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Relationships between biodiversity and biological control in agroecosystems: Current status and future challenges

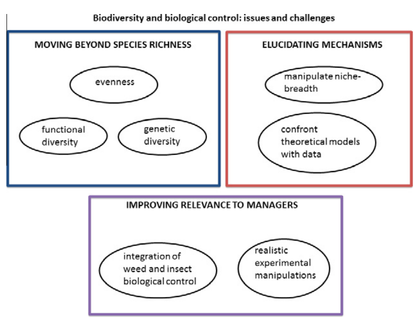
David W. Crowder [a,*], Randa Jabbour [b]

[a] Department of Entomology, Washington State University, PO Box 646382, Pullman, WA, USA
[b] Department of Plant Sciences, University of Wyoming, 1000 E. University Ave., Laramie, WY 82071, USA

HIGHLIGHTS

- Agricultural systems are intensifying to keep up with growing human demands.
- Intensive agriculture can negatively impact biodiversity and biological control.
- We review biodiversity and biological control of arthropod and weedy pests.
- We discuss similarities and differences between biocontrol of arthropods and weeds.
- We suggest novel approaches for examining biodiversity and biological control.

GRAPHICAL ABSTRACT



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ABSTRACT

Agricultural systems around the world are faced with the challenge of providing for the demands of a growing human population. To meet this demand, agricultural systems have intensified to produce more crops per unit area at the expense of greater inputs. Agricultural intensification, while yielding more crops, generally has detrimental impacts on biodiversity. However, intensified agricultural systems often have fewer pests than more "environmentally-friendly" systems, which is believed to be primarily due to extensive pesticide use on intensive farms. In turn, to be competitive, less-intensive agricultural systems must rely on biological control of pests. Biological pest control is a complex ecosystem service that is generally positively associated with biodiversity of natural enemy guilds. Yet, we still have a limited understanding of the relationships between biodiversity and biological control in agroecosystems, and the mechanisms underlying these relationships. Here, we review the effects of agricultural intensification on the diversity of natural enemy communities attacking arthropod pests and weeds. We next discuss how biodiversity of these communities impacts pest control, and the mechanisms underlying these effects. We focus in particular on novel conceptual issues such as relationships between richness, evenness, abundance, and pest control. Moreover, we discuss novel experimental approaches that can be used to explore the relationships between biodiversity and biological control in agroecosystems. In particular, we highlight new experimental frontiers regarding evenness, realistic manipulations of biodiversity, and functional and genetic diversity. Management shifts that aim to conserve diversity while suppressing both insect and weed pests will help growers to face future challenges. Moreover, a greater understanding of the interactions between diversity components, and the mechanisms underlying biodiversity effects, would improve efforts to strengthen biological control in agroecosystems.

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1. Introduction

Human population growth has led to the global expansion of agriculture. The acreage of land used for crops increased by 466%

* Corresponding author.
E-mail address: dcrowder@wsu.edu (D.W. Crowder).

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from 1700 to the 1980s (Meyer and Turner, 1992). This growth, however, has slowed in recent decades as suitable areas for cultivation become increasingly scarce (Matson et al., 1997). As growth of agricultural acreage has stagnated, agricultural systems around the world have intensified. Agricultural intensification is a broad term that encompasses many factors including, but not limited to, increased use of pesticides and fertilizers (see Roubos et al., 2014), increases in farm size, decreases in crop diversity, increases in crop density, and increased numbers of crops grown in a season. This has been due in large part to dramatic increases in crop yields since the 1960s, referred to as the "Green Revolution" (Pingali, 2012), which has been spurred by technological and cultural advances in crop breeding and management (Matson et al., 1997; Krebs et al., 1999; Benton et al., 2003).

While agriculture has kept pace with human population growth, increases in crop yields has also slowed recently (FAO, 2013). Moreover, agricultural intensification has negative local consequences such as reduced biodiversity, increased soil erosion, pollution, and reduced socio-economic sustainability, each of which has other impacts (Matson et al., 1997; Stoate et al., 2001; Kleijn et al., 2006). For example, reducing the number of species (reduced richness) (Hooper et al., 2005; Cardinale et al., 2006) and skewed relative abundance distributions (reduced species evenness) (Hillebrand et al., 2008; Crowder et al., 2010) generally weaken biological control. These harmful consequences of agricultural intensification have led to an increased focus on methods to increase the sustainability of agroecosystems (Tilman, 1999; Foley et al., 2011).

Biological control is a key ecosystem service that is necessary for sustainable crop production (Bianchi et al., 2006; Losey and Vaughan, 2006). Natural enemies such as predators, parasitoids, and pathogens play a central role in limiting damage from native and exotic pests (Hawkins et al., 1999; Losey and Vaughan, 2006). Conservative estimates suggest that the economic value provided by insect natural enemies controlling pests attacking crop plants exceeds $4.5 billion annually in the United States (Losey and Vaughan, 2006). If weedy pests, or pests attacking humans and livestock (not crops) were considered the estimate of pest control provided by insects would likely be much greater. Moreover, a multitude of species act as natural enemies of insect or weedy pests such as birds, bats, fungi, nematodes, and rodents (Kirk et al., 1996; Miller and Surlykke, 2001; Navntoft et al., 2009; Ramirez and Snyder, 2009; Williams et al., 2009; Jabbour et al., 2011). Thus, if these species were considered the economic value of biological control would be far greater than $4.5 billion annually.

To improve and conserve biological control, it is essential to understand the relationships between agricultural intensification, biodiversity, and pest suppression. We addresses this complex issue by first reviewing the effects of agricultural intensification on the biodiversity of natural enemies, and the role of natural enemies in agricultural food webs. We next discuss conceptual models relating biodiversity to natural pest control. Third, we review methodologies for examining the relationship between biodiversity and biological control in agroecosystems. We conclude by discussing areas of research emphasis that, if addressed, would improve our understanding of how biodiversity and biological control operate in agroecosystems.

2. Effects of agricultural intensification on biodiversity

2.1. Non-pest species

Agricultural intensification impacts both pest and non-pest species in agricultural communities. Indeed, much of the evidence of the impacts of agricultural intensification on ecological communities comes from conservation-related studies on non-pest species. Some of the longest-term studies of agricultural intensification and biodiversity have focused on bird populations in Europe, which have declined dramatically over the last half-century (Benton et al., 2003). Donald et al. (2001) showed that bird populations in the UK declined with increases in cereal and milk yields along with fertilizer and tractor usage. Cereal yields alone explained 31% of the variability in declining bird populations, suggesting that intensification of a single crop type can impact diversity (Donald et al., 2001).

There is evidence, however, that agri-environment schemes enacted by many European countries to encourage wildlife have led to resurgence of some bird species (Benton et al., 2003). Agri-environment schemes provide monetary incentives for farmers to manage a portion of their land to promote conservation of biodiversity and reduced impacts on the environment (Benton et al., 2003; Kleijn et al., 2006). By incorporating or conserving natural habitat in agricultural ecosystems to preserve native species, these schemes are designed to buffer against potentially damaging effects from agricultural intensification on biodiversity. Kleijn et al., 2006 compared the abundance and richness of plants, birds, and arthropods at 202 paired locations across five European counties. Each location contained one site managed with an agri-environment scheme and one conventional site. The agri-environment schemes had some positive impacts on abundance and diversity of these groups in each country, while conventional management did not benefit any group (Kleijn et al., 2006). The authors speculated that benefits were due to reduced inputs and disturbances in agri-environment fields. However, the species that benefitted most from agri-environment schemes did not include many species of extinction concern. This suggests that conserving native habitat may not benefit rare species, or that species of extinction concern declined in abundance due to factors other than agricultural intensification.

Crowder et al. (2010, 2012) showed that organic farming systems had marginal positive impacts on richness and significant positive impacts on evenness and abundance compared with conventional systems. These benefits occurred across crop types and were consistent across several organismal groups including arthropods, birds, non-bird vertebrates, plants, and soil organisms. The benefits of organic farming were greatest for the rarest species in conventional systems (Crowder et al., 2012). Other reviews (Bengtsson et al., 2005; Hole et al., 2005) have shown similar positive impacts of organic farming on richness and abundance of organisms. In each case, these results are likely due to reduced insecticide use in organic farming systems and/or increased habitat diversity. For example, granivorous beetle diversity has been shown to be positively associated with habitat complexity on farms (Vanbergen et al., 2010; Trichard et al., 2013), and negatively associated with use of pesticides (Trichard et al., 2013).

2.2. Arthropod pests

Root (1973) suggested that dense, homogenous plant communities facilitated higher herbivore populations. His "resource-concentration hypothesis" posits that specialist pests can locate plant stands, and feed more efficiently, when a single non-diverse crop is present. Thus, intensification may actually be responsible for pest outbreaks so common in monocultures. However, this hypothesis does not hold true for all cases, suggesting that resource-concentration effects are organism dependent (Grez and Gonzalez, 1995). Secondary pest outbreaks, where early-season insecticide applications kill natural enemies and result in late-season outbreaks of pests, have also received attention as a negative impact of agricultural intensification. For example, Gross and Rosenheim (2011) showed that 20% of late-season pesticide costs were attributable to early-season pesticide applications for control

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