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Trap crop diversity enhances crop yield

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ABSTRACT

Diverse plantings provide many benefits for agroecosystem health. For example, "trap crops" that are highly attractive to pests can protect nearby, less attractive host plants. However, it is unclear whether increasing biodiversity of trap crops themselves might increase the effectiveness of this pest-management technique. We examined whether multi-species trap-crop plantings were more effective than any single species at protecting broccoli (*Brassica oleracea* var. *italica*) crops from the crucifer flea beetle, *Phyllotreta cruciferae*. Our trap crop plantings included between one and three plant species (*Brassica juncea*, *Brassica napus*, and/or *Brassica rapa* subsp. *pekinensis*), selected for their attractiveness to the beetles, while keeping total trap crop area constant. We found that only a diverse mix of all three trap-crops significantly improved yields of adjacent broccoli; indeed, the 3-species polyculture provided protection that exceeded that of a monoculture of the most effective single trap crop species. Furthermore, the protective effect of diverse trap crop plantings extended across the broccoli beds. Treating trap crops with an insecticide provided no further benefits for pest control or broccoli yields. Despite clear benefits of trap-crop diversity on yields, the number of flea beetles did not differ in broccoli adjacent to diverse versus simple trap crops, or in the trap-crops themselves. This suggests that plant protection resulted from a change in pest behavior rather than abundance. Our study revealed that increasing biodiversity of trap-crop plantings might be an effective means to enhance the success of the approach in many systems.

1. Introduction

Across many communities, ecosystem function improves as species richness increases (Hooper et al., 2005; Cardinale et al., 2006). This often occurs because increasing biodiversity increases the chance that species occupying complementary niches will co-occur (e.g., Finke and Snyder, 2008). Within agricultural fields, polycultures of two or more crop species often experience less damage from pests than when those same crops are planted as monocultures (Andow, 1991; Letourneau et al., 2011). This may occur because polycultures complicate host-plant location by pests, and because polycultures provide the pests' natural enemies with a more diverse resource base that enhances enemy abundances and biological control (Root, 1973). At the scale of farm landscapes, crop rotation is a diversification scheme that forces pests to continuously relocate and re-colonize their preferred host plants from year to year (Tscharntke et al., 2005, 2007).

Trap cropping is a crop diversification scheme that often promotes pest suppression (Hokkanen, 1991; Shelton and Badenes-Perez, 2006; Cook et al., 2007). Trap cropping relies on pests having preferences for specific plant species, cultivars, or stages (Kennedy, 1965, 1978). Plantings of highly-preferred host plants can arrest arriving pests and "trap" them, indirectly protecting a less-attractive (to the pest), but economically-valuable, nearby crop species (Hokkanen, 1991; Shelton and Badenes-Perez, 2006). For example, surrounding economically-valuable cucumber (*Cucurbita sativa*), butternut squash (*C. moschata*) or watermelon (*Citrullus lanatus*) crops with squash (*C. maxima*) varieties highly attractive to pestiferous beetles and bugs can intercept and arrest the herbivores and thus largely restrict pest damage to the trap crop (Radin and Drummond, 1994; Pair, 1997; Adler and Hazzard, 2009; Dogramaci et al., 2004).

In most cases, trap-cropping schemes use a single attractive plant species to draw-in pests (but see Khan et al., 1997). However,

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there are several reasons to suspect that a diverse mix of trap species could provide more consistent, long-lasting attraction than a single species. First, herbivorous insects often locate and choose hosts using a blend of chemical cues, such that any single chemical constituent is not as attractive as a multi-compound blend (e.g., Nielsen et al., 1979; Webster et al., 2010). In such cases, different trap species that are emitters of different constituent compounds might combine to emit an overall more-attractive mixture. Likewise, the pairing of a trap species that is strongly chemically attractive (important in longer-distance host location) with a second trap species that provides visual/tactile cues (important for close-range host identification), might more-effectively draw in pests than either species alone (Eigenbrode et al., 2015). Furthermore, host plants often vary in their chemical profiles through time (e.g., Wallace and Eigenbrode, 2002; Lambdon et al., 2003), such that pairings of trap species with different attractiveness-phenologies might provide a long-lasting overall draw to the pest.

In a pair of field experiments, we examined whether multi-species trap-crop plantings were more effective than any single trap-crop species at drawing the crucifer flea beetle, *Phyllotreta cruciferae*, away from broccoli (*Brassica oleracea* var. *italica*) plantings. The chemical ecology of host location by this pest is well known (Feeny et al., 1970; Burgess and Wiens, 1980; Lamb, 1983; Gruber et al., 2009; Renwick, 2002; Shelton and Nault, 2004), which allowed us to select putative trap-crops that could attract/arrest the flea beetles. Our experiments lasted until broccoli harvest, providing a measure of impact on yield that is rarely considered in trap crop studies (but see Hokkanen, 1989). We next examined how far any protective effect extended into the protection target, and whether applications of an insecticide to the trap crop (e.g., Cavanagh et al., 2009, 2010) further enhanced crop yield. We replicated our treatments both west of the Cascade Mountains, where summers are relatively wet and cool, and east of the Cascade Mountains, where summers are typically hot and dry (USDA, 2012); we expected that flea beetle abundances and phenology might be quite different under these different environmental conditions. For similar reasons we continued our experiments across each of two separate growing seasons. In total then our study examined (1) whether increasing trap-crop biodiversity enhances pest control through interspecific complementarity among trap crop species; (2) whether the benefits of trap-cropping are seen primarily at the edges of the protection target's planting; (3) if the effectiveness of diverse trap-crops is increased by using insecticidal controls; and (4) whether any protective effect of trap crop biodiversity was consistent across two distinct climates, and across years.

2. Methods

2.1. Natural history and chemical ecology of the crucifer flea beetle

The crucifer flea beetle is an oligophagous pest of *Brassica* crops, accidentally introduced into North America from Eurasia in the 1920s (Milliron, 1953; Westdal and Romanow, 1972). The beetles possess several characteristics that make them good targets for control by trap cropping. First, adults emerge from overwintering sites located in field borders before moving into early-stage *Brassica* crops to feed (Lamb, 1983); this seasonal movement provides an opportunity to intercept flea beetles before they establish on *Brassicas* (Potting et al., 2005). Second, although the species specializes on Brassicaceae, its preference for settling and feeding differs strongly among hosts, providing opportunities for identifying trap crops (Altieri and Schmidt, 1986; Trdan et al., 2005). Third, host preferences of *P. cruciferae* are mediated through contact or long distance cues, including differences in surface wax characteristics that can arrest the insects (Bodnaryk, 1992) and plant volatiles to which they can be strongly attracted. These volatile cues include the hydrolysis products of glucosinolates, primarily allyl isothiocyanate (Feeny et al., 1970; Burgess and Wiens, 1980; Renwick, 2002). Thus, plant species that release large quantities of these chemicals might be more attractive to beetles than crops that are the primary protection target. Variation in chemical profiles, and thus expected attractiveness to the flea beetle, suggests that overall greater attractiveness of a trap-crop planting might be achieved by a diverse trap crop planting that includes species with different chemical profiles, physical structures, and/or volatile profiles.

In a preliminary study, we compared the attractiveness to crucifer flea beetles of five putative trap-crop species: *Barbarea vulgaris* (yellow rocket), *Brassica juncea* (Pacific Gold mustard), *Brassica napus* (Dwarf Essex rape), *Brassica oleracea* var. *acephala* (Green Glaze collard) and *Brassica rapa* subsp. *pekinensis* (pac choi) (Parker, 2012). These species possess relatively high concentrations of glucosinolates and other plant-derived chemicals attractive to crucifer flea beetles (Root and Tahvanainen, 1969; Kinoshita et al., 1979; Shelton and Nault, 2004). They also differ in epicuticular wax characteristics, with all five species tending to possess reduced densities of wax crystals compared with *B. oleracea* var. *italica*, a trait associated with increased feeding by *P. cruciferae* (Bodnaryk, 1992). This study revealed that three of the plants that we examined, *B. juncea, B. napus*, and *B, rapa* subsp. *pekinensis*, were relatively attractive to crucifer flea beetles when the trap crops were planted in single-species monocultures (Parker, 2012); therefore, these three species were chosen for further investigation here.

2.2. Experiment 1: trap-crop biodiversity and broccoli protection

Our first field experiment compared the effectiveness of trap-crop monocultures, or mixtures of 2 or 3 species, of the putative highly-attractive plant species described earlier: *B. juncea, B. napus,* and *B. rapa* subsp. *pekinensis*. We used three metrics to delineate the effectiveness of each trap-crop composition: (1) biomass of nearby broccoli plantings at harvest; (2) abundances of flea beetles within the broccoli planting; and (3) abundances of flea beetles within the trap crop planting. Our methods to measure broccoli yields and flea beetle abundances in the protection target and trap crops was the same in both of the two field experiments we conducted, and are described following the description of Field Experiment 2 (Sections 2.4 and 2.5).

This experiment included four treatments (with replicate numbers described below): (1) **0 trap-crop species**, no trap crop present and the space otherwise occupied by a trap crop in the other treatments maintained as bare earth by plowing; (2) **1 trap-crop species**, with each of the 3 trap crop species planted in separate monocultures as sub-treatments sharing a species richness of 1; (3) **2 trap-crop species**, with each of the 3 different possible combinations of the three trap-crop species planted in different plots as sub-treatments; and (4) **3 trap-crop species**. Trap crop diversity was manipulated using a substitutive design, where the total density of trap-crop plants was the same across simple and diverse trap-crop plantings; this was accomplished by planting each species at one-half its monoculture density in a two-species polyculture or one-third its monoculture density in a three-species polyculture. This design allowed us to examine whether diversity generally improved trap-crop effectiveness, or instead was unique to particular multi-species combinations (Snyder et al., 2006).

We repeated our experiment at two field sites: at Washington State University's Mount Vernon Research and Extension Center, Mount Vernon, WA (west of the Cascade Mountains), and at the