Article

INFLUENCE OF FLOWERING RED CLOVER ON FLOWER VISITATION IN A SWEET CORN AGROECOSYSTEM

Veronica Yurchak*, Anahí Espíndola, Cerruti RR Hooks

Department of Entomology, University of Maryland, College Park, MD, USA

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*Corresponding author: vjohns04@umd.edu

Abstract—Agricultural intensification and the conversion of natural landscapes into annual cropping systems have contributed to declines in pollinator abundance and biodiversity. Increasing the abundance of flowering plants within crop fields is an often-overlooked practice that may be used to help sustain and enhance pollinator populations. In this study, the influence of red clover (*Trifolium pratense*) used as an interplanted living mulch on pollinator richness and visitation rates was evaluated and compared with monoculture sweet corn habitats. Treatments included sweet corn interplanted with red clover or monoculture with or without cover crop residue. Weekly visual observations of foraging floral visitors revealed that multiple species of bumblebees and butterflies, as well as honeybees frequently visited red clover flowers. Observations of visitors foraging on sweet corn tassels during pollen shed revealed distinct insect communities were attracted by sweet corn and red clover plants. Findings provided evidence that the inclusion of red clover in crop fields can increase the diversity and abundance of bees and butterflies on arable lands by serving as an important food source.

Keywords—flower strip, living mulch, floral visitation, crop

INTRODUCTION

Globally, pollinators play a crucial role in the maintenance and sexual reproduction of wild and domesticated plant communities (Aguilar et al. 2006; Klein et al. 2007). Though honeybees (*Apis mellifera*) are often managed as primary crop pollinators, wild bees have been identified as the dominant pollinator in many crop production systems (Winfree et al. 2008; Garibaldi et al. 2013; Mallinger & Gratton 2015). Similar to other arthropod groups, populations of insect pollinators are declining (Council 2007; vanEngelsdorp et al. 2009; Potts et al. 2010; Cameron et al. 2011; Colla et al. 2012). Although, no single factor can entirely explain their decline, habitat loss and fragmentation have been recognized as common drivers (Goulson et al. 2008; Brown & Paxton 2009; Winfree et al. 2009; IPBES 2016). To this point, fragmented and homogeneous landscapes developed from the establishment of annual cropping systems often support a lower abundance and diversity of pollinators than natural landscapes (Winfree et al. 2009; Potts et al. 2010), tentatively due to the low diversity of plants present within these environments (Nicholls & Altieri 2013). In addition to reduced floral heterogeneity, the shorter bloom period of annual crops in monoculture systems can present pollinators an added challenge by concentrating pollen and nectar resources during a limited time. During periods preceding and following crop bloom, these habitats are unsuitable for foraging bees (Winfree 2008).

The presence of flowering living mulches within crop fields can provide foraging pollinators a supplementary food source (Saunders et al. 2013). A living mulch is a cover crop interplanted with a cash crop that lives the entire duration of the cash crop cycle. Red clover (*Trifolium pratense*) is a flowering perennial that has been investigated as a living mulch for its ability to suppress weeds (Yurchak et al. 2023), increase arthropod natural enemies (Kahl et al. 2019), and fix nitrogen (Thilakarathna et al. 2016), thus contributing to the improved sustainability of the farming system. However, red clover is also a preferred plant for foraging bumblebees (*Bombus sp.*) (Goulson et al. 2005; Carvell et al. 2006; Kleijn & Raemakers 2008) and can help augment bumblebee reproduction (Rundlöf et al. 2014). Further, red clover typically flowers from early spring through fall. Thus, if interplanted within a cropping system, red clover can provide wild bee populations an important source of nutrients throughout the crop's life cycle (Williams et al. 2012; Baude et al. 2016). Nevertheless, few studies have investigated the ability of interplanted flowering plants to serve as a food source for pollinators in vegetable systems. As such, the purpose of the current study was to investigate the effectiveness of using red clover as a living mulch to enhance pollinator abundance and richness within sweet corn (*Zea mays* convar. *saccharata* var. *rugosa*) plantings. We hypothesized that pollinator richness and the abundance of bee and butterfly pollinators would be greater in the red clover diversified than monoculture sweet corn plantings.

MATERIALS AND METHODS

EXPERIMENTAL DESIGN AND FIELD OPERATIONS

Field experiments were conducted in 2020 and 2021 at the Central Maryland Research and Education Center in Beltsville, MD (39.011440°, -76.833356°) using sweet corn as the cash crop. Soil at the study site is a Russett-Christiana complex where the Russett surface soil is classified as loam or sandy loam and the Christiana surface soil is classified as silt loam. In both years, the study was surrounded by fields planted into field corn or wheat followed by double-crop soybeans. Treatments were arranged in a Latin square: split-plot design with four replicates. Whole plot treatments measured 83.6 m^2 and included: (1) conventional till (CT), (2) no-till with crimson clover and rye cover crop residue (NT), (3) red clover living mulch with winter killed forage radish residue (LMFR), and (4) red clover living mulch with rolled rye cover crop residue (LMRye) (Fig. 1). The split-plot factor consisted of herbicide treatments: (1) an at-planting application of residual herbicides (herbicide) or (2) no herbicide application (no herbicide).

During early fall, a mixture of crimson clover (*Trifolium incarnatum;* 3.36 kg ha^{-1}), forage radish (*Raphanus sativus*; 3.9 kg ha^{-1}), and cereal rye (*Secale cereale* L. 'Aroostook'; 62.8 kg ha^{-1}) was planted in CT and NT plots. In LMRye plots, rows alternated between two rows of red clover (*Trifolium pratense* L. 'Freedom') and three rows of cereal rye (75.1 kg ha^{-1}) and LMFR plots alternated between two rows of red clover and three rows of forage radish (11.2 kg ha^{-1}). Red clover was seeded at a rate of 9 kg ha^{-1} in LMRye and 16.8 kg ha^{-1} in LMFR plots. All cover crops were drilled at an interrow spacing of 15.2 cm and planted according to recommended seeding rates for each cover crop type and combination. In the spring, when the rye reached anthesis, cover crops in CT plots were mowed, plowed, and incorporated into the soil. Crimson clover senesced naturally, and the forage radish was winter killed. A roller crimper was used to terminate the rye in the NT and LMRye treatments, and temporarily slow red clover growth in LMRye and LMFR plots. In late May, sweet corn [variety: Providence (Syngenta, Wilmington, DE)] was seeded into each plot at an inter-row spacing of 76.2 cm, resulting in 12 crop rows per plot. In LMRye and LMFR plots, sweet corn seeds were planted within the center of the strips of forage radish or rye residue. Plots were overhead irrigated to mitigate periods of low rainfall and a split-application of 28-0-0-5S with boron fertilizer was applied at a rate of 44.8 kg ha^{-1} at planting, and side dressed at a rate of 112.1 kg ha^{-1}. Weeds were manually removed weekly throughout the

Figure 1. Images show the four whole plot treatments during early sweet corn development. CT: conventional till; NT: no-till; LMFR: living mulch + forage radish; LMRye: living mulch + rye.

duration of the experiment. As part of a larger investigation involving weeds, half of each whole plot received an at-planting application of residual herbicides. It was presumed that the herbicide applications would have no impact on the pollinator community. However, insect sampling was conducted separately within each subplot treatment. Timing of field tasks is provided in Appendix I.

FLORAL VISITATION

Visual observations of visitors foraging in red clover flowers were performed weekly throughout the sweet corn growing season in LMFR and LMRye plots. Red clover flowering onset and duration was similar among all experiment plots. As such, all observations were initiated when red clover was entering bloom in mid-June and were repeated five times until early August when most flowers had begun to senesce. Observations were performed for five minutes by a single individual moving slowly in a single direction through each subplot (41.8 m^2). Visual observations were performed during two periods on each sampling date. The first observations occurred between 8:30 am and 10:00 am and the second between 1:00 pm and 2:30 pm. Surveillance of insects visiting sweet corn tassels were performed similarly in all treatments (CT, NT, LMFR, and LMRye) during the sweet corn pollen shed stage. To account for variability in the onset of pollen shed between treatments, two sets of observations were performed during a one-week period in mid-July when sweet corn in all treatments was flowering. All insects observed actively foraging were classified according to the University of Maryland Native Pollinator Survey (Bernauer et al. 2016) and recorded. Easily recognizable bees such as honeybees, bumblebees, and large carpenter bees (*Xylocopa virginica*) were recorded, while more difficult to identify bees were grouped into morphospecies categories such as: long horned bee (Family: Apidae), large dark bee (Families Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae), metallic bee (Family: Halictidae), small dark bee (Families Andrenidae, Apidae, Halictidae, Megachilidae), etc. Visual surveillance accounted for all hymenopteran and lepidopteran insects observed actively foraging within the test plants. Clover inflorescence stage, temperature, cloud cover and wind speed were also recorded, and observations were only performed under wind conditions rated 'still' or 'light breeze' and cloud cover of 'clear' or 'partly cloudy'. Ambient temperatures during all observations were between 21-37 °C. Timing of all sampling activities is provided in Appendix II.

BEE RICHNESS

Pan traps were used to estimate flying insect richness within each treatment during the sweet corn growing season. Although sweep net sampling provides a more accurate representation of the overall floral visitor community (Prado et al. 2017), this was not feasible due to the close proximity of the clover and sweet corn plants. Instead, methods similar to (Droege et al. 2016) were used at each trapping station. 103.5ml SOLO brand plastic cups (Dart Container Corporation Mason, MI) were painted florescent yellow, blue or white and filled halfway with a soapy water solution. Within the clover, a cup of each color was placed on a stand constructed of wooden stakes. The pan traps were positioned just above the height of the red clover, approximately 46 cm above the soil surface, in all treatments (Fig. 2A). Pan traps in red clover were deployed for a 24-hour period, during the associated V3, V9 and corn flowering stages. The V3 and V9 corn stage refers to the vegetative development stages when three and nine fully emerged corn leaves are visible, respectively. During sweet corn flowering, pan traps similar to those described in Wheelock and O'Neal (2016) were used. Tiered stands constructed from 1.83m wooden stakes were used and each stand contained three sets of colored pan traps. The first triad of pans were placed at 2.5cm above the soil surface, the second at corn ear level, and the final at corn tassel height (Fig. 2B). One tiered stand was established per subplot. After 24 hours, all samples were collected, rinsed, dried and frozen for future identification. Samples obtained from each pan color and sampling height were combined and separated according to date. All specimens were identified to species using the Discover Life key (Ascher & Pickering 2020) and confirmed by a bee taxonomist (S. Droege, USGS). Timing of all sampling activities is provided in Appendix II.

STATISTICAL ANALYSES

Morning and afternoon observations within each treatment and insect group were summed

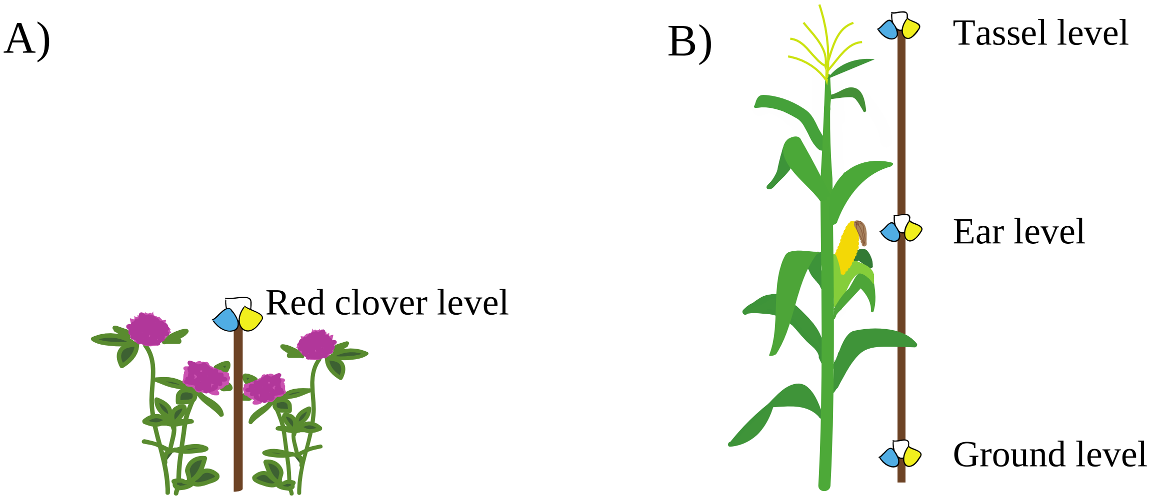

Figure 2. Position of pan trap stand relative to red clover flowers (A) and placement of three-tiered pan trap stand relative to the sweet corn plant anatomy (B).

and analyzed using linear models (LM) to test for differences in total pollinator visitation to red clover or sweet corn flowers with treatment, experiment year, and their interaction as fixed effects. LMs were also used to test for differences in visitation occurrences between pollinator groups. When the LM indicated a significant difference between treatment means or insect groups, post-hoc pairwise comparisons were performed using Tukey-adjusted *p*-values (Lenth 2020).

Species richness (number of taxa) was computed per plot using the 'vegan' R package (Oksanen et al. 2022). LMs were again used to test for differences in insect richness in pan trap captures and Tukey-adjusted *p*-values were used to perform post-hoc pairwise comparisons. Permutational multivariate ANOVAS (PERMANOVA) were used to test for significant differences in community composition across treatments in pan trap samples (Anderson 2017). If a significant effect was detected, Indicator Species Analyses were performed to identify which species were more commonly associated with which treatment.

All data were log transformed when necessary. All statistical analyses were performed using R (v. 4.1.2; R Core Team 2021). All linear models were built using the package 'lme4'(Bates et al. 2015). Post-hoc means comparisons were performed using the package 'emmeans' (Lenth 2020). PERMANOVA community analyses were performed using the 'vegan' package, and Indicator Species Analyses were performed using the package 'indicspecies' (De Cáceres & Legendre 2009). All figures were made using 'ggplot2' (Wickham 2009).

RESULTS

FLORAL VISITATION

A total of 7,728 floral visitors were observed visiting red clover flowers. The most common groups observed were bumblebees (38%), skipper butterflies (Hesperiidae; 25%), and honeybees (11%). In sweet corn, a total of 1,705 bees were observed visiting the corn tassel, and the most common groups observed were honeybees (87%), followed by metallic bees (9%) and large dark bees (4%). A subplot treatment effect was not detected for any data comparisons. As such, results of all data presented are from comparisons made at the whole-plot level.

No effect of year was detected on total floral visitation to red clover flowers ($F_{1,11} = 0.53$, $P = 0.48$). Further, no differences in total floral visitation were detected between the two living mulch treatments (LMFR and LMRye; $F_{1,11} = 1.20$, $P = 0.30$). The number of visitations to red clover significantly differed between insect groups ($F_{12,169} = 54.40$, $P < 0.001$). The insect group observed most frequently visiting red clover flowers was bumblebees. Honeybees, skippers, whites/sulfurs (Family: Pieridae), and brushfoot butterflies (Family: Nymphalidae), excluding monarch

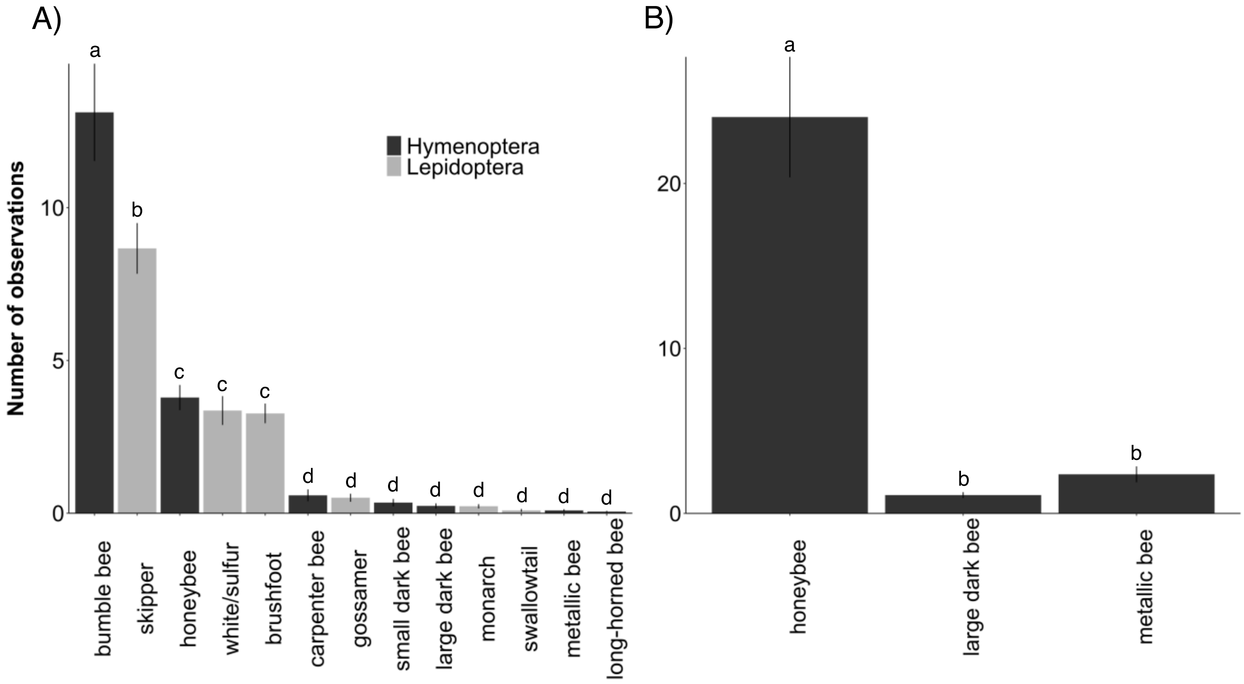

Figure 3. Mean number of insects observed visiting red clover flowers across all observation events and throughout its flowering period (A) and sweet corn tassels during pollen shed (B) over 20-minute periods (10 minutes during mid-morning and early afternoon) in years 2020 and 2021. Insects are organized by groups and groups with the same letter are not significantly different at an alpha=0.05. Different colors in (A) represent insect orders.

butterflies were observed more frequently than the remaining insect categories (Fig. 3A). The least commonly observed groups included carpenter, metallic, long-horned, and small and large dark bees, as well as gossamer-winged (Family: Lycaenidae), monarch (Family: Nymphalidae), and swallowtail (Family: Papilionidae) butterflies.

A year effect was detected on the total number of bees found foraging on sweet corn tassels during visual observations ($F_{1, 23} = 41.32$, $P < 0.001$) with a greater number recorded in 2021 than 2020. However, there was no effect of treatment ($F_{3, 23} = 0.08$, $P = 0.97$) or treatment by year interaction ($F_{3, 23} = 0.10$, $P = 0.96$). The number of visitations to sweet corn tassels significantly differed between insect groups ($F_{2, 81} = 33.21$, $P < 0.001$). Honeybee visitation to sweet corn tassels was greater than other groups observed, and no difference in visitation was detected between large dark or metallic bees (Fig. 3B). Visitation by several groups, including butterflies, large carpenter bees, long-horned bees, bumble bees or small dark bees found visiting red clover flowers, were not observed on sweet corn tassels.

Bee Richness in Pan Traps

A total of 1,083 insects representing 34 species within 14 genera and four families were collected in pan traps. The most common species collected in red clover were *Melissodes bimaculatus* (35%), *Eucera hamata* (13%) and *Lasioglossum pilosum* (8%). The most common species collected in pan traps located contiguous to sweet corn during pollen shed were *Melissodes bimaculatus* (45%), *Agapostemon virescens* (15%), and *Lasioglossum pilosum* (12%).

No effect of treatment ($F_{3,24} = 0.24$, $P = 0.87$), year ($F_{1,24} = 0.22$, $P = 0.64$), or their interaction ($F_{3,23} = 0.43$, $P = 0.73$) was found for bee richness in pan traps positioned at the height of red clover flowers; and no individual bee species was more commonly associated with a treatment (Pseudo-F = 0.79, $P = 0.78$). Further, no differences in total abundance were detected between treatment ($F_{3,23} = 0.44$, $P = 0.73$), year ($F_{1,23} = 0.06$, $P = 0.81$), or their interaction ($F_{3,23} = 0.89$, $P = 0.46$) from pan traps stationed at red clover height. More *M. bimaculatus* were captured in pan traps in red clover than all other groups (Fig. 4A), followed by *E hamata*, which were

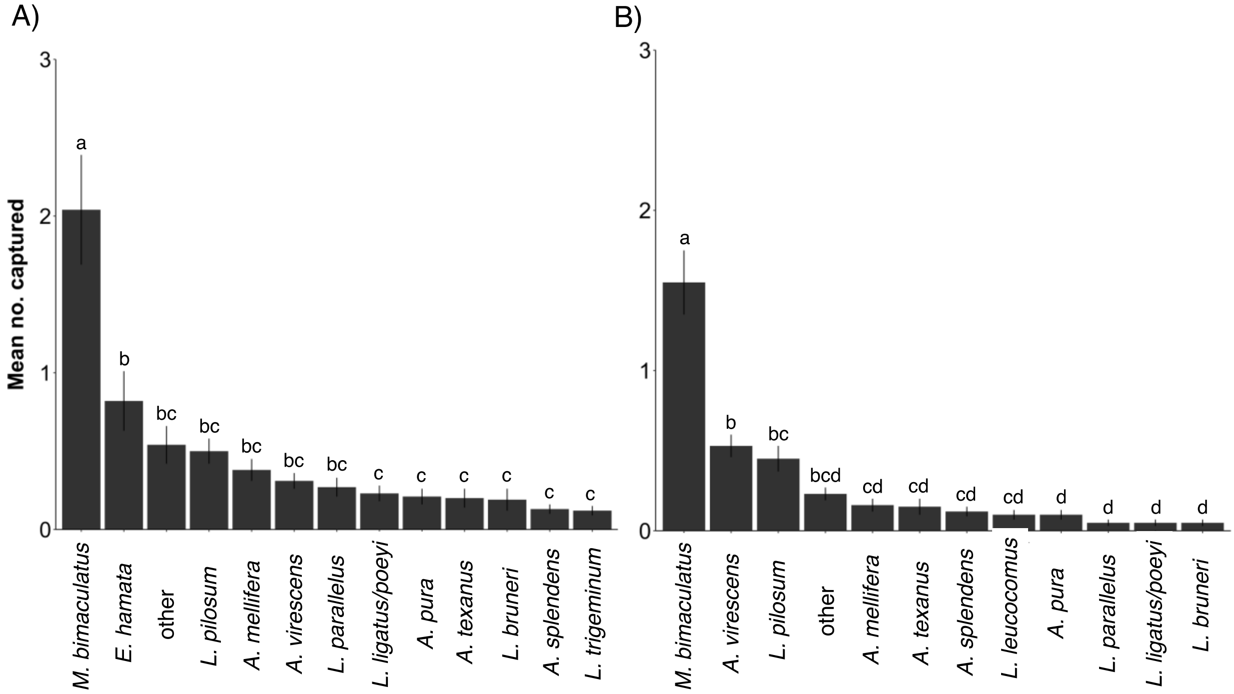

Figure 4. Mean number (± SEM) of species captured per tri-color pan trap group deployed bi-weekly in red clover throughout its flowering period (A) and contiguous to sweet corn plants at two periods during pollen shed (B) in years 2020 and 2021. Note: All bee species that represent less than 1% of the total number captured were combined into the category "other".

captured in greater abundance than *L. ligatus/poeyi, A. pura, A, texanus*, *L. bruneri*, *A. splendens,* and *L. trigeminum.*

Similar to red clover, no significant effect of treatment ($F_{3,23}$ = 1.88, P = 0.16), year ($F_{1,23}$ = 0.74, P = 0.40) or their interaction ($F_{3,23}$ = 0.42, P = 0.74) was found with respect to bee richness in pan traps adjacent. to sweet corn plants during pollen shed; and no individual bee species was more commonly associated with a treatment (Pseudo-F = 0.81, P = 0.76). Further, no differences in bee abundance were detected between treatment ($F_{3,23}$ = 0.89, P = 0.46), year ($F_{1,23}$ = 0.01, P = 0.97), or their interaction ($F_{3,23}$ = 0.97, P = 0.32) in pan traps. An effect of insect group was detected ($F_{11, 144}$ = 35.73, P < 0.001). Pan traps located adjacent to sweet corn plants during pollen shed again captured more *M. bimaculatus* than all other groups (Fig. 4B). The second most common species captured were *A. virescens* and *L. pilosum,* followed by *A. mellifera, A. texanus, A. splendens, L. leucocomus, A. pura, L. parallelus, L. ligatus/poeyi*, and *L. bruneri*.

DISCUSSION

The influence of a flowering living mulch on pollinator abundance and richness was investigated in a pollinator-independent crop. It was hypothesized that the red clover living mulch would increase food resources for floral visitors in monoculture sweet corn plantings; and that this increase would result in greater floral visitor richness and abundance in red clover diversified than monoculture sweet corn habitats. Visual results from weekly pollinator observations in red clover supported our hypothesis; however, numbers within pan traps were similar among treatments. Observations of floral visitation to red clover flowers revealed frequent visits by multiple species of bee and butterfly pollinators throughout the sweet corn growth cycle. Overall, bumblebees were the most frequently observed visitors of red clover flowers, followed by skipper butterflies, honeybees, white/sulfur butterflies and brushfoot butterflies. Visual observations of sweet corn tassels revealed honeybees were the most frequent visitor across all treatments, followed by large dark bees and metallic bees. With the exception of honeybees, differences in the composition of floral visitor groups observed foraging sweet corn and red clover suggests that these plants provide food resources to two distinct communities of insects. Further, red clover flowers supported a diverse community of bees and butterflies throughout the cropping season, while sweet corn tassels offered pollen during the ephemeral blooming period which lasted approximately one week.

Living mulches as in-field resources for bees and butterflies

Living mulches are often investigated for their ability to provide ecosystem services such as weed suppression and/or enhancing populations of arthropod natural enemies (Manandhar & Wright 2016; Kahl et al. 2019; Bhaskar et al. 2021; Bruce et al. 2022; Yurchak et al. 2023). Notwithstanding, flowering living mulches may also enhance floral visitor and potentially pollinator abundance through the provision of food. Most studies evaluating pollinator attractiveness to cover crops have focused on single species annuals or a mixture of annuals with different flowering times so as to extend the blooming period (Carreck & Williams 2002; Mallinger et al. 2019). Further, many of these studies evaluated floral visitor abundance in cover crops planted alone during the summer fallow period in lieu of interplanted within a cash crop (Bryan et al. 2021). Red clover flowers provide bees with season-long access to pollen and nectar resources, including long-tongued bees, many of which have experienced the greatest declines due to their specialized pollen requirements and the restricted availability of long-tubed flowers (Goulson et al. 2005). In a study evaluating floral visitation to fall planted cover crops, Ellis & Barbercheck (2015) suggested that insect support in red clover may be maximized if it remains established during the entire cash crop growing season. Red clover is particularly known to attract foraging bumblebees, including rare and declining species (Goulson et al. 2005; Carvell et al. 2006; Wermuth & Dupont 2010; Rundlöf et al. 2014) which contribute significantly to the pollination of wildflowers and crops (Genung et al. 2023). As such, conservation efforts that support the abundance of these species will promote this ecosystem function.

Bumblebees are generally recognized as efficient pollinators of various field and vegetable crops (Shipp et al. 1994; Cecen et al. 2008; Lowenstein & Minor 2015) and recent efforts have focused on increasing their abundance in field and greenhouse production systems (Nayak et al. 2020). In addition to bumblebees, red clover inclusion in sweet corn plots increased the in-field abundance of honeybees, select solitary bee species, and five butterfly families which were not visually observed or trapped in the no-till (NT) and conventional till (CT) sweet corn habitats. Pollinator abundance in cropping systems outside their blooming period could be influenced by other factors such as management practices and surrounding habitats (Kremen et al. 2002) as well as the availability of nest sites (Dainese et al. 2018). Nest site selection among wild solitary bees is highly variable and influenced by multifarious factors including soil type, compaction, soil moisture, ground surface features, etc., (Antoine & Forrest 2021). While it is unlikely that any of the treatment habitats would have influenced bee abundance by serving as a nesting site, detecting the influence of different land management practices on wild bee nesting will tentatively require a long-term field study.

Studies conducted to increase pollinator conservation in annual cropping systems have done so mostly by manipulating floral resources along field margins. Though increased floral visitor abundance has frequently occurred within these florally-rich field margins, this has not consistently augmented their numbers in the adjacent crop fields (Blitzer et al. 2012; Zamorano et al. 2020; Lowe et al. 2021). This suggests that if the main goal is to attract pollinators into the crop field, interplanting flowering plants within the crop may be more effective as this would expand their attraction beyond field edges. Despite this, research investigating the effects of within field floral diversification on pollinator abundance is limited (Järvinen et al. 2022). In a study evaluating the effects of four corn management practices on pollinator diversity and community composition, Norris et al. (2018) found greater pollinator richness, density and diversity in field corn intercropped with a flowering plant mixture compared to a perennial ryegrass (*Lolium perenne*) intercrop and field corn monoculture. Similarly, Dingha et al. (2021) found that intercropping flowering cowpea (*Vigna unguiculata*) with okra (*Abelmoschus esculentus*), squash (*Cucurbita* pepo) or watermelon (*Citrullus lanatus*) increased pollinator abundance and diversity, as well as cash crop yield compared to monoculture vegetable systems. Pereira et al. (2015) also documented greater pollinator abundance and crop yield in bell peppers (*Capsicum annuum*) interplanted with flowering basil (*Ocimum basilicum*) than monoculture peppers. In contrast, Järvinen et al. (2022) found greater pollinator abundance in monoculture turnip rape (*Brassica rapa* L. ssp. *Oleifera*) compared to turnip rape intercropped with faba bean (*Vicia faba* L.) and faba bean alone. Greater abundance in turnip rape monoculture was attributed to food resources in turnip rape being more easily accessible by foraging bees than in faba bean flowers. The current study contributes to the sparse number of studies evaluating how in-field floral diversification influence floral visitor and pollinator richness and abundance, and highlights the potential use of red clover to increase the abundance of bee and butterfly pollinators in monoculture cropping systems.

Red clover and sweet corn attract different floral visitor communities

Though a more diverse assemblage of floral visitors were observed foraging on red clover flowers than on sweet corn, no treatment differences were detected in their richness or total abundance from pan trap samples collected during the red clover blooming period and sweet corn pollen shed. This indicates that despite being physically close to each other, flowers of the two species effectively attract different floral visitor communities. Further, these results indicate that red clover cultivation can increase bee diversity within sweet corn fields.

The most abundant bees captured from pan traps in red clover were *M. bimaculatus*, *E. hamata* and *L. pilosum.* However, these species were rarely observed visiting red clover flowers and their capture rates were similar among treatments. This suggests they may have been more influenced by trap presence while foraging than the disparate planting systems. Conversely, despite the high numbers of bumblebees observed visiting red clover flowers, they were rarely captured in pan traps. Taken together, these results are in line with those of other studies and suggest that pan trap captures were more representative of the small insect community, while observations of floral visitation provided a better indication of red clover use by bumblebees and butterflies. These results also agree with Bell et al. (2023) who found that pan traps are less effective at capturing *Bombus* sp. than other trapping methods. This suggests that red clover's impact on *Bombus* sp., number and richness cannot be assessed from pan trap data. Pan traps were similarly ineffective in capturing honeybees despite frequent observations of honeybee foraging in corn tassels. In a comparison of pan trap captures and visual observations of foraging pollinators, Roulston et al. (2007) found that despite witnessing over 200 honeybee flower visits, only a single specimen was captured from thirty pan traps. Thus, the low numbers of honeybee and bumblebees captured in this experiment may be attributed to trap inefficiencies.

During sweet corn pollen shed, the most abundant species captured in pan traps were *M. bimaculatus*, A. *virescens*, and *L. pilosum*. Some of these species were frequently observed visiting sweet corn tassels and numbers captured were similar among treatments, suggesting a close association with corn pollen. Correspondingly, a study cataloguing insect floral visitors in Iowa cornfields also recorded high numbers of *M. bimaculatus*, *A. virescens* and *Lasioglossum* species in the subgenus (*Dialictus*) in pan traps (Wheelock & O'Neal 2016). Danner et al. (2014) also identified a strong association between honeybees and corn pollen. These and current findings suggest that corn pollen may serve as a regular food source for some bee groups. Though high numbers of a few bee species may be present in monoculture cornfields during the pollen production period, our results and those of others in corn monoculture systems show that it is not favorable for supporting diverse groups of floral visitors.

Considerations for the implementation of living mulches in cropping systems

The current study highlights that increasing floral resources in the form of interplanted flowering living mulches can augment bee and butterfly richness and abundance within agricultural fields, demonstrating their use for pollinator conservation. Findings from this study also show that groups of floral visitors found foraging on the cash crop and living mulch may differ, and that the presence of a living mulch may not influence the species composition of insects directly foraging the cash crop (at least in the current plant combination). It is also important that careful thought is given to pest management practices deployed within the cash crop. For example, pesticide sprays are a common practice in corn production and could prove fatal to populations of floral visitors (Bloom et al. 2021). In this context, adding a floral source within crop fields exposed to chemical sprays may prove inhospitable to pollinator health. This suggests that the practice of interplanting flowering plants within crop fields to support pollinators may be more favorable to organic agriculture, production of transgenic crops that eliminate or reduce synthetic pesticide use, or perhaps cropping systems that receive nocturnal sprays of pesticides to help avoid accidental exposure (Decourtye et al. 2023). Finally, it is possible that entomophilic crops would experience increased yield or production when interplanted with flowering living mulches, although the potential for competition with the living mulch must also be taken into consideration for vegetable and agronomic crops. Thus, future research should investigate the influences of interplanted red clover and other season-long flowering plants on pollination services and associated yields in pollinator-dependent crops.

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Author contribution

Concept and design VY, AE, & CRRH, data collection VY, data analysis VY, writing VY, edits and approval for publication AE & CRRH.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The data used to write this article are available as supplemental materials in the Appendices.

Appendices

Additional supporting information may be found in the online version of this article:

Appendix I. Timing of field operations

Appendix II. Timing of sampling activities

Appendix III. Taxon totals of red clover floral visitors

Appendix IV. Taxon totals of sweet corn floral visitors

Appendix V. Species totals of pan trap captures in red clover in 2020

Appendix VI. Species totals of pan trap captures in red clover in 2021

Appendix VII. Species totals of pan trap captures in sweet corn in 2020

Appendix VIII. Species totals of pan trap captures in sweet corn in 2021

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