

RESEARCH ARTICLE

Establishing forbs for pollinators in agricultural landscapes of the Great Plains, U.S.A.

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Pollinator insects are declining, partly because grasslands containing forbs they feed on have been converted to cropland. This conversion is prevalent in the Great Plains, home to several imperiled pollinators and 40% of U.S. honeybees. Over 1.0 million hectares of former cropland have been seeded with forbs that could benefit Great Plains pollinators, but success of these seeding efforts is unclear. We quantified forb abundances and factors regulating these abundances in 120 crop fields seeded to forbs and grasses by managers in the Great Plains (Colorado and Montana). Our data indicated a need to improve forb establishment. Two to five growing seasons after seeding, seeded forb cover was <10% in most fields, and no seeded forbs were observed in 23% of fields. Our data also indicated ways to benefit forbs. High grass seed rates and high weed densities shortly after seeding reduced forb cover at the end of the study. Past studies indicate certain post-emergence herbicides sometimes benefit seeded forbs, and we recommend further research in this domain. Instead of beneficial herbicides applied after seeding, managers sometimes applied risky herbicides before seeding that appeared to persist in soil and reduce forb establishment. Seed rates were too low to maximize forb abundances, and much money was wasted buying seeds of species that did not establish. We identified several species with relatively high establishment probabilities that will support most pollinators. For now, these species should be seeded at high rates. Lower rates could become sufficient if effective weed control is implemented.

Key words: bees, butterflies, Conservation Reserve Program, herbicides, weeds, wildflowers

Implications for Practice

- Forbs often fail to adequately establish when sown into agricultural landscapes to benefit pollinators.
- Seeding forbs with high establishment probabilities at rates greater than those often used will increase forb abundances in the Great Plains and likely other systems.
- Controlling weeds will also increase seeded forbs. Past research suggests certain herbicides could be used to control weeds without greatly damaging forbs, but these herbicides are rarely if ever used in forb plantings.

Introduction

Domesticated honeybees (*Apis mellifera* L.), wild bees, and other insects are essential for pollination (Ollerton et al. 2011; Calderone 2012). The pollination these insects provide is valued at \$15 billion annually in the United States alone (Calderone 2012). Pollinators are in decline in many parts of the World (Koh et al. 2016; Kulhanek et al. 2017; Powney et al. 2019). Conversion of grassland plant communities to row cropping and other land uses is contributing to these declines (Goulson et al. 2015; Dolezal et al. 2019), largely because this conversion removes grassland forbs pollinators rely on for forage (Hanberry et al. 2021).

The U.S. Great Plains is a key area where land conversion is impacting pollinators. Many imperiled pollinators are native to the Great Plains (Hanberry et al. 2021), and about 40% of U.S. honeybees summer there after being used to pollinate crops

elsewhere in the country in late winter and spring (Hellerstein et al. 2017). Access to forbs supplying high-quality forage during this summering period is important for maintaining large, healthy colonies needed to pollinate crops (Requier et al. 2017; Smart et al. 2018; Baden-Böhm et al. 2022). In 2 of 10 Great Plains states (North Dakota and South Dakota), 163,000 ha of grasslands near apiaries were converted to row crops between 2006 and 2012 (Otto et al. 2018), and recent conversion to row crops is documented in several other Great Plains states as well (Hellerstein et al. 2017).

Mounting evidence indicates establishing stands of forbs within agricultural landscapes can help stem the decline of pollinators (Haaland et al. 2011; Buhk et al. 2018; Ricigliano et al. 2019; Baden-Böhm et al. 2022). As such, governmental and nongovernmental programs are increasingly incentivizing U.S. and European farmers to seed forbs on portions of their lands (Haaland et al. 2011; Ouvrard et al. 2018).

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In the United States, the largest of these programs is the Department of Agriculture (USDA) Conservation Reserve Program (CRP). Over the last decade in the Great Plains, about 1.1 million hectares have been seeded to mixtures of forbs, grasses, and sometimes other plants as part of the CRP (Farm Services Agency 2022).

Several studies have evaluated these seeding efforts and indicated a need to improve forb establishment and persistence. According to these studies, just fractions of seeded forb species typically establish (Denning & Foster 2017; Arathi et al. 2019; Simanonok et al. 2022), so seeded sites often have just zero to four forb species (Denning & Foster 2017; Vandever et al. 2021), though more species sometimes occur (Simanonok et al. 2022). Low species numbers are concerning because several functionally different forbs are thought necessary to provide forage throughout the growing season (Blaauw & Isaacs 2014; Ouvrard et al. 2018) and support pollinators with different host plant requirements (Dötterl & Vereecken 2010; Nichols et al. 2019; Rivest & Forrest 2019). In addition to having several forb species, sites must have high forb abundances to support pollinators (Baden-Böhm et al. 2022), and studies suggest abundances are often low in the Great Plains (Arathi et al. 2019; Vandever et al. 2021; Simanonok et al. 2022).

In this study, we sought to identify factors regulating forb establishment in semiarid regions of the Great Plains (Colorado and Montana). We investigated former crop fields seeded to forbs and grasses as part of pollinator conservation programs. The factors we considered were the forb species included in the seed mixes, forb and grass seed rates, first growing season precipitation, time since seeding, weeds, and herbicides. Controlled experiments long ago determined these factors can affect forb abundances, but little is known about the importance of these factors in our system. For example, weeds can reduce forb establishment (e.g. Masters et al. 1996; Beran et al. 1999b), but weeds will be unimportant if their abundances are consistently low, which could be the case in croplands previously subjected to rigorous weed control. Also, some herbicides can persist in soil and damage forbs (e.g. Derr 1993; Calkins et al. 1996), but managers may know to avoid these herbicides before seeding forbs. Additionally, forb abundances often increase with increasing forb seed rates (e.g. Carter & Blair 2012; Grman et al. 2013) and decrease with increasing grass seed rates (e.g. Dickson & Busby 2009), but the magnitude of these effects will depend on rates managers sow as well as precipitation, weed abundances, and other factors. Finally, many forbs commonly planted in our study area are also commonly seeded in wetter parts of the Great Plains (Simanonok et al. 2022), and it is unclear which of these forbs can reliably establish here.

Methods

Field Study

Colorado and Montana account for nearly 20% of Great Plains (U.S.A.) cropland that has been seeded to forbs and other plants as part of the CRP program (Farm Services Agency 2022). We contacted USDA personnel to find fields for study and selected all fields seeded with two or more forb species between 2016

and 2019. Fields were in eastern Colorado (87 fields) and western (1 field), central (5 fields), and eastern (27 fields) Montana. Fields were enrolled in the USDA Natural Resource Conservation Service (NRCS), Environmental Quality Incentives Program (8 fields; USDA-NRCS 2022), a joint NRCS, Colorado Parks and Wildlife, and Pheasants Forever initiative (18 fields; Corners for Conservation 2016), a CRP initiative focused on pollinators (62 fields; USDA-FSA 2022), and other CRP

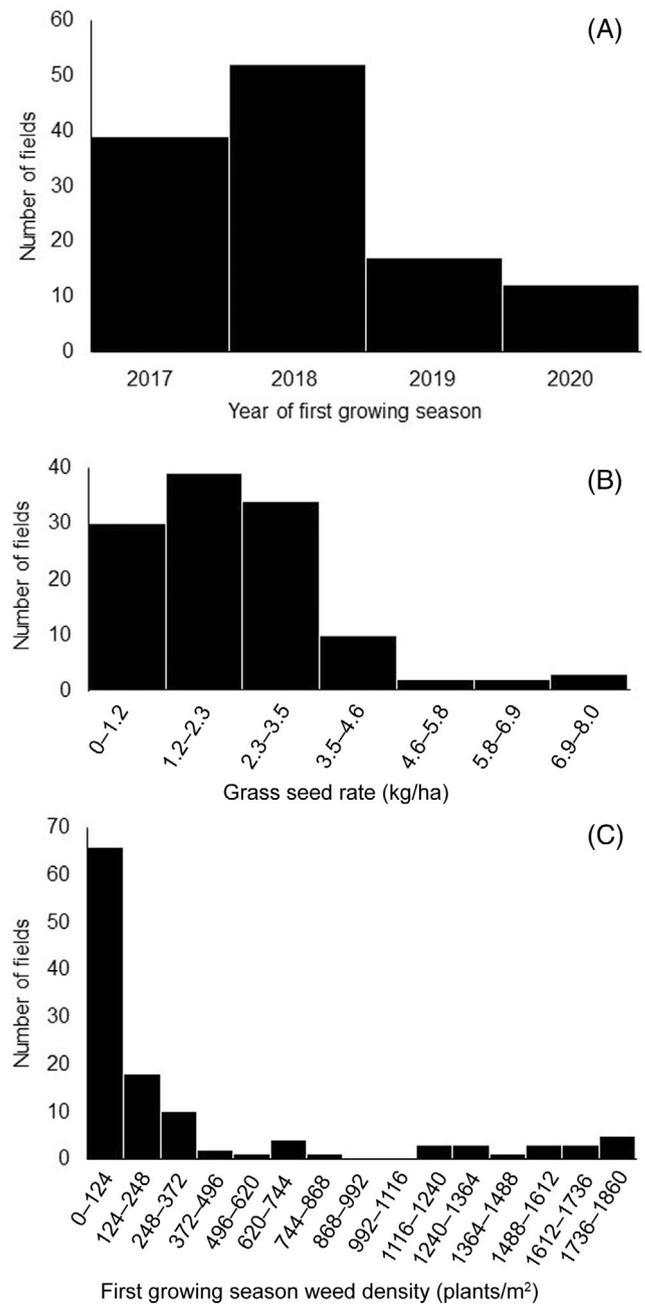


Figure 1. Data on factors affecting forb establishment. The first growing season occurred between 2017 and 2020 (A), and grass seed rates (B) exclude several species that rarely established. Weed density (C) was measured early in the first growing season. Table 1 provides forb seed rate information.

initiatives (32 fields). Field sizes were 33 ± 42 ha (mean \pm 1.0 standard deviation). Soils were primarily loam, silty loam, or sandy loam, though a few fields were clay, clay loam, gravelly loam, loamy sand, or sand (USDA Web Soil Survey 2022). In the growing season before study, most fields were farmed for wheat (*Triticum aestivum* L.), though some fields were farmed for corn (*Zea mays* L.), sorghum (*Sorghum bicolor* [L.] Moench), yellow pea (*Lathyrus aphaca* L.), millet (*Cenchrus americanus* [L.] Morrone), or lentil (*Lens culinaris* Medik.).

Fields had their first growing seasons between 2017 and 2020 (Fig. 1A). Agency personnel in collaboration with landowners were responsible for designing seed mixes that adhered to the guidelines of the seeding programs. Table 1 lists seeded forbs and their seed rates, and all seed rates in this paper are of pure live seed. Excluding species that were rarely or never observed, seeded grasses were slender wheatgrass (*Agropyron trachycaulum* [Link] Malte ex H.F. Lewis), big bluestem (*Andropogon gerardii* Vitman), green needlegrass (*Nassella viridula* [Trin.] Barkworth), switchgrass (*Panicum virgatum* L.), western wheatgrass (*Pascopyrum smithii* [Rydb.] Á. Löve), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] Á. Löve), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), Indiangrass (*Sorghastrum nutans* [L.] Nash), and sand dropseed (*Sporobolus cryptandrus* [Torr.] A. Gray). Figure 1B indicates total grass seed rates.

Fields were seeded by landowners and other managers. Except for two broadcast-seeded fields, all fields were drill-seeded at about a 1.0-cm soil depth. In 49 fields, we estimated seed rates using viability and seed weight information provided by the seed supplier and bulk rates managers calibrated their

equipment to sow. In the other 71 fields, seed rates were measured by collecting the seed being output by the operating seeding equipment. With drill-seeded fields, seed being deposited was collected for 30 m as the drill operated. Row spacing varied between 19 and 24 cm, and seed was collected in plastic bags as it entered seeder tubes supplying seed to three rows. In broadcast-seeded fields, seed deposited on a 24.4-m² tarp was collected. Seed was separated by species and weighed.

We contacted landowners to determine if herbicides were applied prior to seeding that might persist in soil and damage forbs during establishment. We identified two persistent herbicides (metsulfuron methyl and triasulfuron) that were applied to seven fields ≤ 60 days prior to seeding.

For plant measurements, ten 1.0-m² frames were positioned at 10-m intervals along a randomly positioned transect orientated the direction seeding equipment traveled. Densities of seeded species and unseeded species (hereafter weeds) were determined in these frames in June of the first growing season. At the end of the study in 2021, cover of each plant species was visually estimated in late May to early June when all forbs were actively growing and most had flowers or flower buds.

Analysis

We analyzed three response variables that were measured at the end of the study in 2021, which was between two and five growing seasons after seeding depending on field. No seeded forbs were observed in sampling frames of 28 of the 120 fields, and the first response was the binary variable indicating whether

Table 1. Within fields where listed species were sown, their mean low (<25th percentile) and high (>75th percentile) seed rates. No forbs established in 28 of 120 fields, and these fields were excluded in calculating these rates.

Species	Low Rate (kg/ha)	High Rate (kg/ha)	No. of Fields Where Sown
Native			
Blackeyed susan (<i>Rudbeckia hirta</i> L.)	0.02	0.06	48
Blanketflower (<i>Gaillardia aristata</i> Pursh)	0.10	0.19	52
Bundleflower (<i>Desmanthus illinoensis</i> (Michx.) MacMill. ex B.L. Rob. & Fernald)	0.10	0.35	20
Fourwing saltbush (<i>Atriplex canescens</i> (Pursh) Nutt.)	0.28	1.00	16
Lewis flax (<i>Linum lewisii</i> Pursh)	0.07	0.16	80
Maximilian sunflower (<i>Helianthus maximiliani</i> Schrad.)	0.06	0.17	60
Plains coreopsis (<i>Coreopsis tinctoria</i> Nutt.)	0.01	0.03	28
Prairie coneflower (<i>Ratibida columnifera</i> (Nutt.) Wooton & Standl.)	0.04	0.09	77
Purple prairie clover (<i>Dalea purpurea</i> Vent.)	0.07	0.21	78
Rocky mountain beeplant (<i>Cleome serrulata</i> Pursh)	0.16	0.30	34
Rocky mountain penstemon (<i>Penstemon strictus</i> Benth.)	0.03	0.06	16
Western yarrow (<i>Achillea millefolium</i> L.)	0.003	0.02	34
White prairie clover (<i>Dalea candida</i> Michx. ex Willd.)	0.13	0.62	4
Woods rose (<i>Rosa woodsii</i> Lindl.)	1.13	1.24	3
Non-native			
Alfalfa (<i>Medicago sativa</i> L.)	0.04	0.23	57
Annual sunflower (<i>Helianthus annuus</i> L.)	0.17	0.33	22
Cicer milkvetch (<i>Astragalus cicer</i> L.)	0.24	0.39	16
Sainfoin (<i>Onobrychis viciifolia</i> Scop.)	0.86	1.99	46
Small burnet (<i>Sanguisorba minor</i> Scop.)	0.58	1.06	31
Strawberry clover (<i>Trifolium fragiferum</i> L.)	0.02	0.09	8
Yellow sweetclover (<i>Melilotus officinalis</i> (L.) Lam.)	0.08	0.19	45

forbs were observed. We omitted these 28 fields in analyzing the other two responses, so results from analyses of other responses are conditional on forbs being observed. The second (bivariate) response was leguminous and nonleguminous forb cover averaged over sampling frames. Legumes were considered separately from nonlegumes to provide more detailed results and because they might respond differently to management and other factors. Finally, the third response was the binary variable indicating whether individual forb species were observed.

Each response variable was analyzed using a linear or generalized linear model, and each model included seed rate predictors explained in this paragraph and other predictors explained in the next paragraph. Relationships between seed rates and response variables varied widely among forb species. To accommodate this without encountering multicollinearity problems from including many species-specific covariates, we calculated

$$w_j = \frac{1}{n_j} \sum_{i=1}^{n_j} \frac{\text{cover}_{i,j}}{\text{seed rate}_{i,j}},$$

which is average cover per seed weight for species j across the n_j fields where it was sown. We used the w_j to construct a legume and nonlegume covariate for the cover model and a covariate that included both legumes and nonlegumes for the two binary models. To explain how this was done, we consider the legume covariate. Most (90%) seeded legume cover was alfalfa and sainfoin, so the legume covariate included just these species. Defining w_A and $\text{seed rate}_{i,A}$ as the alfalfa values and w_S and $\text{seed rate}_{i,S}$ as the sainfoin values, we define the legume covariate for the $i=1, \dots, 120$ fields as $\log(w_A \times \text{seed rate}_{i,A} + w_S \times \text{seed rate}_{i,S})$. The nonlegume forb covariate was calculated the same way using Maximilian sunflower, small burnet, Lewis flax, annual sunflower, western yarrow, prairie coneflower, and blanketflower, seven species that comprised nearly all (94%) seeded nonlegume forb cover. The covariates that included both legumes and nonlegumes included alfalfa and sainfoin along with these same seven species.

The model indicating whether any seeded forbs were observed was a probit model for binary data (Albert & Chib 1993). Fixed effects controlled for state (Colorado, Montana) and the seven fields where persistent herbicides were applied. Covariates controlled for year of the first growing season, log weed density (plants/m²), log seed rate (kg/ha) of prevalent grass species (see Field study section), and the forb seed rate predictor that included nine species. The model for (log-transformed) cover included the same predictors, except the legume and nonlegume seed rate covariates were included instead of the covariate that combined these groups. Legume and nonlegume cover was zero for 20 and 11 fields, respectively, so we fit a zero-inflated version of the model (Chib 1992). The model indicating whether individual forbs were observed was a probit model with the same predictors, except this model included random effects for plant species and field. In this model, the forb seed rate predictor amounted to rates of individual species multiplied by their weights (w_j).

We estimated the parameters using a Bayesian approach. Most prior distributions were uninformative. In the model quantifying whether any seeded forbs were observed, the weed density prior was $N(-0.1, 0.07)$, where $N(\mu, \sigma)$ indicates the normal

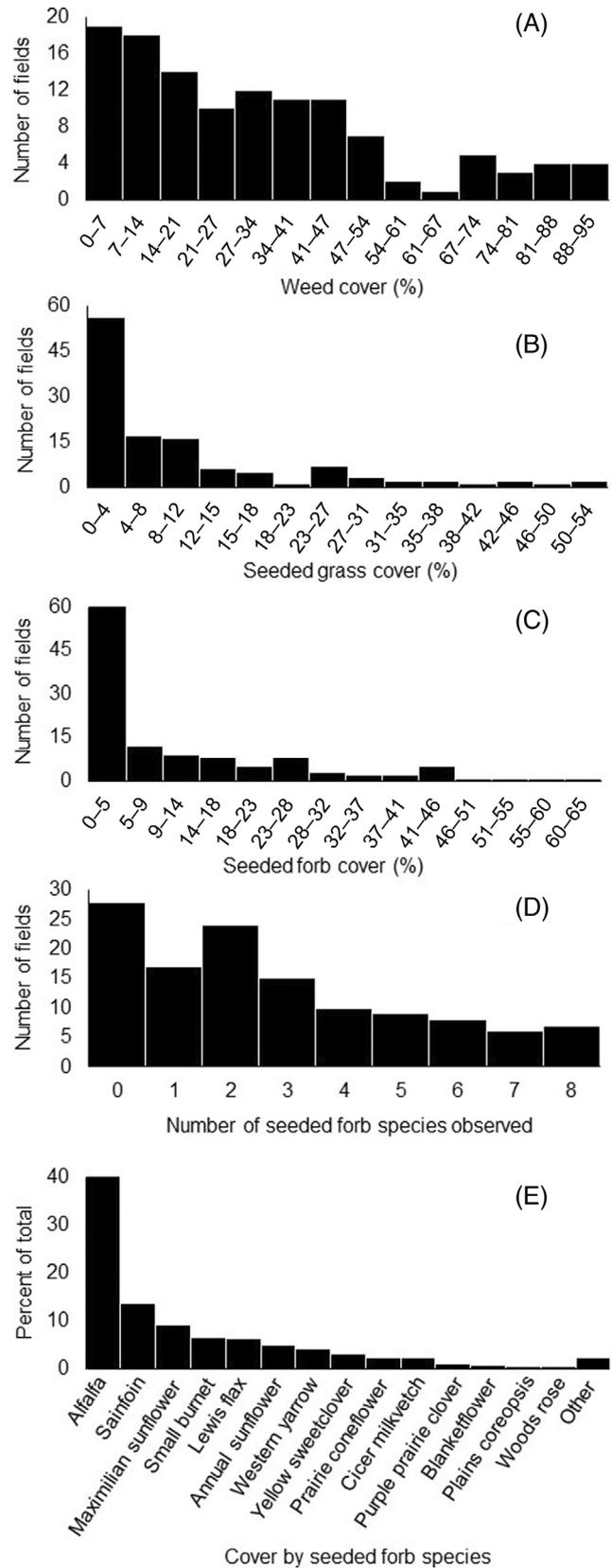


Figure 2. Plant abundances at the end of the study.

distribution with mean μ and standard deviation σ . For the error variance matrix and random effects variance matrix of the plant cover model, marginal prior distributions for correlations were uniform and for standard deviations were Half- $t(2.0, 500)$ (Huang & Wand 2013). Priors for fixed effect and covariate

parameters were uniform, with the following exceptions. For both cover responses, priors for weed density parameters were $N(-0.2, 0.1)$ and for grass seed rate parameters were $N(-0.3, 0.2)$. In the model quantifying whether each individual forb species was observed, priors on weed density and grass seed rate parameters were $N(-0.15, 0.1)$ and on random effects variances were uniform. Controlled experiments support these grass seed rate (e.g. Williams et al. 2002; Dickson & Busby 2009) and weed density priors (e.g. Masters et al. 1996; Canevari et al. 2003; Marushia & Allen 2015). Using these informative priors in place of uniform distributions produced narrower confidence intervals but had little effect on mean estimates.

We used posterior predictive checks to assess whether certain predictors were needed and whether priors were consistent with the data (Gelman et al. 2014). With binary models, the response variable equaled 1 or 0 if forbs were or were not observed, and the test statistic for the checks was the sum of the response when the predictor was below the 25th percentile value minus this same sum when the predictor was above the 75th percentile value. With the plant cover model, the test statistic was the covariance between the predictor and response. These checks indicated priors were consistent with the data ($p \geq 0.16$). The checks supported the decision to exclude a few previously explained predictors from certain models by setting their corresponding parameters to zero ($p \geq 0.08$). Finally, we assessed many other candidate predictors (first growing season precipitation, squared predictors, interactions, predictors regulating competition between legumes and nonlegume forbs) that we excluded from the models based on the checks.

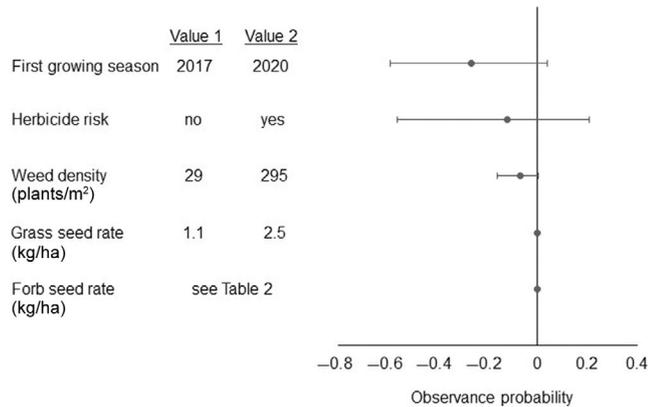


Figure 3. Means (dots) and 95% CI (bars) estimating effects of listed predictors on probabilities seeded forbs were observed. The estimates quantify changes in observation probabilities caused by changing predictors from value 1 to value 2. For example, according to the mean estimate for the first growing season parameter, fields established in 2017 (value 1) had a 0.25 higher probability of having forbs than fields established in 2020 (value 2). For weed density and grass seed rate predictors, value 1 and 2 are 25th and 75th percentile values.

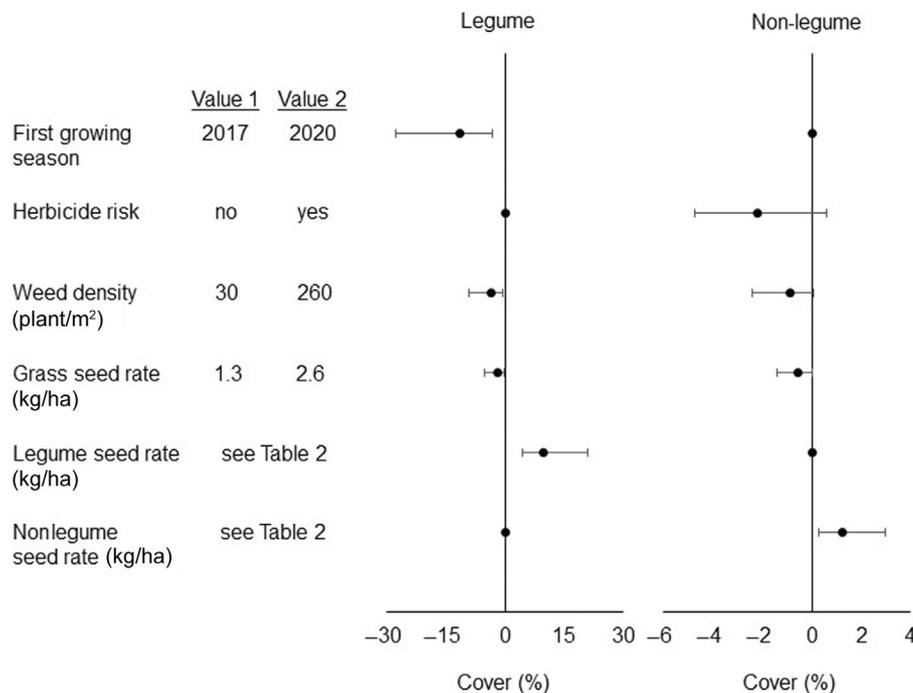


Figure 4. Means (dots) and 95% CI (bars) estimating effects of listed predictors on seeded legume and nonlegume forb cover. These estimates quantify cover changes caused by changing predictors from value 1 to value 2. For example, according to the mean estimate for the first growing season parameter, fields established in 2017 (value 1) had 12% more legume cover than fields established in 2020 (value 2). For weed density and grass seed rate predictors, value 1 and 2 are 25th and 75th percentile values. Data from fields where no seeded forbs were observed were omitted in deriving these estimates.

Results

First growing season (March to June) precipitation was 206 ± 76 mm (mean \pm 1.0 standard deviation), which resembles the 30-year average of 195 ± 28 mm (<https://www.nacse.org/prism/>). Despite this wide variation in precipitation, precipitation predictors were not statistically significant ($p = 0.08$ to 0.45).

In the first growing season, weed density varied widely (Fig. 1C), and we observed 97 weed species, with the densest being kochia (*Bassia scoparia* [L.] A.J. Scott), Russian thistle (*Kali tragus* [L.] Scop.), and witchgrass (*Panicum capillare* L.). At the end of the study, weed cover ranged from nearly 0 to 100% (Fig. 2A), and seeded grass cover was usually low but ranged as high as approximately 50% (Fig. 2B).

Table 2. Seed rate information for the forb cover model. This model included a legume and nonlegume seed rate predictor, and values are mean rates of individual species when values of the predictors were low (<25th percentile) and high (>75th percentile). The predictors omitted 12 forb species that contributed very little cover. A mix of the listed species seeded at the high listed rates maximized forb cover. No forbs established in 28 of 120 fields, and these fields were excluded in calculating the rates.

Species	Legume	Low Rate (kg/ha)	High Rate (kg/ha)
Native			
Blanketflower	No	0.01	0.19
Lewis flax	No	0.03	0.15
Maximilian sunflower	No	0.01	0.17
Prairie coneflower	No	0.04	0.07
Western yarrow	No	0.001	0.02
Non-native			
Alfalfa	Yes	0.01	0.36
Annual sunflower	No	0	0.23
Sainfoin	Yes	0.09	0.45
Small burnet	No	0	0.70

Probability Any Seeded Forbs Were Observed in Fields

The probability seeded forbs were observed was 0.8 (0.6, 0.9) [mean (95% confidence interval)]. Fields seeded earlier had higher probabilities of supporting forbs in sampling frames ($p = 0.05$) (Fig. 3), which indicates seeded forbs colonized sampling frames over time and/or early year(s) of the study were better for forb establishment. The probability seeded forbs were observed declined with increasing weed density ($p = 0.04$) (Fig. 3).

Forb Cover

Seeded forb cover was <5% in half of fields but ranged as high as approximately 60% (Fig. 2C). The nonnative legumes alfalfa and sainfoin comprised about half of seeded forb cover (Fig. 2E). Excluding 28 of 120 fields where no seeded forbs were observed, mean legume cover was 10% (7%, 18%) and mean nonlegume forb cover was 4% (3%, 7%). The first growing season parameter was negative for legumes ($p \leq 0.001$) (Fig. 4), which indicates legumes increased over time and/or early year(s) of the study were better for legume establishment. Certain persistent herbicides applied prior to seeding reduced nonlegume cover ($p \leq 0.001$) (Fig. 4). Legume and nonlegume cover declined with increasing weed density ($p \leq 0.03$) and grass seed rate ($p \leq 0.02$). Legume and nonlegume cover increased with forb seed rate ($p < 0.003$). As legume seed rates increased from the low to high values in Table 2, legume cover increased 10% (4%, 21%) (Fig. 4). Similarly, as nonlegume seed rates increased from low to high values in Table 2, nonlegume forb cover increased 1.2% (0.3%, 3%) (Fig. 4).

Probabilities Individual Forb Species Were Observed

We observed zero to eight seeded forb species per field (Fig. 2D). The species with the greatest establishment probabilities included natives (Lewis flax, sunflower species, and

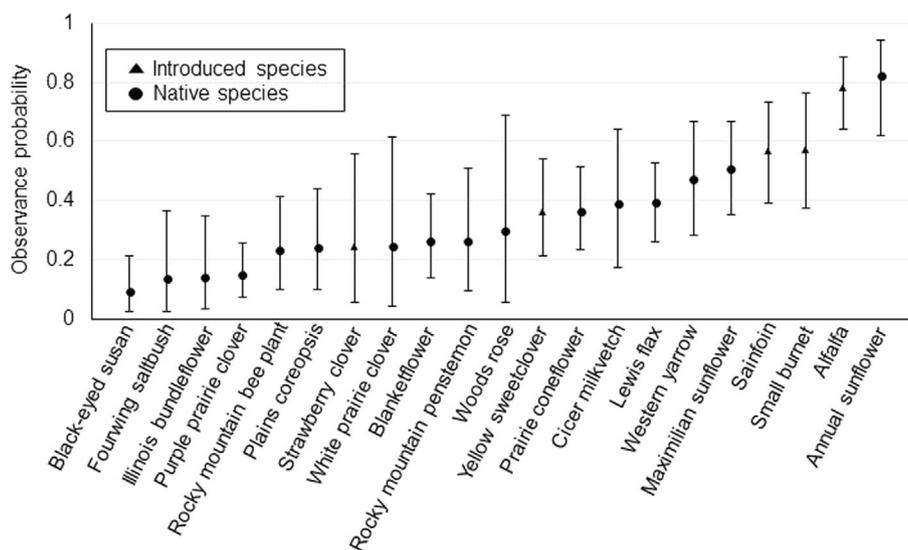


Figure 5. Means (dots) and 95% CI (bars) estimating probabilities species were observed in fields where they were sown.

western yarrow) and non-natives (sainfoin, small burnet, and alfalfa) (Fig. 5).

Discussion

There is a clear need to improve forb establishment in our study region. No seeded forbs were observed in 23% of study fields, and two or fewer forbs were observed in over half of fields. These values resemble those of other Great Plains studies (Arathi et al. 2019; Vandever et al. 2021). Omitting fields where no forbs established, chances of establishment were <50% for 16 of 23 forbs and <30% for 11 forbs. Seeded forb cover was <10% in most fields.

Our data indicated multiple avenues for increasing forb establishment. Persistent herbicides reduced nonlegume forb cover in seven of 120 fields, so more care is needed in herbicide use before seeding. Studies have identified several herbicides that pose risks to seeded forbs (e.g. Erusha et al. 1991; Beran et al. 1999b; McManamen et al. 2018). Additionally, minimum recommended time intervals between applying herbicides and planting crops is standard information on herbicide labels, and this information provides clues about risky applications for forbs.

While certain herbicides applied before seeding pose risks, certain herbicides not used in our study sometimes greatly benefit forbs when applied after seeding. For example, imidazolinones (e.g. imazethapyr, imazamox) and grass-specific herbicides (e.g. clethodim, fluazifop) are commonly used in seedling alfalfa and sometimes greatly increase its growth (e.g. Becker et al. 1998; Canevari et al. 2003). Moreover, with some native forbs of our study, imazethapyr increased stem density from 0 to 10–327/m² (Beran et al. 1999b) and cover from 0 to 15–93% (Masters et al. 1996). Additionally, fluazifop increased native forb cover from 2 to 40% (Marushia & Allen 2015). Unfortunately, except for grass-specific herbicides, imidazolinones and other herbicides also sometimes harm (stunted, thinned) native forbs (Beran et al. 1999a; Beran et al. 2000; Washburn & Barnes 2000; Norcini et al. 2003; Bahm 2011). Whether herbicides increase or decrease forb abundances depends on the forb species, weed density, and other factors (Beran et al. 1999a; Washburn & Barnes 2000). The relevant literature is small, and further testing might reveal the benefits outweigh the harm with certain herbicides.

Weeds may have impacted forbs more negatively than our models indicate. Our weed competition predictor was weed density in the first growing season, but in addition to indicating intense weed competition, high weed densities may indicate conditions favorable for emergence of weeds and seeded forbs alike (e.g. sufficient soil water, low compaction). The slope of the regression of seeded plant densities on weed densities was slightly positive (data not shown), which supports this conjecture. If high weed densities indicate conditions favorable for forb emergence, management that reduces weed densities could increase forb cover more than our estimates indicate.

When the study ended, weed cover was high in many fields. Fields seeded earlier in the study supported more forbs at the end of the study, so either forbs are capable of increasing and displacing weeds over time or earlier growing season(s) of the study were better for forb establishment. Long-term research is

needed to determine whether seeded forbs persist and increase through time in our study area.

Seeding grasses at high rates would help constrain weeds (e.g. Williams et al. 2002; Rinella et al. 2016), but productive grass stands suppress forbs in addition to weeds according to our study and others (e.g. Kindscher & Fraser 2000; Dickson & Busby 2009). Therefore, providing pollinator habitat will likely require tolerating sparse grass stands and some unwanted vegetation. Seeding at least some grasses could be important because grasses are obligate hosts to larvae of some imperiled pollinators, including several Hesperidae species (Hanberry et al. 2021).

Forb cover increased with increasing forb seed rate, so low rates were too low to maximize cover. Among seed mixes we studied, a particular mix of nine species seeded at or near the high listed rates produced the most cover. Determining if still higher rates would further increase cover would require more research, and lower rates might become sufficient if effective weed control is implemented.

Between our study and Simanonok et al. (2022), establishment of many forbs has been evaluated in the western United States. This information should prevent purchasing expensive seed of ill-suited species. Six of the nine forb species we identified as relatively successful in Montana and Colorado were also found to perform well in North Dakota and Minnesota (Simanonok et al. 2022). This suggests some species will prove relatively successful across a wide geographical expanse. However, some species that commonly established in the wetter area of Simanonok et al. (2022) rarely established in our area (e.g. blackeyed susan, purple prairie clover), which suggests some species are suited to only portions of the region.

The nine forbs that performed best in our study provide a good starting point for designing seed mixes, because stands of some or all these forbs meet the needs of many pollinators (Ogle et al. 2019). Some native bees of the Great Plains sometimes show preferences for native plants (Otto et al. 2017; Simanonok et al. 2021), though most of the region's bees appear to be generalists that can feed on many native forbs as well as nonnative forbs like alfalfa and sainfoin (Holm 1966; Kells 2001; Harmon et al. 2011). Many native butterflies and other pollinator insects of the Great Plains can also utilize one or more of the native and nonnative forbs we identified as most successful (Graves & Shapiro 2003; Ogle et al. 2019). Hanberry et al. (2021) identified several native bees and butterflies of concern in the Great Plains, and adults of most or all these species feed on at least some of our nine successful forbs (Swengel & Swengel 1999; Wilson et al. 2010; Swartz et al. 2016). Additionally, these forbs are capable of supplying forage across the early (Lewis flax, sainfoin, yarrow, alfalfa, small burnet), middle (all species), and late (sunflowers, blanketflower, prairie coneflower) part of the growing season (Ogle et al. 2019).

Returning forbs to agricultural landscapes holds promise for maintaining pollinators (Haaland et al. 2011; Ricigliano et al. 2019; Baden-Böhm et al. 2022). Unfortunately, establishing the abundant, species-rich stands of forbs necessary to support diverse pollinator communities has proven challenging (Dötterl & Vereecken 2010; Blaauw & Isaacs 2014; Denning & Foster 2017; Ouvrard et al. 2018;

Arathi et al. 2019; Nichols et al. 2019; Rivest & Forrest 2019; Vandever et al. 2021; Baden-Böhm et al. 2022; Simanonok et al. 2022). This study identified practical avenues for increasing numbers and abundances of forb species.

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