

Wildflowers in Working Landscapes: Establishment Methods and Impacts on Pollinators and
Cattle

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fulfillment of the requirements for the degree of

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ABSTRACT

Insect pollinator populations are in decline globally due to habitat loss and degradation, climate change, pesticide use, and other stressors. These declines have severe implications for the ecosystem services provided by pollinators. Prior research has shown that creating wildflower plots in agricultural contexts is a promising avenue to provide pollinators with habitat. However, several questions remain regarding how these plots interact with grazing systems in particular, and how best to establish native wildflowers in the first place. This thesis explores strategies to provide pollinator habitat in agricultural landscapes, focusing on the establishment of native wildflower plots in cattle pastures over two experiments. The first study investigates wildflower set-aside plots established in pastures at a farm in western Virginia, finding that plots sown with native wildflowers saw pollinator populations more than three times greater than in control pastures ($p < 0.0001$), and far higher floral abundance and diversity than un-enhanced pastures ($p = 0.013$). Cattle stocked in wildflower-enhanced pastures performed similarly to those in control pastures across when all years were analyzed together ($p = 0.211$), though in 2024 when supplemental feeding was delayed, cattle in wildflower paddocks gained less weight ($p = 0.04$). The second experiment explored repeated tillage as a chemical-free site preparation method to reduce weed pressure and facilitate native wildflower establishment. Eight treatments were compared, ranging from minimal tillage to three rounds of seasonal tillage across the growing season, varying frequency and timing of tillage application. Following a year of site preparation, plots were winter seeded with a native wildflower mix. All treatments showed moderate wildflower establishment (> 5 wildflowers/m²) though emergence rates were highly variable, and there was no strong evidence for differences between treatments. There were also no differences in the overall plant community attributable to the tillage treatments. These results suggest that tillage frequency and timing alone do not substantially influence wildflower establishment success, and site-specific factors like

weed seed bank composition and other management decisions may play a more key role.

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GENERAL AUDIENCE ABSTRACT

Pollinating insects are globally threatened by several forces including pesticide use, climate change, and the loss of good quality habitat. The decline of insect pollinators is concerning because they support our food system and a thriving ecosystem more broadly. One method to support pollinators is the creation of wildflower plots on farms as habitats for pollinators, though some questions remain about their establishment and impacts. This thesis focuses on wildflower plots in cattle pastures, with two experiments that investigate the creation of and impacts from wildflower set-aside plots. The first study used wildflower plots in pastures on a farm in western Virginia, finding that plots of native wildflowers were home to more than three times as many pollinators compared to the rest of a field, and that those pollinators were more diverse. The wildflower plots themselves had many more flowers compared to the untreated pastures, and those flowers provided blooms across the season as intended. Cattle in wildflower-enhanced pastures gained similar amounts of weight in 2022 and 2023, but gained less weight than those in typical pastures in 2024 when supplemental feeding was delayed. The second study investigated repeatedly tilling the soil as an herbicide-free means to eliminate weeds and allow for the creation of a wildflower plot. Various combinations of tillage were tested to see if tilling more often or in different seasons affects wildflower establishment. After a year of tillage preparation, the plots were sown with native wildflower seeds. All of the tillage schedules tested saw at least moderate densities of wildflowers growing, though there were no clear differences due to either timing or frequency of tillage. Similarly, the particular tillage schedule did not appear to influence which other plants were growing in the wildflower plots. However, tillage did create conditions for moderate wildflower growth in all cases, which suggests that although tillage works for planting wildflowers, there are several other factors that may be more influential on how effectively wildflower plots can be created.

Dedication

I wish to dedicate this work to my husband Austin, whose support and encouragement have pushed me far further than I would have been capable of alone.

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1. Introduction

Insect populations, and specifically insect pollinator populations, are in decline globally. This trend is driven by a number of factors, including habitat loss and degradation, climate change, and pesticide use (Goulson et al. 2015, LeBuhn and Vargas Luna 2021, Cullen et al. 2019, Kluser and Peduzzi 2007). Habitat loss and degradation in particular have been driven by agricultural intensification and expansion, due to the removal of semi-natural “waste places” at field margins and hedgerows and the fragmentation of what little habitat remains (Cane and Tepedino 2001, Habel et al. 2019). Increasing proportions of agricultural area in the landscape are linked to decreases in pollinator richness and diversity, making an already threatened population more vulnerable to disturbance (Grab et al. 2019).

This decline is particularly concerning because of the immense value provided by pollinating insects. Although precise estimates vary, pollination services from insects account for upwards of \$50 billion of value in the United States by supporting food production and healthy ecosystems more broadly (Losey and Vaughan 2006, Calderone 2012). It is therefore crucial that we conserve the pollinator populations still remaining and shepherd the recovery of what has already been lost.

Fortunately, there are several methods available to support vulnerable pollinator communities, and habitat creation and restoration can offset what has been lost (Haaland et al. 2011, Sexton and Emery 2020, Williams et al. 2015). However, precisely where and how such habitat creation should be conducted is still an open question. Establishment methods vary greatly, and there are countless variables that influence establishment success, including site selection and preparation, weed management, seed selection and rate, timing and method of planting, and the goals of a particular project (Angelella et al. 2019, Barr et al. 2017, Dunn et al. 2020, Glidden et al. 2023, Bellangue et al. 2024).

One promising approach involves the establishment of native wildflower strips or plots in agricultural contexts. Because their conditions are often similar to those preferred by native wildflowers, hayfields and grazing systems may be especially suited to the creation of pollinator habitat (Potts et al. 2009, Isaacs 2009, Korpela et al. 2013, Ouvrard et al. 2018). These plots successfully provide nesting sites, pollen, and nectar

for a range of pollinating insects, though differences in establishment and management often lead to different outcomes.

This research seeks to address two facets of the creation and management of these wildflower plots. First, we analyze how pollinator plots established within cattle pastures influence both local pollinator communities and the productivity of livestock in such a system. Little research has been done on the direct impact on animal performance from wildflower plantings, and we hope to demonstrate a realistic example of such a system. Second, with increasing demand for herbicide-free alternatives to prepare a site for wildflower establishment, we investigate how tillage performs as a weed control and seedbed preparation method. In particular, the experiment uses various timings and frequencies of tillage to provide recommendations for the most effective and reliable approach to creating native wildflower plots that support vital pollinator communities.

2. Chapter 1: Evaluating Wildflower Set-Aside Plots in Cattle Pastures

2.1. Introduction

2.1.1 Scope of the Problem: Pollinator Decline

Pollinators contribute crucial ecosystem services to global agriculture, where 15-30% of food production depends on insect pollination (McGregor 1976). Wild pollinators play a key role alongside managed honey bees (*Apis mellifera*) in providing these pollination services (Losey and Vaughan 2006). However, wild pollinator conservation is increasingly urgent, as the production of crops that require animal pollination outpaces the growth of managed hives (Garibaldi et al. 2014), and many crops are reliant on specialist pollinators rather than generalist honey bees (Klein et al. 2007, Garibaldi et al. 2013). Beyond crop pollination, healthy pollinator populations support broader ecosystem services such as pest control and nutrient cycling, valued at over \$50 billion annually in the U.S. alone (Losey and

Vaughan 2006, Calderone 2012). However, insect populations, including many pollinator species, are in sharp decline globally due to habitat loss and degradation, climate change, and pesticide use (Cane and Tepedino 2001, Goulson et al. 2015, LeBuhn and Vargas Luna 2021).

Agricultural intensification, particularly the removal of field margins and hedgerows, has played a key role in habitat loss. Habitat degradation—including fragmentation and invasion by nonnative species—similarly reduces pollinator richness and disrupts pollination services (Cane and Tepedino 2001, Habel et al. 2019, Grab et al. 2019). Agricultural intensification also reduces both floral and faunal diversity, further harming pollinators reliant on native plants (Potts et al. 2009). Other stressors like climate change and widespread use of insecticides compound these effects, driving pollinator diversity and abundance to decline precipitously in recent years (Forister et al. 2019, Goulson et al. 2015). Declining insect populations have also been implicated in declines in insectivorous bird populations, and the greatest declines were in specialist populations and those associated with agricultural intensification and loss of grassland habitats (Bowler et al. 2019, Tallamy and Shriver 2021)

Pollinator activity correlates strongly with floral diversity (Ghazoul 2006), and grassland ecosystems that are rich in floral diversity provide critical pollinator habitats. However, flower-rich native grasslands are rapidly disappearing, especially in the southeastern U.S., and those that remain are typically relegated to marginal sites. Most grasslands in the region—composed primarily of introduced (non-native) species and managed intensively for livestock production—have low functional diversity (Samson and Knopf 1994, Noss 2013). These landscapes tend to favor generalist species, like honey bees, that can utilize mass-flowering crops and diverse floral resources (Requier et al. 2015, Börschig et al. 2013). The loss of semi-natural habitats and weed removal—hallmarks of intensive agriculture—are linked to declining pollinator populations and pollination services (Bretagnolle and Gaba 2015).

2.1.2 Establishing Pollinator Habitat

Restoring or creating new pollinator habitat is essential to arrest the decline in these species and their attendant ecosystem services, and numerous strategies can increase or enhance their habitat across landscapes. Sown wildflower strips along agricultural field margins enhance insect diversity and abundance (Haaland et al. 2011). Urban wildflower meadows offer similar benefits and are relatively easy to establish (Bretzel et al. 2016).

Larger-scale grassland restoration can also rebuild pollinator populations, with restored sites supporting nearly the same pollinator richness as remnants (Sexton and Emery 2020). However, in one study, wildflower strips sown in hay meadows provided resources for common pollinators but still lacked floral and pollinator diversity. The study suggested incorporating flowers that bloom across the growing season can cater to specialist pollinators and increase diversity (Ouvrard et al. 2018). A similar study within cattle pastures found that reducing management intensity and sowing diverse species mixes boosted pollinator abundance, although more overall management may be required to maintain pasture diversity (Potts et al. 2009).

Key insect pollinators include bees, butterflies, moths, wasps, flies, and beetles. Bees, especially honey bees, are prominent due to their pollen collection behaviors (Williams et al. 2018), but all pollinators contribute to ecosystem services. However, many pollination studies focus only on bees or other conspicuous individual groups like butterflies (Leonhardt and Blüthgen 2012, Nichols et al. 2019, Williams et al. 2015, Tuell et al. 2008, Rollin et al. 2013, Ogilvie and Forrest 2017, Börschig et al. 2013), overlooking other important groups. In one study in Germany, 75% of pollinators visiting agricultural wildflower strips were not bees, highlighting the need for broader study (Grass et al. 2016). Non-bee pollinators also play a substantial role in crop pollination, but respond differently to habitat disturbances and therefore need further study (Rader et al. 2016).

Given the importance of wild and native pollinators besides honey bees, understanding how these groups interact with native wildflowers selected for habitat creation is critical. In U.S. studies, regionally-adapted flower mixes attract far more pollinators than generic mixes (Williams et al. 2015). Prioritizing a smaller selection of highly attractive species covering a range of traits is often more effective than maximizing total species diversity (Warzecha et al. 2018). An ideal pollinator habitat includes diverse flowers that bloom throughout the season, cater to both generalists and specialists, and are native to the region (Barr et al. 2017, Vaughan et al. 2015, Aldrich 2002, Williams et al. 2015). Key attributes include bloom timings that span the growing season, varied flower morphologies, and regional climatic adaptability. Including annuals alongside slower-establishing perennials can provide early-season resources and suppress weeds (Angelella et al. 2019, Isaacs et al. 2009, Barr et al. 2017). Several eastern U.S. wildflowers—such as *Ratibida pinnata* (gray-head coneflower), *Solidago speciosa* (showy goldenrod), and *Silphium perfoliatum* (cup plant)—are particularly attractive to wild bees (Tuell et al. 2008).

2.1.3 Wildflowers in the Context of Temperate Cattle Pastures

Creating pollinator habitat in cattle pastures is a promising approach for supporting pollinators, though it also requires careful planning and implementation. Tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumont., syn. *Lolium arundinaceum* (Schreb.) Darbysh., formerly *Festuca arundinacea* (Schreb)), the dominant forage grass in the eastern U.S. “Fescue Belt,” grows on more than 14 million ha (Stuedemann and Hoveland 1988). As a wind-pollinated, non-native grass, it offers little benefit to pollinators. Floral resources in these pastures primarily come from non-native forage legumes such as white and red clovers (*Trifolium repens* and *T. pratense*) or native and exotic weeds (Woodcock et al. 2014, Bretagnolle and Gaba 2015). However, although fescue-dominated pastures often are extensively managed and have the low-fertility, sunny conditions ideal for wildflower establishment, they still present significant competition that can make establishing wildflowers difficult. Given the difficulty of incorporating wildflowers throughout a pasture, creating wildflower plots separately may be a more reliable method to support pollinators (Coon et al. 2021, Bellangue et al. 2024, Kubesch et al. 2024).

Although forage legumes benefit both pollinators and cattle, they tend to favor generalist pollinators over specialists, with the latter more often relying on native wildflowers (Rollin et al. 2013, Scheper et al. 2021). Some native wildflowers are both pollinator-friendly and suitable for grazing, while others like Carolina horsenettle (*Solanum carolinense*) and common pokeweed (*Phytolacca americana*) are considered undesirable weeds and are rarely grazed (Luginbuhl 2020, Axton and Durgan 1991). Selecting species that balance palatability, pollinator value, and resilience to grazing is crucial. Recent work identified several native forbs that provide high-quality forage, support pollinators, and withstand repeated defoliation (Prigge et al. 2024). Similarly, diverse legume plantings improve forage yield while increasing pollinator visitation (Caudillo et al. 2024).

2.1.4 Study Overview

This project investigated how native wildflower “set aside” plots in cattle pastures develop, attract pollinators, and impact cattle performance. The hypotheses tested were: 1) Planting a carefully selected seed mix will create wildflower plots that bloom from Spring to Fall, 2) these plots will attract far more pollinators than conventional cattle pastures with low

floral diversity, and 3) the impact on cattle performance (measured by weight gain) of these plots will be minimal.

2.2. Methods

2.2.1 Establishment

This research was conducted at the Shenandoah Valley Agricultural Research and Extension Center (SVAREC) in Raphine, Virginia, USA, located at 37.9425° N, 79.221° W, at an elevation of 560 m. Experimental plots were located within long-standing temperate cattle pastures (established in 2002) and predominantly comprised of tall fescue, orchardgrass (*Dactylis glomerata*), Kentucky bluegrass (*Poa pratensis*), and white clover.

The treatment consisted of setting aside a 0.2-hectare section of a cattle paddock and planting native wildflowers to attract and benefit pollinators. Six paddocks of approximately 1.9 hectares were used in this experiment, with three assigned to the wildflower treatment and three left as controls. Treatments (with or without wildflowers) were assigned to paddocks paired based on topography and shape. Each paddock was stocked with six Angus-cross heifers (approximately nine months old, average wt 248.3 +/- 20.8 kg) from May to October every year. Each group of heifers was fed 5.4 kg/day of a blended pellet containing wheat (*Triticum aestivum*) middlings, corn (*Zea mays*) gluten feed, and soybean (*Glycine max*) hulls throughout the first two years, but not until the end of the season in 2024. Cattle were excluded from the wildflower plots using temporary electric fencing for most of the duration of the season, until the wildflowers were done blooming, at which point the fencing was removed to allow access for grazing.

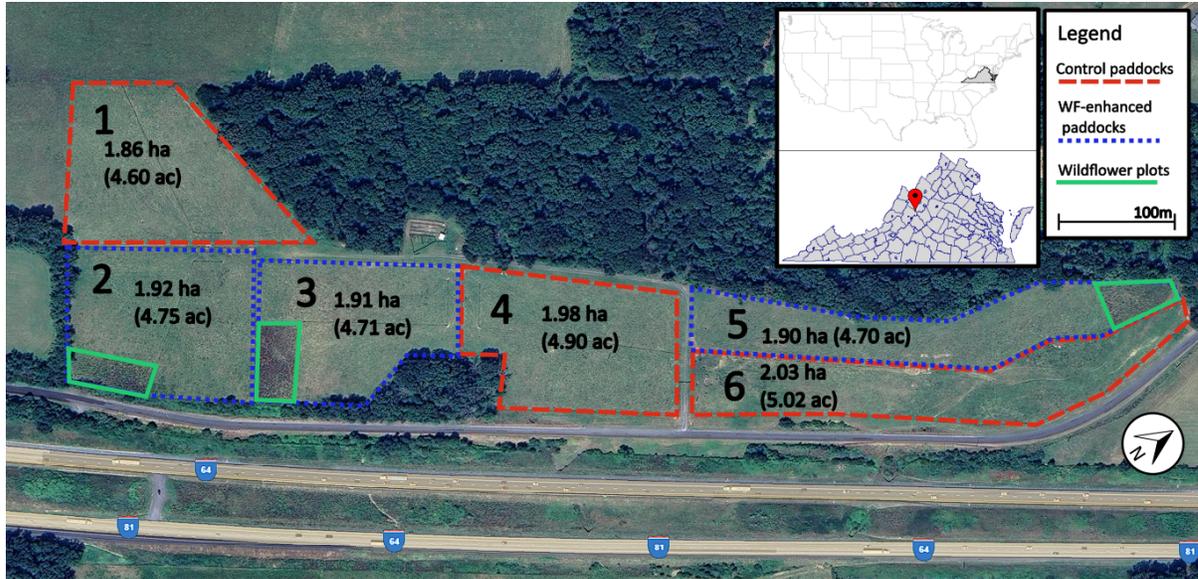


Fig 1: Map of experimental pasture at SVAREC. Wildflower (WF)-enhanced paddocks in blue, with the WF set-aside plots in green. Control paddocks are red. Area listed represents the total paddock area, including WF plots. Map generated using Google Earth (Google LLC. 2023).

The wildflower plots were originally established in June of 2022. The plots were prepared by spraying with glyphosate (*N*-(phosphonomethyl)glycine) at a rate of 5.6 L/ha + 0.5% non-ionic surfactant to kill the existing vegetation. The plots were then seeded the same day with wildflowers using a Great Plains 605NT no-till seed drill. The seed mixture (Table 1) was drilled directly into the killed fescue sod at a target rate of 6.73 kg/ha (6 lb/ac) along with a carrier of cracked corn at 8.96 kg/ha (8 lb/ac). After sowing, management was minimal; the plots were spot-sprayed using a backpack sprayer with 0.5% glyphosate to manage thistles once in the spring of 2024 before the wildflowers emerged. Temporary fencing was used to exclude cattle to allow wildflowers to emerge and establish unimpeded.

Table 1: Seed mixture used to establish wildflower plots.

Common Name	Scientific Name	Type	Target PLS (kg/ha)	Bloom Timing
Calico Aster	<i>Symphotrichum lateriflorum</i>	Wildflower	0.179	August-October
Wild Bergamot	<i>Monarda fistulosa</i>	Wildflower	0.112	July-September
Early Goldenrod	<i>Solidago juncea</i>	Wildflower	0.056	June-August
Flat-top Goldentop	<i>Euthamia graminifolia</i>	Wildflower	0.022	July-October

Common Milkweed	<i>Asclepias syriaca</i>	Wildflower	2.09	June-August
Narrowleaf Mountain Mint	<i>Pycnanthemum tenuifolium</i>	Wildflower	0.022	June-September
Partridge Pea	<i>Chamaecrista fasciculata</i>	Legume	2.25	June-October
Ox Eye Sunflower	<i>Heliopsis helianthoides</i>	Wildflower	1.39	June-September
Black-eyed Susan	<i>Rudbeckia hirta</i>	Wildflower	0.090	May-October
Panicleleaf Trick Trefoil	<i>Desmodium paniculatum</i>	Legume	0.73	July-September

2.2.2 Data Collection

To assess the impact of setting aside a portion of a paddock on animal performance, the cattle were weighed at the beginning (spring) and end (fall) grazing season. Cattle were weighed on two consecutive days to account for day-to-day variance. These weights were averaged and used to determine an average daily weight gain over the grazing season.

Pollinator numbers and diversity were assessed four times over the summer of 2023 and seven times during the summer of 2024. Assessments were performed between 9AM and 3PM on mostly clear, still days that favored pollinator activity. Pollinator counts were obtained using a nondestructive approach, modified from the “snapshot method” described by Garbuzov and Ratnieks (2014). Briefly, the observer walked a randomly-selected, 61-meter transect over the course of 15 minutes and visually counted insect pollinators within a meter of the transect. This method is ideal for quick assessments of pollinators, and, because it is non-lethal, does not remove valuable pollinators from the ecosystem. Because counts were solely visual, species identification was difficult or impossible, so pollinators were binned into eight categories: honey bees, bumble bees, small native bees, large native bees, flies, butterflies and moths, wasps, and beetles, where “small” and “large” native bees are defined as wild bees smaller or larger than a typical honey bee. In the WF-enhanced paddocks, the 61-m transect was split into two 30.5-m transects, one of which was within the wildflower set-aside plot and one in the remaining paddock adjacent to the wildflower plot. In order to standardize the data for analysis, pollinator counts were adjusted to abundance per 10 m.

To determine the plant species present in both experimental and control plots, cover assessments were performed once in June 2023 and once in June 2024. Points were randomly selected within the paddock, and then a 0.25-m² square quadrat frame was placed over the points. At each point, all plant species within the quadrat were identified morphologically to the lowest taxon possible according to *The Flora of Virginia* (Weakley et

al. 2012). This procedure was repeated 16 times in each field to gather a representative sample and the percent cover estimates were averaged. For the wildflower-enhanced paddocks, eight quadrats were taken within the exclusion plots and eight from the rest of the field.

Additionally, floral resources were assessed alongside pollinator counts across the 2024 season. In both WF-enhanced and control paddocks, floral units were counted within eight, 0.25-m² quadrats placed along the same transect used for the pollinator assessments. Flowers both from weeds (non-sown species) and sown wildflower species were counted. For the purposes of this research, a “floral unit” was defined as “any amalgamation of flower heads that a visiting pollinator can walk rather than fly between, such as an umbel in *Apiaceae*” (Woodcock et al. 2014).

2.2.3 Analysis

For the cattle performance data and pollinator community data, linear mixed-effects regressions were used to assess the effects of a WF-enhanced paddock on cattle weight gain and pollinator abundance. The models were fitted using the *lmer* function within the “lme4” package (Bates et al. 2025), p values were generated with the Satterthwaite approximation method from the “lmerTest” package (Kuznetsova et al. 2020), and model fit was evaluated using the *R2* function from the “performance” package (Lüdtke et al. 2021) in R Statistical Software (R Core Team 2024). Analysis for the cattle data used average daily weight gain (ADG) as the response variable, with fixed effects for treatment and year, and their interaction. To account for repeated measures within each plot, a random intercept for the year was included for each plot. Pollinator data were analyzed with pollinator abundance per 10 m as the response variable, and fixed effects for the type of pollinator and treatment. Additionally, individual paddocks were included as a random effect.

The data were also evaluated using principal component analysis (PCA) to visualize relationships between the plots and treatments in terms of pollinator community composition, total vegetation species cover, and floral abundance. Because floral abundance numbers varied greatly in magnitude, the data were log-transformed before calculating a distance matrix.

The cover data were also evaluated with permutational multivariate analysis of variance (PERMANOVA) using the *adonis2* function from the “vegan” package in R (Oksanen et al. 2025). A distance matrix using Hellinger distance was calculated using the

species cover data in each plot, and the effects of both treatment and sampling year were tested. Following this analysis, pairwise comparisons were made to determine which factor (treatment or sampling year, or their interaction) correlated with the distance calculated between observations.

2.3 Results

2.3.1 Cattle Performance

The mean average daily weight gain (ADG) of the cattle in the control group was 0.45 kg (SD=0.134 kg), and the mean ADG of the WF cattle was 0.41 kg (SD=0.158 kg). There was little evidence for a difference in ADG between cattle in the WF paddocks and conventional tall fescue paddocks (Table 2). However, there was strong evidence for a difference in ADG between treatment years, and 2024 had notably lower ADG compared to previous years (0.238 kg/day less than 2022). There was no evidence of interaction effects between year and treatment.

However, the supplemental feed provided to the heifers in 2022 and 2023 was given mostly after weighing in 2024. Although the linear mixed models did not give strong evidence for a difference in weight gain due to wildflower set-asides, comparing only the results from 2024 using a T-test shows a different relationship: here was strong evidence for a difference in ADG in 2024, with heifers in wildflower-enhanced paddocks gaining 22% less weight than in conventional paddocks ($p=0.04$, Fig 2).

Table 2: Mean ADG for each group (treatment and year), and summary of the results of the linear mixed effects regression on the average daily gain data, with estimates given for each parameter. “Intercept (control)” represents control plots in 2022. ADG is average daily gain, measured in kilograms per day.

Group	Mean ADG \pm SD (kg)	Parameters	Estimates (ADG \pm SD) (kg)
WF-enhanced	0.410 \pm 0.158	Treatment WF	-0.046 \pm 0.0368 $p = 0.211$
Control	0.450 \pm 0.134	Year 2023	-0.105 \pm 0.0356 $p = 0.004^{***}$

2022	0.535 ± 0.0952	Year 2024	-0.226 ± 0.0356 p = 0.000***
2023	0.454 ± 0.120	WF:Year 2023	0.047 ± 0.0503 p = 0.352
2024	0.297 ± 0.109	WF:Year 2024	-0.028 ± 0.0503 p = 0.576
		Intercept (Control)	0.560 ± 0.0260 p = 0.000***
		Observations	108
		Log Likelihood	-6.250
		Akaike Inf. Crit.	28.499
		Bayesian Inf. Crit.	49.956
		Note:	*p<0.1; **p<0.05; ***p<0.01

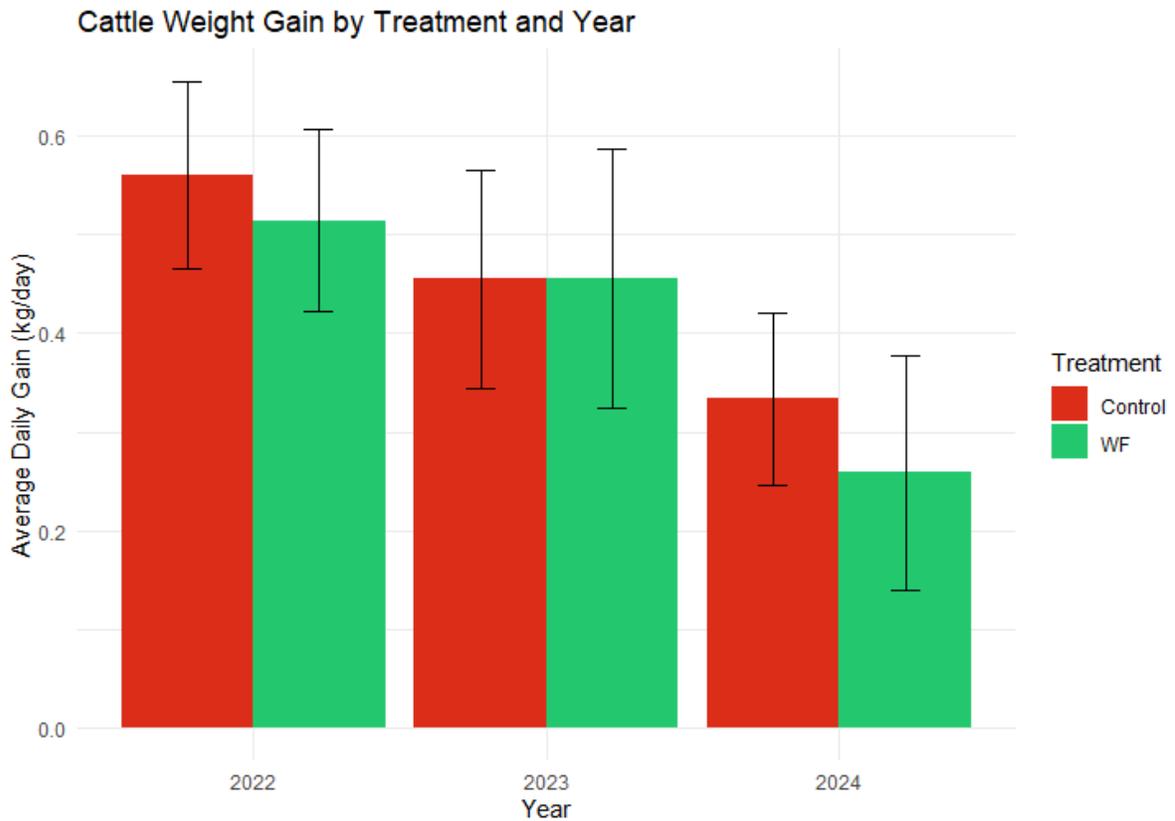


Fig 2: Average daily weight gain (kg/day) of heifers across years. Control heifers grazed in conventional paddocks, WF heifers grazed in paddocks with wildflower set-asides.

2.3.2 Pollinators

The pollinator data reveals strong evidence for a positive effect on our measures of pollinator abundance within the wildflower plots ($p=1.64e-10$), with more than three times as many pollinators in the wildflower set-aside plots compared to control paddocks (Fig 3). There was little evidence that abundance of pollinators in the conventional section outside of the wildflower set-aside plots differed from the control treatment, however ($p=0.168$).

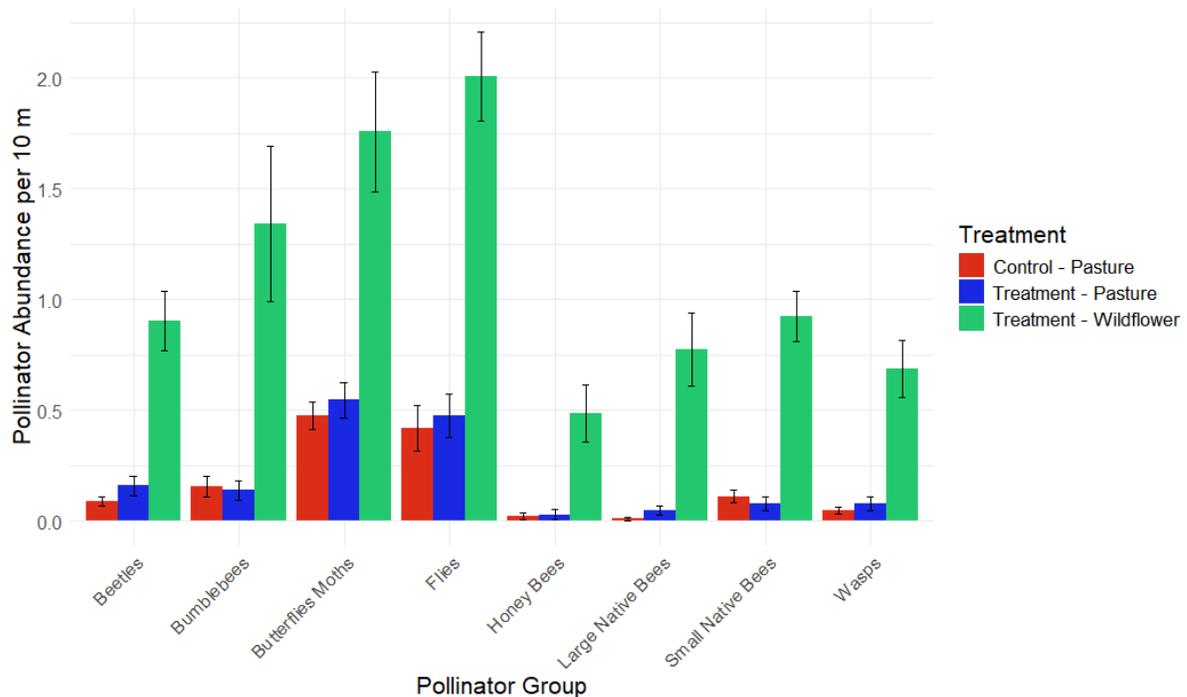


Fig 3: Mean pollinator abundance in each sampling group. “Treatment - Pasture” points represent the conventional tall fescue portion of WF-enhanced paddocks, and “Treatment - Wildflower” points represent samples from within the wildflower set-aside plots.

The results of the PCA demonstrate that pollinator communities in the WF set-aside plots were distinctly different compositionally from both the control paddocks and the conventional pasture portion of the WF-enhanced paddocks (Fig 4). The tight clustering of the control and treatment - pasture points indicates that these samples were quite similar to one another, while the more diffuse spread of the wildflower points indicates a greater degree of diversity in pollinators in those set-aside plots. Due to the lack of clustering of

wildflower points relative to the loadings, the wildflower plots were not consistently associated with a particular pollinator group. However, the wildflower plots had both more pollinators overall and greater plot-to-plot variability compared to the rest of the treatment paddock and the control paddock.

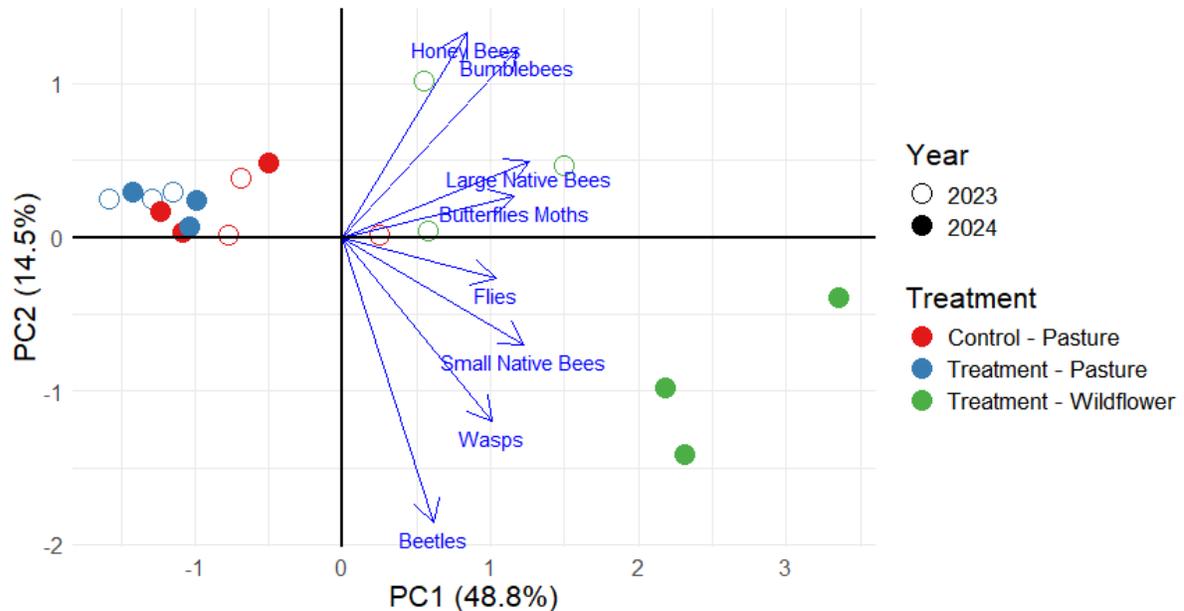


Fig 4: Plot of pollinator community composition, averaged across the year (2023 and 2024) for each section of the paddocks. “Treatment - Pasture” points represent the conventional tall fescue portion of WF-enhanced paddocks, and “Treatment - Wildflower” points represent samples from within the wildflower set-aside plots. PC1 and PC2 are shown. Arrows represent loadings for each pollinator group.

2.3.3 Plant Community Composition

Community composition differed ($p=0.003$) between groups tested, with strong evidence for a difference ($p=0.013$) by paddock treatment, and a weak effect ($p=0.109$) due to sampling year. Year \times treatment interaction was not observed.

The PCA plot of flower abundance (Fig 5) demonstrates how the WF paddocks differed greatly from the control paddocks, and from each other, particularly over time. The clustering of WF points from the same period of time indicates that at a given date, these plots had similar floral communities present. Over the season, however, the floral community

shifted as early blooming species senesced and later blooming flowers emerged. By following the loadings indicated by the blue arrows, it is possible to track the pattern of blooms throughout the season. For example, wild bergamot and black-eyed Susan were observed early but then gave way to partridge pea, oxeye sunflower, and narrowleaf mountain mint in mid-summer, and these species were followed by early goldenrod and calico aster in September. Comparing floral resources between control and wildflower paddocks revealed not only the relative scarcity of flowers in tall fescue paddocks, but also the dominance of weedy flowers in these fields (Fig. 6). The two species with the highest floral abundance in control paddocks were both weeds: bull thistle (*Cirsium vulgare*) and Carolina horsenettle (*Solanum carolinense*).

Plant community composition differed substantially between conventional tall fescue paddocks, and the WF-enhanced paddocks, which were much more diverse (Supp. Fig 1). The three wildflower-enhanced paddocks are a great distance from each other on the PCA plot, as well as far from the tight cluster representing the control paddocks. This corroborates the results of the PERMANOVA, showing that not only does the plant community differ between wildflower and control paddocks, but the wildflower paddocks are more different from one another as compared to the control.

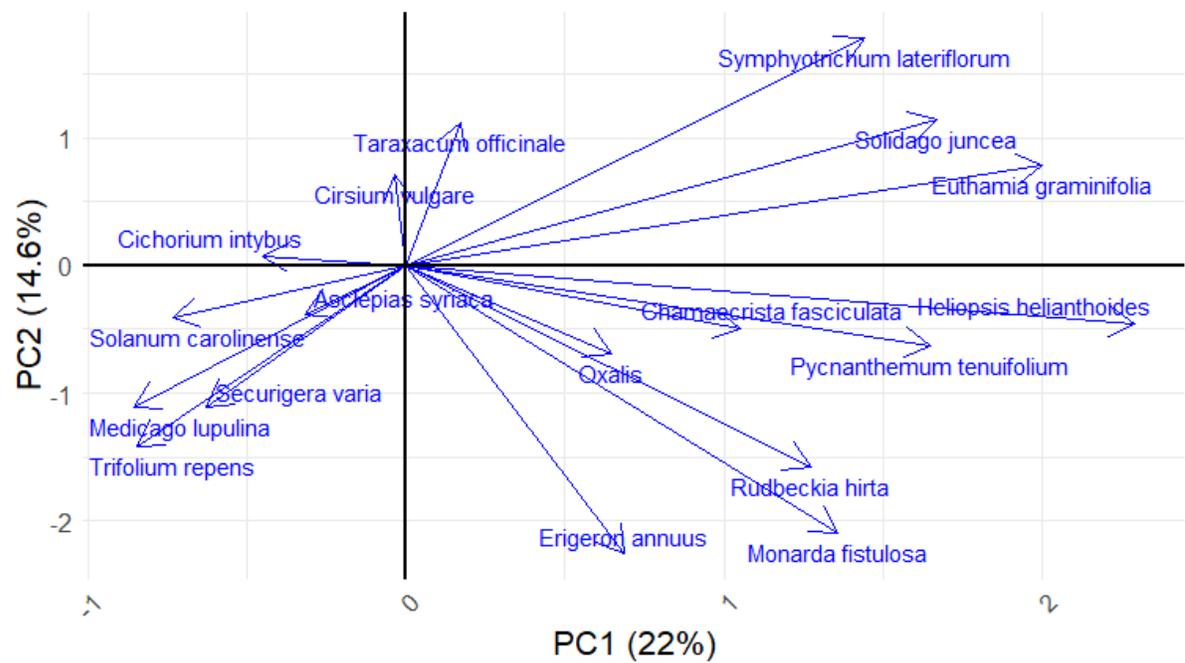
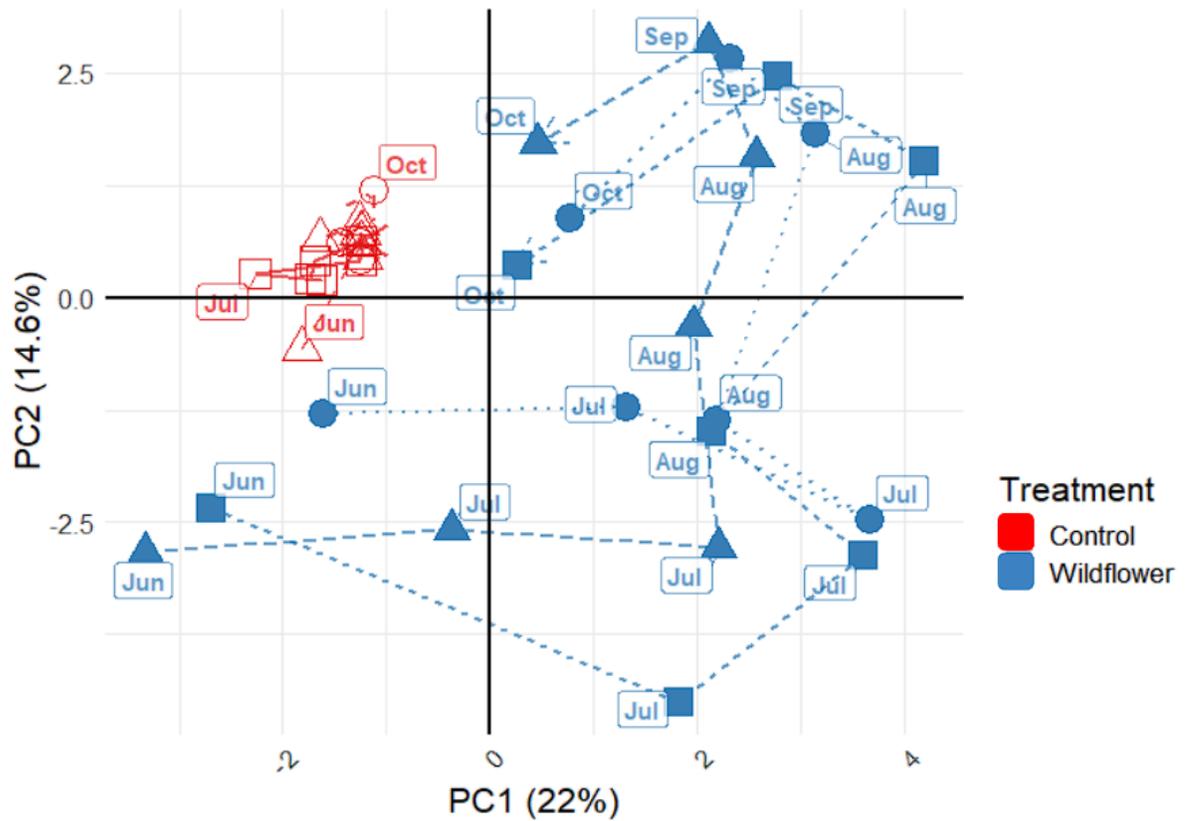


Fig 5: Floral abundance across the 2024 season. Control paddocks represented by empty shapes, and WF-enhanced paddocks have filled shapes. Samples from the

same plot are connected by arrows showing community changes over time. PC1 and PC2 shown, with blue arrows representing loadings for flower species

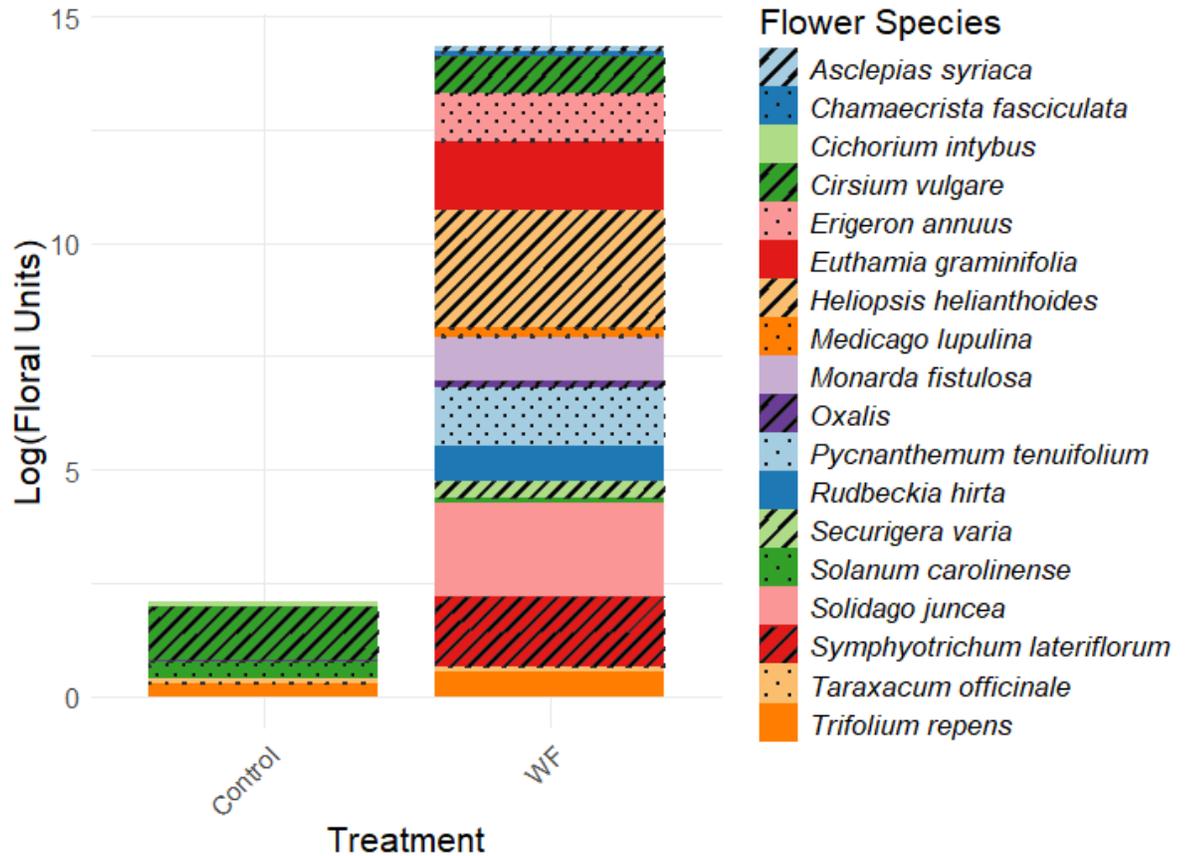


Fig 6: Mean flower abundance between WF pastures and control pastures. Floral counts were log-transformed to account for differences in magnitude between species.

2.4 Discussion

2.4.1 Cattle Performance

This experiment demonstrated that planting native wildflowers in pastures can attract pollinators while maintaining cattle productivity when used alongside supplemental feeding. In 2022 and 2023, the two treatment groups performed similarly despite 10% of the paddock within the WF treatment being allocated to the wildflower exclusion plots. We had hypothesized that removing this area for wildflower establishment might reduce intake and weight gain. Unfortunately, there may be some short term decrease in weight gain when sacrificing a portion of a paddock, though supplemental feeding appears to compensate for this difference.

There may be other factors influencing animal performance as well. Tall fescue was the dominant species (average cover was 59.2%) and the fescue was 100% infected with toxic endophyte (*Epichloë coenophialum*) based on prior (2020) sampling. Thus, weight gain may have been limited more by the effects of fescue toxicosis than by forage availability (Kallenbach 2015). Animals in all paddocks displayed symptoms associated with fescue toxicosis, including rough coats, excessive salivation, and seeking shade on relatively mild days. Dry conditions over the summers of 2023 and 2024 also likely contributed to the overall low animal performance, although wildflowers adapted to local, dry conditions may perform better.

In this particular study, the cattle were temporarily fenced out of the wildflower strips, removing access to a portion of the available forage. Although a typical producer would likely be unwilling to sacrifice such a large proportion of their productive pasture to support pollinators, this may not be a limitation long term. Many of the species sown in this experiment are not only palatable to cattle, but are also tolerant to grazing and yield consistent forage biomass (Prigge et al. 2024). Partridge pea, black-eyed Susan, oxeye sunflower, and a number of other native forbs perform well in a grazing context while also providing floral resources throughout the growing season. After exclusion during the first years of establishment, wildflower plots could be made fully accessible to cattle. Wildflowers planted along with native warm-season grasses have been shown to improve animal performance in tall fescue-dominated pastures (Kubesch 2023). Some caution in interpretation is needed here, as wildflower outcomes and animal performance both may be functions of grazing management, and neither was tested in response to factors such as stocking rate or grazing intensity. However, there is growing evidence that such strategies

can improve nutritional outcomes for livestock while enhancing the resilience of landscapes in the face of environmental disturbances (Villalba, 2024).

2.4.2 Pollinators

The relative abundance of pollinators between treatments is encouraging: even at a relatively small spatial scale, the wildflower plots attracted a great many pollinators as intended. Pollinators were also present in the control fields, and often they were observed visiting flowers of “weed” species in those paddocks. Thistles in particular appeared to attract a large number of pollinators. The weeds present in agricultural contexts are often a major food source for pollinators which have limited access to forb-rich meadows in which they thrive (Bertagnolle and Gaba 2015). There also were no observed spillover effects; pollinator abundance and diversity were quite similar between control paddocks and the non-WF portion of the treatment paddocks. This demonstrates that the wildflower set-aside plots were the key factor that influenced pollinator recruitment.

There did not appear to be any major differences in terms of which pollinators were present in each treatment, and relative abundances of each pollinator group across treatments were largely consistent (Fig 3). Additionally, non-bee species were well-represented, making up 65% of all pollinators sampled. Given the importance of non-bee pollinators and the attractiveness of wildflowers to diverse groups of pollinating insects (Grass et al. 2016, Rader et al. 2016), the results indicate that the benefits of the wildflower plots extended to all pollinator groups sampled. The sampling method may be biased towards larger, more mobile species given that it relied on visual counts. Similarly, there is potential for an individual pollinator to be mis-classified at a glance. However, even accounting for the shortcomings of this method, the difference between treatments is quite clear.

Our results should also be considered within the context of the study landscape. At one end of the spectrum, a surrounding landscape dominated by intensive agriculture can reduce pollinator diversity and pollination services (Grab et al. 2019). Conversely, an increased presence of high quality and semi-natural habitat has been associated with an increase in pollinator richness (Kennedy et al. 2013). As such, it has been suggested that the effectiveness of on-farm wildflower plantings depends on the presence of semi-natural habitat in the surrounding landscape, and plantings that attract the most pollinators having intermediate levels of semi-natural habitat (McCullough et al. 2021). Our study location was

surrounded by a moderate amount of natural or semi-natural landscapes, so the strong effect we saw may be in part due to the landscape, and the applicability of this study may be limited to similar environments. Understanding landscape-scale changes in pollinator communities requires a landscape-scale sampling method, and as such we can only draw conclusions at the field-level scale we studied (Schreber et al. 2019).

2.4.3 Plant Community

Plant community composition data clearly show that establishing the wildflower plots had a strong effect on the botanical makeup of the pastures. Although some of this difference comes from the sown wildflower species, the plant cover in the wildflower plots also tended to be populated by weeds as well, which is likely a result of the establishment method. Killing the existing fescue sod and eliminating competition allowed weeds to emerge from the seed bank, and many of these weed species like bull thistle, daisy fleabane (*Erigeron annuus*) and crown vetch (*Securigera varia*) produce flowers that attract pollinators. More work is needed to determine the best establishment methods for pollinator-supporting species that minimize recruitment of less desirable weed species. Management decisions should also consider trade-offs between increased costs and labor required for weed suppression vs. the production penalty associated with allowing some less desirable species to survive.

Regarding floral abundance in particular, there was also a substantial difference between treatment and control paddocks. Both more floral units and a greater floral diversity were observed in the WF paddocks. However, not all flowers are created equal (see Woodcock et al., 2014); for example, a single milkweed plant may only have three or four “floral units”, while a calico aster could have tens or hundreds. Even log-transforming the data didn’t fully account for these differences, thus species-to-species comparisons are difficult. Despite this, the evidence clearly shows that the wildflower-enhanced paddocks were considerably more flower-rich than the control paddocks. Furthermore, the seasonal trends in the floral community (Fig 5) provided diverse floral resources and sequential blooming, which are both critical to support generalist and specialist pollinator species alike (Williams et al., 2015).

2.5 Conclusions

Cattle pastures in the Mid-Atlantic US provide potential opportunities for pollinator habitat, as environmental conditions in pastures closely match the requirements of many native wildflower species. Wildflowers (especially black-eyed Susan, wild bergamot, and early goldenrod) in this study successfully provided continuous floral resources from spring to fall. The wildflower-enhanced paddocks significantly increased pollinator abundance compared to conventional tall fescue-dominated pastures, with more than three times as many pollinators. Additionally, non-bee pollinators, such as flies, beetles, and butterflies, accounted for 65% of observed pollinators, underscoring the importance of diverse pollinator groups in agricultural landscapes. These findings align with previous research emphasizing the value of non-bee pollinators in crop pollination and ecosystem health.

Although there may be short term losses in animal performance, this decrease was only observed when supplemental feed was delayed in 2024. However, in 2022 and 2023 the establishment of wildflower set-aside plots did not impact cattle weight gain, suggesting that allocating a small portion (10% in this case) of a pasture to pollinator habitat alongside feed supplementation may not detrimentally affect cattle productivity. Furthermore, several wildflower species such as partridge pea and oxeye sunflower are palatable to cattle and tolerant of grazing, making them suitable for integration into grazing systems without sacrificing forage. By temporarily excluding cattle from wildflower areas during critical blooming periods, farmers can maximize floral resources for pollinators while still allowing cattle to graze the plots periodically. This approach could mitigate any potential reduction in forage mass or availability and make the integration of wildflower plots more appealing to farmers.

Despite these encouraging results, the adoption of wildflower-enhanced pastures may be limited by practical considerations, such as the initial cost of seed mixtures and the time and management inputs required for establishment. Although the long-term benefits of supporting pollinator populations—such as improved crop pollination, enhanced ecosystem resilience, and potential production and economic gains—may outweigh these initial investments for pollination-dependent crop systems, this is unclear for pasture-based agriculture. Benefits for livestock may be more a function of diet diversity, and future research should explore the long-term impacts of wildflower-enhanced pastures on both pollinator populations and cattle performance. Further study could also identify methods that simultaneously maximize pollinator support and forage productivity, such as flash grazing

wildflower plots followed by long rest periods. Strategies to optimize establishment and management practices for broader adoption in grassland agriculture systems is also needed.

This study highlights a valuable opportunity to bridge the gap between animal agriculture and biodiversity conservation. By showing how wildflower plots can enhance pollinator abundance while minimally compromising animal performance, this research demonstrates a practical approach for integrating pollinator habitat into working pastures. As climate change, habitat degradation, and other environmental stressors threaten pollinator populations, solutions that benefit both livestock producers and the broader environment at scale are increasingly necessary. This work underscores the potential for such creative solutions, and demonstrates one way to satisfy the need for systems that support both productive agriculture and a biodiverse ecosystem.

3. Chapter 2: Repeated Tillage as Site Preparation for Wildflower Plots

3.1 Introduction

3.1.1 Establishing Wildflowers in Grassland Agriculture Systems

Creating wildflower plots in agricultural systems can support declining pollinator populations, but they are often challenging to establish cheaply, reliably, and quickly. Several studies in different agricultural settings, but especially grassland systems, have found that wildflower plots are an effective conservation tool for supporting pollinators (Korpela et al. 2013, Stroot et al. 2022, Woodcock et al. 2014). These plots provide nectar and pollen, as well as vital habitat and nesting sites. However, the effectiveness of these wildflower plots can vary greatly depending on establishment success (Scheper et al. 2021). Establishment can be labor intensive, and there is no one-size-fits-all, “best method”. The conditions of a

site can help inform what methods are ideal, including previous use, soil characteristics, climate, and existing vegetation cover (Neal 2019, Aldrich 2002). In most cases, removing existing vegetation and suppressing weed growth are crucial first steps, with a wide array of approaches (Bellangue 2023). These include: solarization (using plastic sheeting over the soil surface to capture sunlight and heat, effectively sterilizing the soil underneath), burning, topsoil removal, herbicide applications (often multiple treatments which can be broad-spectrum or specific depending on existing vegetation), mulching, cover cropping, and tillage.

Topsoil removal is an extreme approach that can almost completely eliminate weed pressure by physically removing both soil and the dormant weed seeds it contains, while the reduction in soil fertility can create conditions well-suited for wildflower establishment (Aldrich 2002). One study compared topsoil removal to two herbicides as site preparation methods for the establishment of *Coreopsis lanceolata* in a bahiagrass pasture, finding that removing the upper 13 cm of topsoil was highly effective at eliminating weed pressure, but had lower establishment of *C. lanceolata* than application of glyphosate (Frances et al. 2010). The researchers hypothesized this was possibly due to the presence of thatch left behind from the herbicide, which promoted good conditions for germination, whereas seeds sown onto the bare soil had less moisture retention and more extreme temperatures. At greater depths (30-50 cm), topsoil removal significantly reduces or nearly eliminates the presence of weed propagules in soil, creating conditions for sown native species to thrive and facilitating restoration (Hölzel and Otte 2003). Topsoil inversion is a similar method that buries the topsoil beneath the subsoil instead of totally removing it. One study found that topsoil inversion to a depth of about 40 cm reduced soil fertility, and facilitated the establishment of sown species for the restoration of semi-native grasslands (Glen et al. 2017).

Other methods, such as solarization and fire, are popular approaches that eliminate weeds with minimal soil disturbance. Solarization typically consists of covering a field with plastic sheeting and sealing the edges to trap heat and moisture, creating a greenhouse effect. These conditions drive the germination of weed propagules in soil, but the intense heat eventually kills any vegetation underneath, thus exhausting the soil seed bank. Solarization can be highly effective if done properly, but it could be prohibitively difficult or costly on a large scale and in sites without adequate, consistent sunshine. In some cases, solarization outperforms other site preparation methods like herbicide, tillage, and reverse fertilization, a method that uses soil carbon amendments to immobilize nitrogen and

thus reduce soil fertility and the ability for weeds to establish (Schultz 2001, Maurisha and Allen 2011). However, successful solarization often requires long spans of sunny days, and the duration of solarization is proportional to its success at controlling weeds (Orr et al. 2019).

Fire, on the other hand, inherently comes with safety concerns, requires more expertise, and only works in certain environments, though it can be highly effective in some circumstances (Aldrich 2002). A study comparing prescribed spring fires to solarization to restore invaded grasslands found that both fire and solarization were similarly effective in supporting native perennial establishment, with fire being a less labor-intensive option than solarization (Moyes et al. 2005). The authors also noted that fire may be better suited for larger plots where annual weeds dominate, while solarization may be preferable for smaller plots and those with a deep or abundant seed bank. In another experiment comparing various establishment methods, including herbicides, tillage, and prescribed burning, herbicides (Imazapic in particular) best suppressed weeds and allowed for wildflower establishment, but prescribed fire and tillage were considered potentially useful non-herbicidal methods, with tillage outperforming fire in the first year (Ghajar et al. 2022). This may depend on vegetation type, however, as fire did very little to reduce competition from tall fescue, with herbicides performing far better (Madison et al. 2001).

Herbicide treatments are quite effective at killing existing vegetation and removing competition prior to establishing pollinator habitat, and in many cases are the default approach (Barnes 2004, Norcini and Aldrich 2004). In a study comparing glyphosate to tillage for clearing existing vegetation prior to establishing wildflowers, glyphosate application led to greater establishment success (Angelella et al. 2019). Other studies comparing various establishment methods have also found that herbicides are highly effective as part of a native wildflower plot establishment (Ghajar et al. 2022, Madison et al. 2001). Herbicides may also be useful as a post-plant treatment to limit weed competition if the selected wildflowers tolerate herbicides or if the selected herbicides only target some plant taxa (Beran et al. 1999, Marushia and Allen 2011). However, herbicides may be undesirable for other reasons: a farm may be organic and not use herbicides, and there is evidence that indirect exposure to herbicides can harm the pollinators we are trying to support (Evans et al. 2010, Farina et al. 2019).

Tillage can be a viable chemical-free alternative to herbicide, but studies have found mixed results at reducing weed pressure compared to other methods. Compared to other non-chemical approaches like solarization and topsoil removal, tillage is easier to do at

larger scales, and particularly for on-farm applications, the necessary equipment may already be available (Aldrich 2002). Tillage has been shown to perform similarly to topsoil removal (Edwards et al. 2007) and as well as or better than fire, herbicide, and solarization (Madison et al. 2001, Marushia and Allen 2011, Ghajar et al. 2022, Skousen and Venable 2008) when used to prepare a site for sowing native seeds. However, not all studies found success with tillage: Angelella et al. (2019) compared herbicide application with repeated tillage prior to planting native forbs, finding that herbicide applied before planting led to the greatest forb establishment. Another study tested tillage on glyphosate-killed turf to control weeds and facilitate planting, finding that tillage actually increased weed pressure, likely by surfacing weed seeds from deeper in the soil (Watkinson and Pill 2007). However, there is little consistency in methods across studies that use tillage for site preparation, making comparisons between methods difficult. Studies have used a single round of rotary tillage immediately prior to a spring planting (Angelella et al. 2019, Edwards et al. 2007, Ghajar et al. 2022), single fall or spring disk tillage (Madison et al. 2001, Maurshia and Allen 2011), tilled twice a week apart prior to a summer planting (Watkinson and Pill 2007), all at various or unspecified depths. This creates difficulty in interpreting these studies and understanding how best to use tillage for site preparation.

Other low-intensity establishment methods include mowing, cover cropping, and mulching, although these are typically used as part of a larger strategy that includes some treatment to kill the existing vegetation. These methods keep new weeds from emerging and facilitate wildflower establishment, but results are mixed. Mulching has been shown to substantially improve establishment, especially when paired with wildflower transplants instead of sowing from seed (Watkinson and Pill 2007, Dunn et al. 2020). Mowing can also keep weed pressure low during establishment, but might also open the canopy and facilitate colonization by weeds (Török et al. 2011, Glidden et al. 2023). Cover crops have similarly mixed results, with some experiments showing that an annual cover-crop, especially one that provides resources for pollinators, can suppress the growth of other weeds. However, depending on the seeding rate and weed pressures, a cover crop can also compete with other sown species (Fry et al. 2017, Dunn et al. 2020)

3.1.2 Planting Methods

Another factor in the establishment of a wildflower plot is, of course, the planting of the wildflowers themselves. This can be accomplished by transplanting seedlings directly or

by sowing seeds in the plot directly. Transplanting can lead to greater success than seeding, but may be unfeasible or prohibitively expensive at larger scales. In particular, opting to use transplants instead of sowing seeds led to much higher coverage of planted species; Watkinson and Pill (2007) and Shelton et al. (2024) found that transplanting wildflower seedlings resulted in high levels of establishment, although both studies also point out that establishing larger wildflower plots via transplants may be prohibitively expensive and labor intensive. These results agree with Dunn et al. (2020) who also found high establishment success when using transplants of seedlings instead of seeding directly, but the trade-off in cost and labor complicates the equation. Aldrich (2002) recommends seeding over transplantings for larger projects or in situations where labor and monetary resources are limited. Seeding is therefore likely to be the best approach in the case of large, on-farm wildflower establishment projects.

As for the seeding method, broadcasting seeds by hand or mechanically along with some inert carrier like vermiculite or sand is often recommended, as seeding depth needs to be quite shallow for many wildflower species (Aldrich 2002 and Williams et al. 2018). Seeding via a seed drill can also be a viable means to establish a wildflower plot, especially if there is little bare soil and broadcasting would leave seeds on top of thatch (Neal 2019, Aldrich 2002). Seed microsite availability and seeding rate are closely linked; poor microsite availability can be compensated for with a higher seeding rate and vice versa (Frances et al. 2010). Higher diversity seed mixes and higher seeding rates can lead to greater establishment, but there are diminishing returns at the highest levels (Barr et al. 2017). Timing should also be considered, with evidence that planting in the fall or winter can help break dormancy for some perennial species (Bratcher et al. 1993, Bellangue et al. 2024).

3.1.3 Study Overview

Clearly, there are a wide array of factors influencing native plant establishment. Here, we focus on tilling – a practice for which several basic questions have yet to be answered. Although tillage is a potential chemical-free means to prepare a site for wildflower planting, there is little consistency in how tillage is performed across establishment studies, and it is unclear how tillage timing and frequency influence establishment success. In order to investigate these differences, this experiment sought to establish wildflower plots in western Virginia using a variety of timings and frequencies of tillage. These differences were tested

by analyzing weed community composition before and after tillage, and by comparing the emergence of wildflowers between treatments.

3.2 Methods

3.2.1 Establishment

We conducted a wildflower tillage establishment trial at the Virginia Tech Urban Horticulture Center in Blacksburg, VA (37.219° N, 80.464° W). Soils at the site mainly consist of Duffield-Ernest complex, Groseclose, and Poplimento soil series, and the climate is humid temperate. The area for the main tillage trial consisted of two blocks each containing 24 individual plots, which were 1.8 m wide and 12.2 m long (6 x 40 feet). The treatments consisted of either one, two, or three rounds of rotary tillage. Tillage was conducted either in the spring, summer, or fall, and all combinations of timing were used, as well as a control treatment that received no tillage beyond the initial disking that was applied to all plots. This resulted in eight total treatments: one round of tillage—in spring, summer or fall; two rounds of tillage—once in the spring and summer, once in the spring and fall, or once in the summer and fall; three rounds of tillage—once in the spring, summer and fall; or no tillage (Table 2). For each block, treatments were randomly assigned so that each block contained three replicates, resulting in six total replicates.

These plots had been used previously in a hemp cultivation experiment, and at the beginning of the study the plant community largely consisted of a mix of annual and perennial weeds, as well as several introduced ground cover species like *Trifolium repens* and *Poa pratensis* L. Prior to the tillage treatments, the plots were mowed and shallowly tilled using a disk harrow in the early spring of 2023 to clear the existing vegetation and break up the soil in the plots. The tillage treatments consisted of three passes of a hand-pushed rotary tiller at a depth of approximately 10 cm conducted in the May, July, September of 2023. Over the 2023 season, the plots were occasionally mowed to keep emerging weeds from going to seed and to allow the tiller through the plots.

Following the site preparation in 2023, plots were seeded in the winter of 2024 as there is evidence that the cold temperatures can help break wildflower seed dormancy and increase emergence (Bratcher et al. 1993). The seed mix was prepared with a target of 86.1

seeds/m² (8 seeds/ft²) of each species, with specific weights shown in Table 1. Seeds were obtained from the Roundstone Native Seed Company. Plots were sown by hand-broadcasting using damp sand as a carrier at a ratio of 2:1 sand to seed. Prior to emergence in the spring and once more in early and late summer, plots were mowed to suppress weed competition and allow for wildflower growth.

Table 1: Wildflower seed mix planted in experimental plots at the Urban Horticulture Center in Blacksburg, VA

Scientific name	Common name	PLS kg/ha
<i>Coreopsis lanceolata</i>	Lanceleaf coreopsis	1.77
<i>Linum perenne</i>	Perennial blue flax	1.89
<i>Rudbeckia hirta</i>	Black-eyed susan	0.247
<i>Echinacea purpurea</i>	Purple coneflower	3.37
<i>Agastache foeniculum</i>	Anise hyssop	0.280
<i>Ratibida pinnata</i>	Grey-headed coneflower	0.874
<i>Helianthus maximiliani</i>	Maximilian sunflower	1.98
<i>Solidago juncea</i>	Early goldenrod	0.157
<i>Chamaecrista fasciculata</i>	Partridge pea	6.01

3.2.2 Data Collection and Analysis

Prior to wildflower sowing in 2024, plots were assessed for overall plant community composition three times in 2023 prior to each round tillage. This used repeated random sampling with 0.25 m² quadrats, estimating coverage and identifying weed species to the lowest identifiable taxonomic level, based on the Southern Weed Science Society's Weed Identification Guide. This resulted in a percentage of species cover in each plot across 3 seasons in 2023. Following the wildflower planting in 2024, the plots were assessed for species composition and coverage using the same method monthly from May to October of 2024. Additionally, in July and October emergence of sown wildflower species was assessed using the frequency grid sampling method described in Vogel and Masters (2001). A 5 x 5 wire mesh grid of 15 x 15 cm was overlaid on the plot, and each cell containing a sown wildflower was counted, with separate counts of each species. This was repeated four times per plot, so 100 total squares were counted with a total area of 2.25 m². Multiplying the final count by 0.44 yields a conservative estimate of plants per square meter, and thus provides an approximation for the emergence of sown wildflower species.

Plant community composition was assessed using PCA based on total plant cover. Over the 2023 and 2024 seasons, maximum coverage of each species in each plot was calculated to best represent the full plant community across the growing season because emergence and weed coverage are not uniform across the season. These yearly maximum cover data were then used to create a distance matrix and perform the PCA. Next, plots receiving the same treatments had their coordinates averaged to determine if overall plant communities were different among treatments. To quantitatively test for plant community treatment effects, PERMANOVA (permutational multivariate analysis of variance) was applied to the distance matrix of plant cover data using the *adonis2* function from the “vegan” package in R (Oksanen et al. 2025). To ensure that the variability between treatments was equal and that PERMANOVA is an appropriate test, beta dispersion was also calculated for the community data between treatments. This was conducted using the *betadisper* function in the “vegan” package, and dispersions were compared between treatments using the *permutest* function within the same package.

Using the frequency grid data, wildflower emergence was assessed by fitting a linear mixed-effects model. Using total sown species emergence as the response variable and plot as a random effect, two models were created. One used all eight treatments to determine if there was a significant difference between both frequency and timing of tillage, and the other model grouped treatments by tillage frequency alone. In order to test the effects of tillage frequency alone and the combination of frequency and timing, the two models were compared using the Akaike Information Criterion (AIC), AICc which incorporates a correction for small sample sizes, and the Bayesian Information Criterion (BIC). Both models were fitted using the *glmer* function from the R package “lme4” (Bates et al. 2025), and the p values generated via the Satterthwaite approximation method from the “lmerTest” package (Kuznetsova et al. 2020). Model goodness-of-fit was tested using the *R2* function from the “performance” package (Lüdecke et al. 2021) in R Statistical Software (R Core Team 2024).

3.3 Results

3.3.1 Wildflower Emergence

The emergence of sown wildflowers did not differ substantially between treatments or treatment groups (Table 3). Control plots had an average of 7.39 ± 4.75 wildflowers/m²,

and plots tilled in the Summer and Fall (203) showed the highest emergence at 11.52 ± 8.71 wildflowers/m², while the lowest emergence rates came from plots tilled in the Spring and Fall (202), with 5.06 ± 4.62 . However, standard deviations were high across all groups whether treatments were treated individually or grouped by tillage frequency.

We modeled the effects of tillage timing and frequency on wildflower emergence as well, using mixed effects regression models (Table 5). Models were compared using three criteria: the simpler model (grouping by tillage frequency) had lower values across all three criteria, and had weights close to 1 (Table 4), which suggests that accounting for seasonality in this experiment did not make for a better model. However, none of the tillage treatments showed even moderate evidence that tillage frequency has an effect on wildflower emergence compared to not tilling at all (Group 1: $p = 0.802$, Group 2: $p = 0.980$, Group 3: $p = 0.417$). Furthermore, there was also no evidence for an effect from any treatment using the model that incorporates all treatments (Table 5).

Table 2: Treatment codes and associated tillage sequence. “Group” is used to cluster treatments that received the same number of rounds of tillage.

Treatments	Code	Group
Spring tillage	101	1
Summer tillage	102	1
Fall tillage	103	1
Spring + Summer	201	2
Spring + Fall	202	2
Summer + Fall	203	2
Spring + Summer + Fall	301	3
Control (no tillage)	401	Control

Table 3. Wildflower emergence rates for each treatment and treatment group with (average \pm SD).

Treatment	Wildflower density (plants per m ²)
Control	7.39 ± 4.75
101	7.04 ± 5.15

102	10.34±8.05
103	8.14±4.58
201	8.71±7.17
202	5.06±4.62
203	11.5±8.71
301	10.20±5.98
Group 1	8.49±5.90
Group 2	8.44±7.13
Group 3	10.2±5.98

Table 4. Akaike Information Criterion (AIC), AIC with correction (AICc), and Bayesian Information Criterion (BIC) scores for models of wildflower establishment using all treatments (full model) or only tillage frequency (simplified model).

Treatment Model	Simplified model*	Full model*
AIC (weights)	393.6 (0.891)	397.8 (0.109)
AICc (weights)	395.1 (0.977)	402.6 (0.023)
BIC (weights)	403.0 (0.997)	414.7 (0.003)
RMSE	1.154	1.210

*The simplified model considered only tillage frequency (n=4; 0 to three times in 2023). The full model included frequency in combination with timing (spring, summer, or fall) tillage events (n=8).

Table 5. Model estimates for wildflower establishment based on two different linear mixed-effects models using either all treatments (full model) or only tillage frequency (simplified model).

Simplified model*	Estimate	Std. Error	p
Control (baseline)	2.616	0.312	3.215e-15
101	-0.148	0.473	0.754
102	0.267	0.466	0.566
103	0.171	0.466	0.713
201	0.0156	0.471	0.974
202	-0.453	0.476	0.341
203	0.379	0.465	0.415
301	0.389	0.464	0.401

Full model*			
Control (baseline)	2.616	0.347	5.886e-14
1	0.100	0.400	0.802
2	-0.0102	0.401	0.980
3	0.394	0.486	0.417

*The simplified model considered only tillage frequency (n=4; 0 to three times in 2023). The full model included frequency in combination with timing (spring, summer, or fall) tillage events (n=8).

3.3.2 Plant Cover

Across all 3 PCA plots (Figs 1-3), there is a clear separation between 2023 and 2024 along the first principal component. This trend is especially apparent when averaging by tillage frequency (treatment group, Fig 3). Based on the loadings of the PCA (Fig 4), it appears that all sown wildflowers fall on the same side of the plot as the 2024 data, which may explain the separation between years. Because none of the sown species were present in 2023, only data from 2024 has occurrences of the wildflowers. However, other than the clustering by year, the PCA showed no strong clustering of the treatments, whether plotted individually or grouped by treatment. The points from 2024 are more dispersed than those from 2023, and there is a slight distinction between tillage frequency, with the thrice-tilled plots (code 301) being somewhat separate from the other treatments. However, there is no evidence that these visual differences in PC1 and PC2 correspond to meaningful differences between treatments: beta dispersion between all treatments ($p = 0.371$) and treatment groups ($p = 0.618$) were not different. Results of the PERMANOVA also showed no compelling evidence for differences in community composition between treatments ($p = 0.609$) or between treatment groups ($p = 0.689$).

The PCA failed to account for a meaningful amount of the variation in the weed community data, with only 9.7% of the variance explained by the first principal component and it takes 13 components to account for more than 50% of the variance in the data. According to the scree plot (Supp. Fig 2) components one and two account for the most variance, and the following components fall under 5%. Plots displaying principal components other than the first two also lack any distinct clustering.

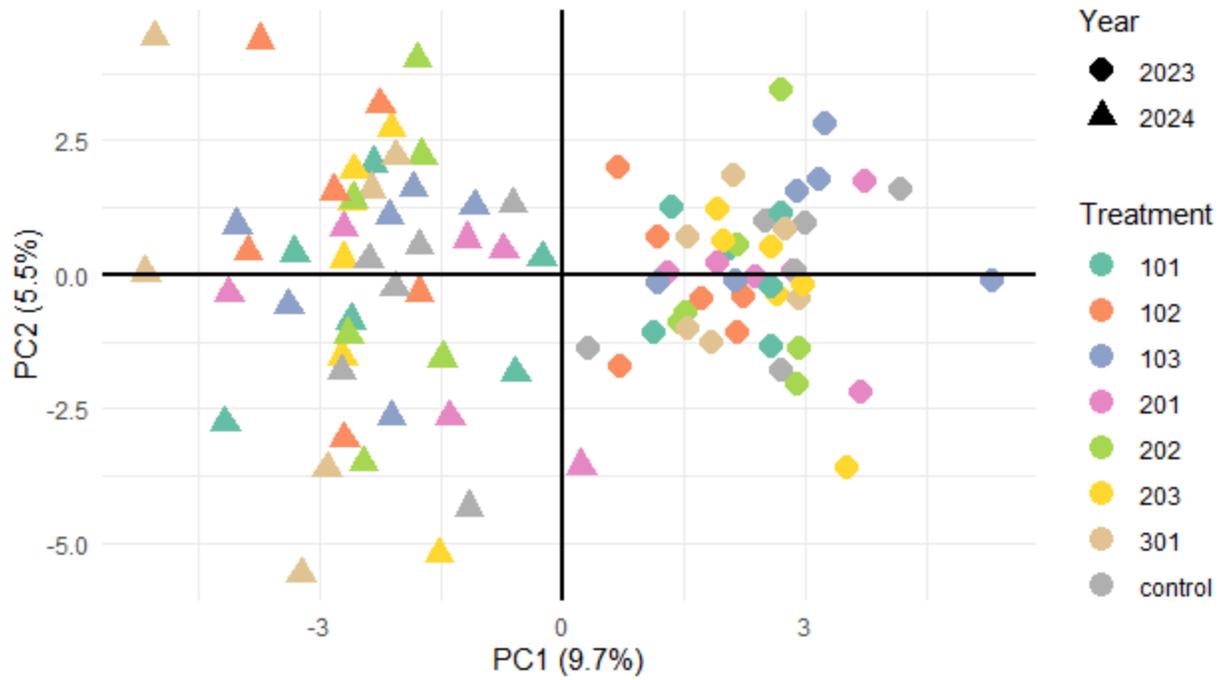


Fig 1: Plot of plant community composition in establishment plots. All plots are shown as individual points. PC1 and PC2 shown.

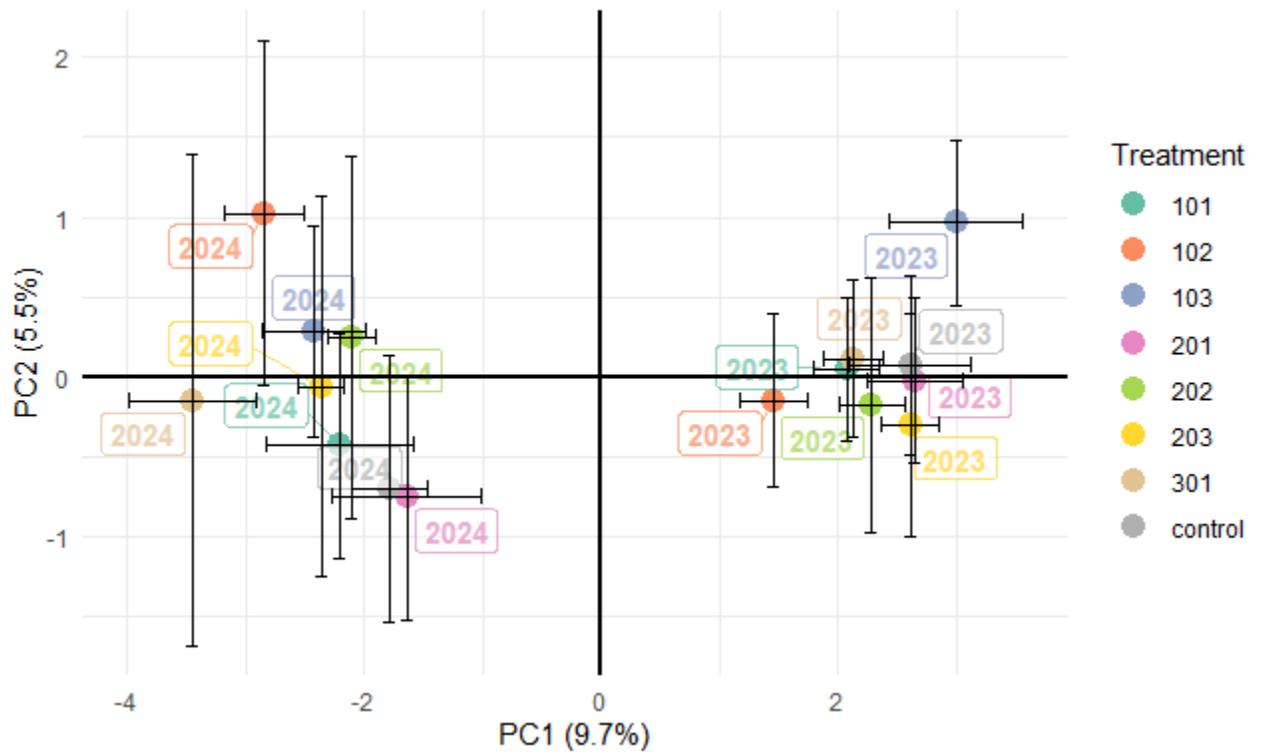


Fig 2: Plot of plant community composition in establishment plots, with points showing the average of each treatment within each year (2023 and 2024) and error bars showing the standard error for each set of plots within the same treatment. PC1 and PC2 shown.

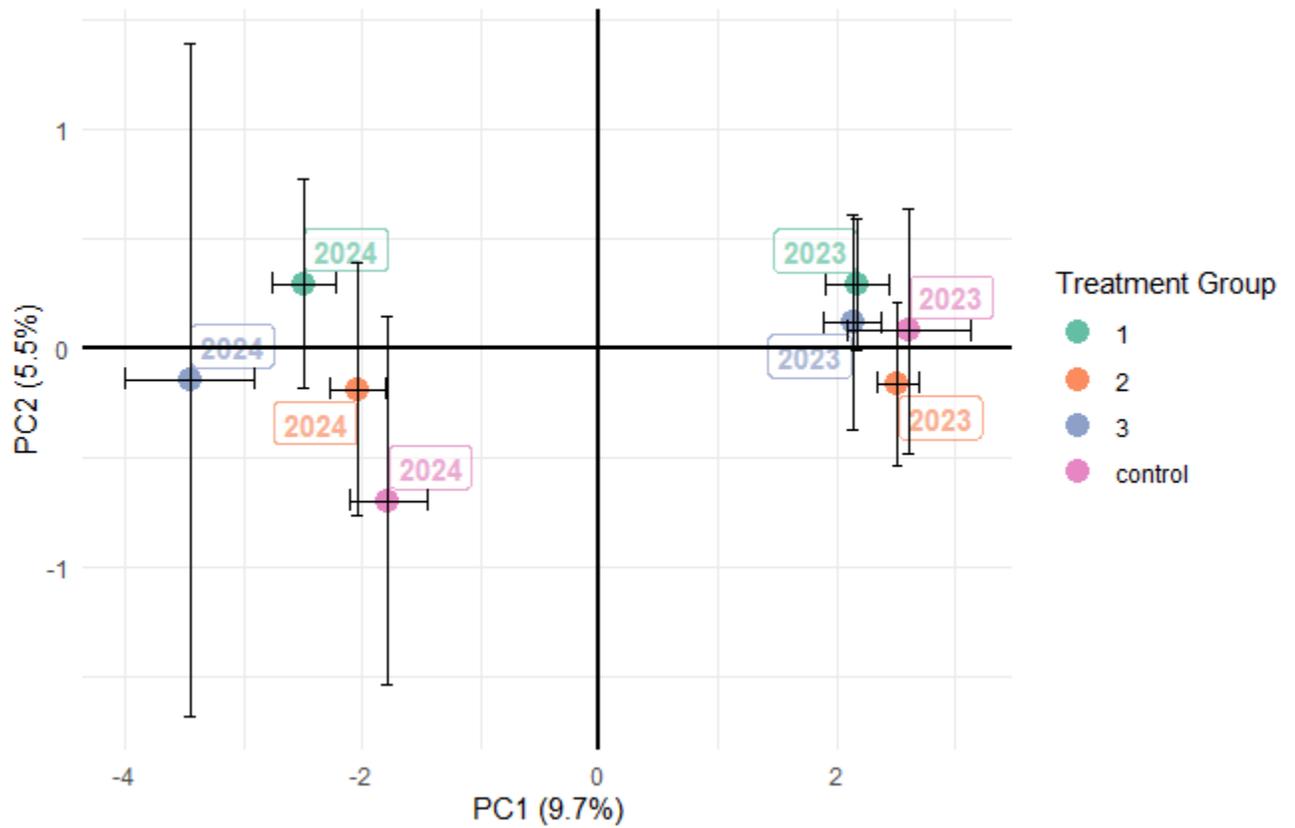


Fig 3: Plot of plant community composition, averaged to the level of treatment group, i.e., tillage frequency alone, ignoring seasonality of treatments, and group number represents the rounds of tillage applied to each plot. Error bars show the standard error for the set of plots within the same treatment group. PC1 and PC2 shown.

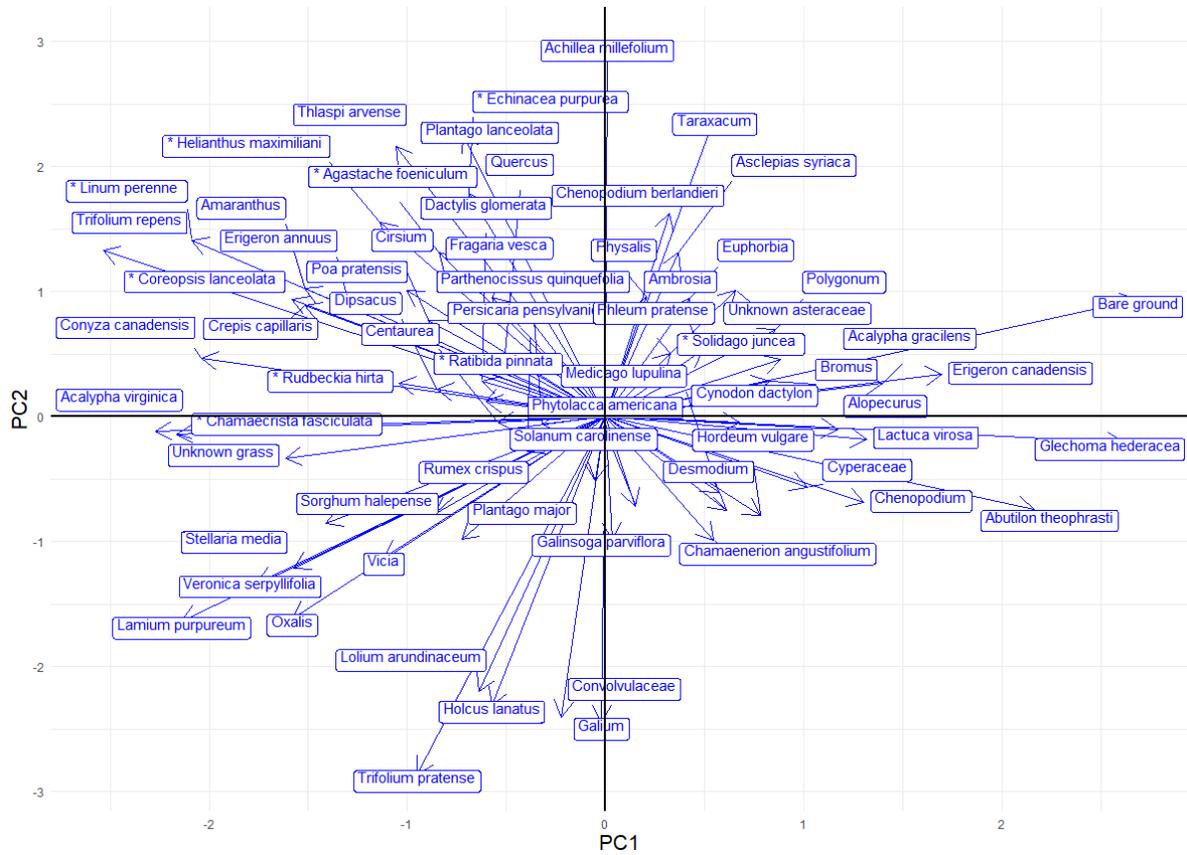


Fig 4: Loadings associated with PC1 and PC2 of the plant community PCA. Sown wildflower species are marked with an asterisk.

3.4 Discussion

This study sought to assess the impact of varying tillage timing and frequency on the establishment of wildflower plots dominated by cool season grasses and weeds. Although wildflower plots are an effective tool to support pollinators, establishment can be challenging due to high competition from weeds that limit wildflower emergence. Despite various tillage treatments, no significant effects were observed on rates of wildflower emergence, which suggests that in this context timing and frequency of tillage do not have a meaningful impact on the success of establishing a wildflower plot.

The PCA on plant community composition revealed very little clustering of points by treatment despite a clear separation between the two years of data collection. The division between years appears to be partially due to the presence of sown wildflowers that were

entirely absent prior to planting in 2023. The year separation may also be due to differences in the overall weed community. Although the weed community did change over time, this change was likely not influenced by the tillage treatments. There was a wider spread in the weed community of plots post-treatment in 2024 which indicates a greater heterogeneity between plots, but this was not correlated with treatments. Although there may still be some effect due to tillage, the variability in weed seed banks may mask what small effect tillage would have at this scale. This is supported by the high standard deviations in wildflower presence across treatments, and the low percentage of variability explained by the PCA.

The lack of consistent differences among treatments detected by the linear mixed effects models and the PERMANOVA is likely due to the high variability in wildflower emergence across all plots (Table 3). These findings are not entirely unexpected and are consistent with other studies (Ghajar et al. 2022, Scheper et al. 2021) that have found high variability in wildflower establishment success despite using site preparation methods that other studies have shown to be successful. There may also be a lack of a clear treatment effect due to the study implementation; before applying the tillage treatments, all plots were mowed and shallowly disked to allow the rotary tiller through the plots. Although this pretreatment was necessary to enable rotary tillage, its application across all plots may have created sufficient disturbance that differences among treatments could not be detected.

The specific weed community present may also limit the ability to see a positive response to tillage and may have been a factor in this study. One study found that different methods to eliminate weed competition have varying effects depending on the traits of the weed species, with tillage reducing the coverage of some weeds and increasing others. For example, Caldwell and Mohler (2001) suggested that tillage may be better suited to certain annual weed species that spread via seeds, while perennial weeds and those that spread via rhizome may actually be exacerbated by tillage. Our plots had considerable amounts of Johnsongrass (*Sorghum halepense*), a nonnative perennial warm-season species that readily spreads both by seeds and rhizomes. In this case tilling likely cut and spread the rhizomes and viable rhizome pieces which then grew into new plants. Additionally, although mowed regularly to reduce seed production and canopy cover of weeds, the experimental plots were established after a number of weeds had already gone to seed, leading to a seed bank full of freshly-dispersed propagules. As Ghajar et al. (2022) noted, “[c]onflicting results across various experiments indicate that complex environment × species interactions likely impact the effectiveness of establishment protocols.”

Although we found no evidence that varying the timing and frequency of tillage influenced wildflower establishment, all treatments had moderate establishment rates (Table 3), ranging from approximately 5 to 11 wildflowers m^{-2} , with most treatments having 7 to 10 wildflowers m^{-2} . What constitutes a “successful” establishment will vary greatly based on specific project goals, although Morgan et al. (1995) stated that at least 5 wildflowers per m^2 are required for a prairie restoration. While our goal was not prairie restoration specifically, this provides an approximate measure of successful establishment. By this metric, all of the treatments had an average establishment that meets their benchmark for success, albeit with high variability.

3.5 Conclusions

Our findings suggest that while tillage treatments can be effective at preparing sites for wildflower establishment, the frequency and timing of tillage alone do not influence wildflower emergence or weed community in the context of this experiment. As noted above, there are several avenues to establishing wildflower plots, and studies show an array of viable methods. However, there is no clear “best” approach; there are often trade-offs in cost, labor, scalability, and efficacy. Dunn et al. (2020) carried out a multi-year study comparing the cost and success of a variety of methods of establishing wildflower plots for pollinators, finding a wide range of costs and labor intensity, as well as a range of establishment success. Although there was some variation among the different treatments, the authors found that those with higher labor and cost tend to have better establishment success and lower weed coverage. Tillage, in turn, may be best suited to contexts with low to moderate weed pressure and circumstances where other establishment methods like solarization or herbicide are infeasible or otherwise undesirable.

Despite the results of this study, tillage has been shown to work just as well as other methods of wildflower plot establishment. Unfortunately, exactly what factors influence the success of tillage remain unclear. It is likely that a complex array of environmental factors, plant community traits, seed mixture, and other management decisions interact to determine outcomes. In this particular experiment, an abundant weed seed bank and community makeup may have reduced the effectiveness of tillage as well. Further research is needed to isolate and determine which factors contribute the most and how they interact; in this study, timing and frequency of tillage were clearly not the most influential on outcomes. Our study

also only observed one year of establishment data, and it can take several years for perennial wildflowers to flourish and for differences in treatments to emerge. The particular conditions present in a given year have a substantial influence on the resulting community in a restoration project (Groves et al. 2020), so replicating this experiment and continuing to track progress over multiple years may reveal stronger trends.

This study highlights the extreme variability in wildflower establishment projects and contributes to a growing body of literature that emphasizes the importance of understanding the site-specific conditions and management techniques when designing pollinator habitat. It is also crucial to assess the longer-term effects of different site preparation methods on plant communities and the ecosystem services we seek to support.

4. Overall Conclusions

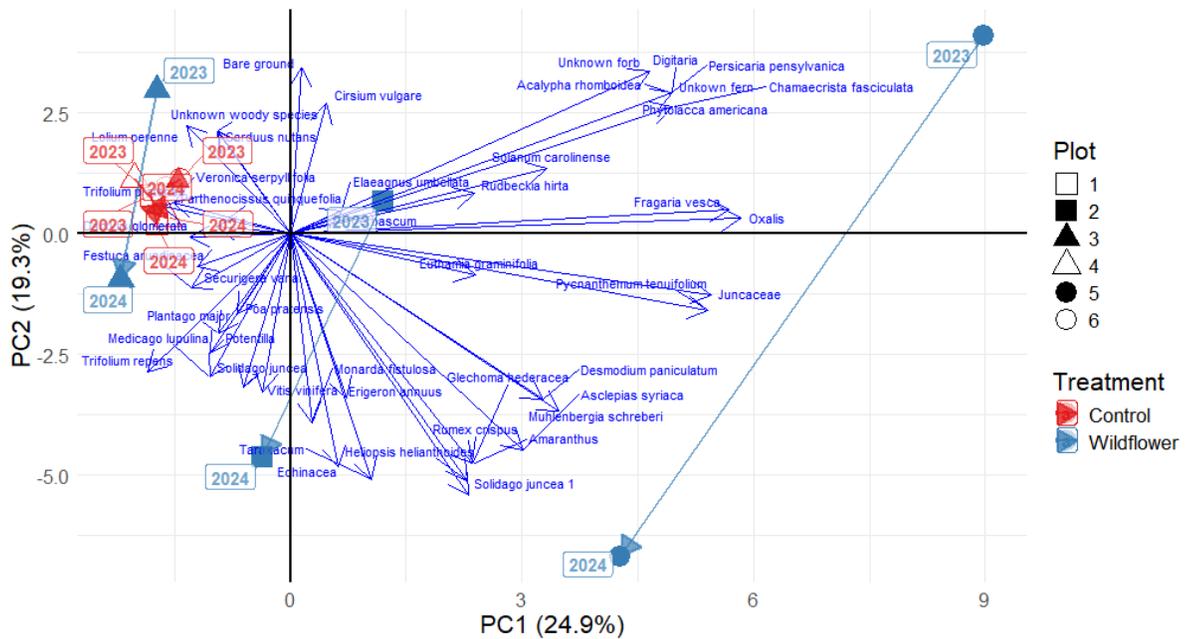
Developing and refining techniques to support declining pollinator populations is a key step in preserving ecosystem services and biodiversity more broadly. Native wildflower plots are a promising tool in the fight against falling insect populations, and incorporating these plots into grazing lands presents a prime opportunity that both supports a thriving ecosystem and maintains the livelihood of producers alike. However, as with most conservation methods, there is no “one size fits all” approach, and even a small-scale project should consider costs, labor, goals, and site-specific conditions to ensure success.

In the on-farm wildflower-enhanced pasture experiment, we found that wildflower set-aside plots can provide a habitat for a diverse community of insect pollinators while also limiting trade-offs in animal performance. Although there may be short term losses in beef productivity associated with the establishment of wildflower set-aside plots, this can be compensated for with supplemental feed or grazing the wildflowers periodically. Planting a mixture of just ten native forbs and legumes provides floral resources throughout the growing season, and attracts an array of pollinators including native bees, wasps, beetles and flies. This approach can be further refined by studying how grazing affects the longevity and floral production of wildflower plots, with the possibility of using a grazing schedule that allows wildflowers time to recover post-grazing. This research would provide better guidance to farmers seeking practical ways to steward the ecosystem they reside in. In the tillage experiment, we observed moderate levels of wildflower emergence across all treatments, although there was no clear difference due to varying timing or frequency of tillage.

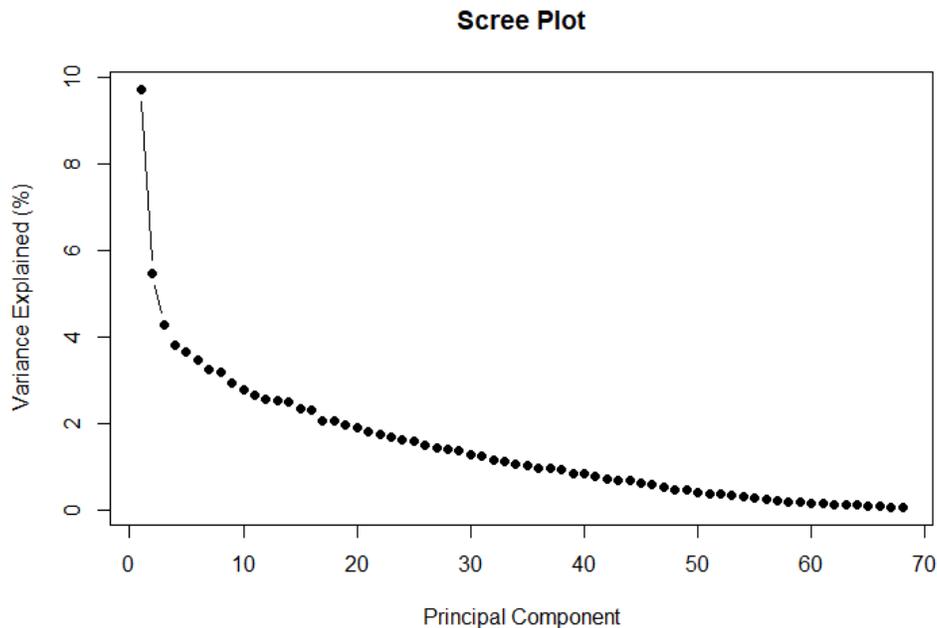
Site-specific conditions clearly play a large role in the success or failure of a particular establishment method, and it remains critically important to understand local conditions to ensure that a wildflower plot will flourish.

Together, these experiments show that although they are a powerful tool of pollinator conservation, creating native wildflower plots comes with an array of important considerations, particularly in regard to site preparation. Further research is certainly needed to understand the nuanced interactions between site conditions, chosen wildflower species, and management practices, as well as how grazing pressure factors in.

5. Supplemental Figures



Supp. Fig 1: Overall species cover in grazing experiment paddocks from 2023 to 2024. Arrows connect plots from 2023 to 2024 showing plant community change over time. PC1 and PC2 shown, with arrows representing loadings for each plant species observed.



Supp. Fig 2: Scree plot showing the proportion of variance explained by each principal component for the PCA of plant cover in the tillage experiment.

6. References

- Abbate, Anthony P., Joshua W. Campbell, Steven M. Grodsky, and Geoffrey R. Williams. 2024. "Assessing the Attractiveness of Native Wildflower Species to Bees (Hymenoptera: Anthophila) in the Southeastern United States." *Ecological Solutions and Evidence* 5 (3): e12363. <https://doi.org/10.1002/2688-8319.12363>.
- Ahren, Jack, Cindy Ann Niedner, and Allen Barker. 1974. *Roadside Wildflower Meadows: Summary of Benefits and Guidelines to Successful Establishment and Management Roadside Wildflower Meadows: Summary of Benefits and Guidelines to Successful Establishment and Management*. Washington, D.C.: National Academies Press. <https://doi.org/10.17226/27346>.
- Aldrich, James H. 2002. "Establishment of Modest-Sized Wildflower Plantings." *NATIVE PLANTS JOURNAL* 3 (1).
- Angelella, Gina M., Laura Stange, Holly L. Scoggins, and Megan E. O'Rourke. 2019. "Pollinator Refuge Establishment and Conservation Value: Impacts of Seedbed Preparations, Seed Mixtures, and Herbicides." *HortScience* 54 (3): 445–51. <https://doi.org/10.21273/HORTSCI113600-18>.

- Axton, Lisa M., and Beverly R. Durgan. 1991. "Plants Poisonous to Livestock." 1991. <https://conservancy.umn.edu/server/api/core/bitstreams/7dad87f1-50f3-4dcc-a57c-1ac02731de82/content>.
- Bardgett, Richard D., James M. Bullock, Sandra Lavorel, Peter Manning, Urs Schaffner, Nicholas Ostle, Mathilde Chomel, et al. 2021. "Combating Global Grassland Degradation." *Nature Reviews Earth & Environment* 2 (10): 720–35. <https://doi.org/10.1038/s43017-021-00207-2>.
- Barnes, Thomas G. 2004. "Strategies to Convert Exotic Grass Pastures to Tall Grass Prairie Communities1." *Weed Technology* 18 (sp1): 1364–70. [https://doi.org/10.1614/0890-037X\(2004\)018\[1364:STCEGP\]2.0.CO;2](https://doi.org/10.1614/0890-037X(2004)018[1364:STCEGP]2.0.CO;2).
- Barr, Stephanie, Jayne L. Jonas, and Mark W. Paschke. 2017. "Optimizing Seed Mixture Diversity and Seeding Rates for Grassland Restoration." *Restoration Ecology* 25 (3): 396–404. <https://doi.org/10.1111/rec.12445>.
- Bates, Douglas, Martin Maechler, Ben Bolker [aut, cre, Steven Walker, Rune Haubo Bojesen Christensen, Henrik Singmann, et al. 2025. "lme4: Linear Mixed-Effects Models Using 'Eigen' and S4." <https://cran.r-project.org/web/packages/lme4/index.html>.
- Bellangue, David, Jacob Barney, Michael Flessner, Jonathan Kubesch, Megan O'Rourke, Benjamin Tracy, and John Leighton Reid. 2024. "Site Preparation and Planting Strategies to Improve Native Forb Establishment in Pasturelands." *Agronomy* 14 (11): 2676. <https://doi.org/10.3390/agronomy14112676>.
- Bellangue, David Nsame. n.d. "Native Forb Establishment in Tall Fescue-Dominated Cattle Pastures."
- Beran, Daniel D., Roch E. Gaussoin, and Robert A. Masters. 1999. "Native Wildflower Establishment with Imidazolinone Herbicides." *HortScience* 34 (2): 283–86. <https://doi.org/10.21273/HORTSCI.34.2.283>.
- Blaauw, Brett R., and Rufus Isaacs. 2014. "Larger Patches of Diverse Floral Resources Increase Insect Pollinator Density, Diversity, and Their Pollination of Native Wildflowers." *Basic and Applied Ecology* 15 (8): 701–11. <https://doi.org/10.1016/j.baae.2014.10.001>.
- Börschig, Carmen, Alexandra-Maria Klein, Henrik von Wehrden, and Jochen Krauss. 2013. "Traits of Butterfly Communities Change from Specialist to Generalist Characteristics with Increasing Land-Use Intensity." *Basic and Applied Ecology* 14 (7): 547–54. <https://doi.org/10.1016/j.baae.2013.09.002>.
- Bratcher, Carlma, John Dole, and Janet Cole. 1993. "Stratification Improves Seed Germination of Five Native Wildflower Species." *Hort Science* 28 (September). <https://doi.org/10.21273/HORTSCI.28.9.899>.

- Breeveld, Alice A., Saskia Pagella, and Jane Fisher. n.d. "Converting Grassland to Wildflower Meadow: Impact on Soil Quality Indicators for Carbon Sequestration - Academia.Edu." Accessed October 17, 2024.
<https://www.academia.edu/2997-6006/1/2/10.20935/AcadEnvSci6238>.
- Brereton, Tom M., Martin S. Warren, David B. Roy, and Katherine Stewart. 2008. "The Changing Status of the Chalkhill Blue Butterfly *Polyommatus Coridon* in the UK: The Impacts of Conservation Policies and Environmental Factors." *Journal of Insect Conservation* 12 (6): 629–38. <https://doi.org/10.1007/s10841-007-9099-0>.
- Bretagnolle, Vincent, and Sabrina Gaba. 2015. "Weeds for Bees? A Review." *Agronomy for Sustainable Development* 35 (3): 891–909.
<https://doi.org/10.1007/s13593-015-0302-5>.
- Bretzel, Francesca, Francesca Vannucchi, Daniela Romano, Fernando Malorgio, Stefano Benvenuti, and Beatrice Pezzarossa. 2016. "Wildflowers: From Conserving Biodiversity to Urban Greening—A Review." *Urban Forestry & Urban Greening* 20 (December):428–36. <https://doi.org/10.1016/j.ufug.2016.10.008>.
- Butters, Jessica Nicole. n.d. "Providing for Pollinators: Conserving and Integrating Natural Habitats to Support Pollinator Conservation Efforts."
- Calderone, Nicholas W. 2012. "Insect Pollinated Crops, Insect Pollinators and US Agriculture: Trend Analysis of Aggregate Data for the Period 1992–2009." *PLOS ONE* 7 (5): e37235. <https://doi.org/10.1371/journal.pone.0037235>.
- Caldwell, Brian, and Charles L. Mohler. 2001. "Stale Seedbed Practices for Vegetable Production." *HortScience* 36 (4): 703–5.
- Cane, James, and Vincent Tepedino. 2001. "Causes and Extent of Declines among Native North American Invertebrate Pollinators: Detection, Evidence, and Consequences." *Conservation Ecology* 5 (1).
<https://doi.org/10.5751/ES-00252-050101>.
- Carrié, Romain, Johan Ekroos, and Henrik G. Smith. 2018. "Organic Farming Supports Spatiotemporal Stability in Species Richness of Bumblebees and Butterflies." *Biological Conservation* 227 (November):48–55.
<https://doi.org/10.1016/j.biocon.2018.08.022>.
- Carvell, Claire, David B. Roy, Simon M. Smart, Richard F. Pywell, Chris D. Preston, and Dave Goulson. 2006. "Declines in Forage Availability for Bumblebees at a National Scale." *Biological Conservation* 132 (4): 481–89.
<https://doi.org/10.1016/j.biocon.2006.05.008>.
- Caudillo, Mia, Andony Melathopoulos, David Eduardo Prado-Tarango, Mary Smallman, Sarah A. Taylor, and Serkan Ates. 2024. "Designing Management Strategies for Sheep Production and Bees in Dryland Pastures." *Agronomy* 14 (1): 24.
<https://doi.org/10.3390/agronomy14010024>.

- Clavel, Joanne, Romain Julliard, and Vincent Devictor. 2011. "Worldwide Decline of Specialist Species: Toward a Global Functional Homogenization?" *Frontiers in Ecology and the Environment* 9 (4): 222–28. <https://doi.org/10.1890/080216>.
- Clay, Keith, and Jenny Holah. 1999. "Fungal Endophyte Symbiosis and Plant Diversity in Successional Fields." *Science* 285 (5434): 1742–44. <https://doi.org/10.1126/science.285.5434.1742>.
- Coon, Jaime J., Nicholas J. Lyon, Edward J. Raynor, Diane M. Debinski, James R. Miller, and Walter H. Schacht. 2021. "Using Adaptive Management to Restore Grasslands Invaded by Tall Fescue (*Schedonorus Arundinaceus*)★." *Rangeland Ecology and Management* 76 (1): 84–94. <https://doi.org/10.1016/j.rama.2021.02.001>.
- Cope, Grace C., Joshua W. Campbell, Steven M. Grodsky, and James D. Ellis. 2019. "Evaluation of Nest-Site Selection of Ground-Nesting Bees and Wasps (Hymenoptera) Using Emergence Traps." *The Canadian Entomologist* 151 (2): 260–71. <https://doi.org/10.4039/tce.2019.3>.
- Cullen, Merissa G., Linzi J. Thompson, James C. Carolan, Jane C. Stout, and Dara A. Stanley. 2019. "Fungicides, Herbicides and Bees: A Systematic Review of Existing Research and Methods." *PLOS ONE* 14 (12): e0225743. <https://doi.org/10.1371/journal.pone.0225743>.
- Davies, Kirk W., and Roger L. Sheley. 2011. "Promoting Native Vegetation and Diversity in Exotic Annual Grass Infestations." *Restoration Ecology* 19 (2): 159–65. <https://doi.org/10.1111/j.1526-100X.2009.00548.x>.
- Dicks, Lynn V., Joscelyne E. Ashpole, Juliana Dänhardt, Katy James, Annelie Jönsson, Nicola Randall, David A. Showler, et al. 2015. "Farmland Conservation." In *What Works in Conservation*, edited by Lynn V. Dicks, Rebecca K. Smith, William J. Sutherland, and Nancy Ockendon, 1:245–84. 2015. Open Book Publishers. <https://www.jstor.org/stable/j.ctt16qzq2p.7>.
- Dunn, Amara, Brian Eshenaur, and Betsy Lamb. 2020. "Demonstrating Creation of Habitat for Beneficial Insects - Year 3 (2020)." <https://hdl.handle.net/1813/103754>.
- Edwards, Andrew R., Simon R. Mortimer, Clare S. Lawson, Duncan B. Westbury, Stephanie J. Harris, Ben A. Woodcock, and Valerie K. Brown. 2007. "Hay Strewing, Brush Harvesting of Seed and Soil Disturbance as Tools for the Enhancement of Botanical Diversity in Grasslands." *Biological Conservation* 134 (3): 372–82. <https://doi.org/10.1016/j.biocon.2006.08.025>.
- Espeland, Erin K., Lora B. Perkins, and Elizabeth A. Leger. 2010. "Comparison of Seed Bank Estimation Techniques Using Six Weed Species in Two Soil Types." *Rangeland Ecology & Management* 63 (2): 243–47. <https://doi.org/10.2111/REM-D-09-00109.1>.

- Evans, Samuel C., Emma M. Shaw, and Ann L. Rypstra. 2010. "Exposure to a Glyphosate-Based Herbicide Affects Agrobiont Predatory Arthropod Behaviour and Long-Term Survival." *Ecotoxicology* 19 (7): 1249–57. <https://doi.org/10.1007/s10646-010-0509-9>.
- Farina, Walter M., M. Sol Balbuena, Lucila T. Herbert, Carolina Mengoni Goñalons, and Diego E. Vázquez. 2019. "Effects of the Herbicide Glyphosate on Honey Bee Sensory and Cognitive Abilities: Individual Impairments with Implications for the Hive." *Insects* 10 (10): 354. <https://doi.org/10.3390/insects10100354>.
- Fiedler, Anna K., Doug A. Landis, and Steve D. Wratten. 2008. "Maximizing Ecosystem Services from Conservation Biological Control: The Role of Habitat Management." *Biological Control, Conservation Biological Control*, 45 (2): 254–71. <https://doi.org/10.1016/j.biocontrol.2007.12.009>.
- Forister, Matthew L., Emma M. Pelton, and Scott H. Black. 2019. "Declines in Insect Abundance and Diversity: We Know Enough to Act Now." *Conservation Science and Practice* 1 (8): e80. <https://doi.org/10.1111/csp2.80>.
- Frances, Anne L., Carrie Reinhardt Adams, and Jeffrey G. Norcini. 2010. "Importance of Seed and Microsite Limitation: Native Wildflower Establishment in Non-Native Pasture." *Restoration Ecology* 18 (6): 944–53. <https://doi.org/10.1111/j.1526-100X.2009.00629.x>.
- Fry, Ellen L., Emma S. Pilgrim, Jerry R.B. Tallwin, Roger S. Smith, Simon R. Mortimer, Deborah A. Beaumont, Janet Simkin, et al. 2017. "Plant, Soil and Microbial Controls on Grassland Diversity Restoration: A Long-Term, Multi-Site Mesocosm Experiment." *Journal of Applied Ecology* 54 (5): 1320–30. <https://doi.org/10.1111/1365-2664.12869>.
- Garbuzov, Mihail, and Francis L. W. Ratnieks. 2014. "Quantifying Variation among Garden Plants in Attractiveness to Bees and Other Flower-Visiting Insects." *Functional Ecology* 28 (2): 364–74. <https://doi.org/10.1111/1365-2435.12178>.
- Garibaldi, Lucas, Luísa Carvalheiro, Sara Leonhardt, Marcelo Aizen, Brett Blaauw, Rufus Isaacs, Michael Kuhlmann, et al. 2014. "From Research to Action: Enhancing Crop Yield through Wild Pollinators." *Frontiers in Ecology and the Environment* 12 (September):439–47. <https://doi.org/10.1890/130330>.
- Ghajar, Shayan M., Jennie F. Wagner, Megan O'Rourke, and Benjamin F. Tracy. 2022. "Evaluating Methods to Establish Biodiverse Pasturelands with Native Grasses and Wildflowers." *Native Plants Journal* 23 (1): 65–74. <https://doi.org/10.3368/npj.23.1.65>.
- Ghazoul, Jaboury. 2006. "Floral Diversity and the Facilitation of Pollination." *Journal of Ecology* 94 (2): 295–304.

- Glen, Emma, Elizabeth A. C. Price, Simon J. M. Caporn, Jacky A. Carroll, Laurence M. Jones, and Richard Scott. 2017. "Evaluation of Topsoil Inversion in U.K. Habitat Creation and Restoration Schemes." *Restoration Ecology* 25 (1): 72–81. <https://doi.org/10.1111/rec.12403>.
- Glidden, Alec J., Mark E. Sherrard, Justin C. Meissen, Mark C. Myers, Kenneth J. Elgersma, and Laura L. Jackson. 2023. "Planting Time, First-Year Mowing, and Seed Mix Design Influence Ecological Outcomes in Agroecosystem Revegetation Projects." *Restoration Ecology* 31 (4): e13818. <https://doi.org/10.1111/rec.13818>.
- Goodell, Karen, and Ingrid M. Parker. 2017. "Invasion of a Dominant Floral Resource: Effects on the Floral Community and Pollination of Native Plants." *Ecology* 98 (1): 57–69. <https://doi.org/10.1002/ecy.1639>.
- "Google Earth." 2023. Online. Google LLC. <https://earth.google.com/web/>.
- Goulson, Dave, Elizabeth Nicholls, Cristina Botías, and Ellen L. Rotheray. 2015. "Bee Declines Driven by Combined Stress from Parasites, Pesticides, and Lack of Flowers." *Science* 347 (6229): 1255957. <https://doi.org/10.1126/science.1255957>.
- Grab, Heather, Michael G. Branstetter, Nolan Amon, Katherine R. Urban-Mead, Mia G. Park, Jason Gibbs, Eleanor J. Blitzer, Katja Poveda, Greg Loeb, and Bryan N. Danforth. 2019. "Agriculturally Dominated Landscapes Reduce Bee Phylogenetic Diversity and Pollination Services." *Science* 363 (6424): 282–84. <https://doi.org/10.1126/science.aat6016>.
- Grass, Ingo, Jörg Albrecht, Frank Jauker, Tim Diekötter, Daniela Warzecha, Volkmar Wolters, and Nina Farwig. 2016. "Much More than Bees—Wildflower Plantings Support Highly Diverse Flower-Visitor Communities from Complex to Structurally Simple Agricultural Landscapes." *Agriculture, Ecosystems & Environment* 225 (June):45–53. <https://doi.org/10.1016/j.agee.2016.04.001>.
- Groves, Anna M., Jonathan T. Bauer, and Lars A. Brudvig. 2020. "Lasting Signature of Planting Year Weather on Restored Grasslands." *Scientific Reports* 10 (1): 5953. <https://doi.org/10.1038/s41598-020-62123-7>.
- Groves, Anna M., and Lars A. Brudvig. 2019. "Interannual Variation in Precipitation and Other Planting Conditions Impacts Seedling Establishment in Sown Plant Communities." *Restoration Ecology* 27 (1): 128–37. <https://doi.org/10.1111/rec.12708>.
- Haaland, Christine, Russell E. Naisbit, and Louis-Félix Bersier. 2011. "Sown Wildflower Strips for Insect Conservation: A Review." *Insect Conservation and Diversity* 4 (1): 60–80. <https://doi.org/10.1111/j.1752-4598.2010.00098.x>.
- Habel, Jan Christian, Michael J. Samways, and Thomas Schmitt. 2019. "Mitigating the Precipitous Decline of Terrestrial European Insects: Requirements for a New

- Strategy." *Biodiversity and Conservation* 28 (6): 1343–60.
<https://doi.org/10.1007/s10531-019-01741-8>.
- Henry, Mickaël, Maxime Béguin, Fabrice Requier, Oriane Rollin, Jean-François Odoux, Pierrick Aupinel, Jean Aptel, Sylvie Tchamitchian, and Axel Decourtye. 2012. "A Common Pesticide Decreases Foraging Success and Survival in Honey Bees." *Science* 336 (6079): 348–50. <https://doi.org/10.1126/science.1215039>.
- Hölzel, Norbert, and Annette Otte. 2003. "Restoration of a Species-Rich Flood Meadow by Topsoil Removal and Diaspore Transfer with Plant Material." *Applied Vegetation Science* 6 (2): 131–40. <https://doi.org/10.1111/j.1654-109X.2003.tb00573.x>.
- Howe, Henry F. 1994. "Response of Early- and Late-Flowering Plants to Fire Season in Experimental Prairies." *Ecological Applications* 4 (1): 121–33.
<https://doi.org/10.2307/1942122>.
- Isaacs, Rufus, Julianna Tuell, Anna Fiedler, Mary Gardiner, and Doug Landis. 2009. "Maximizing Arthropod-Mediated Ecosystem Services in Agricultural Landscapes: The Role of Native Plants." *Frontiers in Ecology and the Environment* 7 (4): 196–203. <https://doi.org/10.1890/080035>.
- James, Lynn F., Dale R. Gardner, Stephen T. Lee, Kip E. Panter, James A. Pfister, Michael H. Ralphs, and Brian L. Stegelmeier. 2005. "Important Poisonous Plants on Rangelands." *Rangelands* 27 (5): 3–9.
[https://doi.org/10.2111/1551-501X\(2005\)27\[3:IPPOR\]2.0.CO;2](https://doi.org/10.2111/1551-501X(2005)27[3:IPPOR]2.0.CO;2).
- Johnston, Christopher R., Patrick E. McCullough, and Donn G. Shilling. 2015. "Native Plant Establishment on Georgia Roadsides." *Agronomy Journal* 107 (3): 990–96.
<https://doi.org/10.2134/agronj14.0555>.
- Kallenbach, R. L. 2015. "BILL E. KUNKLE INTERDISCIPLINARY BEEF SYMPOSIUM: Coping with Tall Fescue Toxicosis: Solutions and Realities^{1,2}." *Journal of Animal Science* 93 (12): 5487–95. <https://doi.org/10.2527/jas.2015-9229>.
- Kennedy, Christina M., Eric Lonsdorf, Maile C. Neel, Neal M. Williams, Taylor H. Ricketts, Rachael Winfree, Riccardo Bommarco, et al. 2013a. "A Global Quantitative Synthesis of Local and Landscape Effects on Wild Bee Pollinators in Agroecosystems." *Ecology Letters* 16 (5): 584–99.
<https://doi.org/10.1111/ele.12082>.
- . 2013b. "A Global Quantitative Synthesis of Local and Landscape Effects on Wild Bee Pollinators in Agroecosystems." *Ecology Letters* 16 (5): 584–99.
<https://doi.org/10.1111/ele.12082>.
- Klein, Alexandra-Maria, Bernard E Vaissière, James H Cane, Ingolf Steffan-Dewenter, Saul A Cunningham, Claire Kremen, and Teja Tschamntke. 2006a. "Importance of Pollinators in Changing Landscapes for World Crops." *Proceedings of the Royal*

- Society B: Biological Sciences* 274 (1608): 303–13.
<https://doi.org/10.1098/rspb.2006.3721>.
- . 2006b. “Importance of Pollinators in Changing Landscapes for World Crops.” *Proceedings of the Royal Society B: Biological Sciences* 274 (1608): 303–13.
<https://doi.org/10.1098/rspb.2006.3721>.
- Kluser, Stéphane, and Pascal Peduzzi. 2007. “Global Pollinator Decline: A Literature Review,” January.
- Korpela, Eeva-Liisa, Terho Hyvönen, Sami Lindgren, and Mikko Kuussaari. 2013. “Can Pollination Services, Species Diversity and Conservation Be Simultaneously Promoted by Sown Wildflower Strips on Farmland?” *Agriculture, Ecosystems & Environment* 179 (October):18–24. <https://doi.org/10.1016/j.agee.2013.07.001>.
- Kubesch, Jonathan Omar Cole. 2023. “Evaluating Native Warm-Season Grass and Wildflower Mixtures for Beef Cattle Production in the Mid-Atlantic.” Virginia Tech. <https://hdl.handle.net/10919/117239>.
- Kuznetsova, Alexandra, Per Bruun Brockhoff, Rune Haubo Bojesen Christensen, and Sofie Pødenphant Jensen. 2020. “lmerTest: Tests in Linear Mixed Effects Models.” <https://cran.r-project.org/web/packages/lmerTest/index.html>.
- Langlois, Alban, Anne-Laure Jacquemart, and Julien Piqueray. 2020. “Contribution of Extensive Farming Practices to the Supply of Floral Resources for Pollinators.” *Insects* 11 (11): 818. <https://doi.org/10.3390/insects11110818>.
- Lautenbach, Sven, Ralf Seppelt, Juliane Liebscher, and Carsten F. Dormann. 2012. “Spatial and Temporal Trends of Global Pollination Benefit.” *PLOS ONE* 7 (4): e35954. <https://doi.org/10.1371/journal.pone.0035954>.
- LeBuhn, Gretchen, and Joshua Vargas Luna. 2021. “Pollinator Decline: What Do We Know about the Drivers of Solitary Bee Declines?” *Current Opinion in Insect Science*, Special Section on Pollinator decline: human and policy dimensions * Social insects, 46 (August):106–11. <https://doi.org/10.1016/j.cois.2021.05.004>.
- Ledvina, Joseph, William J. McShea, Norman A. Bourg, Valentine Herrmann, Thomas Akre, and Amy E. M. Johnson. 2020. “Management Regime and Field Age Affect Species Richness and Cover of Native Forbs and Exotic Species in Virginia Grasslands.” <https://doi.org/10.3368/er.38.2.83>.
- Leonhardt, Sara Diana, and Nico Blüthgen. 2012. “The Same, but Different: Pollen Foraging in Honeybee and Bumblebee Colonies.” *Apidologie* 43 (4): 449–64. <https://doi.org/10.1007/s13592-011-0112-y>.
- “Long-term Declines of European Insectivorous Bird Populations and Potential Causes.” n.d. Accessed April 24, 2025. <https://doi.org/10.1111/cobi.13307>.

- Losey, John E., and Mace Vaughan. 2006. "The Economic Value of Ecological Services Provided by Insects." *BioScience* 56 (4): 311–23.
[https://doi.org/10.1641/0006-3568\(2006\)56\[311:TEVOES\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2006)56[311:TEVOES]2.0.CO;2).
- Lüdecke, Daniel, Mattan S. Ben-Shachar, Indrajeet Patil, Philip Waggoner, and Dominique Makowski. 2021. "Performance: An R Package for Assessment, Comparison and Testing of Statistical Models." <https://doi.org/10.21105/joss.03139>.
- Luginbuhl, JM. 2020. "Poisonous Plants to Livestock." N.C. Cooperative Extension.
<https://content.ces.ncsu.edu/poisonous-plants-to-livestock>.
- Madison, L. Andrew, Thomas G. Barnes, and Jeffery D. Sole. 2001. "Effectiveness of Fire, Disking, and Herbicide to Renovate Tall Fescue Fields to Northern Bobwhite Habitat." *Wildlife Society Bulletin (1973-2006)* 29 (2): 706–12.
- Marushia, Robin G., and Edith B. Allen. 2011. "Control of Exotic Annual Grasses to Restore Native Forbs in Abandoned Agricultural Land." *Restoration Ecology* 19 (1): 45–54. <https://doi.org/10.1111/j.1526-100X.2009.00540.x>.
- McCullough, Christopher T, Gina M Angelella, and Megan E O'Rourke. 2021. "Landscape Context Influences the Bee Conservation Value of Wildflower Plantings." *Environmental Entomology* 50 (4): 821–31.
<https://doi.org/10.1093/ee/nvab036>.
- Morandin, Lora A., Mark L. Winston, Virginia A. Abbott, and Michelle T. Franklin. 2007. "Can Pastureland Increase Wild Bee Abundance in Agriculturally Intense Areas?" *Basic and Applied Ecology* 8 (2): 117–24.
<https://doi.org/10.1016/j.baae.2006.06.003>.
- Morgan, John P., Douglas R. Collicutt, and Jacqueline D. Thompson. 1995. "Restoring Canada's Native Prairies: A Practical Manual." Prairie Habitats.
https://www.npss.sk.ca/docs/2_pdf/RCNP.pdf.
- Moyes, Andrew B., Martha S. Witter, and John A. Gamon. 2005. "Restoration of Native Perennials in a California Annual Grassland after Prescribed Spring Burning and Solarization." *Restoration Ecology* 13 (4): 659–66.
<https://doi.org/10.1111/j.1526-100X.2005.00084.x>.
- Narjes Sanchez, Manuel Ernesto, Juan Andrés Cardoso Arango, and Stefan Burkart. 2021. "Promoting Forage Legume–Pollinator Interactions: Integrating Crop Pollination Management, Native Beekeeping and Silvopastoral Systems in Tropical Latin America." *Frontiers in Sustainable Food Systems* 5 (September).
<https://doi.org/10.3389/fsufs.2021.725981>.
- Neal, Cathy. 2019. "Planting for Pollinators: Establishing a Wildflower Meadow from Seed [Fact Sheet]." Extension. March 26, 2019.
<https://extension.unh.edu/resource/planting-pollinators-establishing-wildflower-meadow-seed-fact-sheet>.

- Nichols, Rachel N., Dave Goulson, and John M. Holland. 2019. "The Best Wildflowers for Wild Bees." *Journal of Insect Conservation* 23 (5): 819–30. <https://doi.org/10.1007/s10841-019-00180-8>.
- Norcini, Jeffrey G., and James H. Aldrich. 2004. "Establishment of Native Wildflower Plantings by Seed: ENH968/EP227, 4/2004." *EDIS* 2004 (7). <https://doi.org/10.32473/edis-ep227-2004>.
- Noss, Reed F. 2013. *Forgotten Grasslands of the South: Natural History and Conservation*. Island Press Washington, DC.
- Ogilvie, Jane E, and Jessica RK Forrest. 2017. "Interactions between Bee Foraging and Floral Resource Phenology Shape Bee Populations and Communities." *Current Opinion in Insect Science, Pests and resistance * Behavioural ecology*, 21 (June):75–82. <https://doi.org/10.1016/j.cois.2017.05.015>.
- Oksanen, Jari, Gavin L. Simpson, F. Guillaume Blanchet, Roeland Kindt, Pierre Legendre, Peter R. Minchin, R. B. O'Hara, et al. 2025. "Vegan: Community Ecology Package." <https://cran.r-project.org/web/packages/vegan/index.html>.
- Ollerton, Jeff, Rachael Winfree, and Sam Tarrant. 2011. "How Many Flowering Plants Are Pollinated by Animals?" *Oikos* 120 (3): 321–26. <https://doi.org/10.1111/j.1600-0706.2010.18644.x>.
- Orr, Matthew R., Ron J. Reuter, and Shanti J. Murphy. 2019. "Solarization to Control Downy Brome (*Bromus Tectorum*) for Small-Scale Ecological Restoration." *Invasive Plant Science and Management* 12 (2): 112–19. <https://doi.org/10.1017/inp.2019.8>.
- Ouvrard, Pierre, Julie Transon, and Anne-Laure Jacquemart. 2018. "Flower-Strip Agri-Environment Schemes Provide Diverse and Valuable Summer Flower Resources for Pollinating Insects." *Biodiversity and Conservation* 27 (9): 2193–2216. <https://doi.org/10.1007/s10531-018-1531-0>.
- Page, Maureen L., and Neal M. Williams. 2023. "Honey Bee Introductions Displace Native Bees and Decrease Pollination of a Native Wildflower." *Ecology* 104 (2): e3939. <https://doi.org/10.1002/ecy.3939>.
- Perović, David, Sagrario Gámez-Virués, Carmen Börschig, Alexandra-Maria Klein, Jochen Krauss, Juliane Steckel, Christoph Rothenwöhrer, Stefan Erasmi, Teja Tschamtker, and Catrin Westphal. 2015. "Configurational Landscape Heterogeneity Shapes Functional Community Composition of Grassland Butterflies." *Journal of Applied Ecology* 52 (2): 505–13. <https://doi.org/10.1111/1365-2664.12394>.
- Perry, Laura G., Spencer A. Cronin, and Mark W. Paschke. 2009. "Native Cover Crops Suppress Exotic Annuals and Favor Native Perennials in a Greenhouse Competition Experiment." *Plant Ecology* 204 (2): 247–59. <https://doi.org/10.1007/s11258-009-9588-1>.

- Porter, J. K. 1995. "Analysis of Endophyte Toxins: Fescue and Other Grasses Toxic to Livestock." *Journal of Animal Science* 73 (3): 871–80.
<https://doi.org/10.2527/1995.733871x>.
- Potts, S. G., B. A. Woodcock, S. P. M. Roberts, T. Tscheulin, E. S. Pilgrim, V. K. Brown, and J. R. Tallowin. 2009. "Enhancing Pollinator Biodiversity in Intensive Grasslands." *Journal of Applied Ecology* 46 (2): 369–79.
<https://doi.org/10.1111/j.1365-2664.2009.01609.x>.
- Potts, Simon G., Jacobus C. Biesmeijer, Claire Kremen, Peter Neumann, Oliver Schweiger, and William E. Kunin. 2010. "Global Pollinator Declines: Trends, Impacts and Drivers." *Trends in Ecology & Evolution* 25 (6): 345–53.
<https://doi.org/10.1016/j.tree.2010.01.007>.
- Poudel, Sanjok, Wayne E. Zeller, John Fike, and Gabriel Pent. 2023. "Condensed Tannins Attributes: Potential Solution to Fescue Toxicosis?" *Agriculture* 13 (3): 672.
<https://doi.org/10.3390/agriculture13030672>.
- Prigge, Jessica L., Eric Bisangwa, Jonathan D. Richwine, Keagan J. Swilling, and Patrick D. Keyser. 2024. "Blooming and Forage Characteristics of Twelve Native Forbs Subjected to Repeated Defoliation." *Agronomy* 14 (1): 28.
<https://doi.org/10.3390/agronomy14010028>.
- Prigge, Jessica L., Eric Bisangwa, Jonathan D. Richwine, Virginia R. Sykes, Jennie L. Z. Ivey, and Patrick D. Keyser. 2024. "Native Forbs Provide Pollinator Resources and Improve Forage Nutrient Composition, Animal Performance, and Pasture Productivity." *Agronomy* 14 (10): 2184. <https://doi.org/10.3390/agronomy14102184>.
- Pywell, Richard F., James M. Bullock, Alan Hopkins, Kevin J. Walker, Tim H. Sparks, Mike J.W. Burke, and Steve Peel. 2002. "Restoration of Species-Rich Grassland on Arable Land: Assessing the Limiting Processes Using a Multi-Site Experiment." *Journal of Applied Ecology* 39 (2): 294–309.
<https://doi.org/10.1046/j.1365-2664.2002.00718.x>.
- R Core Team. 2024. "R: A Language and Environment for Statistical Computing." Vienna, Austria: R Foundation for Statistical Computing.
<https://www.R-project.org/>.
- Rader, Romina, Ignasi Bartomeus, Lucas A. Garibaldi, Michael P. D. Garratt, Brad G. Howlett, Rachael Winfree, Saul A. Cunningham, et al. 2016. "Non-Bee Insects Are Important Contributors to Global Crop Pollination." *Proceedings of the National Academy of Sciences* 113 (1): 146–51. <https://doi.org/10.1073/pnas.1517092112>.
- Requier, Fabrice, Jean-François Odoux, Thierry Tamic, Nathalie Moreau, Mickaël Henry, Axel Decourtye, and Vincent Bretagnolle. 2015. "Honey Bee Diet in Intensive Farmland Habitats Reveals an Unexpectedly High Flower Richness and a

- Major Role of Weeds.” *Ecological Applications* 25 (4): 881–90.
<https://doi.org/10.1890/14-1011.1>.
- Rollin, Orianne, Vincent Bretagnolle, Axel Decourtye, Jean Aptel, Nadia Michel, Bernard E. Vaissière, and Mickaël Henry. 2013. “Differences of Floral Resource Use between Honey Bees and Wild Bees in an Intensive Farming System.” *Agriculture, Ecosystems & Environment* 179 (October):78–86.
<https://doi.org/10.1016/j.agee.2013.07.007>.
- Samson, Fred, and Fritz Knopf. 1994. “Prairie Conservation in North America.” *BioScience* 44 (6): 418–21. <https://doi.org/10.2307/1312365>.
- Scheper, Jeroen, Tibor Bukovinszky, Martinus E. Huigens, and David Kleijn. 2021. “Attractiveness of Sown Wildflower Strips to Flower-Visiting Insects Depends on Seed Mixture and Establishment Success.” *Basic and Applied Ecology* 56 (November):401–15. <https://doi.org/10.1016/j.baae.2021.08.014>.
- Scherber, Christoph, Tatiane Beduschi, and Teja Tschardt. 2019. “Novel Approaches to Sampling Pollinators in Whole Landscapes: A Lesson for Landscape-Wide Biodiversity Monitoring.” *Landscape Ecology* 34 (5): 1057–67.
<https://doi.org/10.1007/s10980-018-0757-2>.
- Schultz, Cheryl B. 2001. “Restoring Resources for an Endangered Butterfly.” *Journal of Applied Ecology* 38 (5): 1007–19.
<https://doi.org/10.1046/j.1365-2664.2001.00659.x>.
- Sexton, Aaron N., and Sarah M. Emery. 2020. “Grassland Restorations Improve Pollinator Communities: A Meta-Analysis.” *Journal of Insect Conservation* 24 (4): 719–26. <https://doi.org/10.1007/s10841-020-00247-x>.
- Shelton, J. S., W. J. Florkowski, and S. V. Pennisi. 2024. “Establishing Native Wildflower Habitats in Urban Settings on a Low Budget.” *Folia Horticulturae* 0 (0).
<https://doi.org/10.2478/fhort-2024-0021>.
- Shelton, Joseph Spencer. 2021. “Does Bed Preparation Impact Native Wildflower Establishment? Cost Analysis and Implications for Biodiversity.” M.S., United States -- Georgia: University of Georgia.
<https://www.proquest.com/docview/2627994310/abstract/9BA149CA8CB2405FPQ/1?sourcetype=Dissertations%20&%20Theses>.
- Skousen, J.G., and C.L. Venable. 2008. “Establishing Native Plants on Newly-constructed and Older-reclaimed Sites along West Virginia Highways.” *Land Degradation & Development* 19 (4): 388–96. <https://doi.org/10.1002/ldr.846>.
- Smith, S. Ray, John B. Hall, Glenn D. Johnson, and Paul R. Peterson. 2009. “Making the Most of Tall Fescue in Virginia.” <http://hdl.handle.net/10919/54990>.
- Southern Weed Science Society. n.d. *Weed Identification Guide*. Champaign, IL 61820: Southern Weed Science Society.

- Steffan-Dewenter, Ingolf, Ute Münzenberg, Christof Bürger, Carsten Thies, and Teja Tscharntke. 2002. "SCALE-DEPENDENT EFFECTS OF LANDSCAPE CONTEXT ON THREE POLLINATOR GUILDS." *Ecology* 83 (5): 1421–32.
[https://doi.org/10.1890/0012-9658\(2002\)083\[1421:SDEOLC\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2002)083[1421:SDEOLC]2.0.CO;2).
- Stroot, Lukas, Annika Brinkert, Norbert Hölzel, Alina Rüsing, and Anna Bucharova. 2022. "Establishment of Wildflower Strips in a Wide Range of Environments: A Lesson from a Landscape-Scale Project." *Restoration Ecology* 30 (4): e13542.
<https://doi.org/10.1111/rec.13542>.
- Stuedemann, John A., and Carl S. Hoveland. 1988. "Fescue Endophyte: History and Impact on Animal Agriculture." *Journal of Production Agriculture* 1 (1): 39–44.
<https://doi.org/10.2134/jpa1988.0039>.
- Tallamy, Douglas W, and W Gregory Shriver. 2021. "Are Declines in Insects and Insectivorous Birds Related?" *Ornithological Applications* 123 (1): duaa059.
<https://doi.org/10.1093/ornithapp/duaa059>.
- Török, Péter, Enikő Vida, Balázs Deák, Szabolcs Lengyel, and Béla Tóthmérész. 2011. "Grassland Restoration on Former Croplands in Europe: An Assessment of Applicability of Techniques and Costs." *Biodiversity and Conservation* 20 (11): 2311–32. <https://doi.org/10.1007/s10531-011-9992-4>.
- Tuell, Julianna K., Anna K. Fiedler, Douglas Landis, and Rufus Isaacs. 2008. "Visitation by Wild and Managed Bees (Hymenoptera: Apoidea) to Eastern U.S. Native Plants for Use in Conservation Programs." *Environmental Entomology* 37 (3): 707–18.
[https://doi.org/10.1603/0046-225X\(2008\)37\[707:VBWAMB\]2.0.CO;2](https://doi.org/10.1603/0046-225X(2008)37[707:VBWAMB]2.0.CO;2).
- Turley, Nash E., Joshua Hogan, Gloria J. Diehl, Aaron C. Stack, and Barbara J. Sharanowski. 2020. "Nationwide Survey on the Barriers to Converting Turfgrass Lawns to Pollinator-Friendly Native Wildflowers." bioRxiv.
<https://doi.org/10.1101/2020.06.02.129452>.
- Ulappa, Amy C., Lisa A. Shipley, Rachel C. Cook, John G. Cook, and Mark E. Swanson. 2020. "Silvicultural Herbicides and Forest Succession Influence Understory Vegetation and Nutritional Ecology of Black-Tailed Deer in Managed Forests." *Forest Ecology and Management* 470–471 (August):118216.
<https://doi.org/10.1016/j.foreco.2020.118216>.
- Vaughan, Mace, Jennifer Hopwood, Eric Lee-Mader, Matthew Shepherd, Claire Kremen, Anne Stine, and Scott H. Black. 2015. "15-007_04_XercesSoc_Farming-for-Bees-Guidelines_web.Pdf." 2015.
https://xerces.org/sites/default/files/2018-05/15-007_04_XercesSoc_Farming-for-Bees-Guidelines_web.pdf.

- Villalba, Juan J. 2024. "Creating Phytochemically Diverse Foodscapes through Landscape Interventions." *Cadernos de Agroecologia* 19 (3).
<https://cadernos.aba-agroecologia.org.br/cadernos/article/view/10152>.
- Vogel, Kenneth P., and Robert A. Masters. 2001. "Frequency Grid: A Simple Tool for Measuring Grassland Establishment." *Journal of Range Management* 54 (6): 653–55. <https://doi.org/10.2307/4003666>.
- Warzecha, Daniela, Tim Diekötter, Volkmar Wolters, and Frank Jauker. 2018. "Attractiveness of Wildflower Mixtures for Wild Bees and Hoverflies Depends on Some Key Plant Species." *Insect Conservation and Diversity* 11 (1): 32–41.
<https://doi.org/10.1111/icad.12264>.
- Watkinson, Jonathon I., and Wallace G. Pill. 2007. "Efficacy of Non-Chemical Weed Control during Plug Establishment of a Wildflower Meadow." *Journal of Environmental Horticulture* 25 (2): 83–88.
<https://doi.org/10.24266/0738-2898-25.2.83>.
- Weakley, Alan S., Bland Crowder, John F. Townsend, and J. Christopher Ludwig. 2012. *Flora of Virginia*. First. Fort Worth, TX: Botanical Research Institute of Texas Press.
- Weiner, Christiane Natalie, Michael Werner, Karl Eduard Linsenmair, and Nico Blüthgen. 2014. "Land-Use Impacts on Plant–Pollinator Networks: Interaction Strength and Specialization Predict Pollinator Declines." *Ecology* 95 (2): 466–74.
<https://doi.org/10.1890/13-0436.1>.
- Williams, Dave, James Eckberg, Jennifer Hopwood, Rae Powers, Mace Vaughan, Karin Jokela, Sarah Foltz Jordan, and Eric Lee-Mader. 2018. "Interseeding Wildflowers to Diversify Grasslands for Pollinators." The Xerces Society for Invertebrate Conservation.
<https://xerces.org/publications/guidelines/interseeding-wildflowers-to-diversify-grasslands-for-pollinators>.
- Williams, Neal M., Kimiora L. Ward, Nathaniel Pope, Rufus Isaacs, Julianna Wilson, Emily A. May, Jamie Ellis, et al. 2015. "Native Wildflower Plantings Support Wild Bee Abundance and Diversity in Agricultural Landscapes across the United States." *Ecological Applications* 25 (8): 2119–31. <https://doi.org/10.1890/14-1748.1>.
- Woodcock, B. A., J. Savage, J. M. Bullock, M. Nowakowski, R. Orr, J. R. B. Tallwin, and R. F. Pywell. 2014. "Enhancing Floral Resources for Pollinators in Productive Agricultural Grasslands." *Biological Conservation* 171 (March):44–51.
<https://doi.org/10.1016/j.biocon.2014.01.023>.
- Wratten, Stephen D., Mark Gillespie, Axel Decourtye, Eric Mader, and Nicolas Desneux. 2012. "Pollinator Habitat Enhancement: Benefits to Other Ecosystem Services." *Agriculture, Ecosystems & Environment* 159 (September):112–22.
<https://doi.org/10.1016/j.agee.2012.06.020>.

