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RESEARCH ARTICLE

Forbs included in conservation seed mixes exhibit variable blooming detection rates and cost-effectiveness: implications for pollinator habitat design

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Although forb-rich plantings for pollinator habitat are becoming more common, natural resource managers lack insight on the cost-effectiveness of forbs seeded in private land conservation programs. Additional information on the possible benefits of including more forb species in a mix may help guide the design of future pollinator habitat. We examined the detection of blooming forbs from seed mixes, colonization of non-seeded blooming forbs, and bee utilization of forbs on private lands enrolled in United States Department of Agriculture (USDA) conservation programs. By obtaining the original seed mixes used on conservation program lands and sampling forbs and bees, we provide a first-hand evaluation of the cost-effectiveness of USDA conservation plantings in a field setting. We identified seeded forbs with the highest blooming detection rates and the most common colonizing forbs across 27 sites, the majority of which were considered young conservation plantings. We additionally designated 16 forbs as the most cost-effective due to their higher-than-average blooming detection rate and lower-than-average seed cost. We found a positive association between seed mix richness and number of blooming, seeded forbs detected and found a negative association with blooming, non-native colonizing forbs, which highlights potential benefits of increasing forb richness in seed mixes. However, we did not observe an association between seed mix richness and wild bee or honey bee counts. Examining the cost-effectiveness of seeded forbs on USDA conservation enrollments and subsequent bee utilization can inform land managers in designing seed mixes for pollinator habitat.

Key words: bees, Conservation Reserve Program, private land conservation programs, seed cost

Implications for Practice

- By pairing average blooming detection rates with seed cost, land managers can select the most cost-effective forbs when designing seed mixes for pollinator habitat.
- Including more forb species in a seed mix may result in fewer blooming, non-native colonizing forb species after seeding, although the mechanism for this relationship is undetermined.
- For every additional forb species added to a mix, our model estimated a 6.2% increase in the number of blooming, seeded forb species detected, which provides managers with a baseline expectation of outcomes for high-diversity plantings that are newly established.

Introduction

Global pollinator declines have emphasized the need to develop conservation strategies that address habitat loss and restore pollinator habitat (Potts et al. 2010; Winfree 2010). Much focus has been placed on pollinator habitat on agriculturally dominant lands in the United States and the European Union. In the European Union, agri-environment schemes offer farmers an opportunity to be compensated financially for adopting various conservation measures where goals include restoring biodiversity (Winfree 2010). In the United States, the Pollinator Health Task Force developed three national goals for pollinator recovery, including the creation or enhancement of 7 million acres of pollinator habitat by 2020 (Pollinator Health Task Force 2015). Although the status of this national goal has not been evaluated, it stimulated significant momentum within federal, state, and local governments to create more diverse, native plant communities as well as pollinator friendly plantings that heavily emphasize seeded forbs (USDA-NRCS 2015). Furthermore, legislators have directed the United States Department of Agriculture (USDA) and other government agencies to develop conservation programs and practices that improve pollinator habitat on private lands in agriculturally important areas. Private landowners can enroll in conservation

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programs, such as USDA's Conservation Reserve Program, where marginally productive cropland is taken out of production and put into conservation perennial covers. More specifically, the 2008 Farm Bill directed the development of a new conservation practice called "Pollinator Habitat" within USDA's Conservation Reserve Program. This conservation practice requires a seed mix of at least nine pollinator friendly forbs, legumes, and/or shrubs with variable bloom periods (USDA-NRCS 2020*a*). Subsequent Farm Bills have proposed additional pollinator habitat initiatives to be administered by USDA and other government agencies. Similarly, specific agri-environment schemes in the European Union have options focusing on enhancing pollen and nectar sources for pollinators through hedgerows, field-border plantings, and flower-rich buffer strips (Wratten et al. 2012).

Although forb-rich plantings are becoming more common, natural resource managers lack insight on the success of seeded forbs and the presence of non-seeded colonizers on private lands enrolled in conservation programs. Even prior to forb-heavy mixes being included in private land conservation plantings, it was recognized that research was needed to determine establishment success (Jelinski & Kulakow 1996). Higher seed cost for forb-heavy mixes can make conservation programs more expensive for landowners and for the federal government. Thus, evaluating the cost-effectiveness of forbs used in conservation programs is warranted. Establishment success of a seed based revegetation project depends on landowner goals, but some performance measurements may include maximizing native plant species richness, suppressing invasive plants, and increasing pollinator value. Achieving post-establishment goals for forb plantings is often more challenging than traditional grassland plantings due to low forb establishment, graminoid competition, and limited weed maintenance options (Dickson & Busby 2009; McCain et al. 2010; Kimball et al. 2015). Small-scale, experimental assessments of forb establishment have been done (Dickson & Busby 2009; Drobney et al. 2020), but data on the establishment of forbs on larger plots of land, like USDA conservation enrollments, are limited.

Achieving conservation goals of forb based plantings can be challenging because of the presence of colonizing forb species (i.e. non-seeded species) after planting (Dickson & Busby 2009). While colonizing species can be native or non-native, a subset of these colonizing forbs may become invasive in forb-heavy plantings and may limit the growth of desired seeded forbs. Ways to decrease the competitiveness of colonizing forbs include adequate site preparation prior to planting, altering seed mix design, and post-seeding management (Meissen et al. 2020), but management techniques involving broadleaf herbicides are more difficult to conduct in forb-heavy plantings. A greater understanding of the most common non-native, colonizing forbs on conservation program lands may help inform future management guidelines for forb based plantings. It is also possible for desired forb species to colonize lands after revegetation (i.e. native, non-seeded species) either from natural seedbanks or dispersal from nearby areas (Lukens et al. 2020). For example, previous studies found that certain *Asclepias* species were equally likely to be present at sites in which it was not planted, suggesting that land managers can expect some degree of milkweed colonization (Lukens et al. 2020). Understanding which native forbs are capable of colonizing newly established conservation lands could be useful information for land managers considering which species to include in seed mixes.

Land managers seeking to improve habitat for pollinators and other wildlife often aim for higher native forb diversity, but few studies have examined the effects of altering the number of forb species included in a seed mix on native plant establishment. In tallgrass prairie systems in the United States, Drobney et al. (2020) found 150 m^2 plots seeded with an extra-high richness mix had increased planted forb richness and cover as well as decreased cover of exotic forbs. Likewise, high richness and high density seeding of a grass-forb mixture resulted in higher seeded, native species richness, and cover (Carter & Blair 2012). Although including more forb species in a mix may increase the cost of the mix, the potential benefits of increased forb richness and increased floral resources for bees merit further investigation. If seeding more forbs results in increased floral resources for bees, it could be assumed that such sites would provide valuable pollinator habitat and increased bee abundance or richness. Data from grasslands plots in the upper Midwest revealed that native bee abundance increased as total floral richness increased, whereas honey bee abundance was positively associated with exotic floral abundance (Bendel et al. 2019).

We examined the detection and colonization rates of blooming seeded and non-seeded forbs and bee utilization of forbs on private lands enrolled in USDA conservation programs. After sampling blooming forbs and bees, we obtained the original seed mixes of each USDA enrollment and used an observational approach to answer the following questions about primarily newly established conservation plantings: (1) Which seeded forb species do we most often observe blooming and which non-seeded, blooming forb species most often colonize on USDA conservation enrollments? (2) Which forb species are most cost-effective (i.e. low seed cost and high blooming detection rate) and which are least cost-effective (i.e. high seed cost and low blooming detection rate)? (3) Is seed mix richness (i.e. the number of forb species in a mix) associated with blooming seeded forbs detected or colonizing forbs detected in subsequent years?; Does this relationship change for native versus non-native colonizing forbs? and (4) Is seed mix richness associated with wild bee or honey bee counts? We hypothesized that seed mix richness would be positively associated with the number of blooming seeded forb species we detected but negatively associated with blooming colonizing forb species detected. For plant-bee interactions, we hypothesized that seed mix richness would be positively associated with wild bee counts at each site. However, honey bee counts would not be as strongly associated with seed mix richness. Detailed information on forb species being seeded on lands enrolled in USDA conservation programs and their ensuing growth and use by bees will enable land managers to make more informed decisions involving forbs in seed mixes.

Methods

Site Selection and Sampling of Blooming Forbs and Bees

Our sites used for the seed mix evaluation were part of a larger research effort to assess honey bee colony response to land use change in the Northern Great Plains, United States (Smart et al. 2018). For the original study on honey bees and land use change, honey bee apiary locations were randomly selected from a registration list in 2014 across a land use gradient in Minnesota, North Dakota, and South Dakota (as described in Smart et al. 2018). Next, randomly selected grassland sites were located that were within a 4.8-km radius of the 38 study apiaries in which plants and bees would be surveyed across transects. The number of transects completed at each site depended on the overall field size. Upon arriving to the site, technicians would visually estimate the total area of the field. Each site received a minimum of two transects regardless of field size. Sites >5 ha received two additional transects for every additional 5 ha grassland available up to a maximum of 16 transects per site. Transects were 20 $\times$ 2–m and were at least 10 m apart from one another within a site. At each transect, technicians counted the number of flowering stems of forbs (i.e. a stem supporting one or more inflorescences) as well as any bee-flower interaction observed (honey bees or wild bees). Bees observed on transects were identified as either honey bees or native, non-*Apis* bees. Forb species nomenclature followed the USDA PLANTS Database (USDA-NRCS 2020*b*). Plant-bee surveys were conducted between 06:45 and 19:40 hours, with 97% of surveys between 09:00 and 18:00 hours. Surveys were not conducted during rain events, wind speeds >40 kph, or temperatures below 15°C. We aimed to sample each site three times per year to capture the variation in blooming forb and bee phenology. Early, mid, and late sampling events were approximately 3–4 weeks apart and ranged from June 8 to September 28.

Conservation Seed Mixes

The overall objective of this study was to assess blooming forb presence from species seeded on conservation program lands. Therefore, we used a subset of sites that fit the following criteria: (1) Private lands that were enrolled in USDA's Conservation Reserve Program (CRP), Environmental Quality Incentives Program (EQIP), or Wetlands Reserve Program (WRP); (2) Seed mixes that included forbs in the mix could be obtained; (3) Sites had at least four transects per site; and (4) Two consistent years of observations (2016 and 2017) with two or three observations per year (multiple bloom periods). This yielded 27 sites for analysis in North Dakota and Minnesota. While the majority of sites were enrolled in CP-42 Pollinator Habitat, other Conservation Practices included CP-327 Conservation Cover, CP-512 Forage and Biomass Planting, CP-23 Wetland Restoration, and others (Table S1). We obtained seed mixes from USDA-Farm Service Agency and USDA-Natural Resources Conservation Service (NRCS) offices. If multiple seed mixes were used within a landowner's property, we identified each area as a separate site based on the distinct Conservation Practices and seed mixes. Each site had a different mix of species with varying amounts of grass and forbs seeded because seed mixes depended on individual landowner goals (Table S1). For example, seed mixes from the late 1990s and early 2000s primarily included non-native pasture grasses and legumes because the focus was historically on providing soil erosion protection. Recently, conservation-focused, high-diversity seed mixes that include many native forb species thought to benefit wildlife are more widely available to landowners than in earlier years of USDA Farm Bill conservation programs. All seed mix information came from original seed mix labels, cost-share documents, or NRCS planning datasheets that included actual species seeded with actual pure live seed (PLS) seeding rates except for one site in which we utilized the planned species seeded and seeding rates. For this particular site, the seed mix was quite simple and only included two commonly seeded legume forb species; therefore, we were confident what was planned for seeding is what the land manager seeded. From each seed mix, we recorded year of seeding, size of site seeded, species seeded, and species-specific seeding rates.

For our research objectives concerning seed mix richness versus blooming forb species detected and floral visitations by bees (questions 3 and 4), we filtered our sites by limiting observations to sites that were recently seeded (i.e. 2011 onwards). Prior to 2011, all seed mixes in our study only included two non-native forb species; therefore, we excluded these older mixes from our analysis to focus on more high-diversity conservation plantings. Focusing on sites that were recently seeded resulted in 22 sites with site age ranging from 1 to 5 years. We defined site age as the number of years from the year of seeding to 2016, our first year of sampling. More than half of the sites were 1 to 2 years old.

Statistical Analyses

Since the number of sampled transects varied based on site size, we standardized our analyses by randomly selecting four transects per site to be used in all the following analyses. To assess our first objective on which seeded forb species were most often observed blooming after planting, we defined blooming detection rate as the proportion of sites in which a seeded forb species was observed flowering during at least one bloom period in either of the 2 years (as in Lukens et al. 2020). We evaluated the colonization of non-seeded blooming forb species by calculating a colonization rate, defined as the proportion of sites in which a non-seeded forb species was observed flowering during at least one bloom period in either of the 2 years. We also calculated the average number of flowering stems per transect for each seeded forb species and each colonizing forb species.

For our second objective on blooming forb detection and cost-effectiveness, we determined the seed cost of each forb species by contacting USDA-NRCS offices to obtain their cost spreadsheet used by regional planners, which included number of seeds per pound of a forb and its average cost per pound. Seed costs were based on multiple vendors, ranging from 2 to 12, and were updated in 2020. If the NRCS cost spreadsheet was missing certain forb species information, we checked seed costs from five regional seed vendors and used the average of those where available (Great Basin Seeds, Hamilton Native Outpost, Albert Lea, Prairie Moon, and Applewood Seed). Additionally, we utilized the PLANTS Database (USDA-NRCS 2020*b*) to obtain missing values for number of seeds per pound. We calculated the cost per 100,000 seeds to standardize cost based on seed size (Otto et al. 2017) and used this for analyses. We restricted our cost-effectiveness evaluation to forb species that were seeded in at least five sites in order to more accurately estimate the blooming detection rate.

Since seeding rate may influence what species establish at a site (Grman et al. 2015), we tested for a correlation between average blooming detection rate and average seeding rate for forb species that were seeded in at least five sites. Because there was a significant positive correlation between average blooming detection rate and average seeding rate (Pearson $r = 0.46$, $p = 0.01$), we analyzed cost-effectiveness within three groupings of seeding rates. Out of the 30 forb species seeded in at least five sites, we designated 10 as the low seeding rate group, 10 as the medium seeding rate group, and 10 as the high seeding rate group. Within each group, we calculated an average blooming detection rate. There was no correlation between average blooming detection rate and seed cost; therefore, we used an overall average seed cost across all three seeding rate groups. We defined the most cost-effective forbs as those with lower-than-average seed costs across all seeding rate groups and higher-than-average blooming detection rates within each seeding rate group, while the least cost-effective had higher-than-average seed costs overall and lower-than-average blooming detection rates.

To address our third objective on seed mix richness and subsequent detected forbs, we calculated the number of blooming seeded and colonizing forb species detected for each site across bloom periods and years. The number of blooming seeded forbs detected represented species that were seeded and observed blooming at each site. The number of blooming colonizing forbs detected represented species that were not seeded at a site but were observed blooming there (separated into native or non-native species). Both estimates for seeded and colonizing forbs were summed across bloom periods and years for each site. For our final objective on seed mix richness and subsequent bee abundance, we calculated the total number of honey bee or wild bee counts for each site summed across bloom periods and years.

We used generalized linear models to examine the relationships between the response variables blooming seeded forb species detected, blooming colonizing forb species detected (split into native or non-native), and bee counts with the predictor variable seed mix richness. We were interested in the relationship between percent forbs in a seed mix and number of blooming seeded forbs detected, but we only retained seed mix richness in our models because this was positively correlated with percent forbs in a seed mix (Pearson $r = 0.7$, $p < 0.001$). We ran separate models for each response variable and we visually checked residual plots for deviations from homoscedasticity or normality. Models for blooming seeded forbs detected and blooming colonizing forbs (both native and non-native) detected were specified with a Poisson distribution. Since distance to an apiary may influence the number of honey bees observed at a site, we included distance to nearest apiary as a predictor variable in our honey bee count model. The distance to nearest apiary was recorded using a North Dakota State University apiary database for apiaries in North Dakota. For Minnesota, we scanned Google Earth imagery and obtained apiary locations from the commercial beekeeper who operated in our area, since an apiary database does not exist for southwestern Minnesota. For honey bee and wild bee count models, we conducted generalized linear models with a quasi-Poisson distribution to account for overdispersion (honey bee dispersion parameter = 57.2; wild bee dispersion parameter = 14.3). All analyses were performed in R 3.6.1 (R Core Team 2021).

Results

USDA Conservation Sites and Seed Mixes

USDA conservation program sites in North Dakota and Minnesota ranged in size from 1 to 218 acres, with an average size of 32 acres (Table S1). The minimum distance between sites ranged from 0.03 to 67.4 km and averaged 10.5 km apart. Some sites were close together in which an individual landowner used two different seed mixes in immediately adjacent fields. Sites were seeded from 1998 to 2015, resulting in site ages of 1–18 years old (seeding to first year of sampling in 2016; Table S1). At each site, the number of seeded species ranged from 4 to 38, with a varying mix of grass and forb species, and an average of 12 forbs seeded per site (range 2–30). A total of 57 forbs were seeded across the 27 sites enrolled in USDA conservation programs (Table S2). The number of sites each forb was seeded in varied from 1 to 17 with the top three most common seeded forbs being *Helianthus maximiliani* (Maximilian sunflower), *Dalea purpurea* (purple prairie clover), and *Rudbeckia hirta* (blackeyed Susan; Table S2).

Blooming Detection and Colonization Rates of Forbs

We detected 58% (33/57) of seeded forbs blooming at sites during sampling (Table S2). Forb species seeded in at least five sites with the highest blooming detection rates were *Astragalus canadensis* (Canadian milkvetch), *Gaillardia aristata* (blanketflower), *Heliopsis helianthoides* (smooth oxeye), *Medicago sativa* (alfalfa), *Melilotus officinalis* (sweetclover), *Ratibida columnifera* (upright prairie coneflower), and *Rudbeckia hirta*; these species were detected at 90% or more of the sites where they were seeded (Table 1). Seeded species with the highest average number of flowering stems per transect included *Medicago sativa*, *Melilotus officinalis*, *Ratibida pinnata* (pinnate prairie coneflower), and *Rudbeckia hirta* (Table 1).

We observed a total of 91 forb species that were considered colonizers, defined as native or non-native blooming species that were not seeded at that site. Forb species with the highest colonization rates were *Cirsium arvense* (Canada thistle), *Melilotus officinalis*, *Sonchus arvensis* (field sowthistle), *Symphyotrichum ericoides* (white heath aster), and *Medicago sativa* (Table 2). Out of the 15 most common colonizers, *Medicago sativa*, *Melilotus officinalis*, *Erigeron strigosus* (prairie fleabane), and *Symphyotrichum lanceolatum* (white panicle aster) had the highest average number of flowering stems per transect (Table 2). *Medicago sativa* and *Melilotus officinalis* were examples of forb species that had high blooming detection rates when seeded (0.91 and 1.00, respectively) yet also had high

Table 1. Blooming detection and seed cost information for forb species seeded in at least five USDA study sites arranged into average seeding rate groups (for all forb species, see Table S2). Blooming detection rate was defined as the proportion of sites in which a seeded forb species was observed blooming during at least one bloom period in either of the 2 years. The average number of flowering stems per transect was calculated across all sites at which the species was seeded. Cost of forb seed was determined from USDA-Natural Resources Conservation Service spreadsheets and local seed vendors. A forb species was considered most cost-effective if it had a higher-than-average blooming detection rate (specific to each seeding rate group: Low = 0.37, medium = 0.60, high = 0.82) and lower-than-average seed cost (overall average: $61.20/100,000 seeds). A forb species was considered least cost-effective if it had a lower-than-average blooming detection rate and higher-than-average seed cost.

Average Seeding Rate Group	*Scientific Name*	*No. of Sites Seeded*	*No. of Sites Observed (Where Seeded)*	*Blooming Detection Rate*	*Flowering Stems per Transect (Average ± 1 SE)*	*Seed Cost ($/100,000 Seeds)*	*Average Seeding Rate (lbs/ac)*	*Cost-Effectiveness*
Low (0.02—0.097 lbs/ac)	*Ratibida columnifera*	5	5	1.00	28.5 ± 7.4	4.5	0.08	Most
	Desmodium canadense	6	4	0.67	5.6 ± 1.6	126.6	0.06	—
	Symphyotrichum novae-angliae	5	3	0.60	2.8 ± 0.6	52.0	0.02	Most
	Achillea millefolium	10	6	0.60	26.8 ± 11.0	2.3	0.05	Most
	Symphyotrichum laeve	10	4	0.40	5.9 ± 1.4	34.5	0.04	Most
	Coreopsis tinctoria	6	2	0.33	3.9 ± 2.9	1.3	0.08	—
	Oligoneuron rigidum	10	1	0.10	4.00	186.9	0.10	Least
	Penstemon grandiflorus	5	0	0.00	NA	98.0	0.05	Least
	Solidago speciosa	5	0	0.00	NA	37.5	0.06	—
	Gentiana flavida	5	0	0.00	NA	17.9	0.07	—
Medium (0.099—0.19 lbs/ac)	*Rudbeckia hirta*	15	14	0.93	47.3 ± 14.2	1.8	0.18	Most
	Oenothera biennis	8	7	0.88	11.6 ± 4.2	4.1	0.11	Most
	Agastache foeniculum	7	6	0.86	7.4 ± 2.2	14.4	0.10	Most
	Helianthus maximiliani	17	14	0.82	20.0 ± 6.2	21.8	0.12	Most
	Monarda fistulosa	12	9	0.75	10.6 ± 2.0	12.8	0.17	Most
	Asclepias syriaca	7	5	0.71	2.6 ± 0.8	269.5	0.16	—
	Ratibida pinnata	7	5	0.71	45.3 ± 13.7	12.9	0.19	Most
	Astragalus canadensis	12	12	1.00	27.5 ± 12.0	42.1	0.28	Most
	Helianthus pauciflorus	6	2	0.33	1.9 ± 0.4	600.0	0.15	Least
	Amorpha canescens	9	0	0.00	NA	67.2	0.12	Least
	Zizia aurea	6	0	0.00	NA	59.9	0.15	—
High (0.28—0.86 lbs/ac)	*Gaillardia aristata*	10	10	1.00	7.2 ± 2.2	8.0	0.42	Most
	Melilotus officinalis	8	8	1.00	160.8 ± 58.0	0.9	0.43	Most
	Medicago sativa	11	10	0.91	244.0 ± 57.7	2.2	0.73	Most
	Heliopsis helianthoides	10	9	0.90	33.6 ± 10.7	39.6	0.39	Most
	Echinacea purpurea	7	6	0.86	7.5 ± 3.7	29.0	0.86	Most
	Linum lewisii	10	8	0.80	11.4 ± 4.1	16.9	0.31	—
	Dalea candida	12	8	0.67	18.6 ± 6.8	26.9	0.28	—
	Dalea purpurea	16	10	0.63	24.5 ± 8.8	14.5	0.40	—
	Chamaecrista fasciculata	7	3	0.43	6.4 ± 4.2	31.0	0.35	—

colonization rates when not included in a seed mix (0.56 and 0.84, respectively).

Cost-Effectiveness of Forbs

There was a wide range in blooming detection rates (0–1.00) and seed cost ($0.85–600 per 100,000 seeds) of forb species that were seeded in at least five sites ($n = 30$; Fig. 1). Forb species seeded at a low rate (0.02–0.097 lbs/ac) had an average blooming detection rate of 0.37, medium seeding rate (0.099–0.19 lbs/ac) species had an average blooming detection rate of 0.60, and high seeding rate (0.28–0.86 lbs/ac) species had an average blooming detection rate of 0.82 (Fig. 1A–C). We designated 16 forb species as the most cost-effective in primarily young conservation plantings due to their higher-than-average blooming detection rate (specific to each seeding rate group) and lower-than-average seed cost overall ($61.20; Fig. 1A–C). There were four forb species that were considered least cost-effective due to their lower-than-average blooming detection rate (specific to each seeding rate group) and higher-than-average seed cost (Table 1).

Seed Mix Richness

The number of blooming seeded forbs detected at a site varied from 2 to 16 (average: 7.7 ± 1.0 SE). Seed mix richness was positively related to blooming seeded forb species detected during surveys (est. = 0.06, SE = 0.01, $z = 6.17$, $p = <0.001$; Table S3; Fig. 2A). For every additional forb species included in a mix, the estimated count of blooming seeded forbs detected

Table 2. Colonization information for the 15 most common colonizing forb species across sampled USDA conservation program sites. Indigenous status for each forb is based on the USDA PLANTS Database (USDA-NRCS 2020*b*). Colonization rate was calculated as the proportion of sites in which a non-seeded forb species was observed blooming during at least one bloom period in either of the 2 years. The number of possible colonization sites was 27 unless the species was seeded at some sites. The average number of flowering stems per transect was calculated across all sites at which the species was not seeded.

Scientific Name	*Indigenous Status*	*No. of Sites Observed (Where Not Seeded)*	*Colonization Rate*	*Flowering Stems per Transect (Average ± 1 SE)*
Cirsium arvense	Non-native	25/27	0.93	12.4 ± 3.7
Melilotus officinalis	Non-native	16/19	0.84	68.0 ± 20.8
Sonchus arvensis	Non-native	19/27	0.70	18.7 ± 4.2
Symphyotrichum ericoides	Native	16/25	0.64	13.6 ± 3.3
Medicago sativa	Non-native	9/16	0.56	148.8 ± 72.3
Cirsium vulgare	Non-native	13/27	0.48	3.1 ± 0.8
Symphyotrichum lanceolatum	Native	12/27	0.44	24.7 ± 9.6
Erigeron strigosus	Native	10/27	0.37	34.1 ± 15.0
Glycyrrhiza lepidota	Native	10/27	0.37	8.2 ± 3.8
Lactuca serriola	Non-native	10/27	0.37	9.3 ± 2.9
Asclepias syriaca	Native	7/20	0.35	1.9 ± 0.4
Oligoneuron rigidum	Native	5/17	0.29	7.7 ± 5.2
Solidago missouriensis	Native	7/26	0.27	12.7 ± 6.0
Ratibida columnifera	Native	5/22	0.23	6.4 ± 1.5
Trifolium pratense	Non-native	6/26	0.23	4.9 ± 2.4

increased by a factor of 1.1, or a 6.2% increase (Table S3; Fig. 2A). The number of blooming native colonizing forb species at each site ranged from 0 to 14 (average: 6.5 ± 0.8 SE). We did not detect an association between seed mix richness and blooming native colonizing forb species detected (est. = 0, SE = 0.01, $z = -0.34$, $p = 0.73$; Table S3; Fig. 2B). The number of blooming non-native colonizing forbs at each site ranged from 2 to 12 (average: 6.1 ± 0.5 SE). There was a

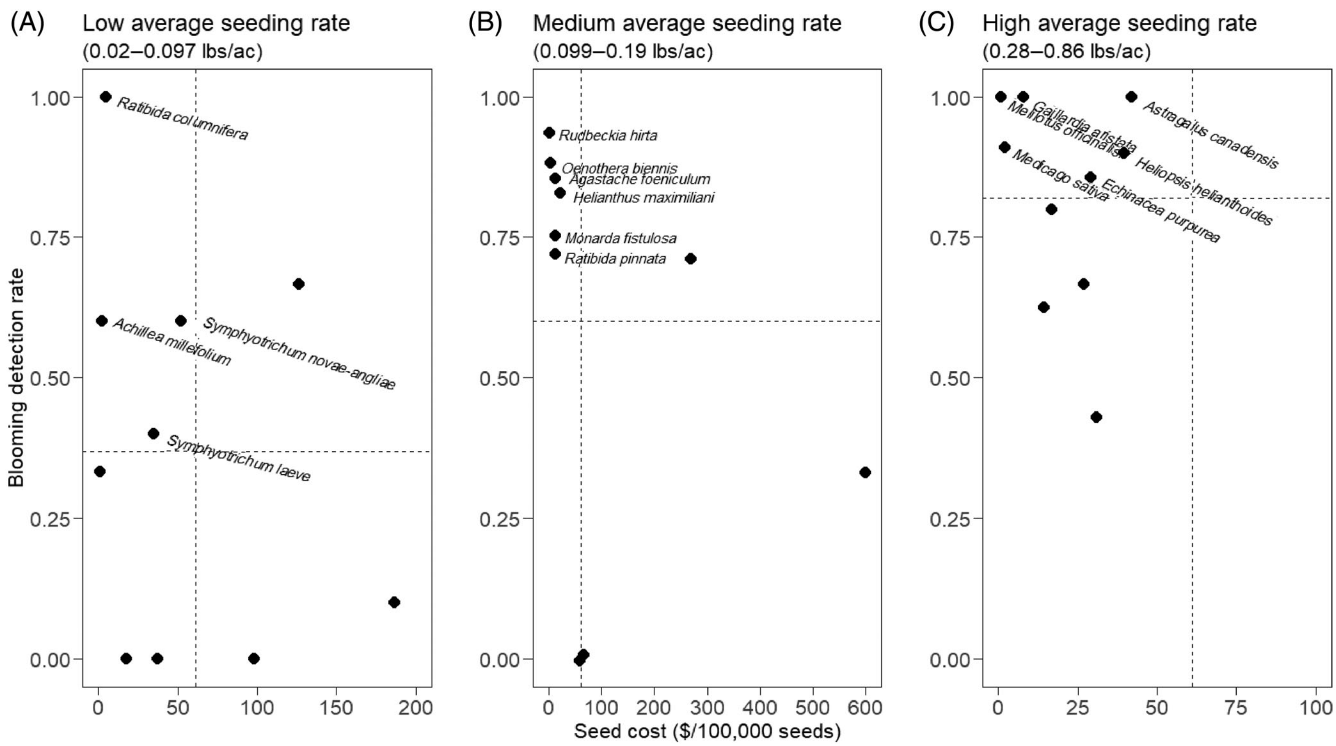

Figure 1. Average seed cost plotted against blooming detection rate for forb species seeded at (A) low, (B) medium, and (C) high average seeding rates. Forb species are shown that were seeded in at least five sites ($n = 30$). Average blooming detection rate varied among seeding rate groups and is represented by the horizontal dashed line: Low seeding rate species averaged 0.37 blooming detection rate, medium seeding rate species averaged 0.60 blooming detection rate, and high seeding rate species averaged 0.82 blooming detection rate. The average seed cost ($61.20/100,000 seeds) across all forb species is represented by vertical dashed lines. The most cost-effective forbs are in the upper left-hand portion of each panel graph (labeled) and the least cost-effective forbs are in the lower right-hand portion (specifics for all species found in Table 1).

significant negative association between seed mix richness and blooming non-native colonizing forbs detected (est. $= -0.03$, SE $= 0.01$, $z = -2.49$, $p = 0.01$; Table S3; Fig. 2C). For every additional forb species seeded, the estimated count of blooming non-native colonizing forbs decreased by a factor of 0.97, or 3% (Table S3; Fig. 2C).

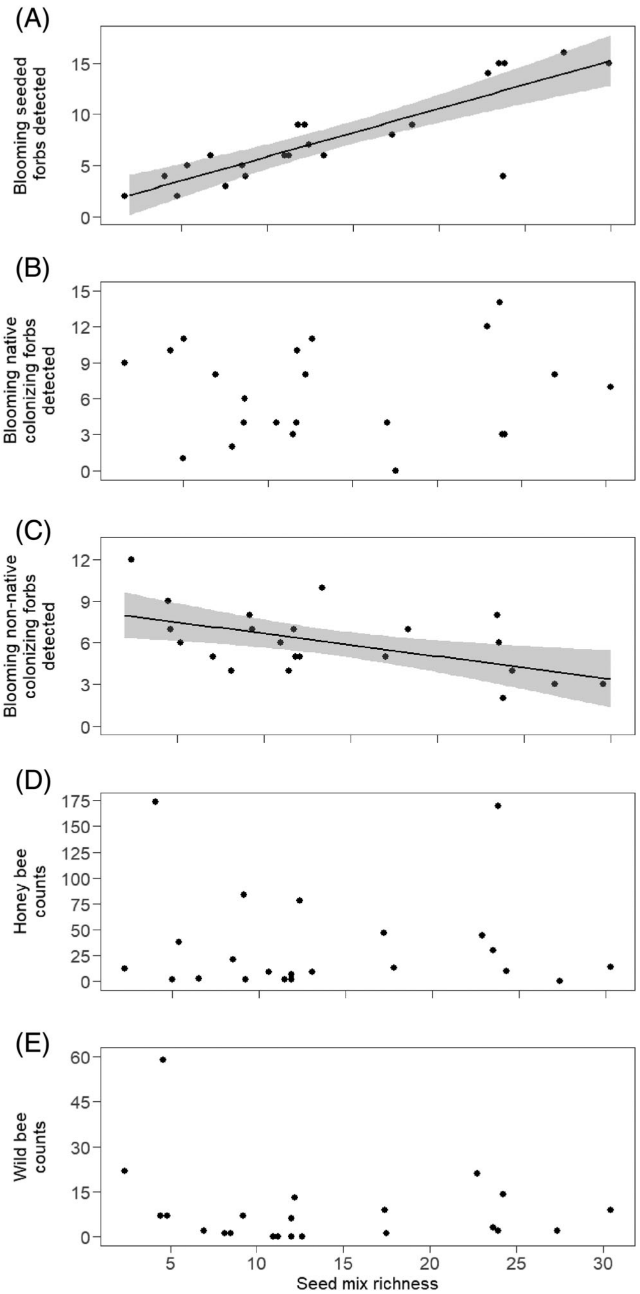

Figure 2. (A) Number of blooming seeded forbs detected, (B) blooming native colonizing forbs detected, (C) blooming non-native colonizing forbs detected, (D) honey bee counts, and (E) wild bee counts as a function of seed mix richness. Each response variable is totaled across 2 years of data collection. Each point represents a site with a distinct seed mix. Linear regressions with shaded 95% CI are plotted only for response variables with statistically significant relationships.

The total number of honey bees observed per site ranged from 0 to 174 (average: 35.0 ± 10.7 SE) while wild bee counts varied from 0 to 59 (average: 8.5 ± 2.8 SE). Sites were an average of 2.0 km away from the nearest apiary. We did not observe any honey bees at one site and four sites had no wild bees observed over the 2 years. After accounting for distance to nearest apiary, we did not detect an association between seed mix richness and honey bee counts (est. $= 0$, SE $= 0.04$, $z = -0.17$, $p = 0.87$; Table S3; Fig. 2D). Likewise, we did not detect an association between seed mix richness and wild bee counts (est. $= -0.04$, SE $= 0.04$, $z = -0.97$, $p = 0.35$; Table S3; Fig. 2E).

Discussion

Enhancing the cost-effectiveness and biological impact of habitat plantings for pollinators is one of the top pollinator research priorities identified by the USDA (USDA 2021). Our research highlights the cost-effectiveness of forbs used in USDA conservation plantings by quantifying blooming forb detection rates and seed cost. Our study builds upon past research that investigated forb establishment (Dickson & Busby 2009; Meissen et al. 2020) by conducting research on private lands enrolled in USDA conservation programs across a three-state area. Dickson and Busby (2009) found that seeded forbs on 2 × 2–m experimental plots established best in treatments without any grass seeded. By examining three different seed mixes seeded into experimental research plots, Meissen et al. (2020) showed that mixes impacted ecological outcomes such as native plant abundance, inflorescence production, and floral richness. Our study builds upon this work by quantifying blooming forb establishment across multiple, private land enrollments with different soil characteristics, pre-establishment site preparation, and post-establishment weed management. Thus, our research provides a first-hand evaluation of the cost-effectiveness of USDA conservation plantings in actual field settings.

USDA conservation programs can address issues associated with crop production on marginal land, such as soil erosion and water quality, by establishing a perennial vegetative cover (Gilley et al. 1997; Reeder et al. 1998). The degree to which USDA conservation enrollments constitute pollinator habitat depends on the abundance and diversity of forbs that successfully establish on an enrollment. Unfortunately, diverse and forb-heavy seed mixes tend to be relatively expensive when compared with a traditional grass planting. A CRP Conservation Practice-42 "Pollinator Habitat" mix, for example, can cost two to six times more than a simpler mix that consists of a few grass species. A high-diversity pollinator mix can also cost more than twice the annual rental payment the landowner receives from USDA. Even though a portion of the seed cost is covered by the program via cost share—recently 50%—some landowners may have difficulty justifying the increased cost needed to create pollinator habitat unless it provides additional ecosystem services or intrinsic value beyond a more general grassland planting. Pollinator plantings are hypothesized to provide additional pollination services to adjacent agricultural fields (Walston et al. 2018; Lonsdorf et al. 2020); however, we are unaware of any research that demonstrates the direct linkage between high-diversity USDA plantings and pollination services on nearby farmland. Addressing this information gap would make high-diversity plantings more enticing to landowners who grow pollinator-dependent crops. In addition to the associated costs and unquantified benefits, examples of failed plantings may have knock-on effects, reducing participant satisfaction and dissuading neighbors from participating themselves. Collectively, this suggests the need for seed mixes to consist of species with the best ratio of forage value to full cost of successful establishment.

Our study identified several forb species from primarily young conservation plantings that had higher-than-average blooming detection rates and lower-than average cost, thereby providing land managers options for designing cost-effective seed mixes in our region. However, seed cost is dynamic and cost-effectiveness can depend on the seed costs of a given year. Our estimates are based on seed costs from 2020; it is possible that different forb species would be considered most cost-effective considering fluctuating seed costs in future years. Further, the cost of more expensive forbs may be brought down if sustained demand through Farm Bill programs for specific species leads to increased propagation and seed harvest. It is worth noting that the forb species seeded at a higher rate had the highest average blooming detection rate. This result is similar to Grman et al. 2015, who found that a sown species was more likely to be detected at prairie restoration sites in Michigan if it was sown at a higher density, suggesting strong evidence for dispersal limitation. In our study, some forb species had fairly high blooming detection rates yet were not considered most cost-effective in our analysis. For example, *Dalea candida*, *Dalea purpurea*, and *Linum lewisii* were detected blooming at 60% or more of sites in which they were seeded, but still had lower-than-average blooming detection rates for the high average seeding group (0.82), meaning these three species were not among the most cost-effective forbs within their group. Although seed cost is an important criterion for land managers and landowners to consider when designing seed mixes, cost-effectiveness may not be the only goal for conservation program lands. There are other conservation objectives to consider, such as increasing biodiversity where land managers may consider establishing a high-diversity planting that includes rare plants. Other considerations for designing conservation seed mixes include soil type, invasiveness of seeded species, phenology, and pollinator preference.

Pollinator forb preference has been identified as one of USDA's research priorities (USDA 2021). Combining results from which seeded forbs are most often observed blooming and pollinator preference research would identify forb species that (1) readily bloom under realized conditions on private lands, (2) provide high pollinator value, and (3) cost less for private landowners and taxpayers. Our previous work on wild bee and honey bee flower preferences (Simanonok et al. 2021) can be combined with our current study to identify forbs that fit these conditions. Out of all non-noxious weed forbs selected by honey bees, all were considered cost-effective in our present study (i.e. forbs with a higher-than-average blooming detection rate and lower-than-average cost). Specifically, *Agastache foeniculum* (blue giant hyssop), *Gaillardia aristata*, and *Melilotus officinalis* were preferentially selected by honey bees, had above average blooming detection rates, and below average cost. Ultimately, landowners and land managers will need to weigh the tradeoffs of including introduced and potentially invasive species (e.g. *Melilotus officinalis*) in their seed mixes even if it may benefit local honey bees and beekeepers. *Echinacea purpurea* (eastern purple coneflower), *Gaillardia aristata*, *Helianthus maximiliani*, *Heliopsis helianthoides*, *Monarda fistulosa* (wild bergamot), *Ratibida columnifera*, and *Ratibida pinnata* were preferentially selected by wild bees (Simanonok et al. 2021) and were considered most cost-effective in our current study. One species was selected by wild bees but was not considered the most cost effective (*Oligoneuron rigidum* [stiff goldenrod]). By pairing information on which forbs are most cost-effective and which forbs are selected by bees, natural resource managers can maximize the biological impact and cost-effectiveness of seed mixes for pollinator habitat.

Some potential caveats of our study are that our blooming detection rates and colonization rates were dependent on the four random transects per site we surveyed, and we did not census all forbs at each site. Furthermore, we only recorded blooming forbs since the intent of the original study was to focus on floral resources available to pollinators. Therefore, it is possible some non-blooming species went undetected. If non-blooming species were included, this may have increased our estimates of detection rates of seeded forbs and subsequent seeded richness at each site. For example, Drobney et al. (2020) included non-blooming species in their plant surveys of experimental research plots and had higher establishment rates of certain forb species, such as *Oligoneuron rigidum* and *Zizia aurea* (golden zizia), compared to our recorded blooming detection rates. Post-planting management, such as mowing, burning, or spot-spraying, may have effects on flowering of desired species in the early establishment years of a conservation planting. For example, Williams et al. 2007 broadcast native forbs into recently burned grassland plots and showed that subsequent frequent mowing increased light availability and the total number of flowering forbs in experimental plots compared to control plots. We did not have access to what, if any, post-planting management was conducted at each site in our study, but this is an important variable that can affect the number of flowering forbs at a seeded site.

Another potential caveat is that we primarily sampled young plantings that were 1–5 years post-establishment with most fields being surveyed at 1–2 years old. Since establishment of planted species can fluctuate (Wilkerson et al. 2014) and plantings can become grass-dominated through time (Larson et al. 2017), it remains unclear whether more mature plantings would exhibit higher blooming detection rates and reduced weed presence. There are forb species that will not mature to flowering status within 1–2 years; therefore, we may be underestimating seeded richness at younger sites, and thus may have underestimated the cost-effectiveness ratings of certain species. Some forbs we rated as least cost-effective may simply be slower to establish and may receive a higher cost-effectiveness rating if more mature conservation plantings were sampled. Sampling conservation plantings across the range of USDA contract lengths (10–15 years) may reveal changes in blooming forb detection rates, cost-effectiveness ratings of seeded species, and colonization rates of non-seeded species. Despite these caveats, we still detected over half of seeded forb species in our surveys. Future studies could assess establishment rates of seeded forbs on USDA conservation enrollments by surveying for all forb species, regardless of bloom status, and sampling older sites.

We found a positive association between seed mix richness and number of blooming seeded forbs detected as well as a negative association with blooming non-native colonizing forbs, highlighting potential benefits of increasing the number of forbs in seed mixes. Likewise, Drobney et al. (2020) found that observed forb richness increased with seed mix richness. Other studies have examined ways in which forb diversity can be increased, such as by decreasing grass seeding density or increasing forb seeding density (Dickson & Busby 2009). In our study, the number of seeded forb species was positively correlated with percent forb in the mix, meaning that mixes with more seeded forb species had fewer seeded grass species. Dickson and Busby (2009) detailed that forb species established best in treatments without any grass seeded and recommended a spatial separation of forb seeds from dominant grass seeds or seeding a low density of dominant grasses. Our results also showed that increased seed mix richness was negatively correlated with blooming non-native colonizing forbs. One potential mechanism for the pattern we observed is that seeding a mix with higher diversity could provide a competitive advantage against invasive exotics that have similar phenology (Larson et al. 2013). Contrary to our findings on colonizing forbs, Meissen et al. (2020) showed higher cover of annual and perennial weeds in a pollinator mix containing a higher percentage of forbs than an economy mix with a lower percentage of forbs. The economy mix, which was grass-dominated, produced high overall native cover and had less bare ground (Meissen et al. 2020). It is possible the contrary relationship we observed may be an artifact of landowners who chose more expensive, higher diversity seed mixes and hence put more effort into pre- and post-planting management. Although we lack data on private landowner management efforts from this study, it is widely known that management plays a significant role in invasive species abundance post-seeding (Norland et al. 2015). Ultimately, the negative correlation we observed between seed mix richness and blooming non-native colonizing forbs is a finding that requires further study.

Even though several studies have described positive effects of habitat restoration on wild bee abundance (see review by Tonietto & Larkin 2018), we did not observe a positive association between seed mix richness and wild bee counts in our study. A recent study has shown that wild bee abundance is not determined by local floral resources and is instead related to landscape composition (Griffin et al. 2021). Likewise, we observed no association between seed mix richness and honey bee counts. For honey bees, there is growing consensus that flower diversity does not stimulate honey bee colony foraging. Rather, honey bees are attracted to abundant flowers on the landscape, regardless of the flower's indigenous status (Carr-Markell et al. 2020). Other studies have examined the relationship between floral abundance and bee richness, with mixed results (Williams et al. 2015; Smith DiCarlo et al. 2020). Although we did handnet wild bees at a subset of transects and used a microscope to identify them, including these data in our paper was impossible due to sampling inconsistencies. This prevented us from estimating wild bee richness for each field. It is possible that wild bee richness may more closely align with seeded forb richness than wild bee abundance, and future research might consider using wild bee richness if the goal is to link forb richness with pollinator metrics.

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Disclaimer statement

The views and conclusions in this article represent the views solely of the author from the U.S. Department of Agriculture but do represent the views of the U.S. Geological Survey.

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Supporting Information

The following information may be found in the online version of this article:

Table S1. List of 27 sites enrolled in the U.S. Department of Agriculture (USDA) conservation programs included in our analyses with associated conservation practices and seed mix information.

Table S2. Blooming detection rate and seed cost information for 57 forb species seeded across 27 USDA conservation program sites.

Table S3. Poisson* and quasi-Poisson# generalized linear model results with the explanatory variable seed mix richness for each of the five response variables.

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