



Review Article

Weeds, Pollinators, and Parasitoids-Using Weeds for Insect Manipulation in Agriculture

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ABSTRACT

The use of weeds as insectary plants is an emerging management tactic by agroecologists to sustain beneficial insect species. Fallow lands have always been used by insects, and are an important part of their diet in fragmented ecosystems. Weeds provide nectar and floral resources to beneficial insects, and provide resources to keep those insects within a field in between flowering events. Using weeds as a tool in agricultural production reliant on pollination allows farmers to increase yield, end herbicide use, and increase biodiversity of both plants and insects. Native weeds expand the range of native insects from natural areas into agroecosystems, supporting insects that buffer against lapses in pollination by agricultural honey bees. Weeds also support parasitoid and predatory insects by providing nectar and pollen to adults, as well as alternative prey. This review examines the plant-insect ecological interactions supported by weeds left within a farm, and their potential role in supporting pollinators and parasitoids.

Introduction

Cultivated crops are often subject to pest pressure, a major focus of agricultural entomological research for the last century. There is a growing interest in environmentally sound pest control, using beneficial insects rather than pesticides, and this approach holds much promise for increasing food production and growing healthy crops without harmful chemicals in foods and the environment. The presence of non-crop plants may be very useful in this approach, and weeds can provide resources that attract and maintain populations of parasitoids, predators, and pollinators. The role of weeds in agriculture as a tool for insect management is an emerging topic of inquiry in agroecology, with multifaceted theories and varied results.

In this review, we examine the possibility that weeds (defined as wild, unwanted plants) can be used in agriculture to increase floral resources for both pollinators and parasitoid insects. Parasitoids benefit the crop by reducing pest insects, and pollinators increase pollination and crop yield. Just as insects disappear with the disappearance of their weeds, they can also reappear when their weeds return (Pickett and Bugg, 1998). The principles of Integrated Pest Management (IPM) in manipulating weeds to increase predators and parasitoids for plant protection can also simultaneously benefit pollination services. We focus here on studies of parasitoids and pollinators, types of insects overshadowed by the focus on predators in the current literature on weed-insect interactions. We will also review the variety of issues and further areas of study in the new field of weed-insect interactions in agriculture.

There are various hypotheses that can help in understanding the interactions of weeds and insects, and why on a case by case instance, results vary from pest reduction to exacerbating pest populations. The “Resource Concentration Hypothesis” states the relative attractiveness of a habitat to a particular insect is based on the concentration of resource host plants or prey species. Weeds can dilute the concentration of the predominant crop plant, and therefore the attractiveness of the crop to its pests. This hypothesis is based on the concept of “Apparency”- hosts that are more apparent are more likely to be attacked (Castagneyrol *et al.* 2013). Crop host plants more apparent to herbivores are more likely to be fed upon, and therefore weeds can alter crop “apparency”, and act as a sort of camouflage against pests.

The “Enemies Hypothesis” states that having more diverse plant habitats supports a greater diversity of prey insects, and thus more stable populations of natural enemies. Monocultures of crop plants are easily detected and exploited by their herbivores, which are more easily diverted and confused in a varied environment (Andow, 1991). The “Diversity Stability Hypothesis” states that increasing species diversity in an ecosystem results in increased stability. Pest outbreaks are less likely to occur in highly diverse ecosystems due to increased diversity and numbers of enemies. Weeds increase biodiversity, which increases the diversity of natural enemy insects available to prey on crop pests. Increasing diversity, therefore, is a pest management method, one increasingly studied in crop management. Parasitic wasps of pests, for example, have increased fecundity due to nectar obtained from weeds, and are supported by immature arthropods living on the weeds (Pavuk and Stinner, 2017). These beneficial insects naturally suppress pest populations, and may enhance agricultural output and quality.

These theories support the premise to study the utility of weeds, and warrant future research to investigate their potential benefit in various crop systems. Previous work has shown increased

success of beneficial parasitoid insects in the presence of weeds, as beneficial insects use nectar or pollen during their adult life stage to increase life span and fecundity (Norris and Kogan, 2000). Similarly, pollinators can have their populations greatly bolstered in the presence of weeds, and have been shown to have a unique relationship with them (Kremen et al. 2002).

Parasitoid Insects

Parasitoid insects, the majority of which are wasps, are used as biological control of pests as they lay their eggs inside of a host to feed on and ultimately kill. Establishment of parasitoids in farms is enhanced by the presence of weeds that provide nectar to adult female wasps (Altieri and Nicholls, 2018), and pest outbreaks are generally less common in the presence of weeds due to increased mortality by natural enemies. Tolerable weed levels enhance these beneficial insects, without reducing crop yield.

Some studies have shown the success of parasitoids with more floral resources. Parasitism rates of armored scales by *Encarsia citrina* increased over time in the presence of floral resources, through incremental growth of parasitoid populations and immigration in response to increased floral resources (Rebek et al. 2006). Similarly, while both hosts and parasitoids feed on shared floral resources, when exposed to common flowering plants, parasitoids benefited eight times more than their leaf-mining hosts (Kehrli and Bacher, 2008). In maize fields, parasitism by *Trichogramma chilonis* of *Helicoverpa armigera* eggs was positively correlated to the proportion of non-crop habitat diversity and other host crops (Liu et al. 2016). Increasing agricultural intensity and loss of biologically diverse habitat would have great reductions in the presence and parasitism of *T. chilonis*.

Weeds adapted to local environments were found to provide similar resources to common insectary plants, like alyssum, to significantly increase whitefly parasitoids longevity, egg load, and fecundity (Araj et al. 2019). Native weeds, therefore, have the potential to act as insectary plants when growing companion plants isn't possible, or can add to the variety of diets for parasitoids. Weeds, then, can greatly bolster the establishment and success of parasitoids.

Weeds can provide alternative prey, that are not crop pests, to parasitoids as well. A study on the parasitoid of grape leafhoppers, *Anagrus*, showed that they overwinter on adjacent habitat to vineyards (Provost and Pedneault, 2016). The vegetation within and around the vineyard provided alternate prey for the parasitoid that isn't a crop pest, and kept this parasitoid in the field between seasons. Similarly, European corn borer infestations were decreased in the presence of weeds. Parasitoids of this pest were supported by moth species living on the weeds in corn fields (Pavuk

and Stinner, 2017). Weeds both provide food for beneficial insects as well as provide oviposition (egg laying) sites. There are better egg survival rates when oviposited on weeds than the crop. In the absence of prey for the larvae of predatory lady beetles, *Coleomegilla maculata* oviposits on weeds rather than the crop, and as a result the eggs had better survival through less predation and parasitism (Cottrell and Yeorgan, 1998). Weeds, therefore, can be a reservoir of alternative prey, and by living on weeds, parasitoids also protect crop yields by reducing pests.

Pollinators

Pollinators are an important, and sensitive, group of insects that can rebound greatly in the presence of floral resources, or alternatively be diminished when they are lacking. There is a pollinator decline crisis in areas of intensive farming, with fewer and fewer pollinators, and increasing agricultural reliance on them. The use of herbicides to reduce weeds limits the availability of nectar provided by plants for pollinators (Altieri and Nicholls, 2018). Agroecosystems have thwarted the opportunity for co-evolution of insects and plants, with massive synchronous blooms of a single species, and vegetational simplification of large expanses of land. This lack of wild plant floral resources within a farm or adjacent to it before and after the crop blooms can cause a decline in pollinators, due to a lack of support when the crop isn't in bloom. Pollinators can use weeds as alternative resources before, during, and after the bloom of a crop, and increase crop yields if given these resources (Carol and David, 1997). Decline in pollinators is interlinked with weed and habitat decline, through increased applications of pesticides and fertilizers (Nicholls and Altieri, 2013), and the expansion of monocultures.

Native bees are important, yet often overlooked, insects in agriculture. The contribution in the United States of wild pollinators is between \$49-310 million, with no cost to farmers for this ecosystem service. Farms near natural habitats containing native bees see them provide full pollination services, without the use of managed honey bees (Kremen et al. 2002). Resident pollinators are healthiest with 15 or more flowering species providing a season-long food supply (Willmer, 2011), and refuges with weeds can provide this floral diversity, while helping alleviate the pollinator decline crisis. Use of adjacent habitats can ameliorate large losses of habitat for pollinators, but if the farm is too large (>5 ha), native pollinators cannot spill over and penetrate into farms (Nicholls and Altieri, 2013). That is why creating strips or pockets of flowering weeds within farms, especially monocultures, can benefit native pollinators (Pickett and Bugg, 1998).

Most farms operate in isolated areas, so that restoring vegetation helps provide floral resources and nesting habitat to native pollinators. Increasing diversity of native bees can buffer against low populations of European honey bees (Kremen et al. 2002). During seasonal fluctuations of crops

and pollinator needs, native pollinators can provide a substantial portion of crop pollination, provided the farm is in near natural habitat. In farms near natural areas, native bee communities were found to provide full pollination services, even for watermelon, a crop with heavy pollination requirements (Kremen et al. 2002). Ecosystem service arguments align with conserving biodiversity arguments, and increasing diversity with weeds can begin this increased diversity within farms.

Weeds are resilient, hardy plant species. Agricultural intensification leads to decreased landscape biodiversity for plants and insects, making weeds a significant part of the remaining floral diversity. Weeds are generally ambophilous, both insect- and wind-pollinated, which promotes genetic diversity and adaptation to environmental disturbances. This generation of gene flow and environmental plasticity allows successful persistence of weeds in arable landscapes. Increased habitat diversity and patches of unmanaged habitat reduce extinction rates of weeds, through increased genetic variability and species richness (Rollin et al. 2016). There is an evolutionary trend in agroecosystems of de-specialization of plant-pollinator networks, lowering the risk of pollinator absence due to disturbance. Mutualistic pollination networks are key ecological processes, and their stability depends on many links between species. The frequency of rare weeds in farmlands is an indicator of the stability of a community, as their presence is in part due to pollinators, which are the slowest to recover after high levels of agricultural intensity (Rollin et al. 2016).

Mass flowering of crops alters floral availability temporarily, changing pollinator preferences and the stability of wild networks. The use of local weeds in farmed land safeguards pollinator diversity and the specialized links between pollinators and specific weeds. It also buffers against possible lapses in pollination by the European honeybee, a troubled species (Paudel et al. 2015), by ensuring native bee health and range in farmland. This link between plants and insects, and the presence of native weeds, can serve as indicators of the biodiversity of arable lands.

Debate/Issues

Using weeds as an insect management tool is a relatively new area of study, and there is still much debate as well as unanswered questions to be evaluated further. The issue of hyperparasitism underscores biological control programs, illuminated through the resource concentration hypothesis. Increased concentrations of crops (host plants) in weed-free plots leads to a greater density of pests. This may send signals and attract parasitoids and hyperparasitoids into weed-free plots, where their host resource (the pest arthropods) is more concentrated. This effect could perhaps negate the benefits of weeds, should weed-free plots have increased parasitism of crop

pests. Without the presence of a hyperparasitoid, *Aphidius ervi*, a biological control agent of aphids, eliminated their populations in a controlled test. However, *A. ervi* itself was eliminated by a hyperparasitoid, *Asaphes suspensus*, within seven generations (Schooler et al. 2011). This phenomenon, however, contrasts with what actually happens in field surveys, in which the hyperparasitoid doesn't entirely eliminate the primary parasitoid, due to disturbances. Small primary parasitoid populations, however, are particularly susceptible to hyperparasitism (Schooler et al. 2011).

Another vein of debate that needs further research is the idea that weeds providing nectar to beneficial insects also can provide resources to crop damaging pests, and may even attract beneficial insects away from the crop. Similarly, the movement between weeds and different crops by individual beneficial insect species is rarely quantified, but assumed to occur (Norris and Kogan, 2000). Increased fecundity of pests has been observed when weeds were present, due to nectar obtained by the adults, which leads to the question on the utility of leaving weeds as a source of nectar for beneficial insects (Shields et al. 2019). Additionally, weeds need to provide alternative prey sources (arthropods) that are not crop pests, seen successfully done in the study of leafhopper parasitoids of vineyards (Provost and Pedneault, 2016). A similar study found some genera of aphid pests on weeds attack crop plants, while the majority of other aphid species did not. They did, however, represent a good source of food for aphid eating predators and parasitoids, and can act as alternative prey when crop aphid populations are low (Pickett and Bugg, 1998). Alternatively, controlling or eradicating weeds to manage pests causes the issue that the weeds may also be supporting beneficial insects; therefore, monitoring of insect pests hosted by weeds can allow managers to anticipate problems. This approach, to understand movements of pests between weeds and crops, has not yet been solidified, and may prove a useful management technique.

The economic value of field margins and weeds as refuge for pollinators to agricultural productivity is relatively unknown, and few farmers manage this vegetation to enhance beneficial insects. Therefore, managing flowering weeds at tolerable levels to provide alternative resources for pollinators within farms is an overlooked habitat management tactic. Native pollinators can provide free pollination services, and further studies on their requirements and success can help provide solutions to the pollinator decline crisis. There are some economic questions left unanswered in this burgeoning field that need to be addressed before farmers can successfully use weeds to manage insects. Information is needed on how increased numbers of beneficial insects affect certain pests, and the economic data of overall impacts on crop yields when trying to manipulate types of insects. The critical period of interference between specific weeds and crops is

likely to differ with crops and regions, and is still unknown; it is important to determine when the benefits of added pollination to crops may outweigh crop interference of weeds for certain species. Farmers need to know when there are enough weeds to support pollinators and predators, but not pull nutrients and interfere with their crop's production.

The effects of granivorous beetles like carabid beetles on weed seed banks is similarly unknown (Collins et al. 2002). Carabid, or ground beetles are primarily used as insect predators, but they can also have negative impacts on weed populations. They consume the weed seedbank in the soil, decreasing the number of subsequent weeds. Beetles, however, are effective predators that can easily move over long distances, meaning weed strips cannot be seen as a crucial pest reservoir (Pickett and Bugg, 1998). This should also be evaluated when assessing carabids use in insect pest management.

Conclusion

Overall, the use of weeds in increasing beneficial insects has shown promise (Araj et al. 2019; Provost and Pedneault 2016; Kremen et al. 2002; Pickett and Bugg 1998). The varying hypotheses dictating the potential for increasing these insects number through increasing plant diversity, and the success of some studies in proving that, show that this merits further study. While this approach may not always prove a success, studies need to be done for specific crop species, regions where they are grown, and varying combinations of weed species, to learn how these variables affect insect ecological dynamics. These, in turn, must be quantified economically, through increased pollination and less pest damage, to gain insight on the feasibility of implementing this across various crop monocultures. This review shows that studies are limited by the lack of big picture insights as to the behavior of insects, and how anthropogenic influences can shift certain types of species dramatically. By increasing parasitoids and pollinators, inevitable interactions between these and other species can occur, and should be studied in agricultural regions, as natural systems vary greatly. Overall, our insights are still limited, and the best management practices moving forward are to quantify the economic ramifications of shifts in insect populations accompanying the increased habitat complexity provided by weeds.

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Conflicts of Interest

Authors declare no conflict of interest.

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