Designing multifunctional, cost-effective prairies for dry marginal lands

Preliminary Technical Report

Prepared by:
Justin Meissen
Tallgrass Prairie Center
University of Northern Iowa

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Introduction

Using reconstructed prairie in contour strips within farm fields reduces surface nutrient runoff for about the same cost as cover crops, and does not carry the uncertainty of replanting every year (Tyndall et al. 2013, Schulte et al. 2017). There is growing evidence that in addition to interrupting 85-90% of N and P in surface runoff, prairie strips reduce the concentrations of shallow groundwater nitrates (Zhou et al. 2014). Prairie root systems fuel the denitrification process (Iqbal et al. 2014), suggesting multiple uses in saturated buffers and marginal lands. Building prairie in the agricultural landscape also enhances other ecosystem services including soil quality, wildlife habitat and resilience to flooding.

Conservation agency staff, professional farm managers and other technical service providers agree that prairie strips are effective at erosion control and nutrient reduction, but many lack the confidence to recommend this practice (Whitehair and Grudens-Schuck 2017). Some key uncertainties stem from unanswered questions about the characteristics of sites where prairie reconstructions can be effectively applied. Specifically, there is a lack of understanding of how site soils influence establishment outcomes and whether seed mixes can be designed to be adaptive to those influences.

If effective methods for prairie reconstruction under different soil moisture conditions can be understood, producers could target marginal farmland for application of prairie-based nutrient reduction practices more confidently. Paired with incentive-based conservation programs, converting marginal farmland to native perennial vegetation may represent a palatable and economically viable land-use choice for many farm owners (Nassauer et al. 2011). In many parts of Iowa, dry, sandy soils are key marginal lands that may represent an opportunity for implementing prairie reconstructions both as in-field and edge-of-field nutrient reduction practices.

Native tallgrass prairie plant communities have existed on dry, excessively drained soils in undisturbed habitats throughout Iowa for centuries (Eilers and Roosa 1994), suggesting that dry prairie could be a viable model for multifunctional perennial vegetation. A previous study found that soil type influences plant diversity outcomes in prairie reconstructions, but noted that seed mix design choices influenced the outcomes the most (Grman et al. 2013). Given the influence of both factors on reconstruction outcomes, designing seed mixes to match site soils should improve establishment and ecological functioning in prairie contour strips or other stands of native perennial vegetation. Choosing species commonly found in dry prairies to create such a mix for dry marginal soils could provide a template for success in establishing durable stands of native perennial vegetation.

Currently, specificity in methods for successful dry prairie reconstruction implementation are lacking. While expert opinion and evidence-based seed mix designs are available for mesic prairie reconstructions (i.e. on soils with medium soil moisture) (Smith et al. 2010), to our knowledge no similar resources are available for practitioners to use when reconstructing dry prairie. Furthermore, costs are rarely or never noted in studies of reconstruction methods, and success rates are not linked to inputs in a way that allows practitioners to choose evidence based means of management decision making.

We assessed the influence of seed mix design, specifically the effect of species habitat matching on dry soils in a series of field trials conducted in recently retired marginal farmland. Our objectives were to 1) evaluate plant establishment, functional diversity, and cost-effectiveness for seed mixes that differed in composition of dry adapted species, and 2) derive an effective seed mix suited to dry marginal soils based on preliminary establishment outcomes.

Materials and Methods

Study site

The study site is located at the Wapsi-Fairbank Demonstration Site near Fairbank, IA (42° 64´ N, 92° 04´ W) in Fayette County (Fig. 1). The soils underlying the study site are primarily well drained Wapsie loam and somewhat excessively drained Burkhardt sand (NRCS 2016). Topographically, the study site consists of low rolling hills, but slopes do not exceed 5% grade. Land use prior to this experiment was agricultural, with corn and soybeans consistently grown in rotation at the site.

We conducted minimal site preparation at the study site. In the summer of 2017, the farm operator grew corn throughout the site. The farm operator used a combine with a chopping corn head to harvest in the fall of 2017. The resulting residue was relatively heavy, but small enough to be successfully seeded into using a no-till drill. The sandy soils on site prevented residue and soil buildup while using the drill and allowed satisfactory seed to soil contact.

Study design

To assess cost-effectiveness and ecological performance of different prairie seed mixes in dry marginal soils, we installed a pilot experiment with a completely randomized design consisting of four replicates in November 2017 (Fig. 2). We worked with the farm operator to identify an area of the farm that was particularly unproductive, and followed up with soil maps to outline a study area on the farm that encompassed some of the most marginal lands (Fig. 3). We established a 77 x 114 m study area, consisting of eight 14 x 70 m plots. In each plot, we randomly assigned a seed mix treatment (n=8). We manipulated seed mix treatments at two levels: 1) diverse dry mix and 2) diverse mesic mix.

We varied seed mix treatments based on soil type customization. We used the Tallgrass Prairie Seed Calculator (http://tallgrassprairieseedcalculator.com) to design two similarly priced seed mixes that were adapted to 1) xeric and 2) mesic soil conditions for Fayette County, IA (Appendix 1). We used the xeric recommendations from the Seed Calculator to create a seed mix containing species that would tolerate the somewhat excessively drained soils on site. We used the mesic recommendations from the Seed Calculator to create a plausible mismatch between soils and species planted, though we ensured that the mismatch was not extreme enough to pose a significant threat of establishment failure. Thus, we did not compare a mix designed for hydric soils to one designed for xeric soils, even though the contrast between those treatments would have been contrasted very distinctly.

Both dry and mesic mixes were similar in price and ecological design. The dry mix cost $911/ha and contained 49 species, while the mesic mix cost $904/ha and contained 46 species (Appendix 1). We designed both mixes so that important functional groups (primarily based on growth and flowering phenology) were represented by multiple species. To calculate costs, we used prices surveyed in 2018 across a diverse set of Upper Midwest seed growers. Among those prices, we chose the lowest reported price to simulate consumer behavior. To ensure accuracy in seeding rates and seed purity, we calculated seeding rates for each species using pure live seed (PLS). We standardized the overall seeding rate among mixes at approximately 440 PLS seeds/ m^2. We purchased seed from native seed nurseries in Iowa and adjacent states in January 2017-2018 and stored the seed in a temperature and humidity controlled (4°C, 45% RH) cooler until planting. We weighed, bagged, and mixed the seed for each plot separately. To ensure soils were stabilized as prairie seedlings established, we included a nurse crop of winter wheat at a rate of 2.5 bu/ha.

We seeded the study site on November 21, 2017. We used a Truax FLX-86U no-till drill with a John Deere JD-5325 tractor to seed each plot independently. To minimize seed contamination between treatments, we cleaned out the drill after seeding each plot. The drill operator started at the west end of each plot and seeded each consecutive plot in the experiment site, moving north to south.

The farm operator conducted establishment mowing over the first growing season to control weed growth. We mowed vegetation throughout the 2018 growing season to 6 inches when most vegetation reached approximately 1 m in height. The southernmost plot contained giant ragweed that grew much taller than the surrounding weeds by the time of mowing, but we did not observe that this influenced native plant establishment. The farm operator mowed two times in mid and late summer, and left the resulting thatch on site.

Data collection and analysis

We measured density (plant genets) and canopy cover in September 2018, and used density estimates to calculate establishment and cost-effectiveness metrics. We sampled late in the year to allow seedlings to grow to a size that allowed confidence in seedling identification. To sample plant density and canopy cover, we used eight 0.25 m^2 quadrats spaced every 9 m along a 70 m transect established randomly in each plot. To reduce edge effects, we did not lay quadrats within 1 m (north/south) or 3 m (east/west) of plot borders. In each quadrat, we counted and identified all individual plants (genets) of seeded species. We recorded canopy cover values for annual weeds, perennial weeds, bare ground, native grass, and native forbs. To assess cost-effectiveness, we divided the number of established native genets of each species observed in each plot by the cost of seed per plot for each species sown (plants/$1). To analyze the effects of seed mix on cost-effectiveness and native plant establishment, we used Welch's *t*-tests. We used *t*- tests to compare differences in vegetation and cost-effectiveness measures (both overall and within functional groups) with a significance threshold of $p < 0.05$ among seed mix treatments.

In order to analyze differences in cost-effectiveness of different functional groups overall, we grouped all plots and used ANOVA with a significance threshold of $p < 0.05$.

Results

Overall, we found that both the mesic and dry adapted seed mixes produced similar first-year plant densities, though we found differences in functional group abundance between seed mixes. On average, the dry adapted mix produced 32 ± 9.1 SE plants/m^2 while the mesic mix produced 31 ± 8.3 SE plants/m^2 (Fig. 3); this small difference was not significantly different. The dry adapted mix produced more spring forb plants (0.88 ± 0.24 SE plants/m^2) than the mesic mix (no plants observed) ($t = 3.66$, $df = 3$, $p < 0.05$). The differences in spring forbs were characterized primarily by the establishment of *Zizia aptera* and *Tradescantia bracteata* in the dry adapted mix, while the congeners *Zizia aurea* and *Tradescantia ohiensis* failed to establish in the mesic mix. Density of other functional groups were similar among seed mixes, and no differences observed were statistically different (Fig. 4). Cool season grass density ranged from 3.88 ± 1.39 SE plants/m^2 to 5.25 ± 1.13 SE plants/m^2, and warm season grass density ranged from 14.50 ± 4.64 SE plants/m^2 to 16.50 ± 4.02 SE plants/m^2. Among other forb groups, densities ranged from 8.50 ± 2.90 SE plants/m^2 to 9.63 ± 2.90 SE plants/m^2 in summer forbs to 1.25 ± 0.43 SE plants/m^2 to 2.00 ± 0.65 SE plants/m^2 in fall forbs. Emergence rates derived from observed species densities are reported in Table 1.

Canopy cover of general vegetation types was typically not different between mixes, though we found marginal evidence for differences in native grass cover between mixes. The general makeup between both mixes was typical for year-old prairie plantings, and was dominated by annual weeds and bare ground (Fig. 5). Annual weed cover ranged from 47.0 to 50.2% canopy cover, while bare ground ranged from 27.8 to 31.7% canopy cover. We recorded less than 3% perennial weed cover in all mixes. We found no statistical differences between seed mixes when comparing weed or bare ground cover. We observed that the dry adapted mix produced more forb cover (15.6 ± 1.8 SE % forb canopy cover) and less grass cover (9.8 ± 1.1 SE % grass canopy cover) compared to the mesic mix (12.5 ± 0.9 SE % forb canopy cover; 13.4 ± 1.6 SE % grass canopy cover), though these differences were not statistically significant (Fig. 5).

Species richness differed by seed mix for some functional groups, though overall richness did not differ between seed mixes. The dry adapted mix produced more spring forb species than the mesic mix ($t = 5.2$, $df = 3$, $p < 0.05$) (Fig. 6). We found no spring forb species in the mesic mix, while we found 0.8 ± 0.05 SE species/ m^2 in the dry adapted mix. The number of warm and cool season grass species produced by each mix was very similar, ranging from 2.8 ± 0.1 SE to 3.0 ± 0.0 SE species/ m^2 for warm season grasses and 0.88 ± 0.10 SE to 0.88 ± 0.05 SE species/ m^2 for cool season grasses. We observed more summer forb species in the dry adapted mix (3.9 ± 0.2 SE species/ m^2) than in the mesic mix (2.9 ± 0.2 SE species/ m^2) though the difference was not statistically significant. Richness of fall species was nearly identical between mixes, ranging from 1.1 ± 0.1 SE to 1.2 ± 0.1 SE species/ m^2. We observed that overall species richness in the dry adapted mix (9.6 ± 1.1 SE species/m^2) was greater than in the mesic mix (7.8 ± 0.6 SE species/m^2) though the difference was not statistically significant (Fig. 6).

Cost-effectiveness was not different between mixes, though overall there were distinct differences among functional groups and individual species. Both mixes were similarly cost-effective, producing from 341.66 ± 91.65 SE plants/$1 in the mesic mix to 346.88 ± 99.65 SE plants/$1 in the dry mix. Functional groups varied considerably in cost-effectiveness (F = 16.3, df = 4, p < 0.001), with warm season grasses (1255.49 ± 232.55 SE plants/$1) and cool season grasses (1073.28 ± 249.28 SE plants/$1) being most cost-effective. Spring forbs were by far the least cost-effective (33.24 ± 15.12 SE plants/$1) functional group. Summer (197.73 ± 38.13 SE plants/$1), and fall (101.86 ± 24.37 SE plants/$1) forbs showed intermediate cost-effectiveness. Of species we observed to establish, black-eyed susan (*Rudbeckia hirta*), Canada wildrye (*Elymus canadensis*), and big bluestem (*Andropogon gerardii*) were the top three most cost-effective species with plants/$1 values ranging from 5643.86 ± 2159.36 SE to 2266.84± 419.73 SE (Table 1). Species with low (but not zero) cost-effectiveness included compass plant (*Silphium laciniatum*), showy goldenrod (*Solidago speciosa*), and Illinois tick trefoil (*Desmodium illinoense*) with plants/$1 values ranging from 12.77 ± 12.77 SE to 42.61 ± 27.20 SE (Table 2).

Discussion

With some exceptions, many important prairie species establish well in dry soils. Overall, establishment of both seed mixes resulted in stands that exceeded minimum seedling density thresholds (>10 plants/m^2) (Smith et al. 2010). We found familiar species that were not necessarily adapted specifically to dry soils but are planted in most prairie reconstructions established reasonably well in our study. Grasses that are usually considered mesic species like indian grass (*Sorghastrum nutans)*, switchgrass (*Panicum virgatum)*, big bluestem (*Andropogon gerardii)*, and Canada wildrye (*Elymus canadensis)* had establishment rates at least ~5-20%, which is typical for other successful prairie reconstructions (Williams et al. 2007). Commonly planted forbs such as common milkweed (*Asclepias syriaca*), Canada milkvetch (*Astragalus canadensis*), showy tick trefoil (*Desmodium canadense*), pale purple coneflower (*Echinacea pallida*), wild bergamot (*Monarda fistulosa*), grey-headed coneflower (*Ratibida pinnata*), black-eyed susan (*Rudbeckia hirta*), compass plant (*Silphium laciniatum*), and rosinweed (*Silphium integrifolium*) all established within typical rates or higher. We found several exceptions; butterfly milkweed (*Asclepias tuberosa*), white wild indigo (*Baptisia alba*), rattlesnake master (*Eryngium yuccifolium*), ox-eye (*Heliopsis helianthoides*), common spiderwort (*Tradescantia ohiensis*), and golden alexander (*Zizia aurea*) all established poorly (<1%). While soil mis-matching may have accounted for the poor performance in some of these species, fall planting may have led to low establishment in others, particularly *A. tuberosa* and *H. helianthoides* (Peters and Schottler 2010) which established readily in an adjacent spring planting. We were surprised to find that several species considered being indicative of wet or moist prairies (sawtooth sunflower (*Helianthus grosseserratus*), sweet coneflower (*Rudbeckia subtomentosa*), New England aster (*Symphyotrichum novae-angliae*) and prairie ironweed *(Vernonia fasciculata*)) also established well in a dry site. It is unknown whether these species established well because of above average precipitation in 2018, or whether these species are consistently adaptable to dry conditions as well.

Species matched to dry soils performed well in most cases, but not all dry adapted prairie species established well under ideal soils. Most dry adapted grasses such as *Bouteloua curtipendula*, *Schizachyrium scoparium*, and *Sporobolus compositus* established at acceptable rates (5-20%) but two species we thought would establish readily given their dry habitat preference— prairie junegrass (*Koeleria macrantha*) and sand dropseed (*Sporobolus cryptandrus*)— established very poorly (< 1%). These grasses have very small seeds, which may explain in part why establishment was comparatively low (Alstad et al. 2018). Dry adapted forbs also generally performed well, with whorled milkweed (*Asclepias verticillata*), prairie coreopsis (*Coreopsis palmata*), Illinois tick trefoil (*Desmodium illinoense*), large beardtongue (*Penstemon grandiflorus*), bracted spiderwort (*Tradescantia bracteata*), and heartleaf golden alexander (*Zizia aptera*) establishing at rates >5%. Some dry adapted forbs such as ground plum (*Astragalus crassicarpus*) and false boneset (*Brickellia eupatoriodes*) performed poorly (0%), though so few seeds of *A. crassicarpus* were sown that it was unlikely that our sampling efforts would have been able to observe it even if it established well. It is unknown why other dry adapted species like *B. eupatoriodes* failed to establish well, though fall planting time may have been an influence (Peters and Schottler 2010).

Seed mixes customized to match site soils result in more ecological functions at similar price. We found that plots planted with the dry adapted mix had multiple species filling each functional group, while the mesic mix was missing the spring forb functional group outright. Given that both mixes were comparable in cost (the dry adapted mix was 0.07% more expensive), matching the dry adapted mix to the dry marginal soils at the Wapsi-Fairbank Demonstration Site resulted in superior ecological outcomes. With this mix, the emerging stand provided potential for high quality pollinator habitat as well as the nutrient reducing benefits stemming from high densities of deep-rooted perennial plants. By failing to match the seed mix to the site soils, planting a mesic mix on our site's dry soils represented a lost opportunity to create a highly multifunctional stand of native perennial vegetation. Grman and others (2015) showed that many prairie species were limited in establishment in large part due to their affinity with soils of varying soil organic matter, and that sandy soils predicted poor outcomes for many species. Our study compliments this work by showing a similar result- our mesic mix that contained several species more adapted to rich loams also did not excel at our sandy site. Our study also shows that these limitations can be overcome by understanding prairie species biology and designing seed mixes that only include species with known affinity to dry soils.

We did not find evidence to support the idea that seed mix matching to dry soils would influence cost-effectiveness, though this may change as plantings mature. Both the dry adapted and mesic mixes produced similar numbers of seedlings per dollar spent after the first growing season. However, based on the phenological diversity of forbs in the dry adapted mix and the absence of spring forbs in the mesic mix, comparing other cost-effectiveness metrics such as number of flowers produced per dollar spent may lead to the dry adapted mix becoming more cost-effective in the long term.

When our results are compared to other studies, cost-effectiveness of prairie reconstruction in dry marginal land is less, but generally comparable to reconstruction in other soils. We found that in dry marginal soils (50 CSR) our reconstructions produced approximately 340 seedlings per dollar spent. In a study of cost-effectiveness on productive soil (87 CSR) using a seed mix similar to the mesic mix in this study, Meissen and others (in review) found year old prairie plantings in Nashua, IA to produce 560 seedlings per dollar spent. The species that drove overall cost effectiveness measures in this study were also similar to those at Nashua. Of the top 10 most cost-effective species in both studies, 60% were shared- *R. hirta*, *E. canadensis*, *S. scoparium*, *A. gerardii*, *S. nutans*, *P. virgatum*, and *M. fistulosa*. Given the highly cost-effective nature of these species and their general prevalence in resulting stands, there is potential for lowering seeding rates of these species to reduce unnecessary spending on seeds while still achieving sufficiently dense prairie reconstructions.

Conclusions

Early indications show that prairie reconstructions on dry soils are effective and forgiving to some degree of seed mix and site soil mismatch. Service providers and conservation practitioners should have confidence in recommending nutrient reduction practices utilizing prairie on dry marginal lands. Importantly, multifunctionality can be increased without increasing costs by ensuring the seed mix consists of dry adapted species. We encourage practitioners to consider modeling seed mixes for dry sites off the one we found to be successful in this study (Appendix 1).

Follow up is necessary to understand the likely long-term effects of soil and seed mix matching. We conducted our study in a year with above average precipitation, and it is unknown how drought conditions (to which the dry adapted mix is expected to tolerate better than the mesic mix) will influence multifunctionality or cost-effectiveness longer term. If drought results in mortality of poorly adapted species comprising functional groups in the mesic mix (e.g. *Symphyotrichum novae-angliae*, *Helianthus grosseserratus*), multifunctionality can be expected to decline over time in the mesic mix, while it should remain stable in the dry adapted mix. Continued monitoring for at least two more years is warranted before full conclusions can be drawn about seed mix- soil matching at the Wapsi-Fairbank Demonstration Site.

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Literature Cited

Alstad, A. O., E. I. Samschen, and L. M. Ladwig. 2018. Fire as a site preparation tool in grassland restoration: seed size effects on recruitment success. Ecological Restoration 36:219–225.

Eilers, L. J., and D. M. Roosa. 1994. The Vascular Plants of Iowa. University of Iowa Press, Iowa City, IA.

Grman, E., T. Bassett, and L. A. Brudvig. 2013. Confronting contingency in restoration: management and site history determine outcomes of assembling prairies, but site characteristics and landscape context have little effect. Journal of Applied Ecology:n/a-n/a.

Grman, E., T. Bassett, C. R. Zirbel, and L. A. Brudvig. 2015. Dispersal and establishment filters influence the assembly of restored prairie plant communities. Restoration Ecology 23:892–899.

Iqbal, J., T. B. Parkin, M. J. Helmers, X. Zhou, and M. J. Castellano. 2014. Denitrification and nitrous oxide emissions in annual croplands, perennial grass buffers, and restored perennial grasslands. Soil Science Society of America Journal 79:239.

Meissen, J. C., A. J. Glidden, M. E. Sherrard, K. J. Elgersma, and L. L. Jackson. (n.d.). Seed mix design and first year management influence multifunctionality and cost-effectiveness in prairie reconstruction. In review. Restoration Ecology.

Nassauer, J. I., J. A. Dowdell, Z. Wang, D. McKahn, B. Chilcott, C. L. Kling, and S. Secchi. 2011. Iowa farmers' responses to transformative scenarios for Corn Belt agriculture. Journal of Soil and Water Conservation 66:18A–24A.

NRCS [Natural Resources Conservation Service]. 2016. Web Soil Survey. https://websoilsurvey.sc.egov.usda.gov/.

Peters, M., and S. Schottler. 2010. The role of forb seeding rate in enhancing floristic diversity in prairie reconstructions. Pages 70–78 *in* D. W. Williams, B. Butler, and D. D. Smith, editors. Proceedings of the 22nd North American Prairie Conference. University of Northern Iowa, Cedar Falls, IA.

Schulte, L. A., J. Niemi, M. J. Helmers, M. Liebman, J. G. Arbuckle, D. E. James, K. Randall, M. E. O. Neal, M. D. Tomer, J. C. Tyndall, P. Drobney, J. Neal, G. Van Ryswyk, L. A. Schulte, J. Niemi, M. J. Helmers, M. Liebman, J. G. Arbuckle, and D. E. James. 2017. Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn–soybean croplands. Proceedings of the National Academy of Sciences 114:11247–11252.

Smith, D., D. Williams, G. Houseal, and K. Henderson. 2010. The Tallgrass Prairie Center guide to prairie restoration in the Upper Midwest. First edition. University of Iowa Press, Iowa City, IA.

Tyndall, J. C., L. A. Schulte, M. Liebman, and M. Helmers. 2013. Field-level financial assessment of contour prairie strips for enhancement of environmental quality.

Environmental Management 52:736–747.

Whitehair, R., and N. Grudens-Schuck. 2017. Prairie strips consultant educational needs assessment: 2017 survey. Ames, IA.

Williams, D. W., L. L. Jackson, and D. D. Smith. 2007. Effects of frequent mowing on survival and persistence of forbs seeded into a species-poor grassland. Restoration Ecology 15:24–33.

Zhou, X., M. J. Helmers, H. Asbjornsen, R. Kolka, M. D. Tomer, and R. M. Cruse. 2014. Nutrient removal by prairie filter strips in agricultural landscapes. Journal of Soil and Water Conservation 69:54–64.

Table 1. Species emergence in dry marginal soils. Values reflect plants observed / seeds sown for each species among all plots where it was planted. Seeded but unobserved species are not included.

Common Name	Scientific Name	n	Emergence (%)	± SE
stiff tickseed	*Coreopsis palmata*	4	69.68	69.68
whorled milkweed	*Asclepias verticillata*	4	46.45	26.82
Canada wildrye	*Elymus canadensis*	8	35.42	7.02
pale purple coneflower	*Echinacea pallida*	8	33.10	9.23
compass plant	*Silphium laciniatum*	8	29.03	29.03
rosinweed	*Silphium integrifolium*	8	29.03	29.03
bracted spiderwort	*Tradescantia bracteata*	4	23.23	13.41
showy partridge pea	*Chamaecrista fasciculata*	8	20.90	5.48
prairie ironweed	*Vernonia fasciculata*	4	18.58	0.00
heartleaf golden alexander	*Zizia aptera*	4	18.58	7.59
common milkweed	*Asclepias syriaca*	8	17.42	8.50
sawtooth sunflower	*Helianthus grosseserratus*	8	17.42	8.99
yellow coneflower	*Ratibida pinnata*	8	14.81	3.45
sideoats grama	*Bouteloua curtipendula*	8	14.32	3.18
wild beebalm	*Monarda fistulosa*	8	13.94	4.65
Illinois ticktrefoil	*Desmodium illinoense*	4	13.94	8.89
little bluestem	*Schizachyrium scoparium*	8	11.71	2.58
big bluestem	*Andropogon gerardii*	8	11.61	2.15
large beardtongue	*Penstemon grandiflorus*	4	11.61	11.61
black-eyed susan	*Rudbeckia hirta*	8	10.45	4.00
Indiangrass	*Sorghastrum nutans*	8	9.39	1.75
showy ticktrefoil	*Desmodium canadense*	4	9.29	5.36
sweet coneflower	*Rudbeckia subtomentosa*	4	6.97	4.45
Canadian milkvetch	*Astragalus canadensis*	8	5.81	1.70
composite dropseed	*Sporobolus compositus*	8	4.96	1.40
switchgrass	*Panicum virgatum*	8	4.65	1.46
New England aster	*Symphyotrichum novae-angliae*	8	3.87	1.63
tall boneset	*Eupatorium altissimum*	8	2.32	2.32
prairie cinquefoil	*Drymocallis arguta*	4	1.74	0.58
stiff goldenrod	*Solidago rigida*	8	1.55	1.01
purple prairie clover	*Dalea purpurea*	8	1.16	1.16
prairie sage	*Artemisia ludoviciana*	8	0.87	0.61
junegrass	*Koeleria macrantha*	4	0.58	0.58
showy goldenrod	*Solidago speciosa*	8	0.58	0.58

Table 2. Number of plants produced from $1 of seed. Values reflect plants per dollar for each species among all plots where it was planted.

Common Name	Scientific Name	n	Plants/$1	± SE
black-eyed susan	*Rudbeckia hirta*	8	5644	2159
Canada wildrye	*Elymus canadensis*	8	3486	691
big bluestem	*Andropogon gerardii*	8	2267	420
little bluestem	*Schizachyrium scoparium*	8	2213	488
sideoats grama	*Bouteloua curtipendula*	8	1967	436
Indiangrass	*Sorghastrum nutans*	8	1439	268
switchgrass	*Panicum virgatum*	8	1180	370
showy partridge pea	*Chamaecrista fasciculata*	8	920	241
wild beebalm	*Monarda fistulosa*	8	792	264
composite dropseed	*Sporobolus compositus*	8	786	222
yellow coneflower	*Ratibida pinnata*	8	484	113
prairie ironweed	*Vernonia fasciculata*	4	450	0
prairie cinquefoil	*Drymocallis arguta*	4	395	132
sawtooth sunflower	*Helianthus grosseserratus*	8	362	187
Canadian milkvetch	*Astragalus canadensis*	8	316	92
stiff tickseed	*Coreopsis palmata*	4	297	297
sweet coneflower	*Rudbeckia subtomentosa*	4	280	178
pale purple coneflower	*Echinacea pallida*	8	252	70
prairie sage	*Artemisia ludoviciana*	8	184	129
New England aster	*Symphyotrichum novae-angliae*	8	183	77
heartleaf golden alexander	*Zizia aptera*	4	162	66
junegrass	*Koeleria macrantha*	4	122	122
large beardtongue	*Penstemon grandiflorus*	4	117	117
whorled milkweed	*Asclepias verticillata*	4	109	63
bracted spiderwort	*Tradescantia bracteata*	4	106	61
showy ticktrefoil	*Desmodium canadense*	4	98	57
common milkweed	*Asclepias syriaca*	8	80	39
tall boneset	*Eupatorium altissimum*	8	77	77
purple prairie clover	*Dalea purpurea*	8	76	76
stiff goldenrod	*Solidago rigida*	8	59	38
rosinweed	*Silphium integrifolium*	8	46	46
Illinois ticktrefoil	*Desmodium illinoense*	4	43	27
showy goldenrod	*Solidago speciosa*	8	35	35
compass plant	*Silphium laciniatum*	8	13	13

Figure 1. Location of study site within Iowa.

Figure 2. Experimental layout at the Wapsi-Fairbank Demonstration Site near Fairbank, Iowa.

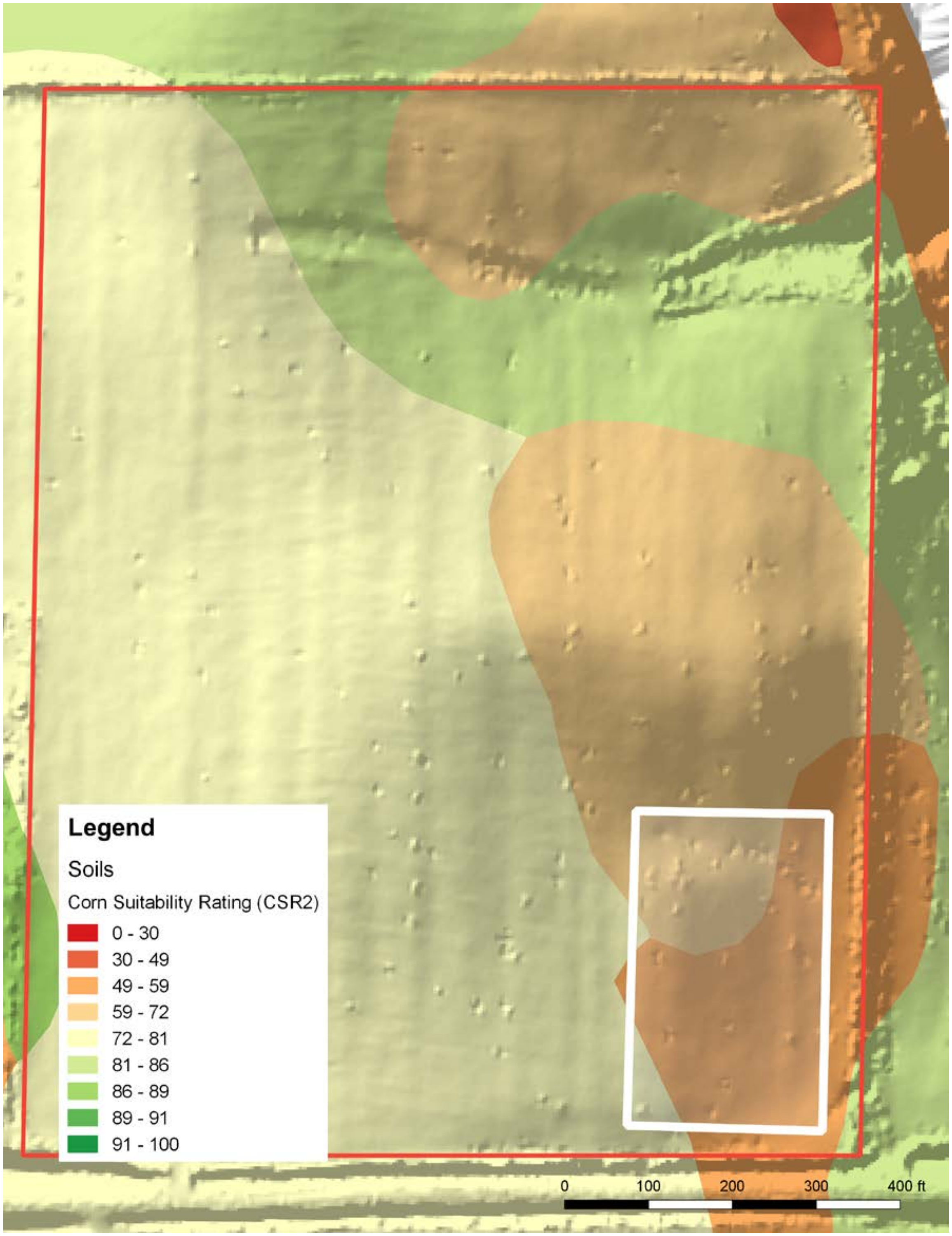

Figure 3. Marginal soils context at the Wapsi-Fairbank Demonstration Site near Fairbank, Iowa.

Figure 4. Density of planted native species overall and among plant functional groups (based on phenology) observed in dry and mesic seed mixes planted on dry marginal lands.

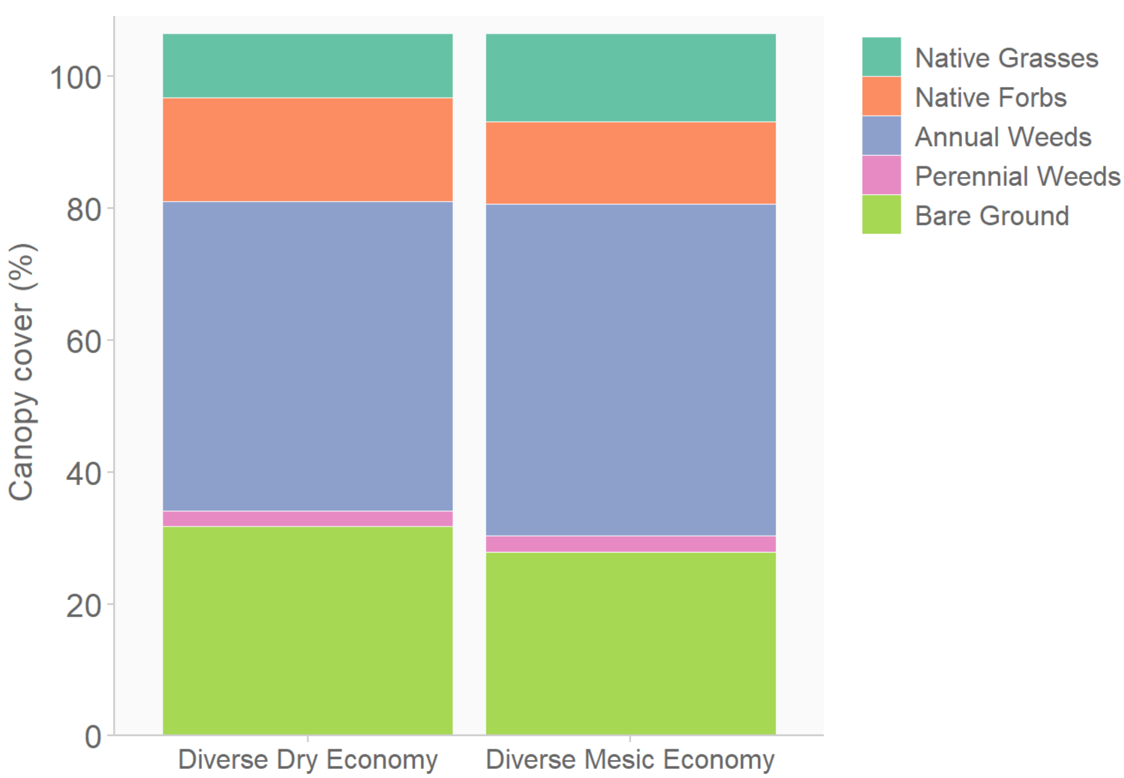

Figure 5. Canopy cover of general vegetation types observed in dry and mesic seed mixes planted on dry marginal lands.

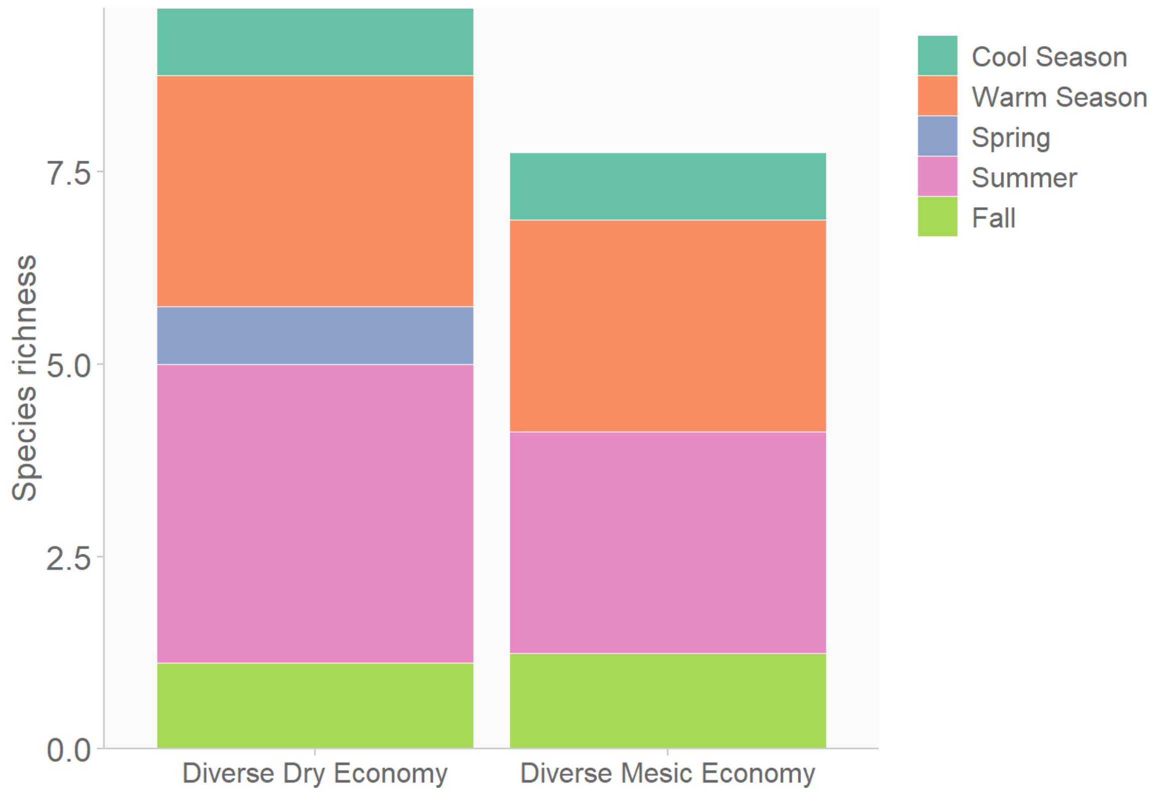

Figure 6. Species richness (# species /m^2) overall and among plant functional groups (based on phenology) observed in dry and mesic seed mixes planted on dry marginal lands.

Appendix 1. Seed mixes planted as treatments at the Wapsi-Fairbank Demonstration Site.

Common Name	*Scientific Name*	*Diverse Dry Economy (seeds/ m^2)*	*Diverse Mesic Economy (seeds/ m^2)*
Cool season grasses			
Kalm's brome	*Bromus kalmii*	NA	5.38
yellowfruit sedge	*Carex annectens*	NA	2.69
Bicknell's sedge	*Carex bicknellii*	NA	2.69
shortbeak sedge	*Carex brevior*	2.69	NA
heavy sedge	*Carex gravida*	0.54	NA
troublesome sedge	*Carex molesta*	NA	2.69
Canada wildrye	*Elymus canadensis*	10.76	10.76
fowl mannagrass	*Glyceria striata*	NA	10.76
junegrass	*Koeleria macrantha*	21.53	NA
Warm season grasses			
big bluestem	*Andropogon gerardii*	10.76	32.29
sideoats grama	*Bouteloua curtipendula*	32.29	32.29
switchgrass	*Panicum virgatum*	10.76	21.53
little bluestem	*Schizachyrium scoparium*	32.29	21.53
Indiangrass	*Sorghastrum nutans*	21.53	32.29
composite dropseed	*Sporobolus compositus*	53.82	43.06
sand dropseed	*Sporobolus cryptandrus*	21.53	NA
prairie dropseed	*Sporobolus heterolepis*	2.69	2.69
Spring forbs			
thimbleweed	*Anemone cylindrica*	1.08	NA
ground-plum	*Astragalus crassicarpus*	0.11	NA
New Jersey tea	*Ceanothus americanus*	0.54	NA
Richardson's alumroot	*Heuchera richardsonii*	21.53	NA
large beardtongue	*Penstemon grandiflorus*	1.08	NA
prairie phlox	*Phlox pilosa*	NA	0.22
bracted spiderwort	*Tradescantia bracteata*	1.08	NA
smooth spiderwort	*Tradescantia ohiensis*	NA	2.15
heartleaf golden alexander	*Zizia aptera*	2.69	NA
golden alexander	*Zizia aurea*	NA	2.69
Summer forbs			
leadplant	*Amorpha canescens*	2.69	2.69
swamp milkweed	*Asclepias incarnata*	NA	1.61
common milkweed	*Asclepias syriaca*	1.08	1.08
butterfly milkweed	*Asclepias tuberosa*	0.43	0.32
whorled milkweed	*Asclepias verticillata*	0.54	NA
Canadian milkvetch	*Astragalus canadensis*	10.76	10.76
white wild indigo	*Baptisia alba*	NA	0.54
showy partridge pea	*Chamaecrista fasciculata*	2.69	2.69

stiff tickseed	*Coreopsis palmata*	0.54	NA
white prairieclover	*Dalea candida*	10.76	NA
purple prairie clover	*Dalea purpurea*	10.76	21.53
showy ticktrefoil	*Desmodium canadense*	NA	2.69
Illinois ticktrefoil	*Desmodium illinoense*	2.69	NA
pale purple coneflower	*Echinacea pallida*	2.15	2.69
rattlesnake master	*Erynigium yuccifolium*	NA	2.15
flowering spurge	*Euphorbia corollata*	1.08	NA
smooth oxeye	*Heliopsis helianthoides*	2.69	5.38
round-head bushclover	*Lespedeza capitata*	1.61	NA
wild beebalm	*Monarda fistulosa*	10.76	10.76
prairie cinquefoil	*Drymocallis arguta*	21.53	NA
common mountain mint	*Pycnanthemum virginianum*	NA	21.53
yellow coneflower	*Ratibida pinnata*	21.53	21.53
black-eyed susan	*Rudbeckia hirta*	10.76	10.76
rosinweed	*Silphium integrifolium*	0.22	0.32
compass plant	*Silphium laciniatum*	0.11	0.22
Fall forbs			
prairie sage	*Artemisia ludoviciana*	21.53	18.84
false boneset	*Brickellia eupatoriodes*	2.69	NA
tall boneset	*Eupatorium altissimum*	2.69	1.61
grass-leaved goldenrod	*Euthamia graminifolia*	NA	10.76
sawtooth sunflower	*Helianthus grosseserratus*	1.08	1.61
prairie sunflower	*Helianthus laetiflorus*	0.32	NA
rough blazingstar	*Liatris aspera*	1.61	NA
prairie blazingstar	*Liatris pycnostachya*	NA	1.61
great blue lobelia	*Lobelia siphilitica*	NA	10.76
sweet coneflower	*Rudbeckia subtomentosa*	NA	10.76
stiff goldenrod	*Solidago rigida*	8.07	8.07
showy goldenrod	*Solidago speciosa*	10.76	10.76
smooth blue aster	*Symphyotrichum laeve*	16.15	8.07
New England aster	*Symphyotrichum novae-angliae*	8.07	8.07
prairie ironweed	*Vernonia fasciculata*	NA	2.69