* L.) monoculture (WM) and maize/wheat intercropping (MWI). However, our understanding of the role of different cropping systems in regulating the abundance and diversity of ground- and soil-dwelling insect herbivores (pests) and arthropod predators (natural enemies of pests), and thus cascading effects on biological pest control services is still poor. To address this important issue, we measured ground- and soil-dwelling insect pests and associated arthropod natural enemies in fields of MM, WM, and MWI using pitfall traps and hand-sorting in spring and summer at six sites in a desert agroecosystem in northwestern China. Each site contained three cropping systems with cultivation for at least five years. We also calculated the abundance- and richness-based ratios of ground- and soil-dwelling arthropod predators to insect herbivores (P: H ratios) as indices for assessing pest biocontrol services. For ground-dwelling communities, we found that MM harbored more abundant and diverse insect herbivores and insect predators than the other systems, whereas MWI harbored more abundant and diverse non-insect predators and had higher P: H ratios compared with the other systems across seasons. For soil-dwelling communities, we found that MM harbored more abundant and diverse insect herbivores than MWI in spring, whereas WM harbored less abundant and diverse insect herbivores than the other systems in summer. However, MWI harbored more abundant and diverse insect predators than the other systems, whereas WM harbored less abundant and diverse non-insect predators than the other systems in either season. Moreover, MM harbored more abundant and diverse non-insect predators than MWI in summer. The P: H ratios were higher in MWI than in MM and WM in spring, but did not differ across cropping systems in summer. Our results demonstrate that the magnitude and direction of the effects of cropping systems are highly season specific and vary across groups of ground- and soil-dwelling herbivores and predators. Furthermore, intercropping delivers greater pest biocontrol services than monoculture systems. These findings provide key insights towards developing more effective intercropping systems for pest suppression.

1. Introduction

The control of insect pests in agroecosystems may be achieved by an integrated pest management (IPM) strategy. One component of the IPM strategy is the use of chemical control on insect pests, in which pesticides are applied to suppress pest populations to limit their damage (Geiger et al., 2010). The other component of the IPM strategy is the use of biological control, in which pest populations are suppressed by natural enemies, such as invertebrate predators and parasitoids (Murdoch et al., 1985; Waage, 1991; Cloutier et al., 1996; Letourneau et al., 2009; Berec et al., 2016). Compared with chemical pest control (Goulson, 2013), biological pest control provides an important ecosystem service (Bianchi et al., 2006; Gardiner et al., 2009; Perovíc et al., 2018) that is a more sustainable and environmentally friendly pest

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management approach that also facilitates environmental protection, agricultural biodiversity conservation, and sustainable crop production (Forsythe, 1990; Bianchi et al., 2006; Bale et al., 2008; Li et al., 2009).

The effectiveness of biological pest control in agroecosystems can be affected by cropping system types (Östman et al., 2001; Zhao et al., 2013; Dong et al., 2016; Roubinet et al., 2017). Cropping systems involve planting one or more crop species within a field in a given period of time in different ways. In general, there are three fundamental cropping patterns: monoculture (involving only one crop species), biculture (involving two different crop species), and polyculture (involving three or more different crop species) (Halty et al., 2017). Different cropping systems vary in plant species diversity (e.g., monoculture, biculture, or polyculture), plant structural diversity (low versus high profile vegetation), as well as tillage disturbance levels and management regimes (Carcamo et al., 1995; Altieri and Nicholls, 2003), so that they differentially disturb the soils of crop fields, and eventually provide distinct microhabitats that can affect habitat suitability for different species of insect pests and their natural enemies. The effectiveness of biological pest control in an agroecosystem depends strongly on predator-prey interactions; i.e., the ecological balance between populations of prey and their predators (Holling, 1965; Huffaker et al., 1976; May and Hassell, 1988). Cropping systems may influence the effectiveness of biological pest control mainly through their differential effects on the abundance, community composition, and diversity of ground- and soil-dwelling insect pests and invertebrate natural enemies. A more diverse and abundant natural enemy community of invertebrates is generally believed to better able to control insect pests (Straub and Snyder, 2006; Tscharntke et al., 2007; Straub et al., 2008; Letourneau et al., 2009; Tylianakis and Romo, 2010). Therefore, it may be possible to quantitatively evaluate the overall effectiveness of biological pest control in cropping systems by using the ratios of natural enemies and insect pests in terms of their abundance and diversity (Letourneau et al., 2009; Zhao et al., 2013).

Among the cropping systems, intercropping is an important farming practice involving two or more crops growing together and coexisting on the same piece of land at the same time (Brooker et al., 2015). Intercropping is practiced by farmers globally (e.g., China, India, Southeast Asia, Latin America and Africa) (Vandermeer, 1989; Seran and Brintha, 2010; Lithourgidis et al., 2011; Rao et al., 2012; Hong et al., 2017). Many earlier studies have documented the benefits of intercropping, including improvements of soil quality, weed control, crop productivity and stability, as well as the utilization of environmental resources (e.g., water, light, and nutrients) for plant growth and development (Vandermeer, 1989; Morris and Garrity, 1993; Li et al., 2000; Zhang and Li, 2003; Picasso et al., 2008; Nasri et al., 2014; Hu et al., 2017; Liu et al., 2018). A review on recent advances in research on intercropping has contributed a comprehensive understanding of the benefits of intercropping over monoculture systems from the multiple perspectives of agronomy, plant physiology, and ecology (Brooker et al., 2015). However, relatively few studies have systematically examined the combined effects of cropping system and crop growth stage on the structure, abundance, and diversity of both ground- and soil-dwelling components of herbivorous and predatory arthropod communities, as well as the potential consequences of altered biodiversity patterns of insect pests and their natural enemies for pest biocontrol services in agroecosystems (Trenbath, 1993; Clark et al., 1998; Rämert et al., 2002; Wang et al., 2008a; Bickerton, 2011; Dong et al., 2016). So far, reports on the responses of different species assemblages of insect pests and their natural enemies aboveground and belowground to cropping systems are still rare, especially in arid drylands, with information in the literature being rather inconsistent (Ugen and Wien, 1996; Li et al., 2009; Bickerton, 2011). These inconsistent effects highlight the necessity of performing more case studies in climatically different eco-regions before drawing a general conclusion on how cropping systems influence the diversity and composition of ground- and soil-dwelling herbivorous and predatory arthropod communities.

China has the largest arid area in the world, covering approximately ~1900, 000 km^2, about 20% of the nation's terrestrial surface (Wang et al., 2010a). Rapid growth of human populations in the arid regions over the last five decades has led to large-scale transformations of natural grasslands to arable lands for increasing the production of grain and oilseed crops (Li et al., 2018). In arid environments, arable lands require high water and fertilizer inputs to maintain soil fertility and sustainable crop production (Wang et al., 2010b). Before the turn of the 20th century, cereal crop production in many arid agroecosystems occurred as diverse cropping patterns, including maize-wheat rotation, wheat-soybean rotation, and maize-soybean rotation, as well as maize-wheat intercropping, wheat-soybean intercropping, and maize-soybean intercropping. Since the onset of the 21st century, particularly over the last decade, maize monoculture (mainly for commercial hybrid seed production) has become the dominant type of cropping system, along with wheat monoculture and maize/wheat intercropping. The widespread adoption of maize monoculture has ultimately led to adverse ecological consequences for maize production, whereby crop yield is increasingly reduced due to damage caused by insect pests (Chen, 2014; Wang et al., 2017). To reduce the degree of damage caused by insect-pests, chemical pesticides are increasingly applied by farmers in maize fields to suppress arthropod pests. Given the significance of pest biocontrol in promoting agricultural biodiversity conservation and sustainable crop production, it is surprising that no studies have been done in this desert agroecosystem to elucidate the role of cropping systems in regulating the diversity and community structure of ground- and soil-dwelling insect herbivores (pests) and arthropod predators (natural enemies of pests) and, thus, ecological cascades on the biocontrol services (Östman et al., 2001; Chaplin-Kramer et al., 2011; Birkhofer et al., 2015).

To address this knowledge gap, a study was performed in an arid region in northwestern China, to investigate how three contrasting cropping systems (maize monoculture, wheat monoculture, and maize-wheat intercropping) influence the abundance, species richness, and community composition of ground- and soil-dwelling insect pests and their arthropod natural enemies. We measured the abundance and species richness of ground- and soil-dwelling representatives of economically important pest insects and their arthropod natural enemies at six sites in an irrigated desert agroecosystem. Further, we analyzed the variables related to soil and plant properties in monocropped maize (*Zea mays* L.) fields, monocropped wheat (*Triticum aestivum* L.) fields, and intercropped maize/wheat fields. Specifically, we aimed to: (1) quantify shifts in the abundance, species richness, and community composition of ground-dwelling pest insects and their natural enemies (spiders versus insect predators) in response to cropping systems; (2) quantify shifts in the abundance, species richness, and community composition of soil-dwelling pest insects and their natural enemies (insect versus non-insect predators) in response to cropping systems; (3) evaluate ecological cascades on the pest biocontrol services by using the calculated abundance- and richness-based ratios of ground- and soil-dwelling arthropod natural enemies to pest insects; and (4) determine the relative importance of the biotic and abiotic factors for the diversity and community composition of ground- and soil-dwelling pest insects and their natural enemies. We hypothesize that different species assemblages of ground- and soil-dwelling insect herbivores and arthropod predators would not follow a consistent pattern of response to cropping systems. We also hypothesize that the effects of cropping systems on the biodiversity of ground- and soil-dwelling insect herbivores and arthropod predators would vary across crop growth stages.

2. Materials and methods

2.1. Study area

The study was conducted in a centuries-old artificial oasis in Linze County, Gansu Province, northwestern China (39°21′ N, 100°07′ E;