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Seed mix design, planting time, and first-year mowing management to improve multifunctionality and cost-effectiveness of tallgrass prairie reconstructions

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SEED MIX DESIGN, PLANTING TIME, AND FIRST-YEAR MOWING MANAGEMENT TO IMPROVE MULTIFUNCTIONALITY AND COST-EFFECTIVENESS OF TALLGRASS PRAIRIE RECONSTRUCTIONS

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Science

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ABSTRACT

The conversion of the Midwestern United States' tallgrass prairies to agriculture has resulted in extensive habitat loss and degradation and a decline in the provisioning of ecosystem services. To restore these services the United States Department of Agriculture created the Conservation Reserve Program (CRP) which provides incentives to agricultural landowners to implement conservation practices designed to meet goals pertaining to single ecosystem services. We studied the effects of seed mix design, planting time, and first-year management on the multifunctionality and cost-effectiveness of prairie reconstructions. We established research plots planted with one of three seed mixes either in the dormant (fall) or spring season with or without first-year mowing management applied. The Economy mix had a 3:1 grass-to-forb ratio consisting of 21 species, the Diversity mix had a 1:1 grass-to-forb ratio with 71 species, and the Pollinator mix had a 1:3 grass-to-forb seeding ratio containing 38 species. We measured native species richness, stem density, canopy cover, canopy fill, and floral resources in each plot over two growing seasons. We also estimated the cost-effectiveness of each seed mix at producing 1000 native stems. Additionally, we compared the effects of seed mix design and mowing management on vegetation outcomes across two sites differing in planting year and cropping history (soybeans versus corn) but sharing a similar experimental design. We found that the Economy mix established the highest number of grasses and native cover but the fewest forbs. The Pollinator mix had the highest number of forb stems and inflorescences but fewest grasses, whereas the Diversity mix established the greatest species richness, an intermediate density of grass stems, comparable forb stems and the highest floral richness. Mowing accelerated native species establishment and increased cost-effectiveness across all seed mixes. Spring planting had a strong influence on the establishment of warm-season grasses, while dormant plantings increased cool-season grasses and spring and fall forbs. The effects of seed mix design and first-year mowing on vegetation outcomes were robust across the two sites. Our results suggest CRP could effectively consolidate multiple existing conservation practices by instead recommending a diverse, evenly-balanced seed mix to provide multifunctional stands. We also recommend first-year mowing as an effective tool to accelerate plant establishment and dormant season planting as no cost approach to increase pollinator habitat quality.

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Entitled: Seed Mix Design, Planting Time, and First-Year Mowing Management to Improve Multifunctionality and Cost-Effectiveness of Tallgrass Prairie Reconstructions

Has been approved as meeting the thesis requirements for the

Degree of Master of Science

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INTRODUCTION

The tallgrass prairies that once dominated more than 80 percent of Iowa's landscape have been reduced to near 0.1 percent due to large shifts in land use (Wright & Wimberly 2013). This change, mainly attributed to agricultural practices, has led to severe habitat loss, fragmentation, and degradation of the tallgrass prairie ecosystem, and has negatively affected the provisioning of ecosystem services, including soil and water quality protection, weed resistance, flood control, carbon sequestration, and wildlife and pollinator habitat. To restore these ecosystem functions in the agricultural landscape, the United States Department of Agriculture (USDA) has created many conservation practices under the umbrella of the Conservation Reserve Program (CRP), the largest federal land retirement conservation program (Stubbs 2014). Traditionally these practices have been designed to meet specific goals pertaining to a single ecosystem service (e.g., soil erosion, pollinator recovery, nutrient reduction) by incentivizing landowners to retire and convert marginal farmland to native vegetation.

The restored CRP prairie plantings can provide a wide range of ecosystem services (Wratten et al. 2012). Many of the native species within these communities develop deep fibrous roots which stabilize the soil, prevent soil erosion, and promote water infiltration (Helmers et al. 2012). Successful establishment of native plants in CRP fields may also suppress weed invasion through preemptive competition (Abernathy et al. 2016; Jewett et al. 1996). Functional diversity can help expand the breadth of ecosystem services that a prairie reconstruction provides. Cool-season C3 grasses often emerge much earlier than warm-season C4 grasses and are thought to provide more benefits in the early phases of a developing prairie. More specifically, because cool-season grasses establish dense stands quickly they increase sediment trapping and become strong competitors against early emerging weeds. Warm-season grasses take longer to establish but increase suitable habitat for wildlife (USDA 2004). Similarly, forbs also demonstrate phenological tendencies where growing and flowering occur at different times throughout spring, summer, and fall. Establishing forbs that persist in each of these seasons may be vital to enhancing pollinator abundances in reconstructions (Havens & Vitt 2016).

As of February 2021, approximately 20.8 million acres were enrolled in CRP in the United States. In Iowa, approximately 1.7 million acres, 5% of the state’s total land area, were enrolled in CRP programs dedicated to enhancing targeted ecosystem services (USDA 2021). One of the most common conservation practices in Iowa is CP25: Rare and Declining Habitat. This practice is designed to provide cover for wildlife and to reduce soil erosion by establishing plots with a high density of native grasses. Another popular practice is CP42: Restoration of Pollinator Habitat. This practice is designed to enhance pollinator abundance by having at least three flowering species in bloom during each of three seasonal periods (spring, summer, and fall). To accomplish this, CP42 stands are planted with a high density of forb species. Historically, conservation practices with objectives that focus on single ecosystem services have been favored and perceived to be easier to implement; however, recent studies suggest such practices may not be optimal for conservation outcomes (Macfadyen et al. 2012).

In contrast, CP43: Science-based Trials of Rowcrop Integrated with Prairie Strips (STRIPS) is a new conservation practice, recently established in the 2019 Farm Bill to create stands with a higher degree of multifunctionality. This program uses diverse vegetation to reduce soil erosion, improve water quality, and provide habitat for wildlife. Experimental field trials evaluating strips at the Neal Smith National Wildlife Refuge have demonstrated that converting 10 percent of land in agricultural crop rotations to prairie strips can decrease up to 90 percent nitrogen and phosphorus in surface runoff and reduce concentrations of shallow groundwater nitrates (Zhou et al. 2014). Additionally, prairie strips can also be useful in enhancing other ecosystem services such as increasing the population and richness of grassland birds (Peterjohn & Sauer 1999; Schulte et al. 2017) and pollinator abundances (Ries et al. 2001; Schulte et al. 2017).

Factors Affecting Prairie Reconstruction Outcomes

In general, prairie reconstruction outcomes are frequently unpredictable as agricultural land can vary dramatically in soil type, soil seed bank, and annual weather (Norland et al. 2018). Previous research has found that management, particularly seed mix design, is an important determinant of successful restoration of native plant communities (Grman et al. 2013). Prairie reconstructions that utilize commercial seed can benefit from applied research focused on establishing multifunctional stands in a cost-effective way and improving the chances of successful implementation through three common facets often utilized in the early phases of a reconstruction: seed mix design, planting time, and first year mowing management.

Seed Mix Design

Seed mix design is one of the most important aspects of a prairie reconstruction when natural seed dispersal is limited because the project's success is often dictated by the establishment of sown species and the degree to which they function in serving ecological goals. While the cost of seed fluctuates year to year due to supply and demand, it remains one of the largest expenses of a reconstruction (Phillips-Mao et al. 2015). From a cost perspective, seed mixes that have a higher ratio of grass-to-forb seed are cheaper than mixes containing lower grass-to-forb ratios; this is because grass seed tends to have a lower production cost relative to forbs (Smith et al. 2010). However, seed mix cost is not an effective way to evaluate the potential of a reconstruction. For instance, in a previous study by Meissen et al. (2020) found that expensive forb-dominant seed mixes (1:3 grass to forb ratio) increased forb and wildflower abundances but left gaps decreasing weed resistance, and low-cost grass-dense seed mixes (3:1 grass to forb ratio) increased native stem density and weed resistance but produced few floral resources. In contrast, a balanced grass to forb seed mix (1:1 grass to forb ratio) established stands with high native stem density, weed resistance, and floral resources comparable to both at a lower cost than the forb-dense stands.

Additionally, a seed mix rich in species may have poor establishment outcomes if the allocation of seed is dominated by a particular functional group, as closely related groups often support similar functional traits (Gómez et al. 2010). For instance, C4 grasses are generally sown due to their low cost, ability to suppress weeds, and quick biomass for fire fuel. But when planted in high densities these grasses result in the loss of forb richness (Dickson & Busby 2009). Additionally, some species such as *Andropogon gerardii* are strong competitors and can suppress forb establishment (Grman et al. 2020) and floral richness (Zirbel et al. 2019). Studies have shown that removing *Andropogon gerardii* can actually increase species richness (McCain et al. 2010; Collins et al. 2002). To create multifunctional stands, high species diversity has been linked to having greater absolute cover than low-diversity mixtures (Levine 2000) and has been shown to be better at maintaining ecosystem functionality due to the subtle but cumulative effects low abundant species can provide at scale and over time (Isbell et al. 2011).

It is common practice for a seed producer to create readily available seed mixes that are efficient to distribute and conform to USDA regulations. However, a more cost-effective approach would be to use custom seed mixes that are designed with local site conditions in mind. To elaborate, a study by Hillhouse & Zedler (2011) found that a third of species planted in CRP sites failed to establish. This suggests that many mixtures contain poor quality seed or are using species not adapted to the local site conditions, resulting in poor species establishment, fewer ecosystem services, and lower cost-effectiveness. To help ensure successful establishment and that the targeted ecosystem services are provided in a reconstruction, restoration practitioners need to consider the importance of timing their planting to match conditions best suited to enhance seed establishment.

Planting Time

In general, tallgrass prairie seed can be planted at any point of the year; however, because crops grow throughout the summer, most CRP plantings occur during the spring or late fall when vegetation has gone dormant. Additionally, seeding time is often dictated by weather and equipment availability, but it could play an important role in the success of a planting. A survey including 43 land practitioners found that almost all of them preferred dormant season seeding, where seeding occurs in the late fall or after the first frost when vegetation is dormant. Compared to spring seeding, dormant seeding allows seed to go through freeze-thaw cycles, increasing seed to soil contact and better mimicking natural stratification and germination conditions (Rowe 2010). However, a 5-year study by Larson et al. (2011) found that functional group establishment was affected by planting time; forb species tended to establish at higher rates with a dormant broadcast seeding, while warm season grasses benefitted from summer drill seeding. In a follow up experiment adding five years to site development, they found similar plant cover across planting time treatments suggesting planting time has more influence on early establishment of a reconstruction (Larson et al. 2017).

Seedling establishment rates are low, and the germination process of many species require specific environmental cues such as proper soil moisture and temperature variation (Chambers & MacMahon 1994). Because of this, many species planted at a mismatched time will be more susceptible to predation and fungal attacks while they wait for the proper cue. Forb seeds are one of the most expensive costs of a reconstruction and identifying the best methods to improve the probability of establishment would increase cost-effectiveness.

Established Mowing Management

First-year mowing management is another method often utilized in the early stages of a prairie reconstruction. Most often, mowing is used to decrease annual weeds while simultaneously increasing forb establishment (Rowe 2010) at a relatively low cost (Phillips-Mao et al. 2015). Annual weeds can be a problem for reconstructions as these plants rapidly establish on agricultural lands and have been shown to be more successful in areas with excess nitrogen (Rothrock & Squiers 2003). Because these weeds are fast growing, they create dense canopy causing shading and light attenuation that may suppress the growth of young native seedlings. Mowing annual weeds during the first growing season can reduce the competition for light and ease the stress of young vegetation. Forb species are often the most affected as it can take them years to develop from seed.

Previous studies support the notion that mowing can increase forb establishment. More specifically, mowing can support the establishment of forbs when sown into warm season grass stands and persist over time (Williams et al. 2007). Additionally, in a previous study Meissen et al. (2020) demonstrated that first year mowing management can increase native species richness, forb stems, and grass stems in the first and second growing season as well as decrease annual weed cover in the second year. Using mowing management to increase native establishment can also reduce invasive species (Smith et al. 2018), increase floral resources (Meissen et al. 2020; Endels et al. 2007), and maintain diversity (Collins et al. 1998). In the context of CRP where reconstructions last for a short duration, accelerated establishment of prairie plants can make a significant difference in ecosystem services at a relatively low cost.

Objective of Study

A previous study (Meissen et al. 2020) found that seed mix design and first-year mowing management improved the provisioning of ecosystem services and the cost effectiveness of prairie reconstructions. Because this study was performed at a single location and landscape dynamics can vary dramatically from site to site and year to year, we designed a field trial to validate and assess the robustness of Meissen et al.'s (2020) conclusions about the effect of seed mix design and first year mowing management on ecological outcomes and cost-effectiveness. We designed our experiment as a replication of Miessen et al. (2020) including identically sized research plots, identical seed mixes, and first year mowing management treatment on land with contrasting cropping history (soybeans versus corn). To build upon current implementation recommendations we doubled the number of experimental plots to incorporate a new factor known to affect prairie reconstruction outcomes: planting time.

Our study aimed to (1) evaluate the effects of seed mix grass-to-forb ratios (3:1, 1:1, and 1:3), planting time (dormant vs. spring), and first-year management (mowed vs. unmowed) on the vegetation outcomes of prairie reconstructions, (2) evaluate how robust these results were across two central Iowa sites with consistent experimental trials, (3) evaluate the degree to which a seed mix with a 1:1 grass-to-forb seed ratio could fulfill the goals of current common conservation practices, and (4) determine how each of the three factors affected cost-effectiveness were measured as the cost to produce 1000 native stems.

CHAPTER 2

MATERIALS AND METHODS

Study Site

We conducted an experiment that included comparative analysis across two sites. The most recent site, referred to as the Cedar Falls site, was located at the University of Northern Iowa's Tallgrass Prairie Center in Cedar Falls, Iowa (42°30' N, 92°28' W) on land previously used in corn production. This site was planted with native vegetation in 2018 and 2019 on relatively level land with less than 5 percent grade and has a soil composition containing a mixture of Clyde-Floyd complex (~90%) and Kenyon loam (~10%) (USDA & NRCS 2019). The comparative site, referred to as the Nashua site, was described in detail in Meissen et al. (2020). Briefly, the site was planted in spring of 2015 at Iowa State Northeast Research and Demonstration Farm in Nashua, Iowa. Soils were mainly Clyde clay loams with a minor component of poorly drained Floyd Loam. Prior to site establishment the land was in production of soybeans at the end of a corn-soybean rotation.

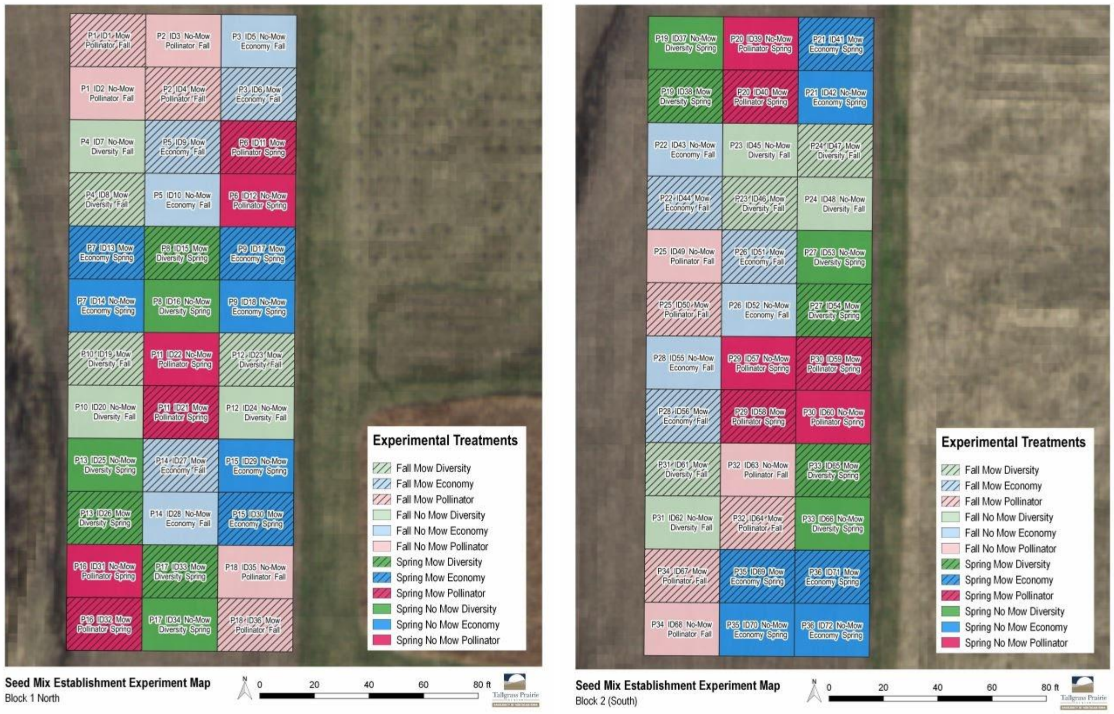

Figure 1: Experimental design of the Cedar Falls site showing the north (left) and south (right) blocks (Image credit: Justin Meissen).

Seed Mixes

Seed mixes were created to be a replication of Meissen et al. (2020) experimental design where we established plots containing one of three different seed mixes. Consistent with the previous experiment, our Economy mix contained 21 species at a 3:1 grass-to-forb ratio and cost of $209 per acre (Appendix A), the Diversity mix contained 71 species at a 1:1 grass-to-forb ratio and cost of $539 per acre (Appendix B), and the Pollinator mix contained 38 species at a 1:3 grass-to-forb ratio costing $808 per acre (Appendix C). In an attempt to replicate the seed mixes exactly, cost in this study may be inflated compared to Meissen et al. (2020) and typical restoration practices because expensive species were not substituted with lower-cost, similar functioning seeds, as commonly done in practice. Each mix was designed to resemble a current conservation practice: the Economy most closely resembles CP25; the Diversity, CP43; and the Pollinator mix, CP42. Seed was purchased in 2018 from native seed nurseries in Iowa and stored in coolers at 4°C and 45 percent RH prior to sowing. Seed for each plot was weighed, bagged, and mixed separately using pure live seed (PLS) to ensure an accurate number of seeds for a seeding rate of approximately 430 PLS m-2.

Experimental Design

This study was set up using a randomized split-plot design within 2 blocks including 3 factors: seed mixes (Economy, Diversity, and Pollinator), first year mowing management (mow versus no-mow) and seeding time (dormant versus spring). A total of 72 plots were established, 36 plots per block, each 8.5 × 6.1-meters. Each block includes 18 split-plots (8.5 × 12.2 meters) evenly distributed between the seed mixes and seeding time. Additionally, each of those plots had one half randomly assigned a mowing treatment. More specifically the design includes 3 seed mixes × 2 mow treatments × 2 seeding times × 3 replicates × 2 blocks = 72 plots (Fig. 1). Seed was planted using a Truax FLX-86U no-till drill with a seeding rate of 40 seeds per square foot. Prior to the site establishment four passes with a disk cultivator were implemented to break up residual corn litter and a final harrow pass was included to prepare soil for seeding. The first seeding treatment (dormant) took place November 2018 while the second (spring) treatment occurred in April 2019.

First Year Management

First-year mowing management occurred during the first growing season (2019). Following Meissen et al. (2020) we mowed half of the plots to approximately 12.7-cm in height when they reached a height of 50 cm. Plots were mowed a total of four times (12 June, 11 July, 8 August, and 28 October) throughout the first growing season. In addition to mowing and contrary to the previous study we clipped the edges of unmowed plot vegetation to a height of 1 m and width of 0.5 m in November to reduce seed contamination via overhang of mainly *Ambrosia trifida*. For both management techniques, thatch was left on site.

Data Collection

Data were collected at the end of each growing season. First-year collection took place in September 2019 and second-year in August 2020. In each plot, we established a single 5.5-m randomized transect running west to east. Along each transect we used five 0.125-m quadrats placed 1-m apart to record sown vegetation greater than 10 cm tall. We recorded the number of plants and stems (ramets) in each quadrat for native forb and grass species. In addition to plant and stem density, we also recorded canopy cover with the same observer performing the visual assessment in both years. Components of canopy cover were documented to the nearest 5 percent and included bare ground, perennial weeds, annual weeds, native sown forbs, native sown grasses, and unplanted natives. Annual weed cover may be underrepresented in unmowed plots due to an abundance of *Ambrosia trifida*, a 2-3 m tall weed assessed separately by estimating overstory canopy cover. Additionally, we recorded the number of inflorescences of native species found rooted within the quadrats. To reduce edge effects, quadrats were not laid within 1-m of plot edges.

To assess site differences, we drew comparisons between Cedar Falls and Nashua by analyzing like treatments in the first and second growing season. Treatments included plots with the three identical seed mixes, first-year management, and spring planting time. Additionally, plot 18 of Nashua was excluded in Meissen et al. (2020) due to flooding and has likewise been omitted from the current analysis. We assessed native species richness and native stem density of both grass and forb species across both seed mix and first year management (mowing) treatments for the first two growing seasons. Cover was assessed for native plants, annual weeds, bare ground, and perennial weeds in the second growing season as it had not been measured in year 1 (2015) at Nashua.

Additional data collection took place at Cedar Falls throughout the second growing season (2020) to evaluate how well the Diversity mix performed in accordance with CP25's goal of providing canopy cover for wildlife and CP42's goal of having three flowering species during each blooming period. To determine how the Diversity mix compared to the Economy mix with respect to canopy fill, we performed a series of light measurements during three seasonal windows (early, 1-8 June; mid 12-22 July; and late, 23-26 August). This survey was conducted between 10:30 a.m. and 3:30 p.m. when the sky was clear to maximize the angle light passes through the canopy while minimizing light interference through cloud cover, respectively. In each plot, we used the same randomized transect approach mentioned above to measured photosynthetically active radiation (uPar) with a light sensor reader (Spectrum Technologies, Inc, Model #3415FX) at the ground level, 1-m, and 2-m (control) heights five times at 1-m intervals.

To determine if the flowering phenology goals of the CP42 program were being met, we used the same randomized transect approach as the stem density survey but doubled the quadrat size to 0.25-m to measured floral species richness and abundance in each plot during three season periods (22 May, 7-10 July, and 17-21 August) in 2020. We also performed a 5-min presence survey to count the richness of flowering species in each plot.

To measure cost-effectiveness, we used the mean cost to produce one thousand stems in 2020 for the combination of treatments (seed mix × mowing × planting time). Using Meissen et al.'s (2020) method, we calculated cost effectiveness by taking the cost of the seed mix (per plot) and dividing it by the variable of interest. Cost to produce one thousand inflorescences was attempted, but due to a low abundance of floral resources in the combined growing seasons at the plot level estimates were either too high (infinite), or artificially low and was subsequently not included in the study.

Data Analysis

We analyzed species richness, stem density, canopy cover and cost of the Cedar Falls sites using repeated measures ANOVA, with seed mix, mowing, and plant time as fixed factors, year as the repeated measure, and plot nested within block as a random factor. To meet the assumptions of normality and homoscedasticity of residual variance, grass and forb stems, native cover including forb and grass cover, annual weeds, and unplanted weeds were cube-root transformed. Perennial weed cover and cost per 1k stems were log(y+0.001) transformed.

In the comparison between Cedar Falls and Nashua, we analyzed species richness and stem density using repeated measures ANOVA with seed mix and mowing as fixed factors, planting age as the repeated measure, and plot nested within block as a random factor. To meet the assumptions of normality and homoscedasticity grass and forb stems were cube-root transformed. Canopy cover comparing both sites was measured using repeated measures ANOVA with seed mix and mowing as fixed factors, and block and within plot as random factors.

We analyzed light availability using repeated measures ANOVA with seed mix, mowing, and plant time as fixed factors, survey time as the repeated measure, and plot nested within block as a random factor. To meet the assumptions of normality and homoscedasticity ground level light was cube-root transformed and 1-m light readings were square (y^2) transformed.

Within year post-hoc comparisons of significant treatment effects were made using Tukey HSD tests. All data were analyzed in R (v. 1. 3. 1093. RStudio Team 2020).

CHAPTER 3

RESULTS

Effects of Seed Mix, and Planting time, and First-year Management

Native Species Richness

At the Cedar Falls site, native species richness did not differ between seed mixes in 2019, but by 2020 the Diversity mix had a significantly higher richness than the Economy and Pollinator mixes (Fig. 2A). First year mowing management resulted in plots with significantly higher native species richness than unmowed plots in the first year (Table 1) (Fig. 2D). In 2019, native species richness was greater in plots where seeding occurred in the dormant season, but this difference was no longer noticeable by 2020 (Fig. 2G).

In comparison to the Nashua site, native species richness trends in spring plantings were similar and did not differ between sites (Table 2). At both sites, the Diversity mix had more native species than the Pollinator mix, while the Economy mix resulted in comparable richness to both in the first and second year (Fig. 3A). First-year mowing increased native forb richness at both sites, particularly in the first growing season (Table 2). In the second year, mowed plots still had greater richness than unmowed; however, the effects were no longer significant (Fig. 3B).

Stem Density

At the Cedar Falls site, stem density of both native grasses and forbs varied significantly among the seed mixes (Table 1). The Economy mix produced more grass stems than both the Diversity and Pollinator mixes in 2019 and 2020. Conversely, the

Pollinator mix produced the fewest grasses across both years (Fig. 2B). Forb stems did not vary much among the seed mixes in 2019, although on average the Pollinator mix produced a greater number of forbs than the other mixes. The effect was clearer in 2020, when the Pollinator mix had significantly more forb stems than the Economy mix, while the Diversity mix was comparable to both (Fig. 2C). First year mowing management also influenced grass and forb stem density (Table 1). Mowing increased grass stem density significantly in both years (Fig. 2E), while forb stem density was only significant in 2020 (Fig. 2F). Planting time did not have an effect on grass stem establishment but had a significant influence on forb stems (Table 1). Forbs were found to have increased establishment in a dormant planting however, Tukey’s post hoc analysis revealed no statistical differences (Fig. 2H,I).

Native stem density was similar across the Cedar Falls and Nashua sites (Table 2). In both years, grass stems densities were greatest in the Economy and Diversity mix compared to the Pollinator mix (Fig. 3C). However, by the second year Nashua’s Economy and Diversity mix had on average more grass stems than Cedar Falls Economy and Diversity mixes which resulted in a significant site × mix interaction (Table 2). Forb stem density was highest in the Pollinator and Diversity mixes across both years and sites while with the Economy mix established significantly fewer forbs (Fig. 3E). Additionally, native stem density of grasses and forbs showed differences in first year mowing management (Table 2). Mowing led to an increase of native grass and forb stems across both sites in each year compared to the unmowed plots (Fig. 3D,E).

Table 1. Repeated measures ANOVA comparing native species richness, grass and forb stems per meter squared between treatments. To meet the assumption of normality grass and forb stems were cube-root transformed. Between values represent variation within the factors, while within represents variation across the repeated measures (years). df = degrees of freedom for numerator and denominator; F = F-statistic; P = p-value. Significant terms ($p < 0.05$) are indicated in bold.

	Species Richness			Grass Stems (m^{-2})			Forb Stems (m^{-2})		
	df	F	P	*df*	F	P	*df*	F	P
Between									
Mow	1, 60	**8.189**	**0.006**	1, 60	**28.488**	**0.000**	1, 60	**12.103**	**0.001**
Seed Mix (SM)	2, 29	2.044	0.148	2, 29	**41.532**	**0.000**	2, 29	**9.721**	**0.001**
Seed Time (ST)	1, 29	3.200	0.084	1, 29	0.026	0.874	1, 29	**4.679**	**0.039**
Mow x SM	2, 60	0.331	0.720	2, 60	0.193	0.825	2, 60	0.202	0.818
Mow x ST	1, 60	0.817	0.370	1, 60	2.229	0.141	1, 60	0.150	0.700
SM x ST	2, 29	2.181	0.131	2, 29	1.671	0.206	2, 29	1.059	0.360
Mow x SM x ST	2, 60	0.142	0.868	2, 60	0.081	0.922	2, 60	0.163	0.850
Within									
Year (Y)	1, 30	**8.479**	**0.007**	1, 30	**84.089**	**0.000**	1, 30	**67.326**	**0.000**
Mow x Y	1, 60	0.426	0.516	1, 60	1.749	0.191	1, 60	0.150	0.700
SM x Y	2, 30	2.163	0.133	2, 30	3.768	0.035	2, 30	1.768	0.188
ST x Y	1, 30	1.838	0.185	1, 30	0.100	0.754	1, 30	0.488	0.490
Mow x SM x Y	2, 60	1.362	0.264	2, 60	0.239	0.789	2, 60	1.264	0.290
Mow x ST x Y	1, 60	0.000	1.000	1, 60	0.001	0.971	1, 60	0.133	0.716
SM x ST x Y	2, 30	1.828	0.178	2, 30	0.197	0.822	2, 30	**3.841**	**0.033**
Mow x SM x ST x Y	2, 30	0.074	0.929	2, 30	0.508	0.604	2, 30	0.139	0.871

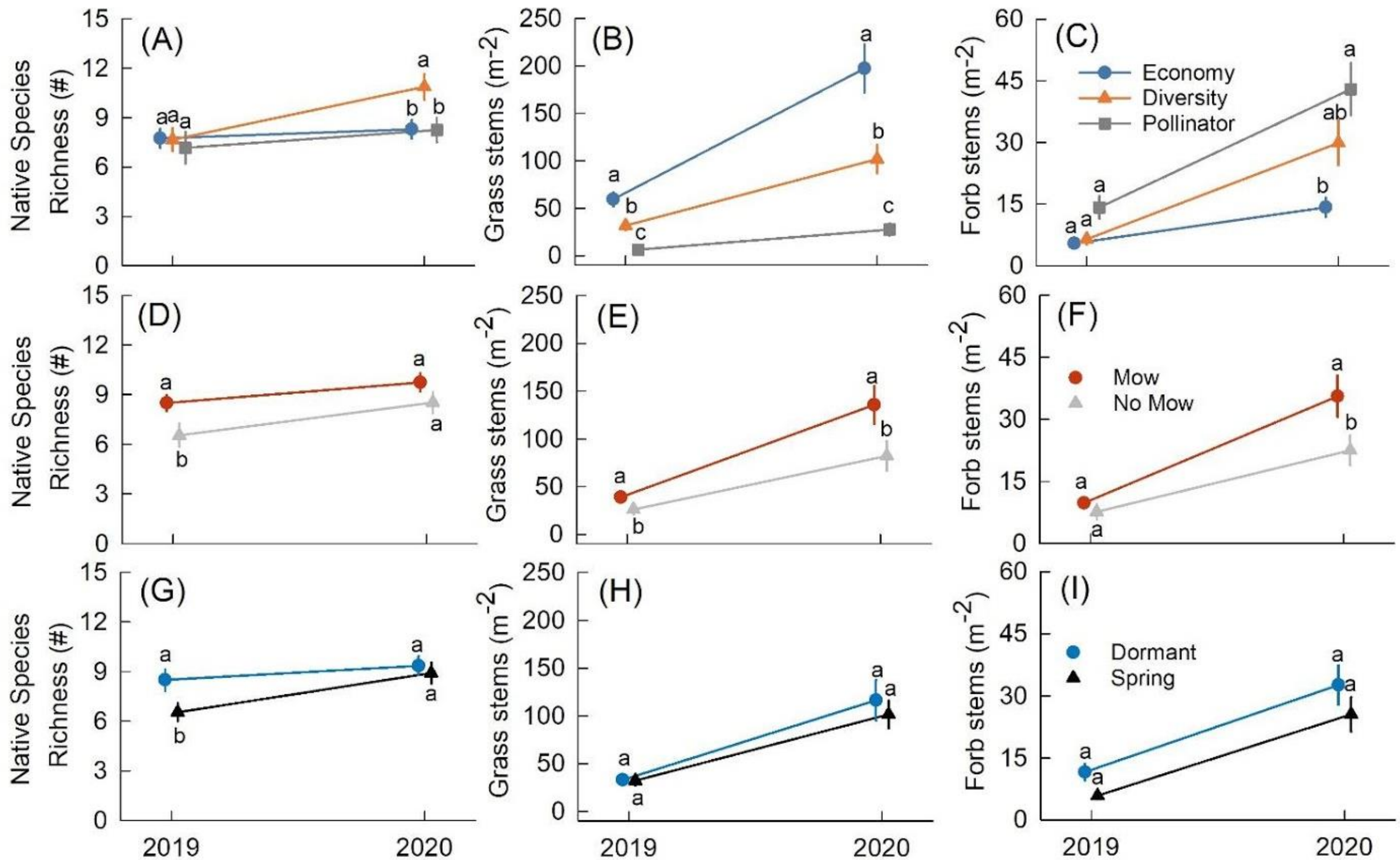

Figure 2. Effects of seed mix (A-C), first-year mowing management (D-F), and planting time (G-I) on native species richness (left column), grass stem density (center column), and forb stem density (right column). Error bars represent ± 1 SE. Lowercase letters denote significant differences within year via different letters.

Table 2. Repeated measures ANOVA comparing native species richness and grass and forb stems per meter squared across the two sites (Cedar Falls and Nashua) and other treatment combinations. To meet the assumption of normality grass and forb stems were cube-root transformed. Between values represent variation within the factors, while within represents variation across the repeated measures (planting age). df = degrees of freedom for numerator and denominator; F = F-statistic; P = p-value. Significant terms ($p < 0.05$) are indicated in bold.

	Species Richness			Grass Stems (m^{-2})			Forb Stems (m^{-2})		
	df	F	P	*df*	F	P	*df*	F	P
Between									
Site	1, 2	0.616	0.514	1, 2	0.053	0.839	1, 2	1.575	0.336
Mow	1, 58	**35.262**	**0.000**	1, 58	**99.680**	**0.000**	1, 58	**18.719**	**0.000**
Seed Mix (SM)	2, 28	**12.221**	**0.000**	2, 28	**84.860**	**0.000**	2, 28	**10.818**	**0.000**
Site x Mow	1, 58	0.832	0.365	1, 58	**5.701**	**0.020**	1, 58	0.101	0.752
Site x SM	2, 28	0.942	0.402	2, 28	**3.765**	**0.036**	2, 28	2.476	0.102
Mow X Mix	2, 58	0.585	0.560	2, 58	0.824	0.444	2, 58	0.625	0.539
Site x Mow x SM	2, 58	0.108	0.898	2, 58	0.532	0.590	2, 58	1.186	0.313
Within									
Planting Age (PA)	1, 30	**36.786**	**0.000**	1, 30	**157.787**	**0.000**	1, 30	**66.693**	**0.000**
Site x PA	1, 30	0.106	0.747	1, 30	**21.163**	**0.000**	1, 30	0.672	0.419
Mow x PA	1, 58	1.663	0.202	1, 58	2.906	0.094	1, 58	0.004	0.952
SM x PA	2, 30	1.416	0.258	2, 30	**10.102**	**0.000**	2, 30	**5.562**	**0.009**
Site x Mow x PA	1, 58	0.151	0.699	1, 58	0.051	0.822	1, 58	0.002	0.961
Site x SM x PA	2, 30	0.624	0.542	2, 30	**3.709**	**0.036**	2, 30	0.661	0.524
Mow x SM x PA	2, 58	1.289	0.283	2, 58	1.552	0.221	2, 58	0.373	0.690
Site x Mow x SM x PA	2, 58	1.176	0.316	2, 58	0.084	0.920	2, 58	1.953	0.151

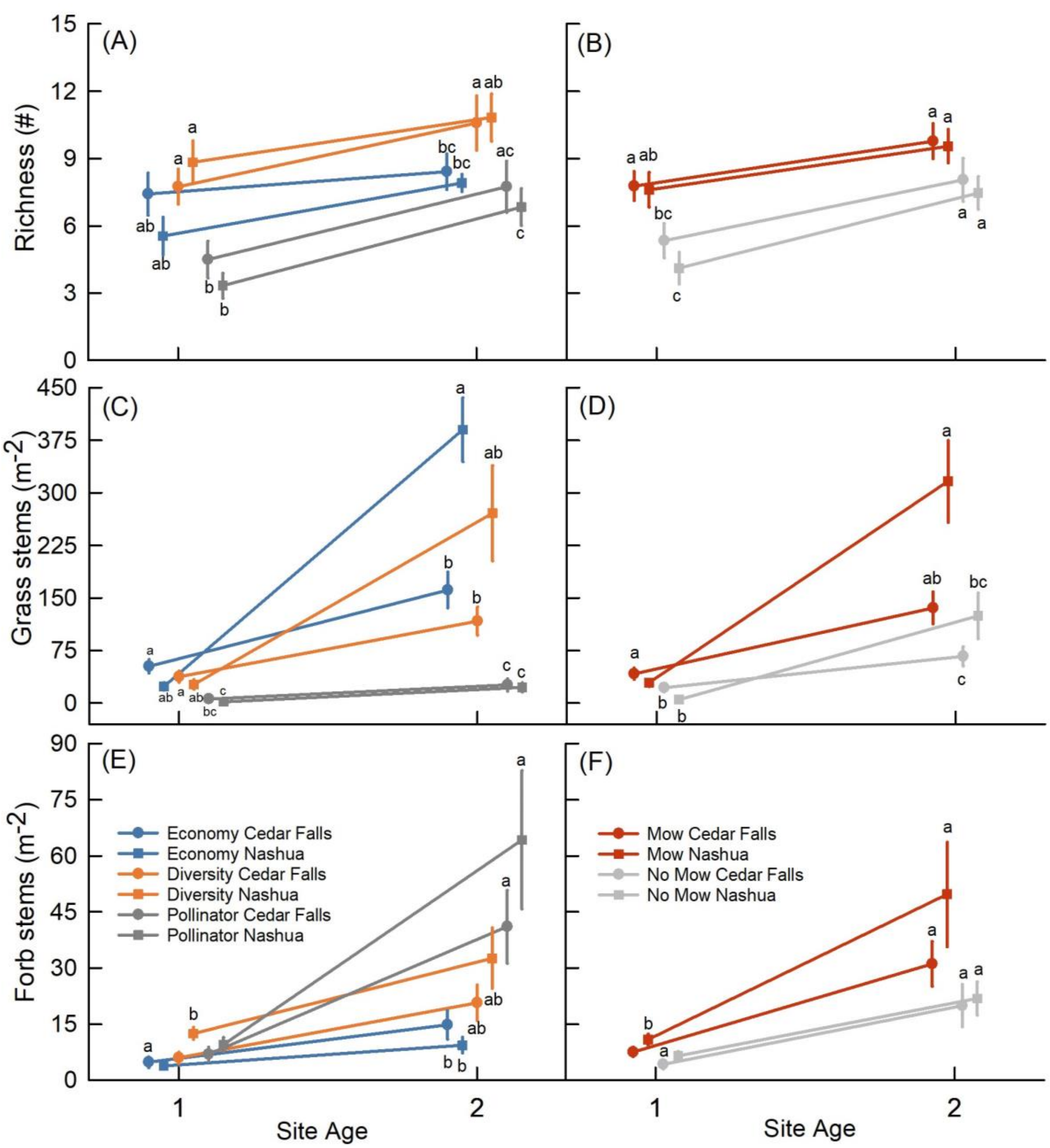

Figure 3. Effects of seed mix (A,C,E), first-year mowing management (B,D,F), and) on native species richness (top row), grass stem density (center row), and forb stem density (bottom row) for the first two growing seasons at Cedar Falls and Nashua. Error bars represent ± 1 SE. Lowercase letters denote significant differences within year via different letters.

Canopy Cover

At the Cedar Falls site, canopy cover of total natives, forbs, and grasses varied among the seed mixes (Table 3). Differences in native plant cover were marginal in the 2019, while the Economy and Diversity mix had greater native cover than the Pollinator mix in 2020 (Fig. 4A). Across both years native grass cover was highest in the Economy mix and lowest in the Pollinator mix (Fig 4B). Similarly, native forb cover was highest in the Pollinator mix in 2019, while both the Pollinator and Diversity mix had greater forb cover in 2020 than the Economy mix (Fig. 4C). Mowing had a significant effect on native plant and forb canopy cover in the first year, but this effect was no longer significant in the second year. However, in both years mowing produced significantly more native grasses. On average, mowed plots produced more native plant cover than unmowed plots, but the effects were not significant (Fig. 4D,E,F). Similarly, native plant cover was higher in dormant seeded stands across all years (Fig. 4G,H,I), but the effects were only significant in the first growing season (Table 3).

Table 3. Repeated measures ANOVA comparing canopy cover of total native plants (sown), forbs and grasses between treatment combinations. To meet the assumption of normality all three measures were cube-root transformed. Between values represent variation within the factors, while within represents variation across the repeated measures (years). df = degrees of freedom for numerator and denominator; F = F-statistic; P = p-value. Significant terms ($p < 0.05$) are indicated in bold.

	Total Native Cover			Grass Cover			Forb Cover		
	df	F	P	*df*	F	P	*df*	F	P
Between									
Mow	1, 60	**28.792**	**0.000**	1, 60	**37.110**	**0.000**	1, 60	**14.762**	**0.000**
Seed Mix (SM)	2, 29	**3.339**	**0.050**	2, 29	**44.952**	**0.000**	2, 29	**15.268**	**0.000**
Seed Time (ST)	1, 29	**8.897**	**0.006**	1, 29	0.655	0.425	1, 29	**8.681**	**0.006**
Mow x SM	2, 60	0.711	0.495	2, 60	0.427	0.654	2, 60	0.089	0.915
Mow x ST	1, 60	0.803	0.374	1, 60	2.939	0.092	1, 60	0.018	0.893
SM x ST	2, 29	2.145	0.135	2, 29	1.755	0.191	2, 29	2.584	0.093
Mow x SM x ST	2, 60	0.002	0.998	2, 60	0.118	0.889	2, 60	0.028	0.972
Within									
Year (Y)	1, 30	**162.260**	**0.000**	1, 30	**130.206**	**0.000**	1, 30	**70.627**	**0.000**
Mow x Y	1, 60	**4.069**	**0.048**	1, 60	0.954	0.333	1, 60	1.141	0.290
SM x Y	2, 30	**4.296**	**0.023**	2, 30	**18.621**	**0.000**	2, 30	2.599	0.091
ST x Y	1, 30	0.180	0.674	1, 30	0.088	0.769	1, 30	1.948	0.173
Mow x SM x Y	2, 60	1.743	0.184	2, 60	2.259	0.113	2, 60	3.658	0.032
Mow x ST x Y	1, 60	0.651	0.423	1, 60	0.040	0.842	1, 60	0.542	0.465
SM x ST x Y	2, 30	1.260	0.298	2, 30	0.875	0.427	2, 30	1.976	0.156
Mow x SM x ST x Y	2, 30	0.499	0.610	2, 30	0.216	0.807	2, 30	0.340	0.713

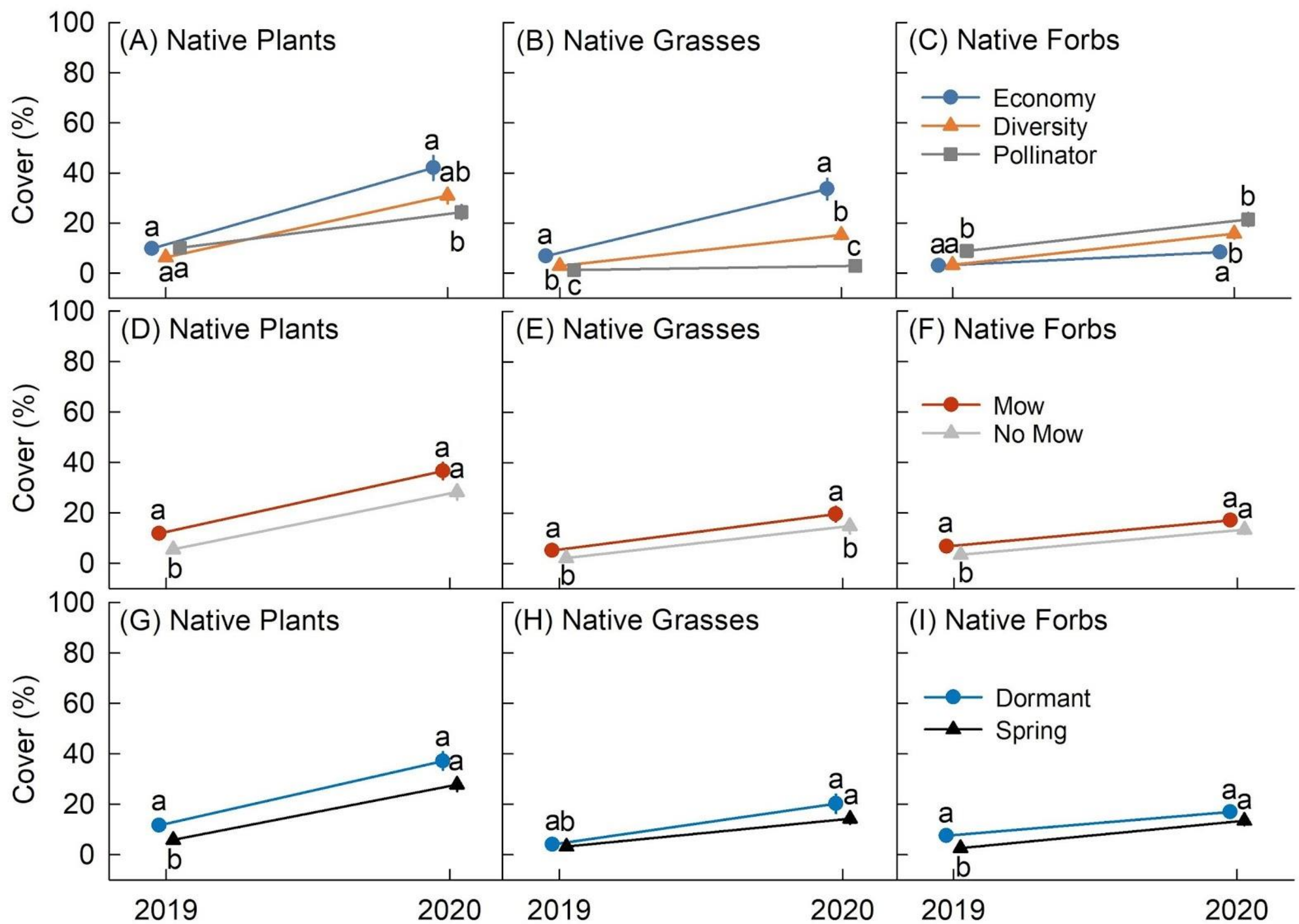

Figure 4. Canopy cover of native sown plants (left column), native sown grasses (center column), and native sown forbs (right column) by seed mix (A-C), first-year mowing management (D-F), and planting time (G-H). Error bars represent ± 1 SE. Lowercase letters denote significant differences within year via different letters.

At the Cedar Falls site, canopy cover of annual weeds, bare ground, unplanted natives, and perennial weeds did not differ among seed mixes across either year (Table 4). In 2020 annual weeds were lowest in the Economy mix, while bare ground cover was highest in the Pollinator mix (Fig. 5A,B). Unplanted natives and perennial weed cover increased slightly across all mixes by 2020, but no differences between mixes were found (Fig. 5C,D). First-year mowing management led to differences in annual weeds, bare ground, and perennial weed cover (Table 4). By the second growing season, stands that had been mowed had fewer annual weeds and decreased bare ground, while annual weeds of unmowed plots increased (Fig. 5E,F). Unplanted natives and perennial weeds accounted for less than 15 and 5-percent of site cover, respectively. Both were greater in mowed plots compared to unmowed plots during 2019 with no differences between mowing treatments by 2020 (Fig. 5G,H). Dormant season planting led to stands with less bare ground in 2020 (Table 4; Fig. 5J) compared to spring planting. Dormant plantings also produced stands with fewer annual weeds and unplanted native cover, but those effects were not significant (Fig. 5I,K).

Table 4. Repeated measures ANOVA comparing cover of annual weeds, bare ground, unplanted natives, and perennial weeds between treatment combinations. To meet the assumption of normality annual weeds and unplanted natives were cube-root transformed and perennial weeds were log transformed + 0.001. Between values represent variation within the factors, while within represents variation across the repeated measures (years). df = degrees of freedom for numerator and denominator; F = F-statistic; P = p-value. Significant terms ($p < 0.05$) are indicated in bold.

	Annual Weeds			Bare Ground			Unplanted Natives			Perennial Weeds		
	df	F	P	*df*	F	P	*df*	F	P	*df*	F	P
Between												
Mow	1, 60	**7.046**	**0.010**	1, 60	**90.406**	**0.000**	1, 60	2.676	0.107	1, 60	**9.808**	**0.003**
Seed Mix (SM)	2, 29	1.432	0.255	2, 29	0.307	0.738	2, 29	3.197	0.056	2, 29	0.981	0.387
Seed Time (ST)	1, 29	2.010	0.167	1, 29	**7.762**	**0.009**	1, 29	0.908	0.349	1, 29	3.671	0.065
Mow x SM	2, 60	2.291	0.110	2, 60	1.551	0.220	2, 60	0.611	0.546	2, 60	0.060	0.942
Mow x ST	1, 60	0.821	0.369	1, 60	0.121	0.730	1, 60	**4.046**	**0.049**	1, 60	0.073	0.788
SM x ST	2, 29	1.078	0.354	2, 29	0.378	0.688	2, 29	1.583	0.223	2, 29	0.136	0.873
Mow x SM x ST	2, 60	1.377	0.260	2, 60	2.179	0.122	2, 60	0.036	0.964	2, 60	1.010	0.370
Within												
Year (Y)	1, 30	**6.696**	**0.015**	1, 30	**287.377**	**0.000**	1, 30	**101.796**	**0.000**	1, 30	**13.532**	**0.001**
Mow x Y	1, 60	**38.489**	**0.000**	1, 60	**31.983**	**0.000**	1, 60	**5.573**	**0.022**	1, 60	0.809	0.372
SM x Y	2, 30	**4.820**	**0.015**	2, 30	**4.101**	**0.027**	2, 30	1.089	0.350	2, 30	0.131	0.878
ST x Y	1, 30	0.217	0.645	1, 30	0.429	0.517	1, 30	0.068	0.797	1, 30	1.795	0.190
Mow x SM x Y	2, 60	0.174	0.841	2, 60	1.634	0.204	2, 60	0.101	0.904	2, 60	0.395	0.675
Mow x ST x Y	1, 60	0.403	0.528	1, 60	0.395	0.532	1, 60	0.015	0.904	1, 60	1.647	0.204
SM x ST x Y	2, 30	1.371	0.269	2, 30	1.304	0.286	2, 30	3.011	0.064	2, 30	0.919	0.410
Mow x SM x ST x Y	2, 90	0.606	0.549	2, 90	0.328	0.722	2, 90	0.066	0.936	2, 90	0.396	0.674

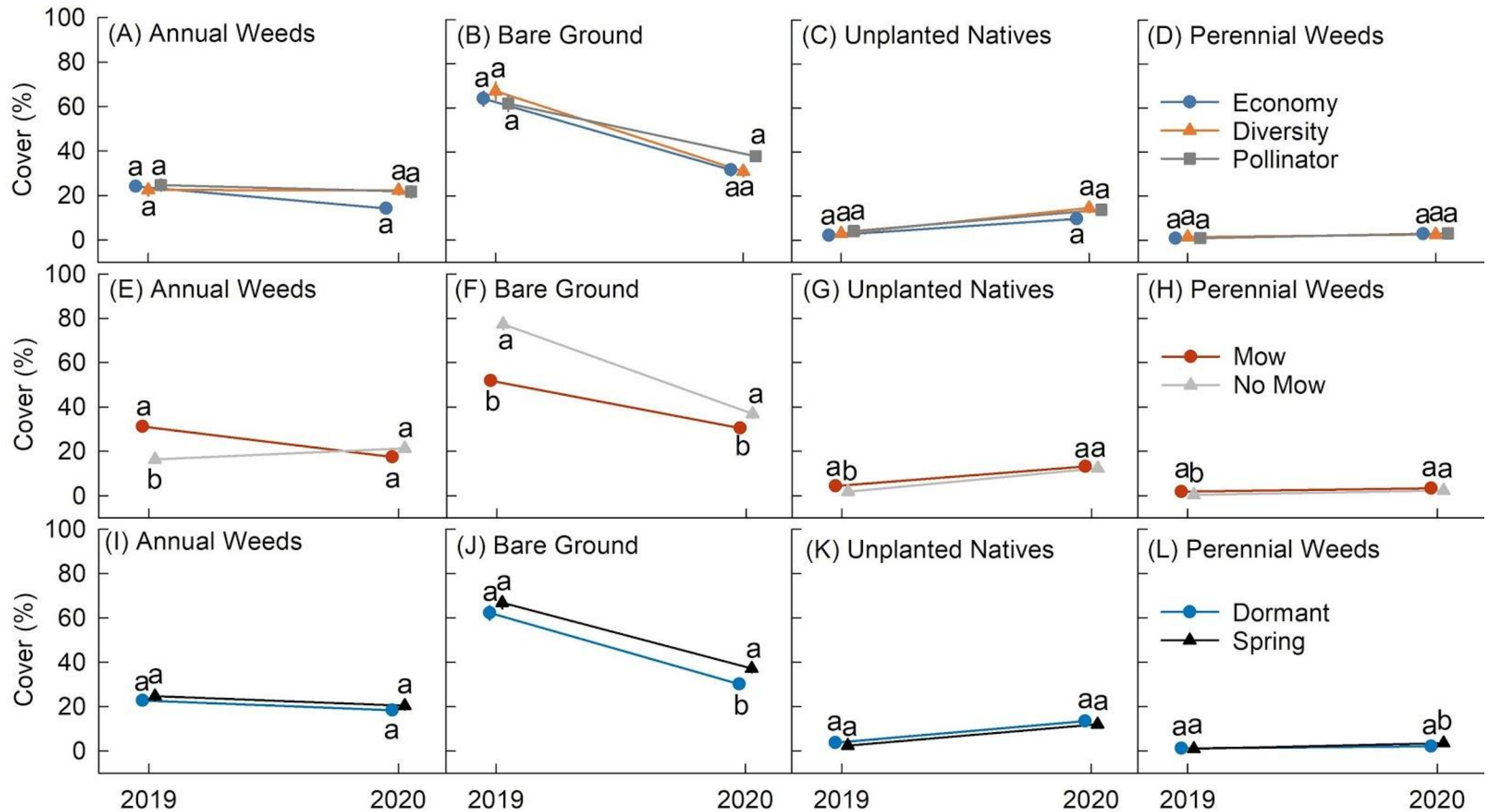

Figure 5. Canopy cover of annual weeds (first column), bare ground (second column), unplanted natives (third column), and perennial weeds (fourth column) based on seed mix (A-D), first-year mowing management (E-H), and planting time (I-L). Error bars represent ± 1 SE. Lowercase letters denote significant differences within year via different letters.

Canopy cover of native plants, annual weeds, bare ground, and perennial weeds each showed differences between the two sites in the second growing season (Table 5). More specifically, the Cedar Falls site had fewer native plant and annual weed cover, and more bare ground across all seed mixes. However, canopy cover patterns between the different seed mix design were apparent at both sites and produced differences in native plant and annual weed cover (Table 5). Within both sites the Economy and Diversity mix established stands with greater native plant cover and fewer annual weed cover than the Pollinator mix. Similarly, mowing led to increased native plant cover and on average a decrease in annual weeds in both sites (Table 5).

Table 5. Repeated measures ANOVA comparing cover of native plants, annual weeds, bare ground, and perennial weeds across the two sites (Cedar Falls and Nashua) in the second growing season and other treatment combinations. To meet the assumption of normality native plants and bare ground were square root transformed and perennial weeds were log transformed + 0.1. Between values represent variation within the factors. df = degrees of freedom for numerator and denominator; F = F-statistic; P = p-value. Significant terms ($p < 0.05$) are indicated in bold.

	Native Plants			Annual Weeds			Bare Ground			Perennial Weeds		
	df	F	P	*df*	F	P	*df*	F	P	*df*	F	P
Between												
Site	1, 2	14.052	0.064	1, 2	**24.908**	**0.038**	1, 2	**74.930**	**0.013**	1, 2	**26.638**	**0.036**
Mow	1, 29	**48.211**	**0.000**	1, 29	**52.795**	**0.000**	1, 29	0.388	0.538	1, 29	0.750	0.394
Seed Mix (SM)	2, 28	**5.603**	**0.009**	2, 28	**4.256**	**0.024**	2, 28	1.709	0.199	2, 28	0.187	0.831
Site x Mow	1, 29	**5.948**	**0.021**	1, 29	**43.106**	**0.000**	1, 29	**6.614**	**0.016**	1, 29	0.005	0.947
Site x SM	2, 28	0.127	0.882	2, 28	0.470	0.630	2, 28	0.055	0.947	2, 28	1.078	0.354
Mow X Mix	2, 29	0.181	0.835	2, 29	0.016	0.984	2, 29	0.479	0.624	2, 29	1.735	0.194
Site x Mow x SM	2, 29	0.336	0.717	2, 29	0.435	0.651	2, 29	2.356	0.113	2, 29	1.393	0.264

Functional Group Stem Density

In mowed plots, warm-season grass stem density was significantly higher than unmowed plots across both years, and the effects were more pronounced by 2020 (Table 6; Fig. 6A). First-year management did not affect cool-season grass cover (Table 6). Additionally, both warm and cool-season grasses varied across planting times (Table 6). More specifically, spring plantings on average had increased warm-season grasses, but the effects were only significant in 2020 (Fig. 6C). In contrast, dormant plantings increased cool-season grasses significantly across both years (Fig. 6D).

Table 6. Repeated measures ANOVA comparing warm and cool-season stems per meter squared between treatments. To meet the assumption of normality both warm and cool-season grass stems were cube-root transformed. Between values represent variation within the factors, while within represents variation across the repeated measures (years). df = degrees of freedom for numerator and denominator; F = F-statistic; P = p-value. Significant terms ($p < 0.05$) are indicated in bold.

	Warm Season Stems (m^{-2})			Cool Season Stems (m^{-2})		
	df	F	P	*df*	F	P
Between						
Mow	1, 60	**62.822**	**0.000**	1, 60	0.030	0.862
Seed Mix (SM)	2, 29	**27.714**	**0.000**	2, 29	**64.238**	**0.000**
Seed Time (ST)	1, 29	**9.473**	**0.005**	1, 29	**20.483**	**0.000**
Mow x SM	2, 60	2.141	0.126	2, 60	0.326	0.723
Mow x ST	1, 60	0.517	0.475	1, 60	0.988	0.324
SM x ST	2, 29	0.815	0.453	2, 29	2.390	0.109
Mow x SM x ST	2, 60	0.321	0.726	2, 60	0.738	0.482
Within						
Year (Y)	1, 30	**19.030**	**0.000**	1, 30	**77.757**	**0.000**
Mow x Y	1, 60	**6.246**	**0.015**	1, 60	0.527	0.471
SM x Y	2, 30	0.511	0.605	2, 30	**7.288**	**0.003**
ST x Y	1, 30	1.993	0.168	1, 30	0.765	0.389
Mow x SM x Y	2, 60	0.423	0.657	2, 60	1.044	0.358
Mow x ST x Y	1, 60	0.012	0.914	1, 60	0.160	0.690
SM x ST x Y	2, 30	1.001	0.379	2, 30	0.487	0.619
Mow x SM x ST x Y	2, 60	0.201	0.818	2, 60	0.130	0.878

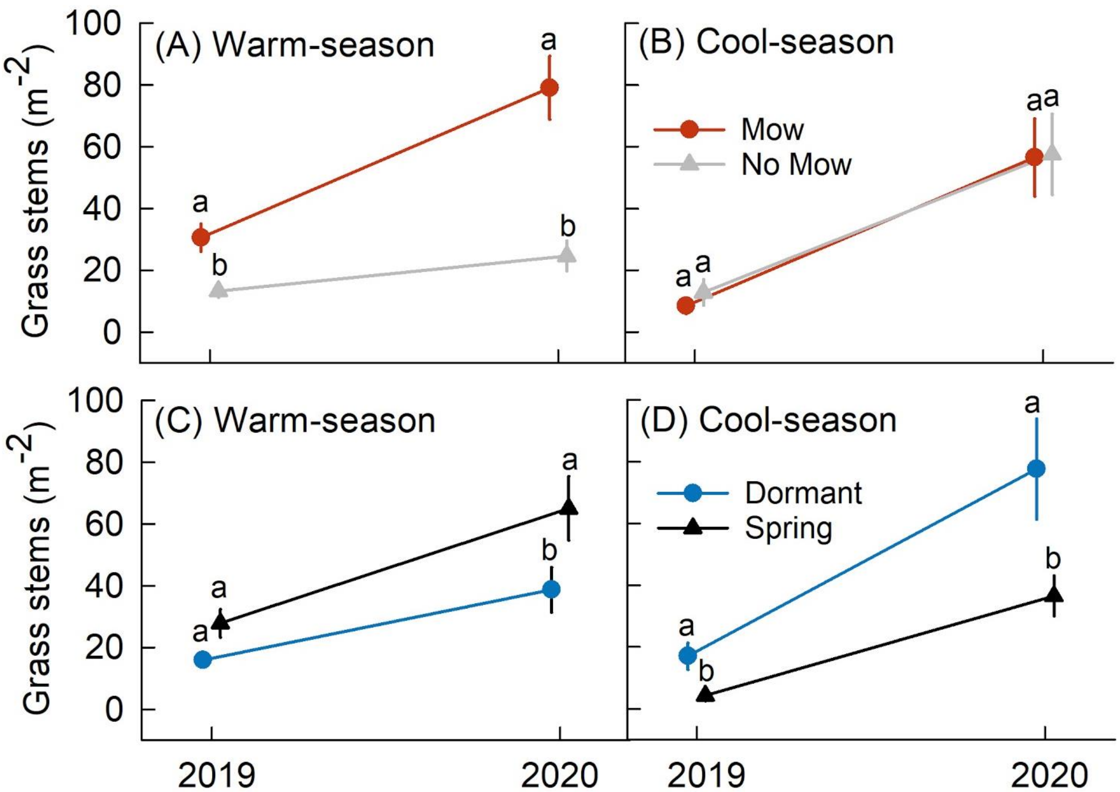

Figure 6. Stem density of warm-season (left column) and cool-season grasses (right column) based on first-year mowing management (A-B) and planting time (C-D). Error bars represent ± 1 SE. Lowercase letters denote significant differences within year via different letters.

Mowing had no effect on spring forbs while summer forb stem density was significantly higher than unmowed plots with effects more pronounced by 2020 (Table 7; Fig. 7B). Mowing management's influence on fall forbs stem density was statistically significant (Table 7), however, there was a significant three-way interaction (Table 7) that obscures the interpretation of Fig. 7C. Planting time significantly affected spring and fall forb stem density, but not summer forb stems (Table 7). Dormant plantings increased spring forb stem density by 2020 and had a more pronounced effect on fall forbs in both 2019 and 2020 (Fig. 7DF).

Table 7. Repeated measures ANOVA comparing spring, summer, and fall forb stems per meter squared between treatments. To meet the assumption of normality both warm and cool-season grass stems were cube-root transformed. Between values represent variation within the factors, while within represents variation across the repeated measures (years). df = degrees of freedom for numerator and denominator; F = F-statistic; P = p-value. Significant terms ($p < 0.05$) are indicated in bold.

	Spring Forb Stems (m^{-2})			Summer Forbs Stems (m^{-2})			Fall Forbs Stems (m^{-2})		
	df	F	P	*df*	F	P	*df*	F	P
Between									
Mow	1, 60	2.526	0.117	1, 60	**9.853**	**0.003**	1, 60	**8.129**	**0.006**
Seed Mix (SM)	2, 29	**7.329**	**0.003**	2, 29	**6.938**	**0.003**	2, 29	**11.145**	**0.000**
Seed Time (ST)	1, 29	**21.835**	**0.000**	1, 29	0.012	0.914	1, 29	**21.430**	**0.000**
Mow x SM	2, 60	1.443	0.244	2, 60	0.633	0.534	2, 60	1.779	0.178
Mow x ST	1, 60	0.051	0.821	1, 60	0.908	0.344	1, 60	0.460	0.500
SM x ST	2, 29	0.595	0.558	2, 29	0.676	0.517	2, 29	1.195	0.317
Mow x SM x ST	2, 60	0.825	0.443	2, 60	1.062	0.352	2, 60	3.143	0.0503
Within									
Year (Y)	1, 30	**17.874**	**0.000**	1, 30	**45.385**	**0.000**	1, 30	**27.153**	**0.000**
Mow x Y	1, 60	0.464	0.498	1, 60	0.580	0.449	1, 60	0.329	0.568
SM x Y	2, 30	1.387	0.265	2, 30	1.447	0.251	2, 30	1.459	0.248
ST x Y	1, 30	1.239	0.275	1, 30	1.535	0.225	1, 30	0.150	0.701
Mow x SM x Y	2, 60	0.619	0.542	2, 60	1.229	0.300	2, 60	1.654	0.200
Mow x ST x Y	1, 60	0.464	0.498	1, 60	0.326	0.570	1, 60	0.037	0.848
SM x ST x Y	2, 30	0.791	0.463	2, 30	1.723	0.196	2, 30	2.035	0.148
Mow x SM x ST x Y	2, 60	0.618	0.542	2, 60	0.453	0.638	2, 60	2.809	0.068

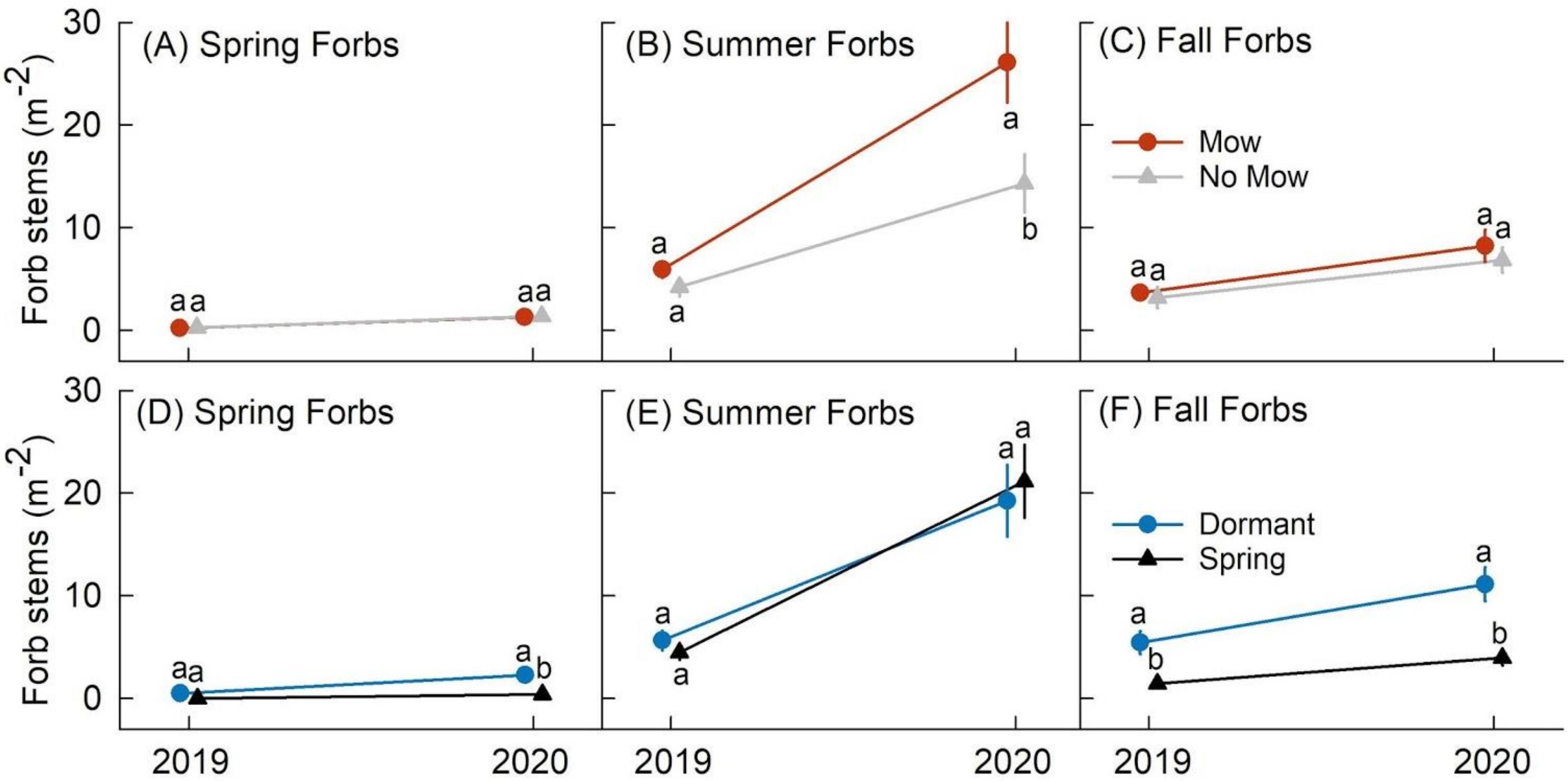

Figure 7. Forb stem density of spring (left column), summer (center column), and fall (right column) forbs based on first-year mowing management (A-C) and planting time (D-F). Error bars represent ± 1 SE. Lowercase letters denote significant differences within year via different letters.

Canopy Fill

Canopy fill measured by percent uPar availability at the ground level did not show differences between seed mixes or first-year management (Table 8). This is most likely due to the canopy's continued growth throughout the summer. However, there was a consistent trend where dormant plantings had less available uPar suggesting that they are denser than the spring plantings. This effect was significant in the late growing period (Fig. 8C). At a height of 1-m where it takes more time for canopy to fill, we saw differences in seed mix design and planting time but not first-year mowing management (Table 8). By mid-summer the Diversity and Economy mixes had significantly more canopy fill than the Pollinator mix. This trend continued into late summer where the Diversity mix showed the greatest degree of canopy fill followed by the Economy mix (Fig. 8A). At 1-m we found that the dormant planting had significantly more canopy fill in mid-summer, but that effect was no longer significant by late summer (Fig. 8C).

Table 8. Repeated measures ANOVA comparing uPar availability at ground and 1-m heights between treatment combinations. To meet the assumption of normality measurements at ground level were cube-root transformed and 1-m height were squared. Between values represent variation within the factors, while within represents variation across the repeated measures (time period). df = degrees of freedom for numerator and denominator; F = F-statistic; P = p-value. Significant terms ($p < 0.05$) are indicated in **bold**.

	Ground Level (uPar)			One Meter (uPar)		
	df	F	P	*df*	F	P
Between						
Mow	1, 90	0.454	0.502	1, 90	0.529	0.469
Seed Mix (SM)	2, 29	0.433	0.653	2, 29	**3.834**	**0.033**
Seed Time (ST)	1, 29	**7.796**	**0.009**	1, 29	**5.154**	**0.031**
Mow x SM	2, 90	1.742	0.181	2, 90	0.459	0.634
Mow x ST	1, 90	**4.575**	**0.035**	1, 90	0.187	0.666
SM x ST	2, 29	0.712	0.499	2, 29	0.816	0.452
Mow x SM x ST	2, 90	0.372	0.690	2, 90	1.930	0.151
Within						
Time Period (TP)	2, 60	**56.346**	**0.000**	2, 60	**162.339**	**0.000**
Mow x TP	2, 90	2.478	0.090	2, 90	0.459	0.633
SM x TP	4, 60	1.817	0.137	4, 60	1.941	0.115
ST x TP	2, 60	0.963	0.388	2, 60	2.557	0.086
Mow x SM x TP	4, 90	0.598	0.665	4, 90	0.233	0.919
Mow x ST x TP	2, 90	1.132	0.327	2, 90	1.236	0.295
SM x ST x TP	4, 60	0.516	0.724	4, 60	0.649	0.630
Mow x SM x ST x TP	4, 90	0.104	0.981	4, 90	0.513	0.726

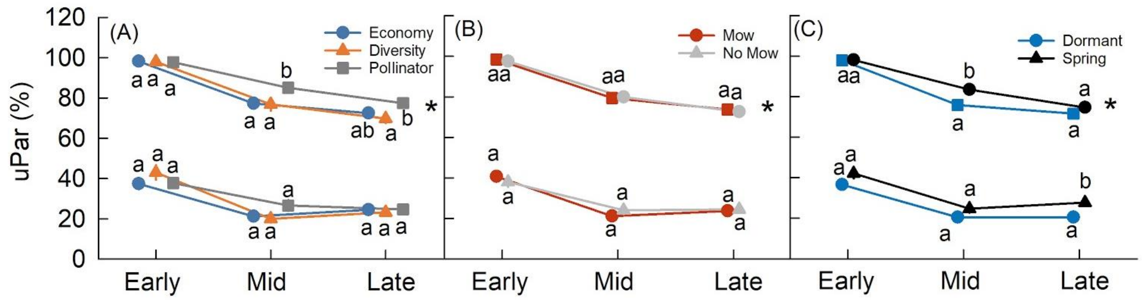

Figure 8. Percent photosynthetically active radiation (uPar) at ground level and 1-m height (*) over the three survey time periods (early, mid, and late) in 2020 based on seed mix (A), first-year mowing management (B), and planting time (C). Error bars represent ± 1 SE. Lowercase letters denote significant differences within year via different letters.

<u>Inflorescences</u>

Cumulative floral resources for pollinators varied significantly among the seed mixes in both years (Table 9). The Pollinator mix produced the highest number of flowers while the Economy mix produced the fewest (Fig. 9). Mowing marginally influenced floral abundance (p=0.055) while planting time planting time produced no differences (Table 9) (Fig. 9).

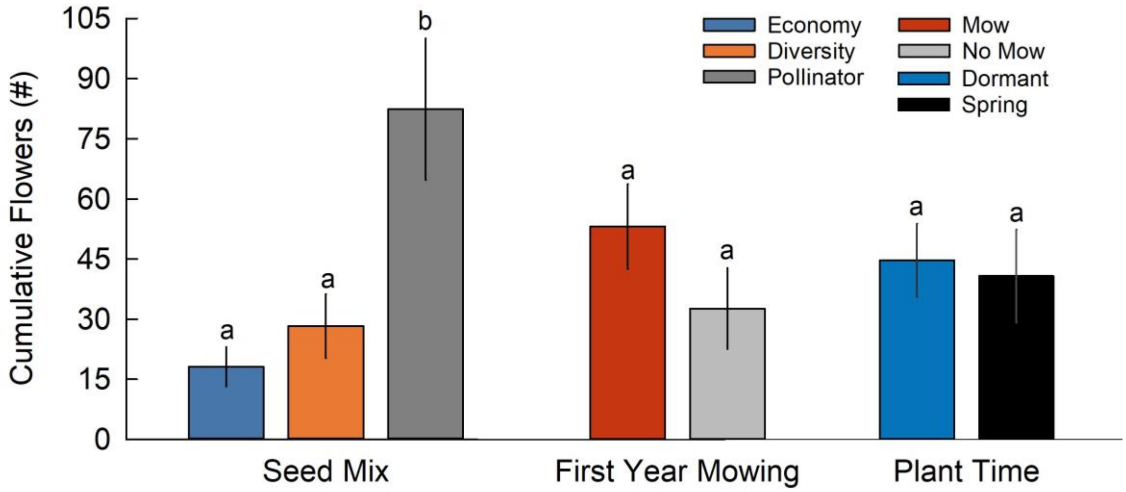

Figure 9. Cumulative flowers from 2019-2020 based on seed mix, first-year mowing management, and planting time. Error bars represent ± 1 SE. Lowercase letters denote significant differences within year via different letters.

Floral richness was affected by all three treatments (Table 9). In 2019, seed mix design did not influence floral richness, but by 2020 the Diversity mix had significantly higher richness, the Economy mix had the lowest, while the Pollinator mix was between them (Fig. 10A). Floral richness was also significantly greater in plots that had been mowed (Fig. 10B) and those that had been planted in the dormant season (Fig. 10C) across both years.

Table 9. Repeated measures ANOVA comparing floral richness and cumulative flowers between treatment combinations. To meet the assumption of normality floral richness was square root transformed and cumulative flowers were cube-root transformed. Between values represent variation within the factors, while within represents variation across the repeated measures (year). df = degrees of freedom for numerator and denominator; F = F-statistic; P = p-value. Significant terms (p < 0.05) are indicated in bold.

	Cumulative Flowers			Floral Richness		
	df	F	P	*df*	F	P
Between						
Mow	1, 30	3.990	0.055	1, 60	**81.695**	**0.000**
Seed Mix (SM)	2, 29	**9.317**	**0.001**	2, 29	**5.992**	**0.007**
Seed Time (ST)	1, 29	1.383	0.249	1, 29	**68.408**	**0.000**
Mow x SM	2, 30	0.850	0.437	2, 60	0.786	0.460
Mow x ST	1, 30	0.604	0.443	1, 60	1.441	0.235
SM x ST	2, 29	1.181	0.321	2, 29	1.807	0.182
Mow x SM x ST	2, 30	1.131	0.336	2, 60	0.868	0.425
Within						
Year (Y)				1, 30	**370.749**	**0.000**
Mow x Y				1, 60	3.607	0.062
SM x Y				2, 30	**11.057**	**0.000**
ST x Y				1, 30	2.392	0.132
Mow x SM x Y				2, 60	0.276	0.760
Mow x ST x Y				1, 60	1.218	0.274
SM x ST x Y				2, 30	**3.919**	**0.031**
Mow x SM x ST x Y				2, 60	1.726	0.187

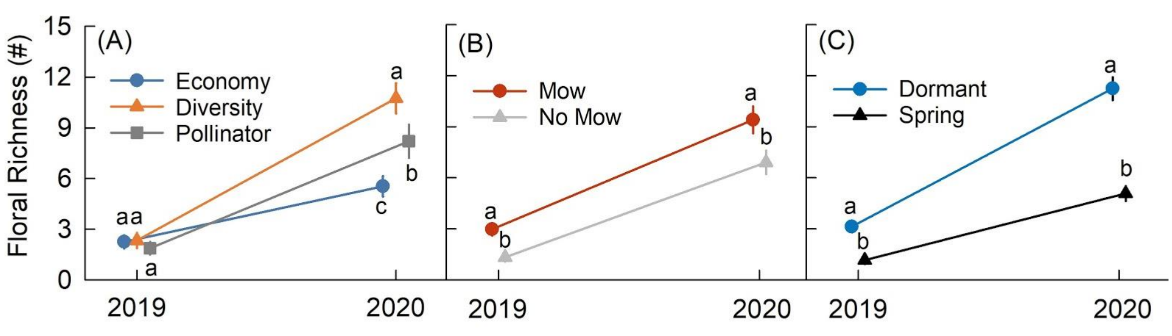

Figure 10. Mean floral richness by seed mix (A), first-year mowing management (B), and planting time (C). Error bars represent ± 1 SE. Lowercase letters denote significant differences within year via different letters.

Floral Resources

The number of floral resources available in the second growing season did not show seed mix design differences in the ANOVA model (Table 10). However, post-hoc analysis suggests the Pollinator mix produced significantly more flowers than the Economy and Diversity mixes in the mid-season (Fig. 11A). This is most likely attributed to Rudbeckia hirta which accounted for 95 percent of the total flowers in the Pollinator mix with a total of 2,071 inflorescences (Table 11). Additionally, floral richness within survey quadrats did not show differences through seed mix design (Table 10) and was found to be similar across all seed mixes (Fig. 11B). While quadrat level richness did not account for seed mix differences; floral presence, the timed measure of richness showed that seed mixes did produce varying richness (Table 10), and while mixes were the same in the early and mid-surveys by the late survey the Diversity mix had the highest number of different flowers present (Fig. 11C).

Table 10. Repeated measures ANOVA comparing flowers per meter squared, floral richness per meter squared and floral presence between treatment combinations. To meet the assumption of normality flowers and floral richness were log(y) + 0.001 transformed and floral presences was cube-root transformed. Between values represent variation within the factors, while within represents variation across the repeated measures (time period). df = degrees of freedom for numerator and denominator; F = F-statistic; P = p-value. Significant terms ($p < 0.05$) are indicated in bold.

	Flowers (m^{-2})			Floral Richness			Floral Presence		
	df	F	P	*df*	F	P	*df*	F	P
Between									
Mow	1, 90	**9.856**	**0.002**	1, 90	**8.508**	**0.004**	1, 90	**65.733**	**0.000**
Seed Mix (SM)	2, 29	1.051	0.363	2, 29	0.250	0.78	2, 29	**5.398**	**0.010**
Seed Time (ST)	1, 29	0.006	0.937	1, 29	0.161	0.691	1, 29	**121.049**	**0.000**
Mow x SM	2, 90	2.694	0.073	2, 90	2.485	0.089	2, 90	0.078	0.925
Mow x ST	1, 90	0.042	0.839	1, 90	0.343	0.56	1, 90	**6.067**	**0.016**
SM x ST	2, 29	0.041	0.960	2, 29	0.076	0.927	2, 29	0.877	0.427
Mow x SM x ST	2, 90	1.760	0.178	2, 90	1.952	0.148	2, 90	2.415	0.095
Within									
Time Period (TP)	2, 60	**84.77**	**0.000**	2, 60	**71.167**	**0.000**	2, 60	**781.341**	**0.000**
Mow x TP	2, 90	0.056	0.946	2, 90	0.058	0.944	2, 90	**9.15**	**0.000**
SM x TP	4, 60	2.147	0.086	4, 60	2.045	0.099	4, 60	**9.444**	**0.000**
ST x TP	2, 60	**3.748**	**0.029**	2, 60	**3.974**	**0.024**	2, 60	**23.511**	**0.000**
Mow x SM x TP	4, 90	2.405	0.055	4, 90	2.371	0.058	4, 90	0.252	0.908
Mow x ST x TP	2, 90	**3.208**	**0.045**	2, 90	**3.367**	**0.039**	2, 90	**8.395**	**0.000**
SM x ST x TP	4, 60	1.570	0.194	4, 60	1.593	0.188	4, 60	1.172	0.332
Mow x SM x ST x TP	4, 90	0.668	0.616	4, 90	0.701	0.593	4, 90	**4.234**	**0.003**

Table 11. Floral richness and evenness from floral density surveys at each of the three blooming periods.

	Economy			Diversity			Pollinator		
	Species	Percent	Total	Species	Percent	Total	Species	Percent	Total
Early	*Zizia aurea*	100.00%	4				*Zizia aurea*	100.00%	21
Mid	*Rudbeckia hirta*	74.36%	438	*Rudbeckia hirta*	86.01%	461	*Rudbeckia hirta*	95.00%	2073
	Heliopsis helianthoides	10.53%	62	*Pycnanthemum pilosum*	4.66%	25	*Ratibida pinnata*	2.47%	54
	Monarda fistulosa	7.13%	42	*Heliopsis helianthoides*	3.54%	19	*Monarda fistulosa*	2.34%	51
	Ratibida pinnata	6.11%	36	*Ratibida pinnata*	2.99%	16	*Astragalus canadensis*	0.09%	2
	Astragalus canadensis	1.87%	11	*Monarda fistulosa*	1.87%	10	*Dalea candida*	0.09%	2
				Astragalus canadensis	0.93%	5			
Late	*Heliopsis helianthoides*	31.03%	18	*Pycnanthemum pilosum*	35.38%	23	*Rudbeckia hirta*	68.75%	22
	Ratibida pinnata	27.59%	16	*Heliopsis helianthoides*	27.69%	18	*Helenium autumnale*	25.00%	8
	Rudbeckia hirta	15.52%	9	*Rudbeckia hirta*	13.85%	9	*Ratibida pinnata*	6.25%	2
	Rudbeckia subtomentosa	15.52%	9	*Chamaecrista fasciculata*	9.23%	6			
	Helenium autumnale	10.34%	6	*Symphyotrichum laeve*	9.23%	6			
				Euthamia graminifolia	1.54%	1			
				Ratibida pinnata	1.54%	1			
				Vernonia fasciculata	1.54%	1			

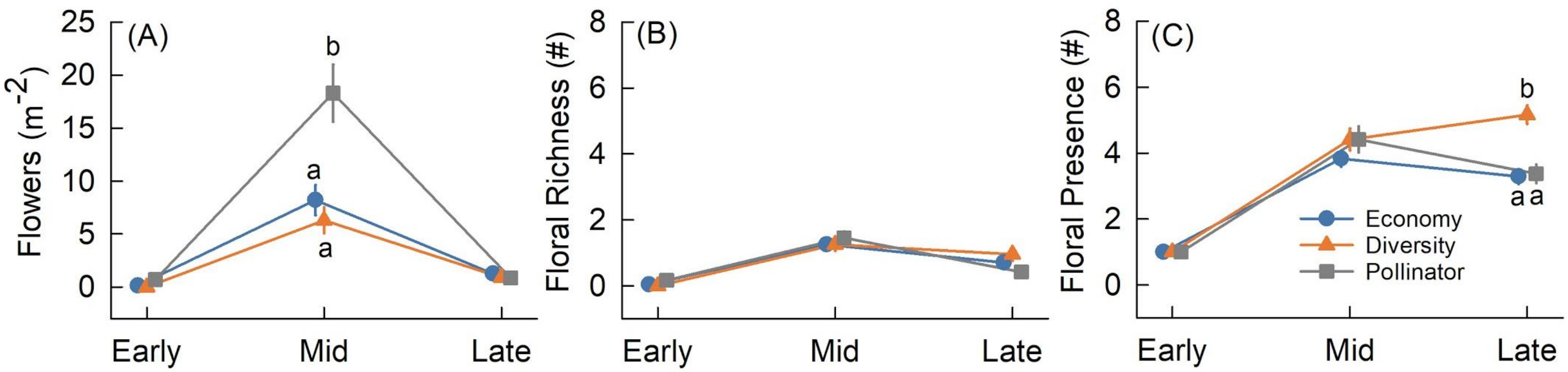

Figure 11: Flower density (A), floral richness (B) and floral presence (C) during the three survey periods (early, mid, and late) in 2020. Error bars represent ± 1 SE. Lowercase letters denote significant differences within year via different letters.

Cost-Effectiveness

The cost to produce 1000 native stems varied among two treatments: seed mix design and first year mowing management (Table 12). Among the seed mixes, the Economy mix had the lowest cost ($0.41 ± 0.08), the Pollinator mix cost the most ($9.52 ± 5.07), and the Diversity mix fell between them but with a cost ($1.69 ± 0.41) closer to the Economy mix (Table 13). When first year mowing was applied the cost per 1000 native stems decreased across all seed mix treatments. Planting time did not affect cost effectiveness (Table 12).

Table 12. Repeated measures ANOVA comparing cost to produce one thousand stems in stands during the second growing season (2020) between treatment combinations. To meet the assumption of normality cost to produce one thousand stems was log transformed + 0.001. Between values represent variation within the factors. df = degrees of freedom for numerator and denominator; F = F-statistic; P = p-value. Significant terms ($p < 0.05$) are indicated in bold.

	Cost 1k Stems		
	df	F	P
Between			
Mow	1, 87	**17.984**	**0.000**
Seed Mix (SM)	2, 29	**84.819**	**0.000**
Seed Time (ST)	1, 29	1.670	0.207
Mow x SM	2, 87	0.232	0.794
Mow x ST	1, 87	2.627	0.109
SM x ST	2, 29	1.360	0.273
Mow x SM x ST	2, 87	0.664	0.517
Within			
Year (Y)	1, 87	**108.648**	**0.000**
Mow x Y	1, 87	0.755	0.387
SM x Y	2, 87	0.109	0.897
ST x Y	1, 87	0.195	0.660
Mow x SM x Y	2, 87	0.193	0.825
Mow x ST x Y	1, 87	0.290	0.592
SM x ST x Y	2, 87	0.671	0.514
Mow x SM x ST x Y	2, 87	0.184	0.832

Table 13. Mean cost to produce 1000 native stems in 2020 across treatment combinations. Standard error is indicated in parenthesis.

		Cost 1k Stems		
		Economy	Diversity	Pollinator
Mix		$0.41 (0.08)	$1.69 (0.41)	$9.52 (5.07)
Mow				
	Dormant	$0.23 (0.05)	$1.38 (0.47)	$4.80 (2.61)
	Spring	$0.32 (0.11)	$0.84 (0.16)	$3.25 (0.89)
No Mow				
	Dormant	$0.60 (0.30)	$1.60 (0.21)	$4.39 (1.16)
	Spring	$0.50 (0.11)	$2.94 (1.51)	$25.63 (19.88)

CHAPTER 4

DISCUSSION

In this study we evaluated the effects of seed mix design, planting time, and first-year mowing management on the vegetation outcomes of prairie reconstructions. We found all three treatments influenced native species establishment and that seed mix design and mowing had the most influence on native stem density. Planting time did not affect overall stem density; however, it strongly influenced functional group composition. Spring planting favored warm-season grasses, whereas dormant season planting favored cool-season grasses and spring and fall forbs. In addition to evaluating vegetation outcomes, this study also evaluated how robust the effects of seed mix design and mowing treatments were across two central Iowa sites. Our results suggest that these two treatments had more influence on establishment trends than local site conditions. Overall, Nashua established a greater abundance of native stems than Cedar Falls, but the establishment patterns within seed mix and mowing treatments stayed similar across sites. Our third inquiry addressed the ability of a diverse, evenly balanced grass-to-forb mix to simultaneously fulfill the goals of common conservation practices. We found that the Diversity mix produce stands with similar canopy fill to the Economy mix, which is in line with the canopy cover goals of CP25. However, our assessment of the Diversity mix's ability to produce floral resources for pollinators consistent with the goals of CP42 produced conflicting results. We found that the Diversity mix produced far fewer inflorescences compared to the Pollinator mix, however, floral richness was greater in the

Diversity mix than the Pollinator. Neither mix produced three species in bloom during each of the three seasonal periods defined by CP42.

Seed Mix Design

Native establishment differed between seed mixes in a manner consistent with the proportion of seed in the mix. We found the Economy mix (3:1 grass to forb) had the highest number of grasses and native cover but established the fewest forbs. In contrast, the Pollinator mix (1:3 grass to forb) established the fewest grasses but had the highest forb stem density. The Diversity mix (1:1 grass to forb) established the greatest species richness and a grass stem density intermediate to the other mixes but was comparable to the Economy mix in grass cover. It also had similar forb establishment to the Pollinator mix. These establishment results are consistent with Larson et al. (2011), Larson et al. (2017) and Meissen et al. (2020); both reported an increase in native stem density with proportion of grasses in the seed mix. An increase in native stem density and cover has been shown to decrease excess nutrients and soil erosion (Boyd 1942; Zuazo & Pleguezuelo 2009). Our results suggest that both the Diversity and Economy mixes would be suitable candidates to fulfil these ecosystem functions, both of which are principal targets of the CP25 and CP43 conservation practices.

Planting Time

Planting time strongly influenced the establishment of different plant functional groups. While the benefits of a spring planting came from a greater establishment of warm-season grasses, dormant plantings increased native species richness and native cover of both grasses and forbs in the first year. This result was most likely due to the cumulative effects of an increase in cool-season grasses and fall forbs in dormant plantings. Our results were consistent with other studies, where planting time had minimal effects on overall stem density but influenced the establishment of native species (Peters & Schottler 2010) and functional group composition (Larson et al. 2011; Larson et al. 2017). We speculate that fall forbs perform better when planted in a dormant season because it more closely resembles their natural dispersal mechanisms and conditions for stratification and germination (Rowe 2010). Because fall forbs are the last to set seed, they may require a higher degree of cold stratification before germination compared to other forbs (Chambers & MacMahon 1994). While spring plantings establish warm-season grasses more efficiently, from an implementation point of view our observations suggest it may be more cost-efficient to plant in the dormant season to increase establishment of high-cost forbs, a necessary component of CP42.

First Year Mowing Management

Native species establishment was strongly influenced by first year mowing management. We found that mowing increased native stem density, richness, and, to a lesser extent, native cover compared to unmowed plots. This increase can be attributed to the positive effect mowing had on warm-season grasses and summer forbs, as there were no biological differences in other functional groups between mowing treatments. Many of the results mowing had on stand establishment at Cedar Falls were consistent with Meissen et al. (2020). However, while mowing reduced annual weeds at Cedar Falls, the degree was much less than that of Meissen et al. (2020). We believe this difference is most likely due to not including overstory canopy cover in the analysis of annual weed cover. *Ambrosia trifida* were the dominant annual weed and much of it was too tall (2-3 m) to establish an accurate measure of canopy cover. Other potential factors include variances in weed abundance and richness in the seed bank between the two studies as some weed species may be more tolerant to mowing. Our results suggest mowing can be an effective tool to aid in the success of many conservation practices.

Site Comparison

Many studies implement experiments at one location or in small plots which can result in outcomes reflecting local site conditions in lieu of treatment differences (Gibson et al. 1993). Our results demonstrated that local site conditions affected overall vegetation outcomes, but that the effects of the seed mix and mowing treatments were largely consistent between sites. We found the Nashua site established a larger number of native species compared to Cedar Falls. However, at both sites, the Economy mix produced the most native grasses and the Pollinator mix established the greatest forb stem density, while the Diversity mix produced stands with comparable native stem densities and had the highest native species richness. As expected, both sites also differed in their ability to suppress weeds and exposure of bare ground. At both sites in the second year, the Economy and Diversity mix had the lowest expression of annual weeds, and the Diversity mix had the least bare ground. In contrast, both annual weeds and bare ground were increased in the Pollinator mix compared to the other mixes. It is unclear why there were fewer native stems and cover at the Cedar Falls Site compared to Nashua, but one possible mechanism could be low levels of precipitation during optimal growing periods for young plants (Fay & Schultz 2009). In July and August of 2019 and 2020 the amount of precipitation in Cedar Falls was less than half the amount of Nashua in 2015 and 2016 (Appendix D).

Mowing was found to accelerate native species establishment at both sites; native species richness, grass stems, and forb stems were more abundant in mowed compared to unmowed plots. However, in the second year, the effects of mowing differed between sites with respect to bare ground, annual weeds, and perennial weeds. Mowing's suppression of annual weeds at the Cedar Falls site was much less than at Nashua. While these differences could be related to variation in local weed richness or site conditions, another factor could be that the greater native species establishment at Nashua altered competitive interactions in such a way that weed establishment differed among sites (Abernathy et al. 2016). Overall, our results suggest that seed mix design and first year mowing have more influence on vegetation outcomes than local site conditions and can be paired to increase the chances of a successful prairie reconstruction.

Canopy Fill

Canopy fill is often a secondary consideration in prairie reconstructions, but it plays an important role in enhancing wildlife habitat. Dense, canopy-forming vegetation is an important habitat element providing shelter, nesting substrate, and cover from predators for many vertebrate and invertebrate wildlife species (Davis et al. 2007; Kohler et al. 2020; Myers et al. 2015; Winter et al. 2005). In our study the Diversity and Economy mix had a high number of stems which acted to fill gaps in the canopy to a higher degree and at a faster rate than the Pollinator mix. To our surprise, mowing did not have an effect on canopy fill. However, we found dormant plantings filled canopy gaps more thoroughly than plots planted in the spring. Our results suggest that a dormant planting paired with either the Economy or Diversity mixes would provide suitable habitat and escape cover for wildlife, two of the target goals in CP25.

Floral Resources

Floral resources differed between seed mixes in a manner consistent with the proportion of forbs in each seed mix. The Pollinator mix established a greater number of floral resources while the Economy mix produced the fewest. The Diversity mix established a comparable number of flowers to the Economy mix but had a greater richness and evenness than the other mixes which may be more beneficial to increasing pollinator abundances (Hopwood 2008) than a stand heavily dominated by one species, as was observed in the Pollinator mix. Overall, many differences in floral resources between seed mixes were consistent with Meissen et al. (2020) but the Diversity mix's total flower abundance was much lower than expected. This inconsistency may in part be attributed to a difference in floral resource establishment over the growing season each study sampled. More specifically, in the current study, we assessed floral abundance only in the first and second growing seasons, while Meissen et al. (2020) monitored floral abundance during the second through fourth growing seasons, which may be necessary for forbs to have enough time to obtain the nutrients for a successful bloom.

Additionally, we found no seed mix produced three blooming species in the early season, which is one of the goals of CP42. This is most likely attributed to low seeding rates (0.63, 4.41, and 13.45%) of early season forbs in the Economy, Diversity, and Pollinator Mixes (Appendix A,B,C). Our results also incorporated seasonal surveys to account for inflorescence phenology, but this may not be the best method as it leaves gaps between surveys throughout the growing season. Perhaps a better method would be to count the number of (senesced) flowers at the end of the season which would account for different stages of blooming (i.e., senesced, flowering, and budding) then pair that with known bloom times to measure variation across floral seasons. From the perspective of ecosystem services, these results suggest the Pollinator mix would provide the greatest number of floral resources for pollinators and the Economy mix would provide the least. Total floral resources provided by the Diversity mix were intermediate to the other two mixes; however, the Diversity the greatest species richness. Neither the Diversity or Pollinator mix, which was designed as a CP42 seed mix achieved this program's goal. Future research is needed to determine whether CP42 mixes should prioritize floral abundance or diversity and to develop seed mixes and management techniques leading to more successful establishment of early season forbs.

Cost-Effectiveness

The cost-effectiveness to produce 1000 native stems differed between seed mixes. The Economy mix ($209 per acre) was the most cost-effective at producing native stems and the Diversity mix ($539 per acre) followed close behind, while the Pollinator mix ($808 per acre) was the least cost-effective mix. Mowing’s influence on accelerating native species establishment improved that cost-effectiveness across all seed mixes. While planting time did not produce significant cost differences to produce native stems the benefits a dormant season planting provides by increasing spring and fall forbs represents a no cost alternative to increase pollinator resources.

CONCLUSIONS

The Conservation Reserve Program is made up of over 40 conservation practices, many of which focus on single or a few compatible ecosystem services. Due to the relatively short-term nature of 10-year CRP contracts, accelerating early establishment of native plants through improved seeding methods and first-year management can yield significant ecosystem benefits over the duration of a CRP contract. Our results demonstrate that CRP could effectively consolidate some of these practices by utilizing a diverse grass-to-forb balanced seed mix consistent with CP43 standards to provide habitat with a high degree of multifunctionality. We found that mowing can accelerate native species establishment, improve pollinator habitat, and increase cost-effectiveness across multiple seed mix grass-to-forb ratios, suggesting that CRP should continue to utilize first-year mowing management as a tool. Few studies consider the impact of local site conditions on reconstruction outcomes; however, our study provides evidence that seed mix design and first year mowing management are robust factors that can be utilized on many locations across the corn belt. Additionally, because forbs represent one of the largest costs of implementing CRP conservation practices, practitioners should consider planting in the dormant season as a no cost approach to increase pollinator habitat.

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APPENDIX A

Species list and seeding rates of the Economy Mix (3:1 grass-to-forb seeding ratio) at the Northeast Research and Demonstration Farm and University of Northern Iowa's Tallgrass Prairie Center.

Common Name	*Scientific Name*	*Plant Type*	*Functional Group*	*PLS m^{-2}*	*% mix*
Canada wildrye	*Elymus canadensis*	grass	cool-season	46.3	10.75%
big bluestem	*Andropogon gerardii*	grass	warm-season	46.3	10.75%
side-oats grama	*Bouteloua curtipendula*	grass	warm-season	46.3	10.75%
switchgrass	*Panicum virgatum*	grass	warm-season	32.3	7.50%
little bluestem	*Schizachyrium scoparium*	grass	warm-season	46.3	10.75%
Indiangrass	*Sorghastrum nutans*	grass	warm-season	46.3	10.75%
tall dropseed	*Sporobolus compositus*	grass	warm-season	59.2	13.75%
Canada milkvetch	*Astragalus canadensis*	forb	summer (legume)	10.8	2.50%
purple prairie clover	*Dalea purpurea*	forb	summer (legume)	10.8	2.50%
prairie sage	*Artemisia ludoviciana*	forb	fall	10.8	2.50%
prairie cinquefoil	*Drymocallis arguta*	forb	summer	10.8	2.50%
tall boneset	*Eupatorium altissimum*	forb	fall	5.4	1.25%
ox-eye sunflower	*Heliopsis helianthoides*	forb	summer	5.4	1.25%
wild bergamot	*Monarda fistulosa*	forb	summer	10.8	2.50%
stiff goldenrod	*Solidago rigida*	forb	fall	5.4	1.25%
yellow coneflower	*Ratibida pinnata*	forb	summer	10.8	2.50%
black-eyed susan	*Rudbeckia hirta*	forb	summer	5.4	1.25%
sweet coneflower	*Rudbeckia subtomentosa*	forb	fall	8.1	1.88%
showy goldenrod	*Solidago speciosa*	forb	fall	5.4	1.25%
New England aster	*Symphyotrichum novae-angliae*	forb	fall	5.4	1.25%
golden alexander	*Zizia aurea*	forb	spring	2.7	0.63%
	Overall Total:			430.4	

APPENDIX B

Species list and seeding rates of the Diversity Mix (1:1 grass-to-forb seeding ratio) at the Northeast Research and Demonstration Farm and the University of Northern Iowa's Tallgrass Prairie Center.

Common Name	*Scientific Name*	*Plant Type*	*Functional Group*	*PLS m*$^{-2}$	*% mix*
prairie brome	*Bromus kalmii*	grass	cool-season	2.7	0.63%
Canada wildrye	*Elymus canadensis*	grass	cool-season	10.8	2.54%
fowl mannagrass	*Glyceria striata*	grass	cool-season	10.8	2.54%
big bluestem	*Andropogon gerardii*	grass	warm-season	21.5	5.07%
side-oats grama	*Bouteloua curtipendula*	grass	warm-season	32.3	7.61%
switchgrass	*Panicum virgatum*	grass	warm-season	21.5	5.07%
little bluestem	*Schizachyrium scoparium*	grass	warm-season	21.5	5.07%
Indiangrass	*Sorghastrum nutans*	grass	warm-season	21.5	5.07%
tall dropseed	*Sporobolus compositus*	grass	warm-season	53.8	12.68%
prairie dropseed	*Sporobolus heterolepis*	grass	warm-season	2.7	0.63%
yellow fox sedge	*Carex annectens*	sedge	cool-season	10.8	2.54%
Bicknell's sedge	*Carex bicknellii*	sedge	cool-season	1.1	0.25%
plains oval sedge	*Carex brevior*	sedge	cool-season	2.7	0.63%
heavy sedge	*Carex gravida*	sedge	cool-season	0.2	0.05%
field oval sedge	*Carex molesta*	sedge	cool-season	2.7	0.63%
leadplant	*Amorpha canescens*	forb	summer (legume)	2.2	0.51%
Canada milkvetch	*Astragalus canadensis*	forb	summer (legume)	10.8	2.54%
white wild indigo	*Baptisia lactea*	forb	summer (legume)	0.2	0.05%
partridge pea	*Chamaecrista fasciculata*	forb	summer (legume)	3.2	0.76%
purple prairie clover	*Dalea purpurea*	forb	summer (legume)	10.8	2.54%
showy tick trefoil	*Desmodium canadense*	forb	summer (legume)	1.6	0.38%
Illinois tick trefoil	*Desmodium illinoense*	forb	summer (legume)	2.7	0.63%
round-headed bushclover	*Lespedeza capitata*	forb	summer (legume)	0.5	0.13%

Common Name	*Scientific Name*	*Plant Type*	*Functional Group*	*PLS m^{-2}*	*% mix*
wild garlic	*Allium canadense*	forb	spring	1.1	0.25%
Canada anemone	*Anemone canadensis*	forb	spring	0.2	0.05%
thimbleweed	*Anemone cylindrica*	forb	spring	0.5	0.13%
prairie sage	*Artemisia ludoviciana*	forb	fall	10.8	2.54%
swamp milkweed	*Asclepias incarnata*	forb	summer	1.1	0.25%
common milkweed	*Asclepias syriaca*	forb	summer	2.2	0.51%
butterfly milkweed	*Asclepias tuberosa*	forb	summer	0.3	0.08%
whorled milkweed	*Asclepias verticillata*	forb	summer	0.5	0.13%
New Jersey tea	*Ceanothus americanus*	forb	spring	0.5	0.13%
prairie coreopsis	*Coreopsis palmata*	forb	summer	0.4	0.10%
prairie cinquefoil	*Drymocallis arguta*	forb	summer	10.8	2.54%
pale purple coneflower	*Echinacea pallida*	forb	summer	2.2	0.51%
rattlesnake master	*Eryngium yuccifolium*	forb	summer	2.2	0.51%
tall boneset	*Eupatorium altissimum*	forb	fall	2.7	0.63%
flowering spurge	*Euphorbia corollata*	forb	summer	1.1	0.25%
grass-leaved goldenrod	*Euthamia graminifolia*	forb	fall	10.8	2.54%
northern bedstraw	*Galium boreale*	forb	summer	1.1	0.25%
bottle gentian	*Gentiana andrewsii*	forb	fall	5.4	1.27%
bigtooth sunflower	*Helianthus grosseserratus*	forb	fall	1.6	0.38%
prairie sunflower	*Helianthus pauciflorus ssp. pauciflorus*	forb	fall	0.2	0.05%
ox-eye sunflower	*Heliopsis helianthoides*	forb	summer	5.4	1.27%
prairie blazingstar	*Liatris pycnostachya*	forb	fall	1.1	0.25%
Michigan lily	*Lilium michiganense*	forb	summer	0.1	0.03%
great blue lobelia	*Lobelia siphilitica*	forb	fall	10.8	2.54%
wild bergamot	*Monarda fistulosa*	forb	summer	8.1	1.90%
stiff goldenrod	*Solidago rigida*	forb	fall	8.1	1.90%
wild quinine	*Parthenium integrifolium*	forb	summer	1.1	0.25%
foxglove beardtongue	*Penstemon digitalis*	forb	spring	10.8	2.54%
prairie phlox	*Phlox pilosa*	forb	spring	0.2	0.05%
shootingstar	*Primula meadia*	forb	spring	1.1	0.25%

Common Name	*Scientific Name*	*Plant Type*	*Functional Group*	*PLS m^{-2}*	*% mix*
hairy mountain mint	*Pycnanthemum pilosum*	forb	summer	8.1	1.90%
slender mountain mint	*Pycnanthemum tenuifolium*	forb	summer	10.8	2.54%
common mountain mint	*Pycnanthemum virginianum*	forb	summer	10.8	2.54%
yellow coneflower	*Ratibida pinnata*	forb	summer	10.8	2.54%
black-eyed susan	*Rudbeckia hirta*	forb	summer	8.1	1.90%
sweet coneflower	*Rudbeckia subtomentosa*	forb	fall	8.1	1.90%
rosinweed	*Silphium integrifolium*	forb	summer	0.2	0.05%
compass plant	*Silphium laciniatum*	forb	summer	0.1	0.03%
showy goldenrod	*Solidago speciosa*	forb	fall	8.1	1.90%
smooth blue aster	*Symphyotrichum laeve*	forb	fall	5.4	1.27%
New England aster	*Symphyotrichum novae-angliae*	forb	fall	5.4	1.27%
sky-blue aster	*Symphyotrichum oolentangiense*	forb	fall	2.7	0.63%
purple meadow rue	*Thalictrum dasycarpum*	forb	summer	0.5	0.13%
prairie spiderwort	*Tradescantia bracteata*	forb	spring	0.5	0.13%
Ohio spiderwort	*Tradescantia ohiensis*	forb	spring	1.1	0.25%
ironweed	*Vernonia fasciculata*	forb	fall	2.7	0.63%
Culver's root	*Veronicastrum virginicum*	forb	summer	5.4	1.27%
golden alexander	*Zizia aurea*	forb	spring	2.7	0.63%
	Overall Total:			441.8	

APPENDIX C

Species list and seeding rates of the Pollinator Mix (1:3 grass-to-forb seeding ratio) at the Northeast Research and Demonstration Farm and University of Northern Iowa's Tallgrass Prairie Center.

Common Name	*Scientific Name*	*Plant Type*	*Functional Group*	*PLS* m^{-2}	*% mix*
Junegrass	*Koeleria macrantha*	grass	cool-season	31.6	7.32%
big bluestem	*Andropogon gerardii*	grass	warm-season	3.6	0.82%
side-oats grama	*Bouteloua curtipendula*	grass	warm-season	3.4	0.80%
little bluestem	*Schizachyrium scoparium*	grass	warm-season	29.1	6.72%
tall dropseed	*Sporobolus compositus*	grass	warm-season	17.8	4.11%
prairie dropseed	*Sporobolus heterolepis*	grass	warm-season	3	0.70%
yellow fox sedge	*Carex vulpinoidea*	sedge	cool-season	19.8	4.58%
Canada milkvetch	*Astragalus canadensis*	forb	summer (legume)	3.3	0.77%
white wild indigo	*Baptisia lactea*	forb	summer (legume)	0.6	0.15%
white prairie clover	*Dalea candida*	forb	summer (legume)	22.5	5.20%
purple prairie clover	*Dalea purpurea*	forb	summer (legume)	25.2	5.82%
common milkweed	*Asclepias syriaca*	forb	summer	1.6	0.37%
butterfly milkweed	*Asclepias tuberosa*	forb	summer	3.4	0.80%
prairie cinquefoil	*Drymocallis arguta*	forb	summer	9	2.09%
pale purple coneflower	*Echinacea pallida*	forb	summer	6.2	1.44%
rattlesnake master	*Eryngium yuccifolium*	forb	summer	8.9	2.07%
sneezeweed	*Helenium autumnale*	forb	fall	20.6	4.75%
alumroot	*Heuchera richardsonii*	forb	spring	27.7	6.39%
prairie blazingstar	*Liatris pycnostachya*	forb	fall	8.7	2.02%
wild bergamot	*Monarda fistulosa*	forb	summer	19.7	4.55%
stiff goldenrod	*Solidago rigida*	forb	fall	8.1	1.87%
foxglove beardtongue	*Penstemon digitalis*	forb	spring	10.3	2.39%
prairie phlox	*Phlox pilosa*	forb	spring	0.3	0.07%

Common Name	*Scientific Name*	*Plant Type*	*Functional Group*	*PLS m^{-2}*	*% mix*
common mountain mint	*Pycnanthemum virginianum*	forb	summer	8.7	2.02%
yellow coneflower	*Ratibida pinnata*	forb	summer	11.8	2.74%
black-eyed susan	*Rudbeckia hirta*	forb	summer	25.5	5.90%
rosinweed	*Silphium integrifolium*	forb	summer	0.4	0.10%
compass plant	*Silphium laciniatum*	forb	summer	0.8	0.17%
showy goldenrod	*Solidago speciosa*	forb	fall	3.8	0.87%
heath aster	*Symphyotrichum ericoides*	forb	fall	7.9	1.82%
smooth blue aster	*Symphyotrichum laeve*	forb	fall	4.3	1.00%
New England aster	*Symphyotrichum novae-angliae*	forb	fall	15.9	3.68%
sky-blue aster	*Symphyotrichum oolentangiense*	forb	fall	3.1	0.72%
Ohio spiderwort	*Tradescantia ohiensis*	forb	spring	4.7	1.09%
ironweed	*Vernonia fasciculata*	forb	fall	14.2	3.28%
Culver's root	*Veronicastrum virginicum*	forb	summer	31.6	7.32%
prairie violet	*Viola pedatifida*	forb	spring	1.1	0.25%
golden alexander	*Zizia aurea*	forb	spring	14.1	3.26%
	Overall Total:			432.4	

APPENDIX D

Mean monthly precipitation (cm) for the first two growing seasons at Nashua and Cedar Falls. Data collected from National Oceanic and Atmospheric Administration (NOAA 2021).

		Monthly Precipitation (cm)							
Site	Year	Marc	April	May	June	July	August	Septembe	October
Nashua	2015	1.93	11.00	8.92	14.68	10.16	11.25	6.63	4.09
Nashua	2016	11.13	3.89	9.55	27.18	17.96	18.59	37.90	5.89
Cedar Falls	2019	4.29	7.47	17.12	15.80	2.92	8.00	14.86	14.15
Cedar Falls	2020	7.67	4.09	13.39	26.62	11.86	4.24	12.37	6.30