Prepared in cooperation with the U.S. Fish and Wildlife Service

Evaluation of Restoration Methods to Minimize Canada Thistle (*Cirsium arvense*) Infestation

Open-File Report 2009–1130

U.S. Department of the Interior
U.S. Geological Survey

Cover. Minnesota restoration field. Photograph by Diane L. Larson, U.S. Geological Survey, taken July 19, 2006.

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KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Conversion Factors

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
	Mass	
gram	0.03527	ounce, avoirdupois (oz)

Constituent concentrations in soil are given in micrograms per gram (μg/g).

Evaluation of Restoration Methods to Minimize Canada Thistle (*Cirsium arvense*) Infestation

By Diane L. Larson

Abstract

The National Wildlife Refuge System has an active habitat restoration program and annually seeds thousands of hectares with native plant species. The noxious weed, Canada thistle (*Cirsium arvense*), plagues these restorations. This study evaluates planting methodology and seed mixes with the goal of recommending optimal methods to reduce infestation of noxious weeds, especially Canada thistle, in new restorations. Three planting methods (dormant season broadcast, growing season [summer] broadcast, and growing season [summer] drill) were fully crossed with three levels of seed diversity (10, 20, and 34 species [plus a fourth level, 58 species, on the three sites in Iowa]) in a completely randomized design replicated on nine sites in Minnesota and Iowa. The propagule bank of Canada thistle was evaluated at each site. Planting occurred in winter 2004 and spring-summer 2005. Here I report on results through summer 2007. None of the planting methods or seed mix diversities consistently resulted in reduced abundance of Canada thistle. Soil texture had the strongest influence; sites with greater proportions of clay had greater frequency and cover of Canada thistle than did sandy sites. At the Minnesota study sites, the dormant broadcast planting method combined with the highest seed diversity resulted in both the greatest cover of planted species as well as the greatest richness of planted species. At the Iowa sites, planted species richness was slightly greater in the summer drill plots, but cover of planted species was greatest in the dormant broadcast plots. Richness of planted species at the Iowa sites was maximized in the high diversity plots, with the extra-high diversity seed mix resulting in significantly lower species richness. Individual species responded to planting methods idiosyncratically, which suggests that particular species could be favored by tailoring planting methods to that species.

Introduction

Restoration is a hallmark of the National Wildlife Refuge System (U.S. Fish and Wildlife Service, 1999, p. 12). Region 3 of the U.S. Fish and Wildlife Service harbors one of the largest tallgrass prairie restorations in the world at Neal Smith National Wildlife Refuge (NWR), located in Iowa. Efforts to preserve and restore such rare habitats are at the core of the Service's mission to "…administer a national network of lands and waters for the conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations of Americans" (National Wildlife Refuge System Improvement Act of 1997).

This study was done by U.S. Geological Survey in cooperation with Region 3 of the U.S. Fish and Wildlife Service. It represents the efforts of personnel at Neal Smith NWR and at Litchfield, Morris, and Fergus Falls Wetland Management Districts (WMDs), Minnesota, to experimentally test the effects of three seeding methods and three (four in Iowa) seed diversity mixes on the success of restoration plantings. In this report, I describe changes in species richness and vegetative cover of the planted native species as well as cover and stem counts of Canada thistle from 2005 through 2007.

Methods

We combined three planting methods (dormant-season broadcast [hereafter referred to as "dormant broadcast"], growing-season broadcast [hereafter "summer broadcast"], and growing-season drill [hereafter "summer drill"]) with three (four in Iowa) seed diversities (10, 20, or 34 species, plus 58 at Neal Smith NWR in Iowa) in a completely randomized design on each of nine sites (two at each of the WMDs and three at Neal Smith NWR). Each treatment was replicated 12 times at each site, for a total of 108 12- × 12-m "cells" planted at each site. Within each cell we delineated a permanently marked 6- × 2-m sample plot. Here we counted all thistle stems. On a 0.25- × 4-m subplot within the sample plot, we measured species richness and cover of all species present. These cover and richness measurements were completed by a contractor from the University of Minnesota in 2005 and 2006 and by a contractor from Iowa State University in 2007, with help from station staff in each year.

Prior to seeding, seedbank samples were collected at a subset of cells at each site. These samples were analyzed for thistle propagules by contractors at the U.S. Department of Agriculture, Agricultural Research Service's Morris field station. In addition, soil samples were collected for texture and nitrogen analyses; these samples were analyzed by contractors at the University of Minnesota.

Basic statistical analyses of the data were performed by using repeated measures analysis of variance (ANOVA) (SAS GLM, version 9.2) for the years 2005–07. Because Canada thistle abundance, as described below, was much greater on the Minnesota study sites than at the Neal Smith NWR sites in Iowa, Minnesota and Iowa sites were analyzed separately for all analyses. When high-order interaction terms made ANOVAs hard to interpret, structural equation models were used to evaluate differences in response variables (for example, cover of Canada thistle, cover of planted species) that might be attributed to multivariate, site-specific characteristics (for example, soil texture, nitrogen cycling).

Results and Discussion

Soil texture and propagule bank results were reported in the 2006 interim report and are summarized here. There was no spatial structure in soil texture within sites, but sites did differ from each other in the percentage of sand, silt, and clay in their soil (fig. 1). Meeker, at Litchfield WMD, was the sandiest site and also had the smallest percentage of clay. Sites Orbweaver and Production, at Neal Smith NWR, had the least sand and the highest percentage of silt. (Tables of results of all ANOVAs in this report are compiled in appendix 1.)

The range of values for soil characteristics at Minnesota and Iowa sites is presented in table 1. Results presented in this report can likely be generalized within these ranges but should not be used to extrapolate outside of them.

Thistle seed was detected on nine plots at site Heinola (Fergus Falls WMD), five plots at site Fahl (Morris WMD), and one plot each at sites Diekmann (Morris WMD), Meadows (Fergus Falls WMD), and Kandiyohi (Litchfield WMD). No thistle seeds were found at Meeker (Litchfield WMD) or at Production, Orbweaver, and Harmison (Neal Smith NWR). No root fragments from any site sprouted. The lack of a thistle propagule bank at most sites, combined with the obvious presence of Canada thistle in the vegetation, suggests either that windblown seeds are entering the sites or that our sampling intensity was insufficient to adequately characterize the thistle seedbank.

Thistle Stem Counts

Because of the vast difference in the amount of thistle at the Neal Smith NWR (Iowa) sites and the WMD (Minnesota) sites (fig. 2), as well as the landscape-level differences (for example, proximity to thistle infestations) between the NWR and the WMD sites, I have analyzed these two data sets separately by using repeated measures ANOVA for the years 2005–07 in Minnesota and Iowa.

There was a significant interaction between site and planting method with respect to thistle stem counts at both the Minnesota and Iowa study sites (fig. 3). In Minnesota, the dormant broadcast method had more thistle stems at three sites, fewer at one site, and did not vary from the other planting methods at two sites. The increase between 2005 and 2006 was much larger than between 2006 and 2007 at all Minnesota sites except Diekmann. In Iowa, only Production showed a substantial increase in thistle stems over time, and this increase was greatest in the dormant broadcast plots. In

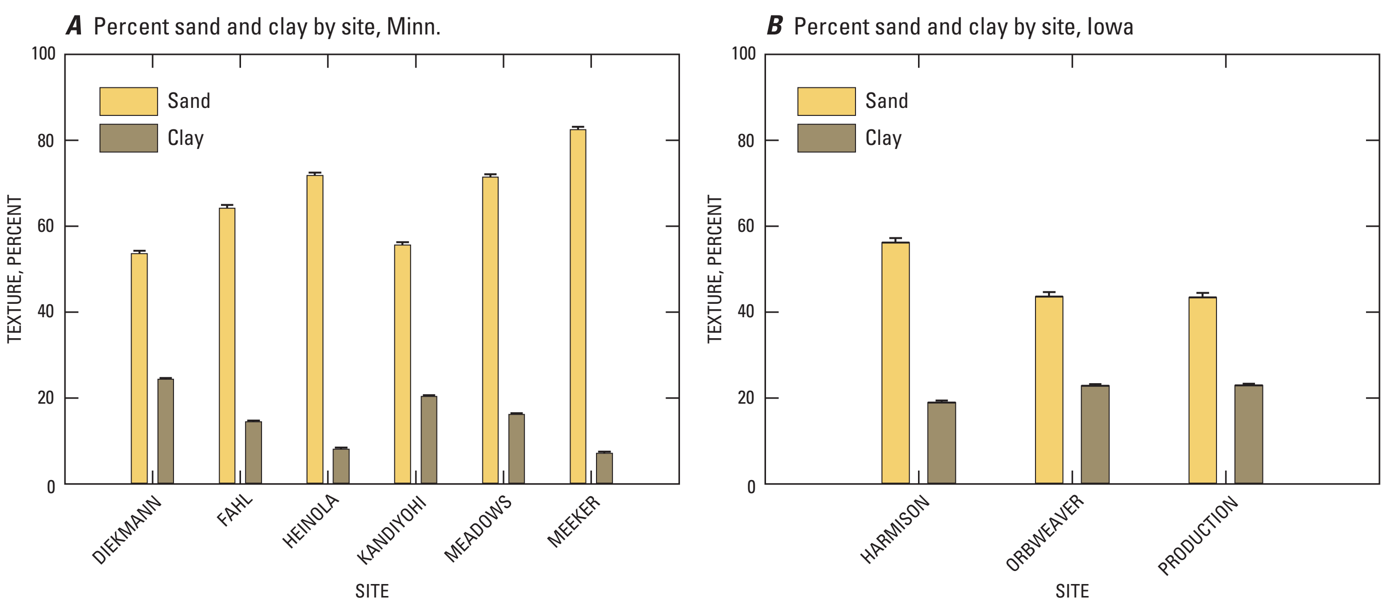

Figure 1. Soil texture at study sites in Minnesota (*A*) and Iowa (*B*). Shown are least square means and standard errors.

Table 1. Range of values for soil characteristics.

[Values reported are means for study sites within the two States, with the range for individual plots in parentheses. %, percent; µg, microgram; g, gram]

Soil variable	Minnesota sites (range)	Iowa sites (range)
Sand (%)	53–82 (48–91)	43–56 (42–75)
Silt (%)	10–24 (2–29)	25–34 (13–38)
Clay (%)	7–24 (5–29)	19–23 (10–25)
Nitrogen mineralization rate (µg/g soil/day)	0.77–1.1 (0.470–2.113)	0.81–0.96 (0.379–1.627)
Net nitrification (µg/g soil/day)	1.6–2.8 (0.852–5.793)	1.3–1.7 (0.802–2.911)

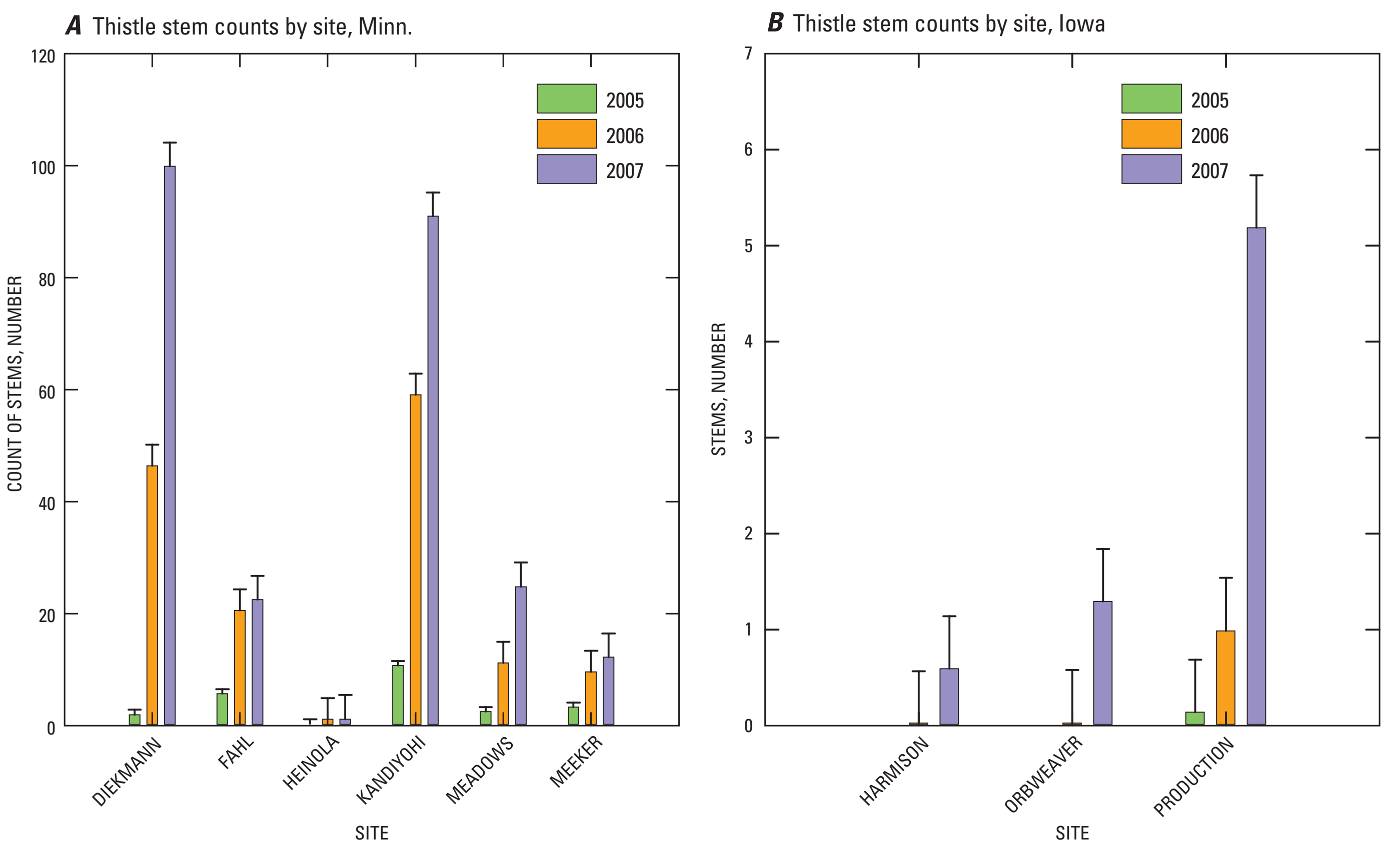

Figure 2. Canada thistle stem counts at sites in Minnesota (*A*) and Iowa (*B*). Note that the y-axis differs between the two graphs. Shown are least square means and standard errors.

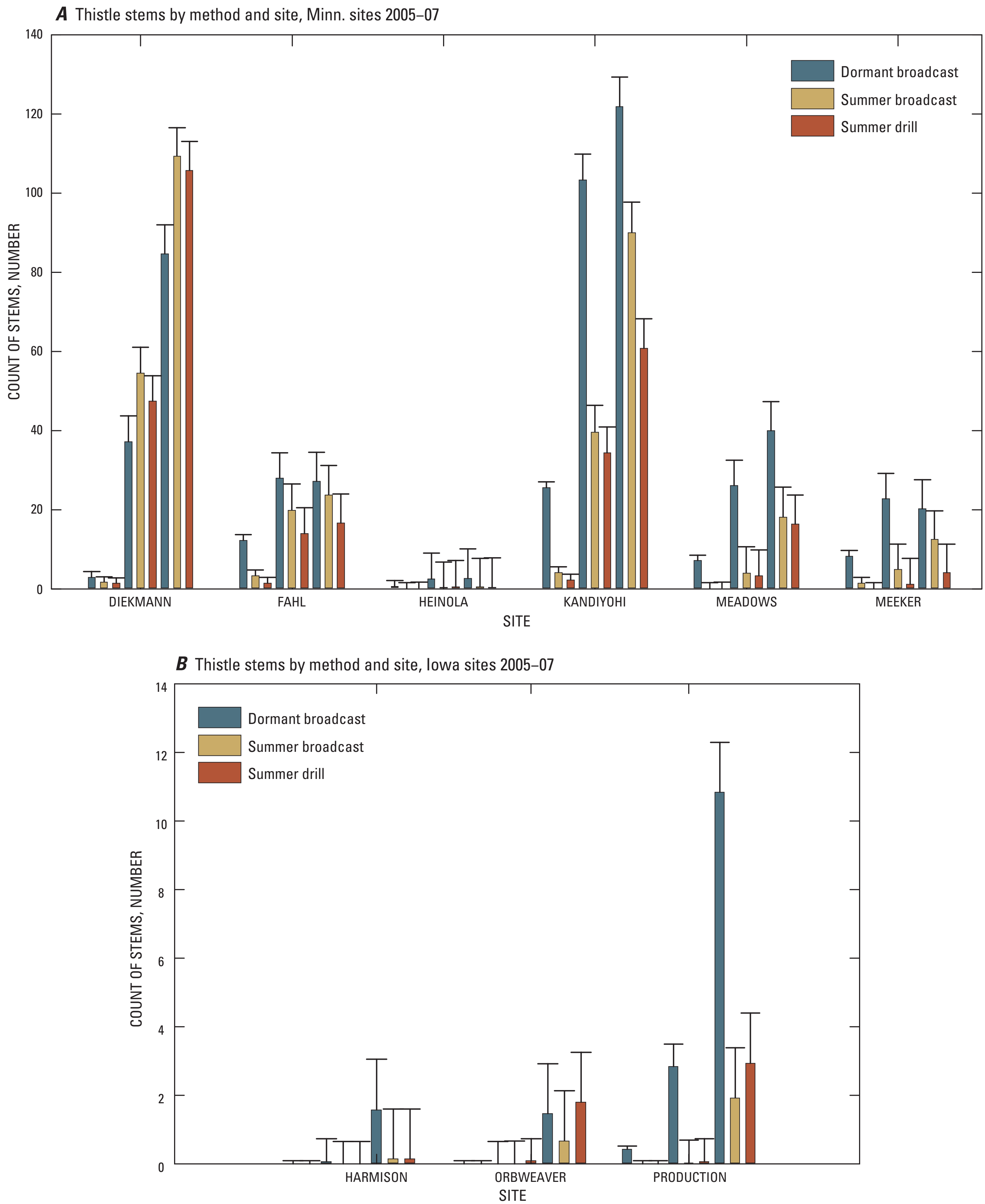

Figure 3. Canada thistle stem counts by site and method for Minnesota (*A*) and Iowa (*B*) sites. For each site, the first three bars are 2005 counts, the second three are 2006, and the third three are 2007. Note the different range of the y-axes in the two graphs. Shown are least square means and standard errors.

addition, the Iowa sites had a significant method-by-diversity interaction (fig. 4). The low diversity plots had more thistle stems in 2007 than did the plots of other diversity levels.

Thistle Cover

In the repeated measures analysis, there was a significant interaction between site and planting method over time at both the Minnesota and the Iowa sites (fig. 5). In Minnesota, thistle cover has continued to increase at Diekmann, Kandiyohi, and Meadows but has leveled off at the other three sites. Dormant broadcast plots tended to have more thistle than did the other two planting methods at Fahl and Kandiyohi but less at Diekmann. In Iowa, only Production has undergone a significant increase in thistle cover over the 3 years, and this increase has been primarily in the dormant broadcast plots, as was the case for thistle stem counts.

Thistle cover in Iowa was also influenced by diversity of the seed mix, and effect of the seed mix varied by planting method (fig. 6). The low diversity seed mix in the dormant broadcast method had the highest thistle cover at the Iowa sites in 2007. All other method-by-diversity combinations had similar amounts of thistle cover in 2007. Although thistle cover has increased over the 3 years of the study, it is still substantially lower in Iowa than in the Minnesota sites, with the exception of Heinola.

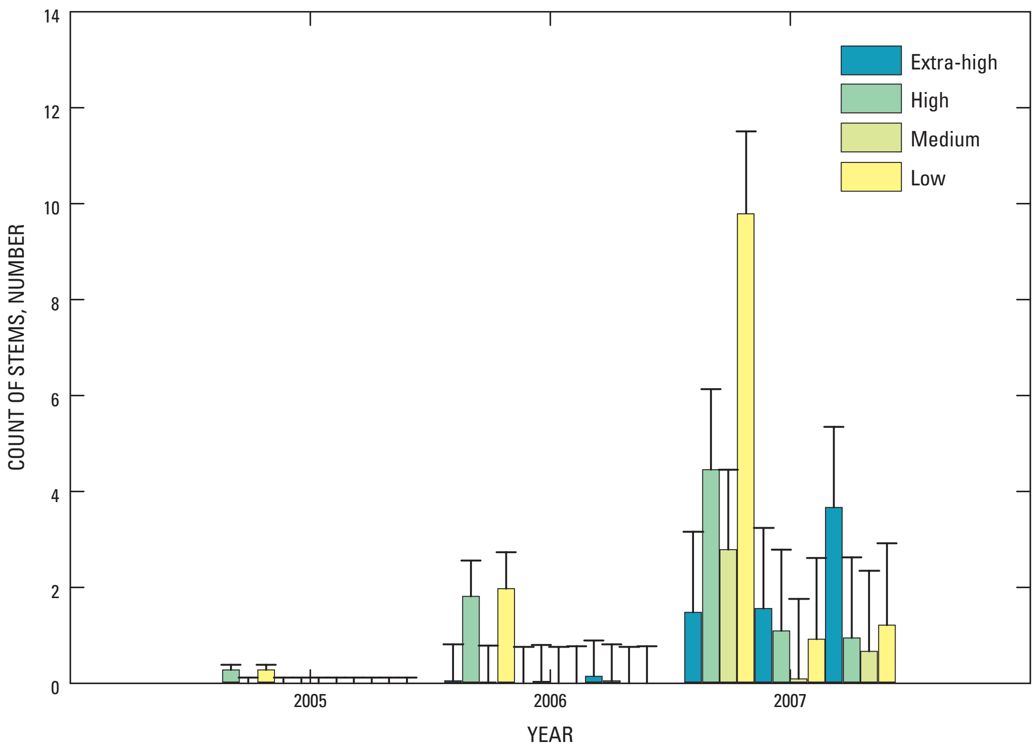

Figure 4. Canada thistle stem counts by method and seed mix diversity at the Iowa sites. For each year, the first four bars represent the dormant broadcast method, the second four represent the summer broadcast, and the third four represent the summer drill. Shown are least square means and standard errors.

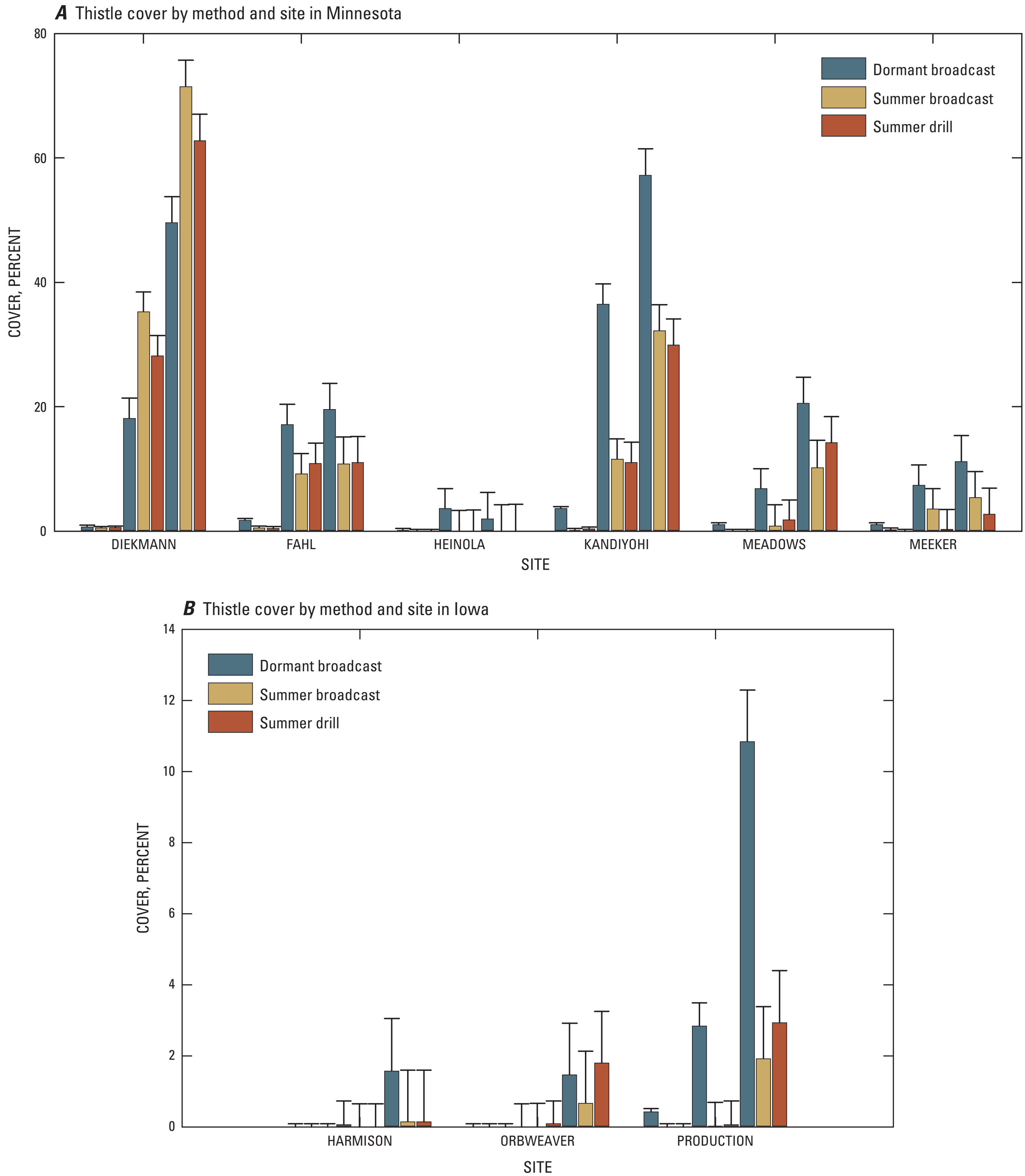

Figure 5. Thistle cover as a function of planting method and site in Minnesota (*A*) and Iowa (*B*). Within each site, the first three bars represent 2005 measurements, the second three represent 2006 measurements, and the third three represent 2007 measurements. Note that the y-axes differ on the two graphs. Shown are least square means and standard errors.

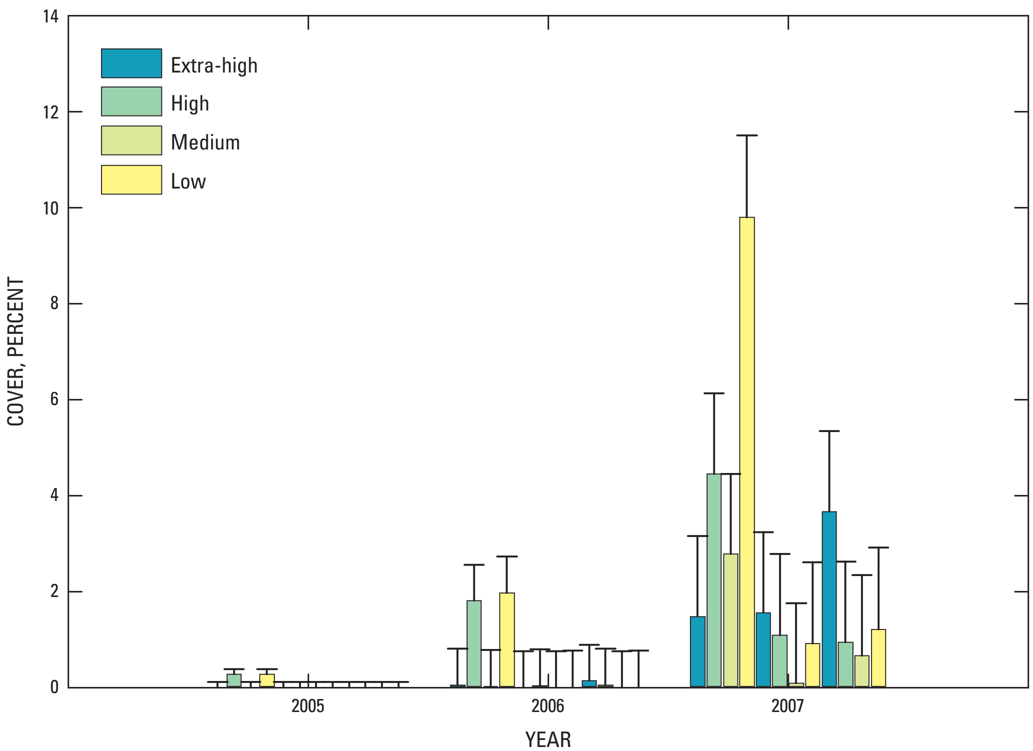

Figure 6. Canada thistle cover as a function of planting method and seed mix diversity at Iowa sites. Within each year, the first three bars represent the dormant broadcast method, the second three represent the summer broadcast, and the third three represent the summer drill. Shown are least square means and standard errors.

Planted Species Cover

In Minnesota, cover of planted species varied by method, and this variation differed depending on site (fig. 7). Cover of planted species increased over the 3 years of the study, with the dormant broadcast planting method showing the largest amount of cover in each year for each site except Diekmann, where the summer drill had a slight advantage over the other two planting methods. Cover of planted species in summer broadcast and summer drill plots was generally similar, except at Kandiyohi, where the summer broadcast lagged behind the summer drill. The difference between the effects of seed mix diversity levels on cover of planted species has been accentuated over time, with the high diversity seed mix having the greatest and the low diversity seed mix having the lowest cover of planted species in both 2006 and 2007 (fig. 8).

In Iowa, cover of planted species varied significantly by site (fig. 9); cover increased in each year, with Orbweaver having the highest cover of planted species in both 2006 and 2007. There was a significant interaction between planting method and seed mix diversity (fig. 10) as well. The extra-high seed diversity treatment had lower than expected cover of planted species. The dormant broadcast method generally produced greater cover of planted species than did the other two planting methods. Planted cover in the summer broadcast and summer drill methods was especially depressed in the extra-high diversity seed mix in 2006 and 2007.

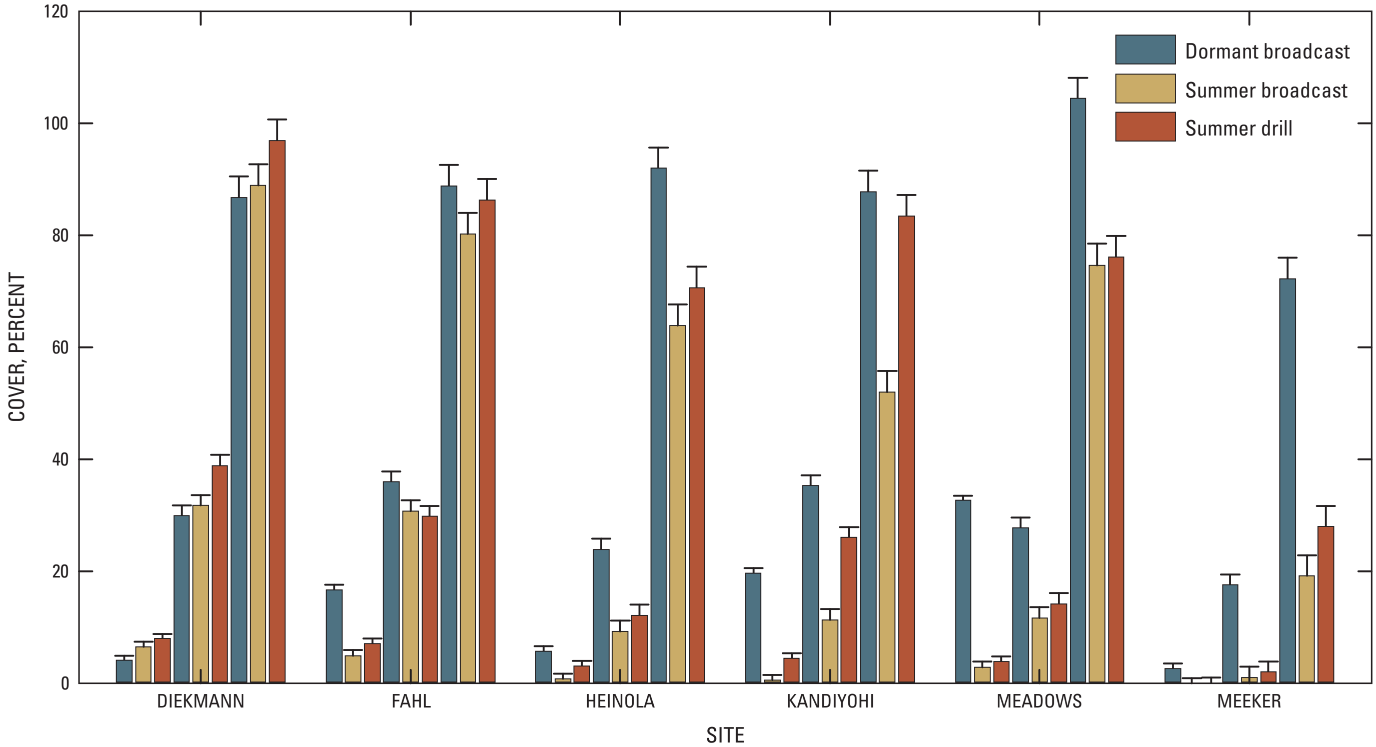

Figure 7. Cover of planted species as a function of planting method and site at Minnesota sites. Within each site, the first three bars represent 2005 measurements, the second three 2006 measurements, and the third three 2007 measurements. Shown are least square means and standard errors.

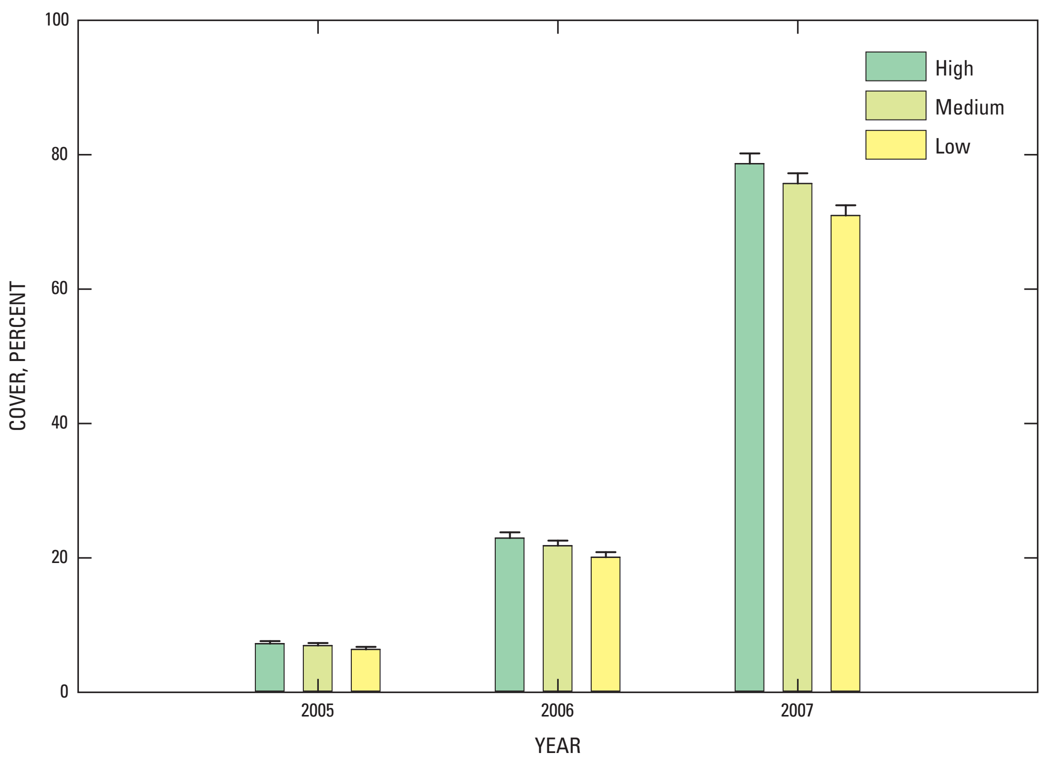

Figure 8. Cover of planted species over time as a function of seed mix diversity at Minnesota sites. Shown are least square means and standard errors.

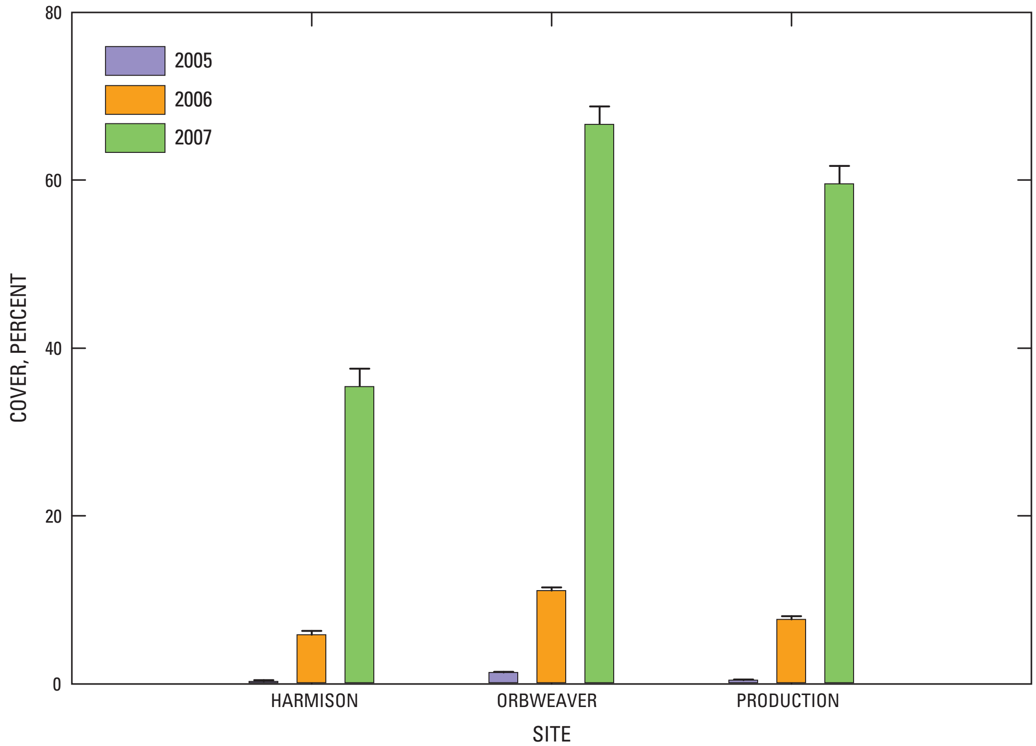

Figure 9. Cover of planted species over 3 years at Iowa sites. Shown are least square means and standard errors.

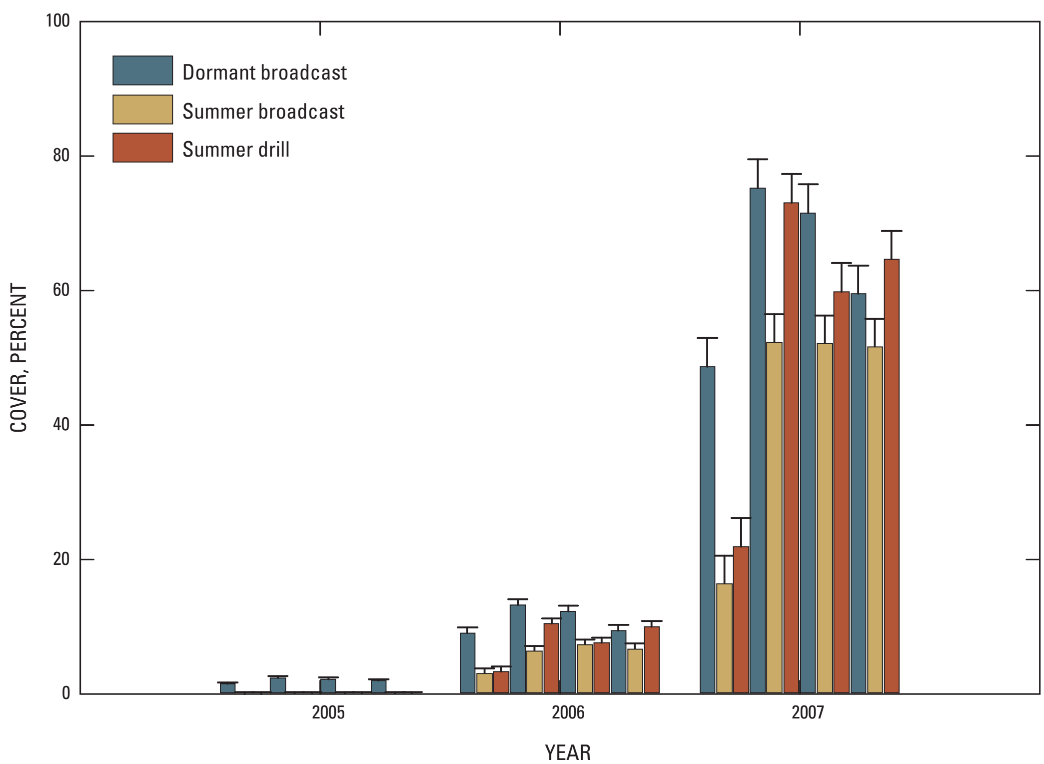

Figure 10. Cover of planted species as a function of planting method and seed mix diversity at Iowa sites. Within each year, the first three bars refer to the extra-high diversity, the next three to the high diversity, the next three to the medium diversity, and the last three to the low diversity. Shown are least square means and standard errors.

Species Richness

Unlike in 2005 and 2006, when we only measured species richness in the subplots used to measure cover, in 2007 we counted the number of species in the entire 2- × 6-m plot. Therefore, this ANOVA evaluated the effects of site, planting method, seed diversity, and their interactions in 2007 only.

In Minnesota sites, richness of planted species varied in a complex three-way interaction among site, planting method, and seed diversity (fig. 11). In most cases, the high diversity seed mix resulted in greater species richness than did the medium and low diversity mixes; however, at Kandiyohi, Meadows, and Meeker, the high and medium diversity mixes did not differ when the summer broadcast planting method was used. At every site in Minnesota, the dormant broadcast planting method combined with the high diversity seed mix resulted in the greatest number of desired species.

Richness of planted species at the Iowa sites varied by site and seed mix diversity (fig. 12*A*) and by method and seed mix diversity (Figure 12*B*). The extra-high diversity seed mix resulted in lower species richness than did the high diversity mix in every case; only in the dormant broadcast planting method did more species become established from the extra-high diversity mix than from the medium diversity mix. The low diversity seed mix had higher species richness in the summer drill planting method than in the other two methods; the medium diversity seed mix did not vary in species richness among the three planting methods.

The complete list of species in the seed mixes and their proportional representation in the plots can be found in appendix 2 (Minnesota) and appendix 3 (Iowa).

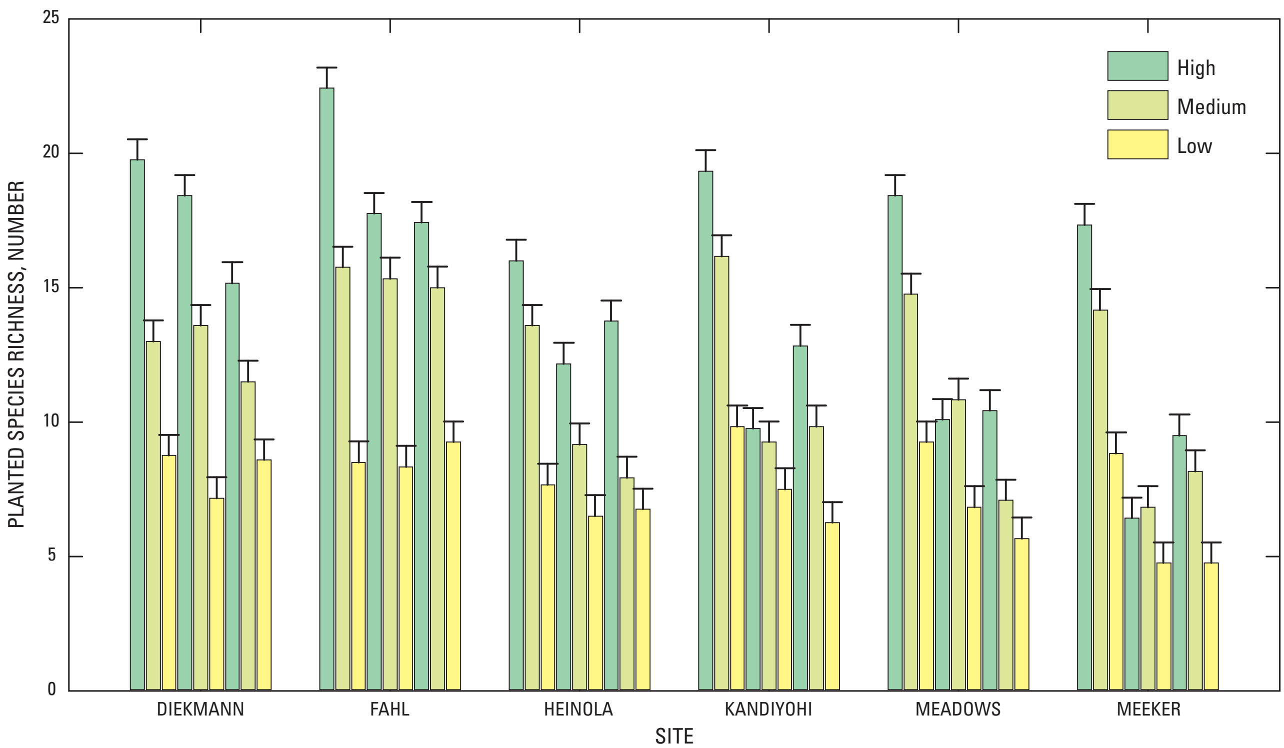

Figure 11. Richness of planted species as a function of site, planting method, and seed mix diversity at sites in Minnesota. Within each site, the first three bars represent the dormant broadcast method, the second three represent the summer broadcast, and the third three represent the summer drill. Shown are least square means and standard errors.

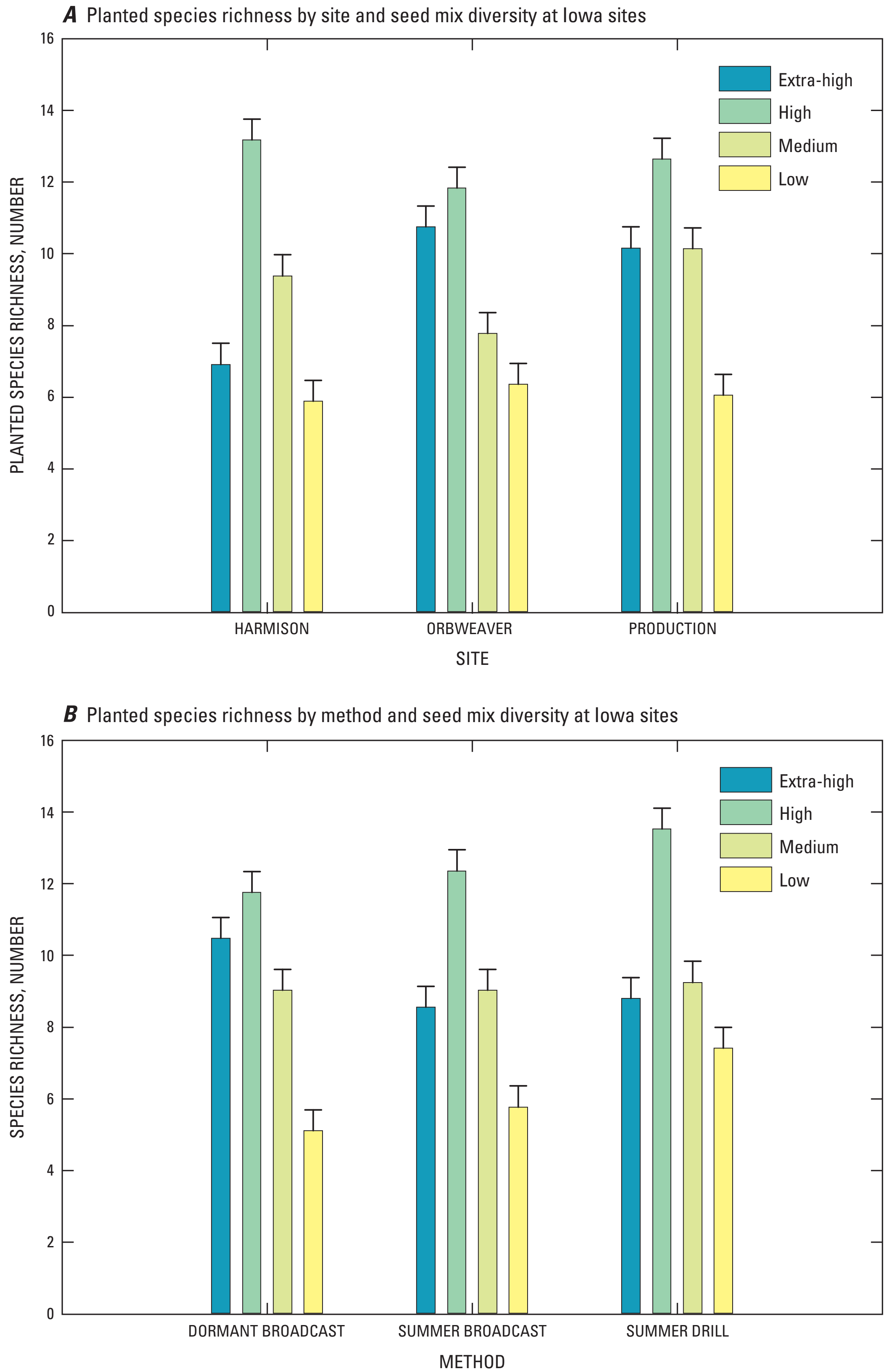

Figure 12. Planted species richness at Iowa sites. *A*, Richness as a function of site and seed mix diversity. *B*, Richness as a function of planting method and seed mix diversity. Shown are least square means and standard errors.

Minnesota

Only two species that were planted at Minnesota sites failed to appear by 2007: *Carex bicknellii* and *Liatris aspera*. Many species were less frequently encountered as the diversity of the seed mix increased (table 2), which is expected because the amount of seed was kept constant as more species were added. *Lespedeza capitata* was an exception to this trend. Among the grasses, *Elymus canadensis* and *E. trachycaulus* appeared on virtually every plot on which they were planted; *Andropogon gerardii* and *Bouteloua curtipendula* also had high establishment. *Sorghastrum nutans* and *Sporobolus asper*, however, were encountered on only about a quarter of the plots where they were planted (appendix 2). Four of the five most prevalent forbs were in the Asteraceae; the fifth was a mint. Among the five least prevalent forbs were three asters, a rose, and a lily (appendix 2).

The most frequent pattern encountered for individual species in Minnesota was a site-by-method interaction (figs. 13, 14, and 15). In only one case, *Ratibida columnifera* at Kandiyohi, was the summer broadcast clearly superior to the other two planting methods. Several species, including *Aster novae-angliae*, *Sorghastrum nutans*, *Coreopsis palmata*, *Panicum virgatum*, *Sporobolus asper*, and *Zizia aurea* were generally favored by the dormant broadcast planting method. *Dalea candida* was mainly favored by the summer drill planting method. In many cases, both dormant broadcast and summer drill produced similar results. Three species, *Verbena stricta*, *Artemisia ludoviciana*, and *Solidago rigida*, had significant three-way interactions among site, diversity, and method, which rendered the result difficult to interpret.

Table 2. Proportion of plots at Minnesota sites in which a species was encountered as a function of diversity of the seed mix.

[Shown are least square means plus or minus (+) standard error. NA, species not present in the low diversity mix]

Species	Diversity of seed mix		
	High	Medium	Low
Dalea purpurea	0.33+0.027	0.45+0.027	0.50+0.027
Aster novae-angliae	0.36+0.026	0.39+0.026	0.54+0.026
Heliopsis helianthoides	0.82+0.021	0.93+0.021	NA
Coreopsis palmata	0.54+0.027	0.63+0.027	NA
Dalea candida	0.35+0.026	0.43+0.026	NA
Lespediza capitata	0.39+0.026	0.28+0.026	NA
Potentilla arguta	0.19+0.024	0.31+0.024	NA

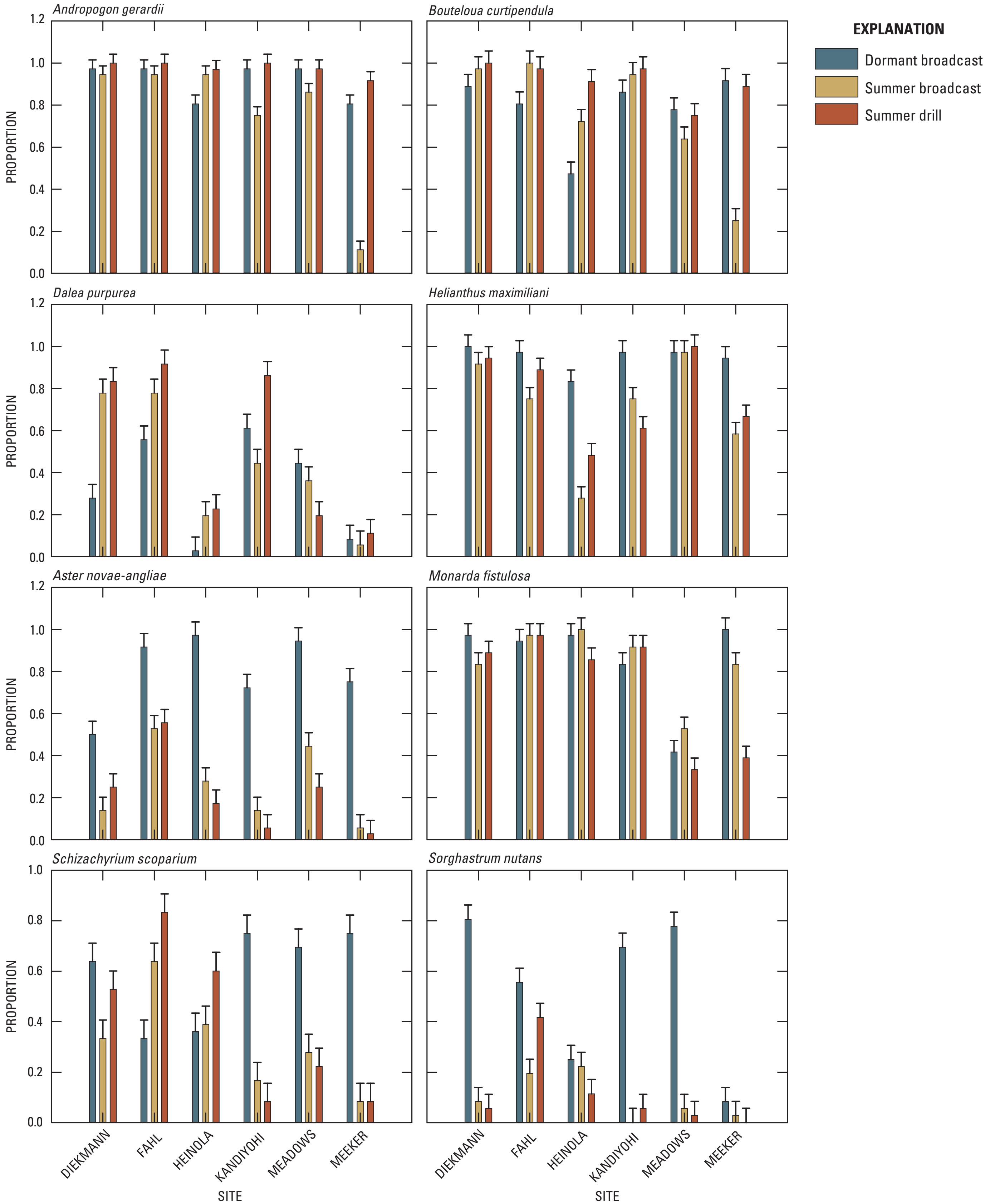

Figure 13. Species-specific responses to planting methods within sites at Minnesota sites for species present in all three seed mixes. Proportion refers to the proportion of plots in which each species was encountered. Shown are least square means and standard errors.

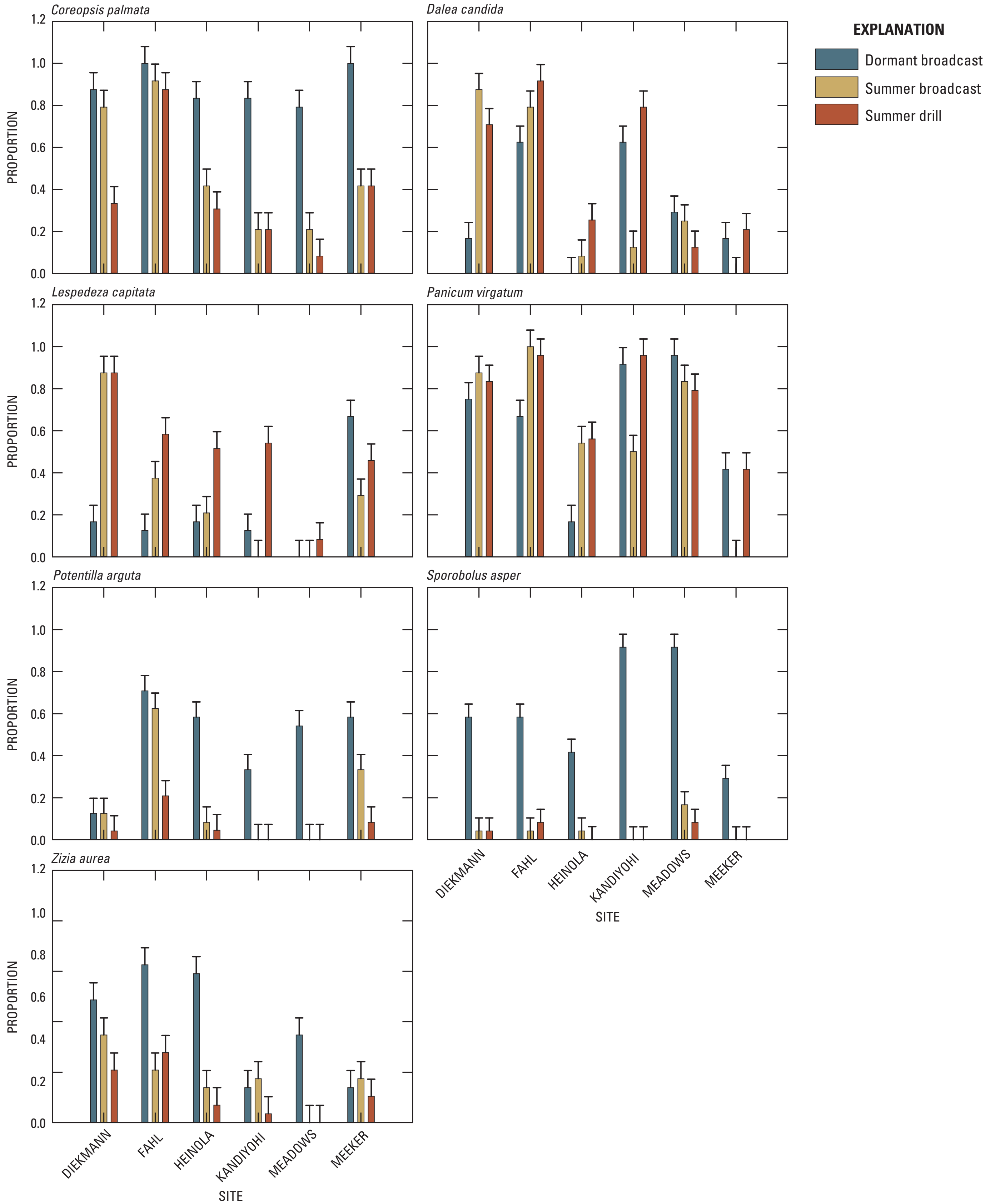

Figure 14. Species-specific responses to planting methods within sites at Minnesota sites for species present in the medium and high diversity seed mixes. Proportion refers to the proportion of plots in which each species was encountered. Shown are least square means and standard errors.

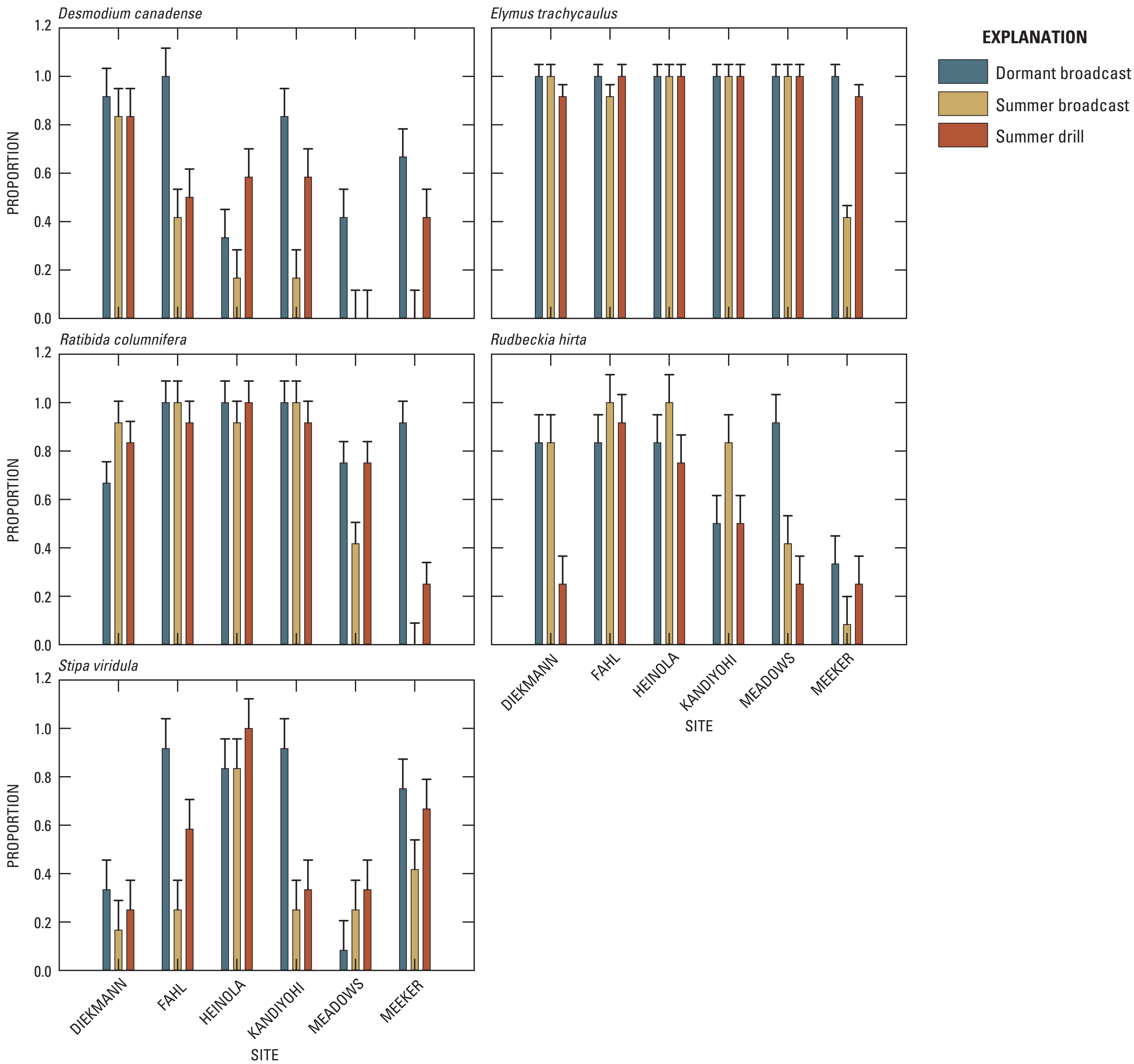

Figure 15. Species-specific responses to planting methods within sites at Minnesota sites for species present in the high diversity seed mix only. Proportion refers to the proportion of plots in which each species was encountered. Shown are least square means and standard errors.

Iowa

Seven species that were planted at Iowa sites were not encountered in our 2007 surveys: *Phlox pilosa*, *Amorpha canescens*, *Aster azureus*, *Coreopsis tripteris*, *Gentiana flavida*, *Sporobolus heterolepis*, and *Tradescantia bracteata*. Of these, *P. pilosa* was in the high and extra-high diversity seed mix, and the rest were in only the extra-high diversity mix (appendix 3). Surprisingly, several species that were in all four of the seed mixes were rarely encountered in the survey. These included *Verbena stricta*, *Helianthus occidentalis*, and *Aster novae-angliae*. As in Minnesota, some species had a significant relation to seed mix diversity, and most of those had greater frequencies in the lower diversity plots, again because of a higher proportion of seed of each species included in that mix (table 3). While there were always large declines in frequency between high and extra-high plots, there were many cases where there was little difference in frequency between high and medium diversity. Of the species that varied significantly by planting method as a main effect (table 4), some were strongly favored by either summer drill or dormant broadcast; none were favored by summer broadcast. Despite the overall similarity among the three sites (table 1, fig. 1), many species varied substantially in the proportion of plots occupied as a function of site (table 5).

Table 3. Proportion of plots at Iowa sites in which a species was encountered as a function of diversity of the seed mix.

[Shown are least square means plus or minus (±) standard error. Of the species shown, only *M. fistulosa* was included in the low diversity mix; *R. pinnata* was not present in the medium diversity mix]

Species	Diversity of seed mix			
	Extra-high	High	Medium	Low
Monarda fistulosa	0.38±0.045	0.44±0.045	0.56±0.045	0.69+0.045
Dalea candida	0.14±0.041	0.37±0.041	0.32±0.041	
Lespedeza capitata	0.26±0.042	0.65±0.042	0.64±0.042	
Panicum virgatum	0.60±0.042	0.81±0.042	0.76±0.042	
Sporobolus asper	0.37±0.044	0.53±0.044	0.43±0.044	
Ratibida pinnata	0.33±0.042	0.77±0.042		

Table 4. Proportion of plots at Iowa sites in which a species was encountered as a function of planting method.

[Shown are least square means plus or minus (±) standard error]

Species	Method		
	Dormant broadcast	Summer broadcast	Summer drill
Monarda fistulosa	0.43±0.039	0.47±0.039	0.65±0.039
Schizachyrium scoparium	0.24±0.037	0.32±0.037	0.46±0.037
Sorghastrum nutans	0.63±0.035	0.65±0.035	0.79±0.035
Panicum virgatum	0.68±0.042	0.67±0.042	0.82±0.042
Potentilla arguta	0.18±0.028	0.10±0.028	0.028±0.028
Sporobolus asper	0.69±0.044	0.32±0.044	0.31±0.044
Tradescantia ohiensis	0.24±0.050	0.18±0.050	0.42±0.050
Asclepias tuberose	0.67±0.073	0.22±0.073	0.31±0.073
Desmodium canadense	0.17±0.075	0.42±0.075	0.56±0.075

Table 5. Proportion of plots at Iowa sites in which a species was encountered as a function of site.

[Shown are least square means plus or minus (±) standard error]

Species	Site		
	Harmison	Orbweaver	Production
Monarda fistulosa	0.44±0.039	0.49±0.039	0.63±0.039
Dalea candida	0.37±0.041	0.15±0.041	0.32±0.041
Heliopsis helianthoides	0.55±0.039	0.70±0.039	0.80±0.039
Panicum virgatum	0.63±0.042	0.78±0.042	0.75±0.042
Potentilla arguta	0.17±0.028	0.01±0.028	0.13±0.028
Sporobolus asper	0.41±0.044	0.56±0.044	0.36±0.044
Asclepias tuberosa	0.25±0.073	0.42±0.073	0.53±0.073
Delphinium virescens	0.14±0.066	0.11±0.066	0.44±0.066
Desmodium canadense	0.22±0.075	0.42±0.075	0.50±0.075
Thalictrum dasycarpum	0.22±0.070	0.11±0.070	0.61±0.070

Seven species had a significant interaction between site and seed mix diversity (fig. 16). In general, species that occurred only in the extra-high diversity mix were not as represented in the plots as were those in the high diversity seed mix. *Rudbeckia hirta* and *Tradescantia ohiensis* were exceptions to this trend.

Five species had significant interactions between planting method and seed mix diversity (fig. 17). Again, species in the extra-high diversity mix were generally less frequent than those in the lower diversity mixes, with *R. hirta* an exception. Of these species, *Heliopsis helianthoides* tended to do better in the dormant broadcast treatment, but the others were generally slightly better represented in the summer drill and summer broadcast.

Six species had significant interactions between planting method and site (fig. 18). Here again, and in contrast to results at the Minnesota sites, the summer planting methods often showed superior performance to the dormant broadcast method; however, substantial variation among the species suggests that methods tailored to individual species—for example, staggered planting times—may yield the best results. Four species, *Verbena stricta*, *Dalea purpurea*, *Astragalus canadensis*, and *Stipa spartea*, had significant three-way interactions among site, planting method, and diversity, which rendered the results difficult to interpret.

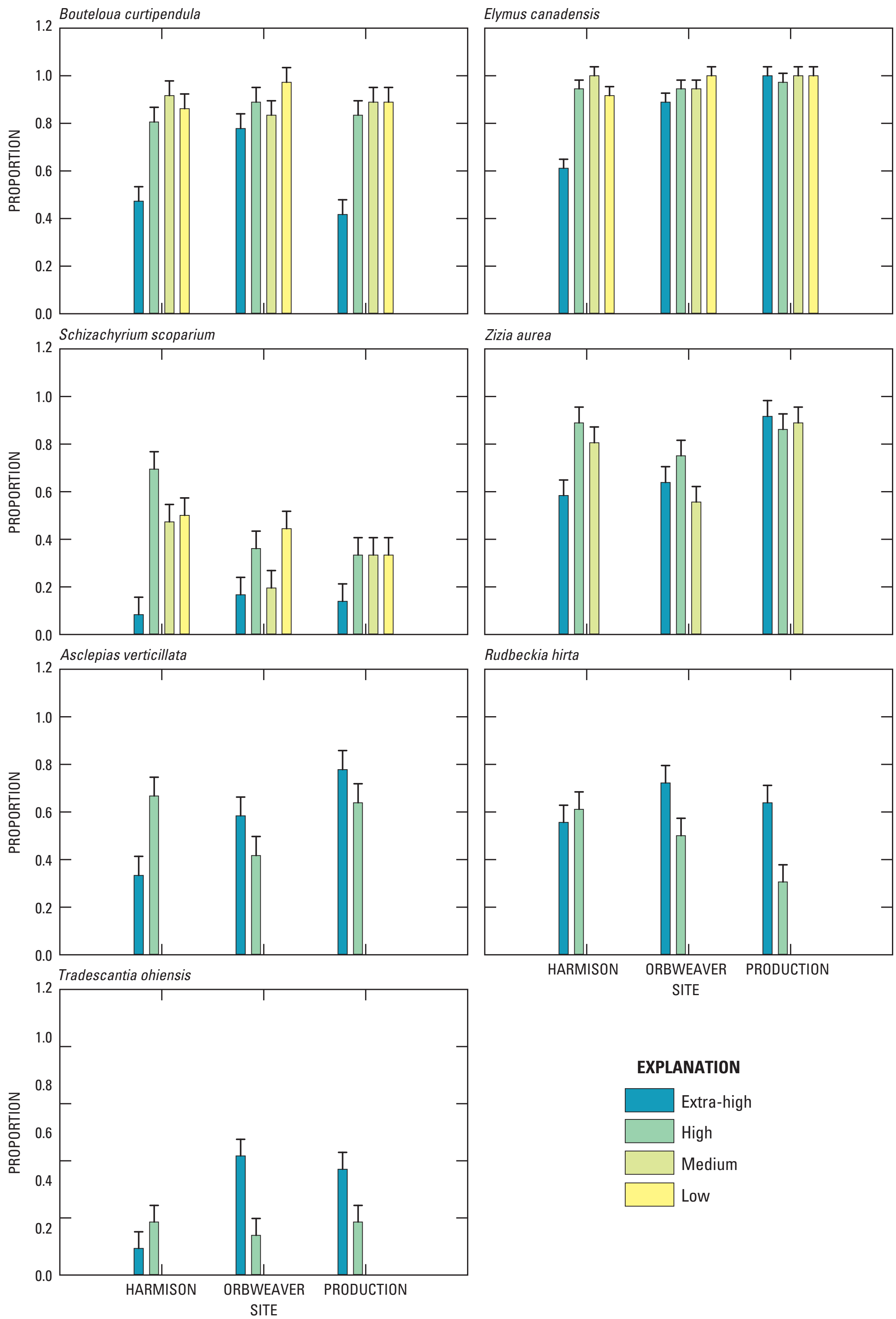

Figure 16. Species-specific responses to site and seed mix diversity at Iowa sites. Proportion refers to the proportion of plots in which the species was encountered to all plots in which the species was planted. Shown are least square means and standard errors.

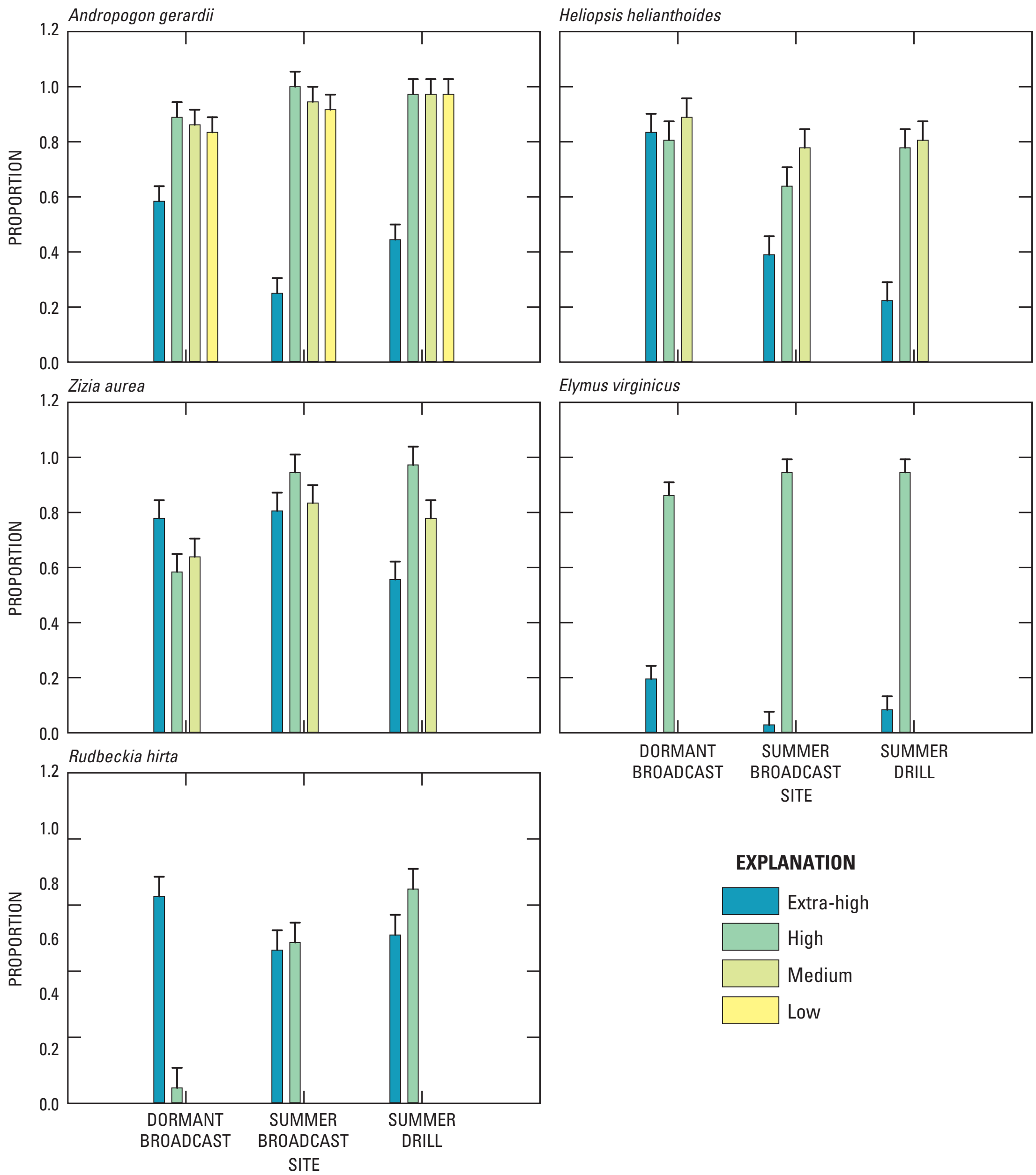

Figure 17. Species-specific responses to planting method and seed mix diversity at Iowa sites. Proportion refers to the proportion of plots in which the species was encountered to all plots in which the species was planted. Shown are least square means and standard errors.

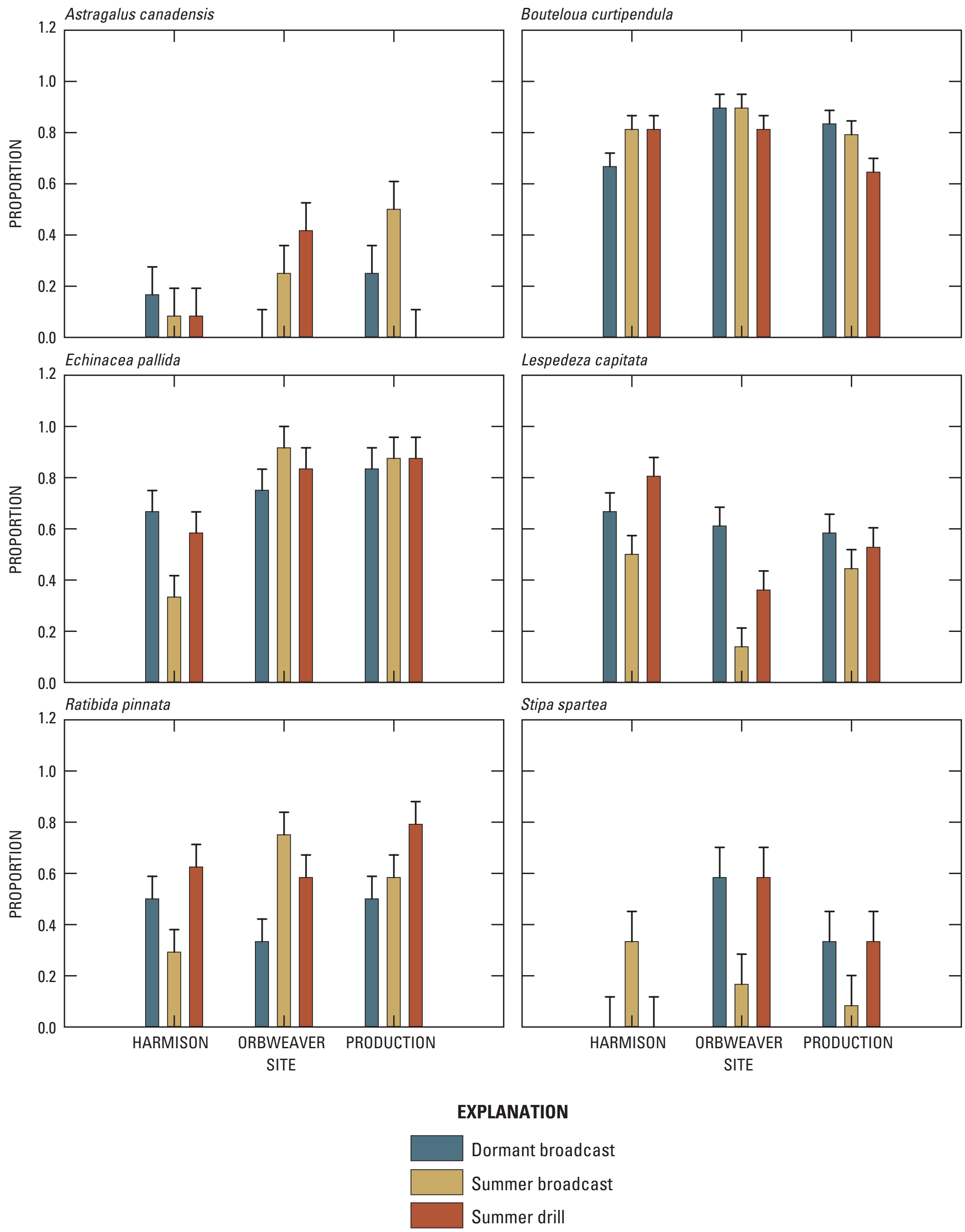

Figure 18. Species-specific responses to planting method and site at Iowa study sites. Proportion refers to the proportion of plots in which the species was encountered to all plots in which the species was planted. Shown are least square means and standard errors.

Synthesis

The results presented so far suggest that the dormant broadcast planting method will tend to optimize the establishment of planted species at Minnesota sites, regardless of site or diversity of the seed mix. At the Iowa sites, richness of the planted species tended to be optimized by the summer drill method, at least for low through high diversity seed mixes. Cover of planted species, on the other had, was highest for the dormant broadcast plots at sites in both Minnesota and Iowa. Higher diversity seed mixes, at least through approximately 34 species, resulted in greater species richness; results from the extra-high diversity mix at the Iowa sites suggest that there may be a maximum seed mix diversity, above which there is not only no gain in richness but indeed a loss in realized species richness and cover of planted species. The importance of this deficit in native recruitment is not yet clear; if more “conservative” seeds germinate in subsequent years, the higher diversity may ultimately prove to be the more resilient to invasion.

Results with respect to Canada thistle are less straightforward. No single planting method or seed diversity level resulted in consistently lower infestations of Canada thistle across sites. To begin to understand the relations among site-specific variables, such as soil texture and nitrogen cycling, and the response variable, abundance of Canada thistle, I used structural equation models (McCune and Grace, 2002) for the Minnesota sites. I took a model-generating approach (Jöreskog and Sörbom, 1996) to develop the model with data from 2005 to 2007 with the aim of understanding what factors most influenced Canada thistle cover in 2007. I started with a model that included percent sand, percent clay, and nitrification, as well as Canada thistle cover in 2005, 2006, and 2007 and cover of planted species in 2006 (fig. 19).

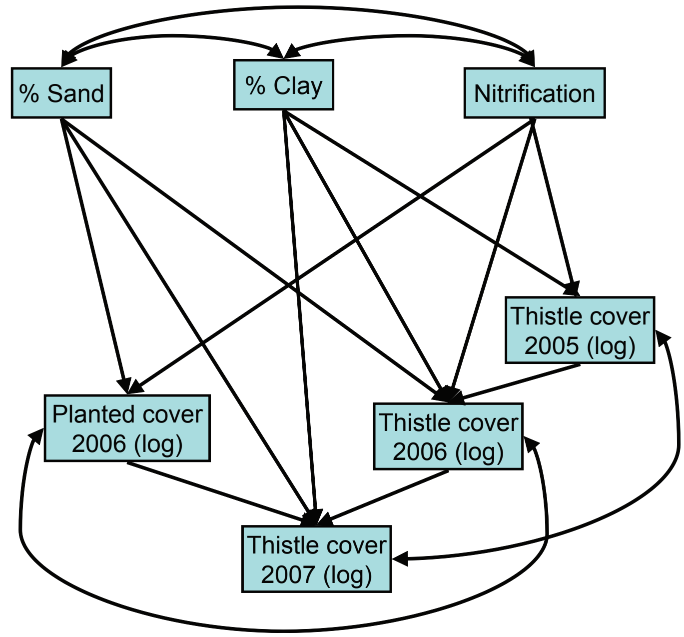

Figure 19. Hypothesized model for effects of soil characteristics on Canada thistle cover. Straight arrows are causal pathways; curved arrows represent correlations between variables.

Minnesota Sites

Because nitrification was never significant for either the full model or the multigroup model (in which model structure and parameters were compared among the three planting methods), I removed it from the model. Likewise, I removed pathways that were never significant and for which I had no compelling biological rationale for their preservation. The resulting model (fig. 20) fit the data well for all three planting methods (Chi-square = 16.73, df = 12, P = 0.160). The total standardized effects point out several useful patterns in the data (table 6). First, cover of planted species in 2006 had a weak but significant negative effect on thistle cover in 2007 in both the dormant broadcast and summer drill plots; the effect was not significant in the summer broadcast plots (fig. 20). This result suggests that cover of planted species had already begun to influence Canada thistle populations, at least in these two planting methods.

Second, the negative effect of percent sand on cover of planted species was much larger in plots that were planted in the summer than in the dormant season plots (fig. 20), probably because of reduced water availability in sandy soils. Sandy sites may therefore benefit from a dormant broadcast planting method because increased cover of planted species ultimately also should mean less cover of Canada thistle (table 6). In contrast, clay strongly favored Canada thistle in all three planting methods.

Third, thistle cover in 2006 strongly influenced thistle cover in 2007 in all three planting methods; the effect of 2005 on 2006 Canada thistle cover was not as strong (table 6). The implication of this result is that Canada thistle is not (yet, at least) regulated by density dependence. It would be tempting to conclude that, given the strong influence of previous thistle cover on subsequent thistle cover, rapid control of incipient infestations would benefit new restorations. Canada thistle cover, however, did not increase between 2006 and 2007 at two study sites (Fahl and Meeker; fig. 5), and no control efforts were mounted at these sites. Future surveys, planned for 2009, will help discern if, by improving cover and diversity of planted species, managers can adequately control Canada thistle without resorting to herbicides or other disruptive methods.

Iowa Sites

Canada thistle occurred on only 12 of 110 plots for which we have soil data at Neal Smith NWR in 2007. (By contrast, 116 of 214 plots with soil data in Minnesota contained Canada thistle in 2007.) Five of the 12 Iowa plots had been infested in 2006, but none of these had been infested in 2005. The

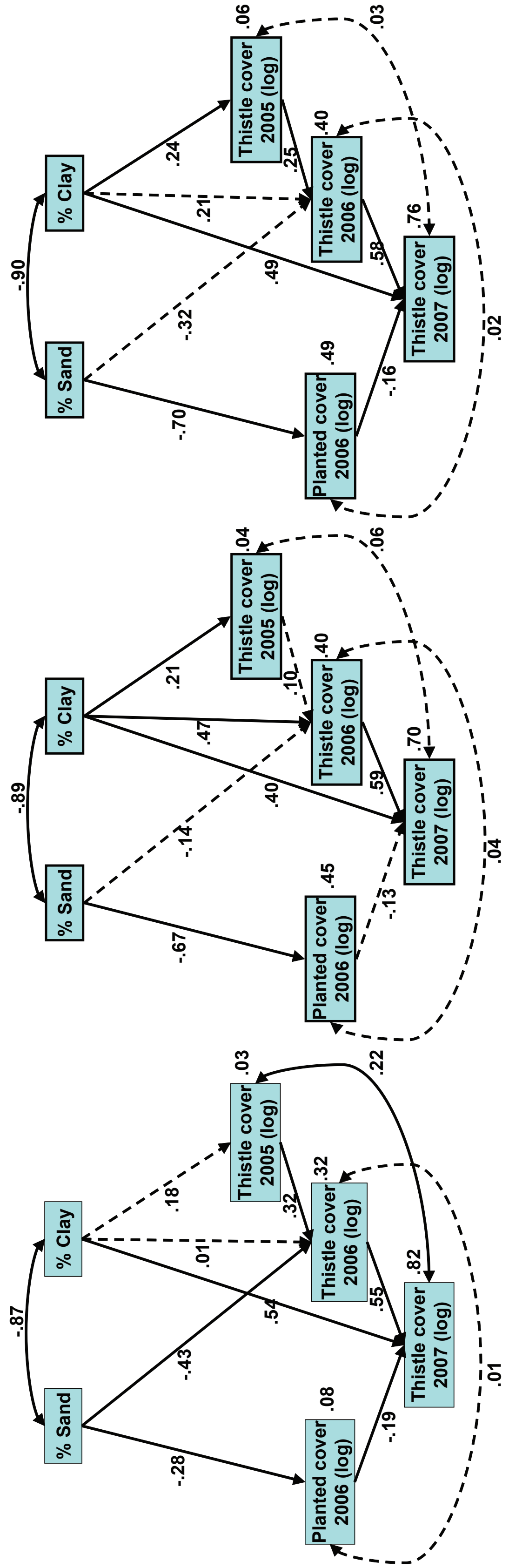

Figure 20. Structural equation models for dormant broadcast (*A*), summer broadcast (*B*), and summer drill (*C*) planting methods at Minnesota sites. Dotted lines refer to nonsignificant pathways; solid lines refer to significant pathways. Numbers next to lines are the standardized path coefficients; numbers next to variables in boxes are the coefficients of variation for those variables.

Table 6. Standardized total effects for the dormant broadcast, summer broadcast, and summer drill planting methods at Minnesota sites.

[Total effects take into account all the path coefficients between the variable in the column title and the variable in the row title (refer to fig. 14 to see the paths between the variables). For example, the total effect of percent (%) clay on thistle cover in 2007 dormant broadcast plots was 0.562, which means that for every increase of 1 standard deviation in percent clay, thistle cover in 2007 increased by 0.562 standard deviations. Entries of 0.000 indicate paths that were not present in the model]

Response variable	% Clay	Thistle cover 2005	% Sand	Thistle cover 2006	Planted cover 2006
Dormant broadcast					
Thistle cover 2005	0.176	0.000	0.000	0.000	0.000
Thistle cover 2006	.046	.323	-.432	.000	.000
Planted cover 2006	.000	.000	-.284	.000	.000
Thistle cover 2007	.562	.177	-.182	.547	-.194
Summer broadcast					
Thistle cover 2005	0.211	0.000	0.000	0.000	0.000
Thistle cover 2006	.493	.104	-.141	.000	.000
Planted cover 2006	.000	.000	-.668	.000	.000
Thistle cover 2007	.688	.061	.003	.585	-.128
Summer drill					
Thistle cover 2005	0.242	0.000	0.000	0.000	0.000
Thistle cover 2006	.271	.252	-.318	.000	.000
Planted cover 2006	.000	.000	-.700	.000	.000
Thistle cover 2007	.651	.146	-.075	.581	-.158

two plots that had Canada thistle in 2005 were free of thistle in 2006 and 2007. Under these circumstances, any statistical model for the Iowa sites would be tenuous at best and likely to lead to false conclusions. It would seem that there is a strong component of chance with respect to infestation at Neal Smith NWR, which suggests that a landscape perspective may be valuable in understanding Canada thistle establishment. Because the study sites at Neal Smith NWR are surrounded by refuge lands, their proximity to thistle propagules may be substantially less than that of the Minnesota sites, which are surrounded by agricultural lands, roads, irrigation ditches, and the like.

Acknowledgments

J. Larson and K. Wahl worked long hours in the field to collect the data that form the basis of this report, and I am grateful for their dedication. M. Sovada, R. Gleason, and J. Grace provided comments on a previous draft that improved the clarity of this report.

References

Jöreskog, K.G., and Sörbom, D., 1996, LISREL 8—user's reference guide: Chicago, Scientific Software International.

McCune, B., and Grace, J.B., 2002, Analysis of ecological communities: Gleneden Beach, Oreg., MjM Software Design.

U.S. Fish and Wildlife Service, 1999, Fulfilling the promise—the National Wildlife Refuge System, visions for wildlife, habitat, people, and leadership: Arlington, Va., U.S. Fish and Wildlife Service.

Appendixes

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
Sand (Minn.)	field	5	21,526.922	4,305.3844	259.33	<0.0001	fig. 1
Clay (Minn.)	field	5	8,292.5578	1,658.5116	396.99	<.0001	fig. 1
Nitrogen mineralization (Minn.)	field	5	3.0564167	.6112833	20.92	<.0001	table 1
Nitrification (Minn.)	field	5	26.302954	5.2605908	17.91	<.0001	table 1
Sand (Iowa)	field	2	4,136.664	2,068.332	51.6	<.0001	fig. 1
Clay (Iowa)	field	2	386.31769	193.15884	27.25	<.0001	fig. 1
Nitrogen mineralization (Iowa)	field	2	.4569387	.2284694	7.77	.0007	table 1
Nitrification (Iowa)	field	2	3.8760873	1.9380437	31.44	<.0001	table 1
Thistle stems (Minn.)	time	2	455,070.3	227,535.15	378.94	<.0001	fig. 2
	time*site	10	448,881.84	44,888.185	74.76	<.0001	
	time*method	4	10,194.527	2,548.6318	4.24	.002	
	time*diversity	4	4,055.3033	1,013.8258	1.69	.1503	
	time*method*diversity	8	5,039.7591	629.9699	1.05	.3968	
	time*site*diversity	20	10,510.546	525.5273	.88	.6198	
	time*site*method	20	34,199.321	1,709.966	2.85	<.0001	fig. 3
	time*site*method*diversity	40	18,150.649	453.7662	.76	.8659	
	error(time)	1,162	697,728.72	600.455			
Thistle cover (Minn.)	time	2	158,366.98	79,183.49	353.66	<.0001	
	time*site	10	145,300.15	14,530.015	64.9	<.0001	
	time*method	4	2,111.0438	527.7609	2.36	.0519	
	time*diversity	4	73.1075	18.2769	.08	.988	
	time*method*diversity	8	1,504.0752	188.0094	.84	.5676	
	time*site*diversity	20	2,420.8419	121.0421	.54	.9501	
	time*site*method	20	13,064.728	653.2364	2.92	<.0001	fig. 5
	time*site*method*diversity	40	4,564.045	114.1011	.51	.9954	
	error(time)	1,178	263,747.61	223.8944			

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
Cover of planted species (Minn.)	time	2	1,657,100.9	828,550.46	5,433.61	<0.0001	
	time*site	10	82,791.485	8,279.148	54.29	<.0001	
	time*method	4	14,085.451	3,521.363	23.09	<.0001	
	time*diversity	4	2,662.757	665.689	4.37	.0017	fig. 8
	time*method*diversity	8	2,073.077	259.135	1.7	.0942	
	time*site*diversity	20	2,744.104	137.205	.9	.5877	
	time*site*method	20	30,725.239	1,536.262	10.07	<.0001	fig. 7
	time*site*method*diversity	40	5,685.824	142.146	.93	.5925	
	error(time)	1,178	179,628.56	152.486			
Thistle stems (Iowa)	time	2	1,387.8434	693.92171	26.83	<.0001	
	time*site	4	927.58399	231.896	8.97	<.0001	fig. 2
	time*method	4	556.64002	139.16001	5.38	.0003	
	time*diversity	6	238.89879	39.81647	1.54	.1622	
	time*method*diversity	12	673.42692	56.11891	2.17	.0115	fig. 4
	time*site*diversity	12	303.37791	25.28149	.98	.4685	
	time*site*method	8	590.07078	73.75885	2.85	.0039	fig. 3
	time*site*method*diversity	24	821.89777	34.24574	1.32	.1375	
	error(time)	784	20,273.53	25.85909			
Thistle cover (Iowa)	time	2	1,387.8434	693.92171	26.83	<.0001	
	time*site	4	927.58399	231.896	8.97	<.0001	
	time*method	4	556.64002	139.16001	5.38	.0003	
	time*diversity	6	238.89879	39.81647	1.54	.1622	
	time*method*diversity	12	673.42692	56.11891	2.17	.0115	fig. 6
	time*site*diversity	12	303.37791	25.28149	.98	.4685	
	time*site*method	8	590.07078	73.75885	2.85	.0039	fig. 5
	time*site*method*diversity	24	821.89777	34.24574	1.32	.1375	
	error(time)	784	20,273.53	25.85909			

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
Cover of planted species (Iowa)	time	2	715,892.13	357,946.06	1,910.23	<0.0001	
	time*site	4	43,823.534	10,955.883	58.47	<.0001	fig. 9
	time*method	4	14,770.297	3,692.5743	19.71	<.0001	
	time*diversity	6	54,769.826	9,128.3043	48.71	<.0001	
	time*method*diversity	12	7,082.3988	590.1999	3.15	.0002	fig. 10
	time*site*diversity	12	4,034.3185	336.1932	1.79	.0451	
	time*site*method	8	675.9155	84.4894	.45	.8903	
	time*site*method*diversity	24	3,936.4474	164.0186	.88	.6375	
	error(time)	792	148,407.82	187.3836			
Richness of planted species (Minn.)	site	5	2,115.0245	423.0049	59.12	<.0001	
	method	2	2,383.1065	1191.5533	166.54	<.0001	
	diversity	2	5,870.0834	2,935.0417	410.23	<.0001	
	site*method	10	760.02355	76.002355	10.62	<.0001	
	site*diversity	10	522.65221	52.265221	7.31	<.0001	
	method*diversity	4	459.39597	114.84899	16.05	<.0001	
	site*method*diversity	20	329.05834	16.452917	2.3	.0011	fig. 11
Richness of planted species - Iowa	site	2	60.847222	30.423611	2.49	.084	
	method	2	54.347222	27.173611	2.23	.1093	
	diversity	3	2,246.2847	748.76157	61.35	<.0001	
	site*method	4	7.888889	1.972222	.16	.9576	
	site*diversity	6	387.70833	64.618056	5.29	<.0001	fig. 12
	method*diversity	6	185.09722	30.849537	2.53	.0206	fig. 12
	site*method*diversity	12	94.888889	7.907407	.65	.8009	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Minnesota: low diversity seed mix				
Elymus canadensis	field	5	0.0123354	0.0024671	0.8	0.5513	
	method	2	.0030761	.001538	.5	.6083	
	diversity	2	.0123353	.0061677	1.99	.1369	
	field*method	10	.0339404	.003394	1.1	.3614	
	field*diversity	10	.0246811	.0024681	.8	.6305	
	method*diversity	4	.0061625	.0015406	.5	.737	
	field*method*diversity	20	.0678912	.0033946	1.1	.3466	
Andropogon gerardii	field	5	10.12031	2.024062	32.23	<.0001	
	method	2	5.4276292	2.7138146	43.21	<.0001	
	diversity	2	.0806323	.0403161	.64	.5266	
	field*method	10	10.606116	1.0606116	16.89	<.0001	fig. 13
	field*diversity	10	.8659045	.0865905	1.38	.1861	
	method*diversity	4	.3548754	.0887189	1.41	.2283	
	field*method*diversity	20	1.5957348	.0797867	1.27	.1919	
Bouteloua curtipendula	field	5	8.8376826	1.7675365	15.25	<.0001	
	method	2	3.1305159	1.5652579	13.51	<.0001	
	diversity	2	.1838343	.0919171	.79	.4529	
	field*method	10	12.250295	1.2250295	10.57	<.0001	fig. 13
	field*diversity	10	.5786612	.0578661	.5	.8908	
	method*diversity	4	.3671357	.0917839	.79	.5306	
	field*method*diversity	20	1.7266777	.0863339	.74	.7799	
Monarda fistulosa	field	5	22.372154	4.4744307	41.42	<.0001	
	method	2	2.282012	1.141006	10.56	<.0001	
	diversity	2	.333435	.1667175	1.54	.2145	
	field*method	10	6.5375387	.6537539	6.05	<.0001	fig. 13
	field*diversity	10	1.305904	.1305904	1.21	.2818	
	method*diversity	4	.3348444	.0837111	.77	.5417	
	field*method*diversity	20	2.3681077	.1184054	1.1	.3485	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Minnesota: low diversity seed mix—Continued				
Helianthus maximiliani	field	5	14.889545	2.977909	27.83	<0.0001	fig. 13
	method	2	6.8312544	3.4156272	31.92	<.0001	
	diversity	2	3.7625013	1.8812506	17.58	<.0001	
	field*method	10	4.8695565	.4869557	4.55	<.0001	
	field*diversity	10	2.6298965	.2629897	2.46	.007	
	method*diversity	4	.9993553	.2498388	2.33	.0544	
	field*method*diversity	20	2.8869559	.1443478	1.35	.1416	
Verbena stricta	field	5	3.6867155	.7373431	4.25	.0008	
	method	2	34.501616	17.250808	99.4	<.0001	
	diversity	2	6.1138842	3.0569421	17.61	<.0001	
	field*method	10	3.6691501	.366915	2.11	.0217	
	field*diversity	10	4.17995	.417995	2.41	.0082	
	method*diversity	4	.209874	.0524685	.3	.8764	
	field*method*diversity	20	5.8237197	.291186	1.68	.0326	
Dalea purpurea	field	5	42.455657	8.4911314	53.92	<.0001	
	method	2	3.9224855	1.9612427	12.45	<.0001	
	diversity	2	3.350501	1.6752505	10.64	<.0001	table 2
	field*method	10	10.410178	1.0410178	6.61	<.0001	fig. 13
	field*diversity	10	2.4473146	.2447315	1.55	.1167	
	method*diversity	4	.2524014	.0631004	.4	.8082	
	field*method*diversity	20	2.426913	.1213457	.77	.7505	
Schizachyrium scoparium	field	5	6.5528265	1.3105653	6.94	<.0001	
	method	2	8.5668761	4.2834381	22.67	<.0001	
	diversity	2	.6019867	.3009934	1.59	.2042	
	field*method	10	23.891609	2.3891609	12.64	<.0001	fig. 13
	field*diversity	10	1.8311474	.1831147	.97	.4692	
	method*diversity	4	.7807563	.1951891	1.03	.3894	
	field*method*diversity	20	4.4105715	.2205286	1.17	.2771	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Minnesota: low diversity seed mix—Continued				
Aster novae-angliae	field	5	13.818237	2.7636473	19.23	<0.0001	
	method	2	45.295901	22.64795	157.6	<.0001	
	diversity	2	3.9299426	1.9649713	13.67	<.0001	table 2
	field*method	10	4.9070813	.4907081	3.41	.0002	fig. 13
	field*diversity	10	1.5479018	.1547902	1.08	.3776	
	method*diversity	4	.2724451	.0681113	.47	.7549	
	field*method*diversity	20	3.4132579	.1706629	1.19	.2585	
Sorghastrum nutans	field	5	7.8908534	1.5781707	13.75	<.0001	
	method	2	25.817209	12.908605	112.45	<.0001	
	diversity	2	.026941	.0134705	.12	.8893	
	field*method	10	13.812005	1.3812005	12.03	<.0001	fig. 13
	field*diversity	10	1.6738515	.1673852	1.46	.1513	
	method*diversity	4	.3064191	.0766048	.67	.6149	
	field*method*diversity	20	2.3120229	.1156012	1.01	.4514	
			Minnesota: medium diversity seed mix				
Heliopsis helianthoides	field	5	3.6985629	0.7397126	7.76	<0.0001	
	method	2	.1402277	.0701138	.74	.4798	
	diversity	1	1.3099	1.3099	13.75	.0002	table 2
	field*method	10	.9715318	.0971532	1.02	.4258	
	field*diversity	5	.4817439	.0963488	1.01	.4107	
	method*diversity	2	.1251523	.0625761	.66	.5191	
	field*method*diversity	10	1.3464634	.1346463	1.41	.1719	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Minnesota: medium diversity seed mix—Continued				
Panicum virgatum	field	5	23.721397	4.7442795	32.37	<0.0001	
	method	2	1.3553801	.6776901	4.62	.0104	
	diversity	1	.0048851	.0048851	.03	.8552	
	field*method	10	9.0035873	.9003587	6.14	<.0001	fig. 14
	field*diversity	5	.2618517	.0523703	.36	.8775	
	method*diversity	2	.5884901	.2942451	2.01	.1357	
	field*method*diversity	10	1.6562967	.1656297	1.13	.3381	
Coreopsis palmata	field	5	15.08533	3.0170659	19.79	<.0001	
	method	2	21.086193	10.543097	69.16	<.0001	
	diversity	1	.7786429	.7786429	5.11	.0244	table 2
	field*method	10	5.4007859	.5400786	3.54	.0002	fig. 14
	field*diversity	5	.9269755	.1853951	1.22	.3007	
	method*diversity	2	.2380637	.1190319	.78	.4587	
	field*method*diversity	10	.9183009	.0918301	.6	.812	
Artemisia ludoviciana	field	5	11.103233	2.2206466	17.11	<.0001	
	method	2	28.520653	14.260326	109.88	<.0001	
	diversity	1	2.1160408	2.1160408	16.3	<.0001	
	field*method	10	8.7565371	.8756537	6.75	<.0001	
	field*diversity	5	.889739	.1779478	1.37	.2342	
	method*diversity	2	.8618027	.4309014	3.32	.0372	
	field*method*diversity	10	2.5660609	.2566061	1.98	.0345	
Solidago rigida	field	5	8.4166667	1.6833333	10.84	<.0001	
	method	2	29.926036	14.963018	96.37	<.0001	
	diversity	1	1.3299748	1.3299748	8.57	.0036	
	field*method	10	2.2891523	.2289152	1.47	.1465	
	field*diversity	5	.4133417	.0826683	.53	.7518	
	method*diversity	2	.6779907	.3389953	2.18	.114	
	field*method*diversity	10	3.4799022	.3479902	2.24	.015	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Minnesota: medium diversity seed mix—Continued				
Dalea candida	field	5	27.172649	5.4345298	38.57	<0.0001	
	method	2	2.7984049	1.3992025	9.93	<.0001	
	diversity	1	.7556866	.7556866	5.36	.0211	table 2
	field*method	10	12.323736	1.2323736	8.75	<.0001	fig. 14
	field*diversity	5	1.2046525	.2409305	1.71	.1312	
	method*diversity	2	.4211715	.2105858	1.49	.2256	
	field*method*diversity	10	2.1534433	.2153443	1.53	.1269	
Lespedeza capitata	field	5	15.868303	3.1736606	21.63	<.0001	
	method	2	6.9306761	3.4653381	23.62	<.0001	
	diversity	1	1.4014388	1.4014388	9.55	.0021	table 2
	field*method	10	10.995391	1.0995391	7.49	<.0001	fig. 14
	field*diversity	5	1.5981448	.319629	2.18	.0558	
	method*diversity	2	.0574209	.0287105	.2	.8224	
	field*method*diversity	10	1.3421344	.1342134	.91	.5195	
Zizia aurea	field	5	7.1571765	1.4314353	9.01	<.0001	
	method	2	8.4949923	4.2474962	26.74	<.0001	
	diversity	1	.002309	.002309	.01	.9041	
	field*method	10	5.0023433	.5002343	3.15	.0007	fig. 14
	field*diversity	5	.7872679	.1574536	.99	.4228	
	method*diversity	2	.0879572	.0439786	.28	.7583	
	field*method*diversity	10	.9937226	.0993723	.63	.7922	
Potentilla arguta	field	5	8.9335248	1.786705	14.16	<.0001	
	method	2	12.990843	6.4954214	51.49	<.0001	
	diversity	1	1.5718075	1.5718075	12.46	.0005	table 2
	field*method	10	4.3266952	.4326695	3.43	.0002	fig. 14
	field*diversity	5	.1035165	.0207033	.16	.9755	
	method*diversity	2	.7215798	.3607899	2.86	.0584	
	field*method*diversity	10	1.4395852	.1439585	1.14	.3299	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Minnesota: medium diversity seed mix—Continued				
Sporobolus asper	field	5	3.9211693	0.7842339	8.62	<0.0001	
	method	2	31.864391	15.932196	175.22	<.0001	
	diversity	1	.0577246	.0577246	.63	.4261	
	field*method	10	4.590312	.4590312	5.05	<.0001	fig. 14
	field*diversity	5	.4246329	.0849266	.93	.4587	
	method*diversity	2	.2959241	.147962	1.63	.1978	
	field*method*diversity	10	.2564997	.02565	.28	.985	
			Minnesota: high diversity seed mix				
Elymus trachycaulus	field	5	1.3703704	0.2740741	9.58	<0.0001	
	method	2	.4814815	.2407407	8.41	.0003	
	field*method	10	2.0185185	.2018519	7.05	<.0001	fig. 15
Ratibida columnifera	field	5	10.208333	2.0416667	21.75	<.0001	
	method	2	1.1944444	.5972222	6.36	.0021	
	field*method	10	5.6388889	.5638889	6.01	<.0001	fig. 15
Rudbeckia hirta	field	5	11.259259	2.2518519	14.08	<.0001	
	method	2	2.2314815	1.1157407	6.98	.0012	
	field*method	10	5.212963	.5212963	3.26	.0006	fig. 15
Solidago speciosa	field	5	2.9814815	.5962963	4.69	.0005	
	method	2	2.3981482	1.1990741	9.43	.0001	
	field*method	10	2.0462963	.2046296	1.61	.1059	
Stipa viridula	field	5	11.148148	2.2296296	12.44	<.0001	
	method	2	2.8148148	1.4074074	7.85	.0005	
	field*method	10	4.5185185	.4518519	2.52	.0071	fig. 15
Desmodium canadense	field	5	11.425926	2.2851852	14.07	<.0001	
	method	2	6.6759259	3.337963	20.55	<.0001	
	field*method	10	3.6574074	.3657407	2.25	.0164	fig. 15

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Minnesota: high diversity seed mix—Continued				
Asclepias verticillata	field	5	11.814815	2.362963	12.59	<0.0001	
	method	2	3.1203704	1.5601852	8.31	.0003	
	field*method	10	1.4351852	.1435185	.76	.6628	
Echinacea angustifolia	field	5	9.6527778	1.9305556	11.73	<.0001	
	method	2	4.1111111	2.0555556	12.49	<.0001	
	field*method	10	2.6111111	.2611111	1.59	.1127	
			Iowa: low diversity seed mix				
Elymus canadensis	field	2	1.1435185	0.5717593	11.32	<0.0001	
	method	2	.2407407	.1203704	2.38	.0936	
	diversity	3	1.537037	.5123457	10.14	<.0001	
	field*method	4	.1342593	.0335648	.66	.6169	
	field*diversity	6	2.0046296	.3341049	6.62	<.0001	fig. 16
	method*diversity	6	.1296296	.0216049	.43	.8604	
	field*method*diversity	12	.9953704	.0829475	1.64	.0777	
Andropogon gerardii	field	2	.0324074	.0162037	.15	.8612	
	method	2	.3101852	.1550926	1.43	.2403	
	diversity	3	20.618056	6.8726852	63.42	<.0001	
	field*method	4	.0787037	.0196759	.18	.9479	
	field*diversity	6	.9861111	.1643519	1.52	.1713	
	method*diversity	6	2.5416667	.4236111	3.91	.0008	fig. 17
	field*method*diversity	12	.7916667	.0659722	.61	.8351	
Bouteloua curtipendula	field	2	1.1157407	.5578704	4.1	.0172	
	method	2	.4212963	.2106482	1.55	.2136	
	diversity	3	8.5740741	2.8580247	21.02	<.0001	
	field*method	4	1.412037	.3530093	2.6	.036	fig. 18
	field*diversity	6	2.1064815	.3510803	2.58	.0182	fig. 16
	method*diversity	6	.5231482	.0871914	.64	.6971	
	field*method*diversity	12	2.087963	.1739969	1.28	.2276	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Iowa: low diversity seed mix—Continued				
Monarda fistulosa	field	2	2.5740741	1.287037	5.91	0.0029	table 5
	method	2	3.9490741	1.974537	9.07	.0001	table 4
	diversity	3	5.5555556	1.8518519	8.51	<.0001	table 3
	field*method	4	1.4537037	.3634259	1.67	.1561	
	field*diversity	6	2.0555556	.3425926	1.57	.1532	
	method*diversity	6	2.4027778	.400463	1.84	.0901	
	field*method*diversity	12	3.6944444	.3078704	1.41	.156	
Helianthus occidentalis	field	2	.0416667	.0208333	1.11	.3298	
	method	2	.0416667	.0208333	1.11	.3298	
	diversity	3	.3032407	.1010803	5.4	.0012	
	field*method	4	.125	.03125	1.67	.1565	
	field*diversity	6	.3842593	.0640432	3.42	.0027	
	method*diversity	6	.162037	.0270062	1.44	.1973	
	field*method*diversity	12	.337963	.0281636	1.5	.1198	
Verbena stricta	field	2	.0185185	.0092593	2.2	.1122	
	method	2	.0185185	.0092593	2.2	.1122	
	diversity	3	.0277778	.0092593	2.2	.0876	
	field*method	4	.037037	.0092593	2.2	.0683	
	field*diversity	6	.0555556	.0092593	2.2	.0422	
	method*diversity	6	.0555556	.0092593	2.2	.0422	
	field*method*diversity	12	.1111111	.0092593	2.2	.0112	
Dalea purpurea	field	2	1.6712963	.8356482	7.25	.0008	
	method	2	.837963	.4189815	3.63	.0273	
	diversity	3	1.8703704	.6234568	5.41	.0012	
	field*method	4	3.037037	.7592593	6.58	<.0001	
	field*diversity	6	.6990741	.1165124	1.01	.418	
	method*diversity	6	.8657407	.1442901	1.25	.2792	
	field*method*diversity	12	2.6481482	.220679	1.91	.0313	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Iowa: low diversity seed mix—Continued				
Schizachyrium scoparium	field	2	2.1435185	1.0717593	5.55	0.0042	
	method	2	3.6296296	1.8148148	9.39	.0001	table 4
	diversity	3	7.212963	2.404321	12.45	<.0001	
	field*method	4	1.2592593	.3148148	1.63	.1659	
	field*diversity	6	2.8009259	.466821	2.42	.0263	fig. 16
	method*diversity	6	2.1481482	.3580247	1.85	.0877	
	field*method*diversity	12	.962963	.0802469	.42	.9574	
Aster novae-angliae	field	2	.0324074	.0162037	.65	.5241	
	method	2	.1712963	.0856482	3.42	.0337	
	diversity	3	.0625	.0208333	.83	.4769	
	field*method	4	.037037	.0092593	.37	.8302	
	field*diversity	6	.0972222	.0162037	.65	.6925	
	method*diversity	6	.1805556	.0300926	1.2	.3044	
	field*method*diversity	12	.2222222	.0185185	.74	.7126	
Sorghastrum nutans	field	2	.6666667	.3333333	1.86	.1568	
	method	2	2.375	1.1875	6.63	.0015	table 4
	diversity	3	13.358796	4.4529321	24.87	<.0001	
	field*method	4	.5833333	.1458333	.81	.5165	
	field*diversity	6	2.3703704	.3950617	2.21	.0417	
	method*diversity	6	.9398148	.1566358	.87	.5135	
	field*method*diversity	12	1.6018519	.1334877	.75	.7067	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Iowa: medium diversity seed mix				
Artemisia ludoviciana	field	2	0.1666667	0.0833333	2.48	0.0859	
	method	2	.2407407	.1203704	3.58	.0292	
	diversity	2	.1666667	.0833333	2.47	.0859	
	field*method	4	.2037037	.0509259	1.51	.1985	
	field*diversity	4	.2222222	.0555556	1.65	.1617	
	method*diversity	4	.0925926	.0231482	.69	.6011	
	field*method*diversity	8	.462963	.0578704	1.72	.0935	
Coreopsis palmata	field	2	.0432099	.0216049	.9	.4096	
	method	2	.0061728	.0030864	.13	.88	
	diversity	2	.154321	.0771605	3.2	.0423	
	field*method	4	.0864198	.0216049	.9	.467	
	field*diversity	4	.0493827	.0123457	.51	.7272	
	method*diversity	4	.1975309	.0493827	2.05	.0879	
	field*method*diversity	8	.0987654	.0123457	.51	.8474	
Dalea candida	field	2	2.8888889	1.4444444	7.92	.0004	table 5
	method	2	.7962963	.3981482	2.18	.1145	
	diversity	2	3.2407407	1.6203704	8.88	.0002	table 3
	field*method	4	1.7037037	.4259259	2.34	.0556	
	field*diversity	4	1.0925926	.2731482	1.5	.2028	
	method*diversity	4	.5185185	.1296296	.71	.5851	
	field*method*diversity	8	.5925926	.0740741	.41	.9167	
Heliopsis helianthoides	field	2	3.4506173	1.7253086	10.37	<.0001	table 5
	method	2	4.1728395	2.0864198	12.54	<.0001	
	diversity	2	6.8950617	3.4475309	20.72	<.0001	
	field*method	4	.8827161	.220679	1.33	.2601	
	field*diversity	4	.6604938	.1651235	.99	.4119	
	method*diversity	4	3.8271605	.9567901	5.75	.0002	fig. 17
	field*method*diversity	8	.9506173	.1188272	.71	.679	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Iowa: medium diversity seed mix—Continued				
Lespedeza capitata	field	2	4.4506173	2.2253086	11.44	<0.0001	
	method	2	4.0246914	2.0123457	10.35	<.0001	
	diversity	2	10.635802	5.3179012	27.35	<.0001	table 3
	field*method	4	2.0308642	.5077161	2.61	.0357	fig. 18
	field*diversity	4	.4197531	.1049383	.54	.7067	
	method*diversity	4	.1790124	.0447531	.23	.9213	
	field*method*diversity	8	1.4320988	.1790124	.92	.4996	
Panicum virgatum	field	2	1.3395062	.6697531	3.58	.0291	table 5
	method	2	1.4876543	.7438272	3.97	.0198	table 4
	diversity	2	2.7098765	1.3549383	7.24	.0009	table 3
	field*method	4	.9753086	.2438272	1.3	.269	
	field*diversity	4	1.1975309	.2993827	1.6	.1744	
	method*diversity	4	.7160494	.1790124	.96	.4317	
	field*method*diversity	8	1.4320988	.1790124	.96	.4703	
Potentilla arguta	field	2	1.462963	.7314815	8.78	.0002	table 5
	method	2	1.1851852	.5925926	7.11	.001	table 4
	diversity	2	.2962963	.1481482	1.78	.1708	
	field*method	4	.6851852	.1712963	2.06	.0867	
	field*diversity	4	.3518519	.087963	1.06	.3788	
	method*diversity	4	.3518519	.087963	1.06	.3788	
	field*method*diversity	8	.5555556	.0694444	.83	.5738	
Solidago rigida	field	2	.2407407	.1203704	1.38	.2533	
	method	2	.462963	.2314815	2.65	.0721	
	diversity	2	.462963	.2314815	2.65	.0721	
	field*method	4	.462963	.1157407	1.33	.2601	
	field*diversity	4	.6851852	.1712963	1.96	.1001	
	method*diversity	4	.2962963	.0740741	.85	.4952	
	field*method*diversity	8	1.1111111	.1388889	1.59	.1266	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Iowa: medium diversity seed mix—Continued				
Sporobolus asper	field	2	2.2283951	1.1141975	5.22	0.0059	table 5
	method	2	10.395062	5.1975309	24.34	<.0001	table 4
	diversity	2	1.3765432	.6882716	3.22	.0412	table 3
	field*method	4	.1790124	.0447531	.21	.933	
	field*diversity	4	1.0864198	.2716049	1.27	.281	
	method*diversity	4	.308642	.0771605	.36	.836	
	field*method*diversity	8	.8950617	.1118827	.52	.8382	
Zizia aurea	field	2	3.1358025	1.5679012	10.09	<.0001	
	method	2	2.0432099	1.0216049	6.57	.0016	
	diversity	2	.8209877	.4104938	2.64	.073	
	field*method	4	.1604938	.0401235	.26	.9046	
	field*diversity	4	1.7160494	.4290124	2.76	.028	fig. 16
	method*diversity	4	3.4197531	.8549383	5.5	.0003	fig. 17
	field*method*diversity	8	.7098765	.0887346	.57	.8016	
			Iowa: high diversity seed mix				
Asclepias verticillata	field	2	2.0833333	1.0416667	4.57	0.0114	
	method	2	.5277778	.2638889	1.16	.3159	
	diversity	1	.0046296	.0046296	.02	.8868	
	field*method	4	.3888889	.0972222	.43	.789	
	field*diversity	2	2.8425926	1.4212963	6.24	.0024	fig. 16
	method*diversity	2	.8981482	.4490741	1.97	.1419	
	field*method*diversity	4	1.1296296	.2824074	1.24	.2951	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Iowa: high diversity seed mix—Continued				
Aster ericoides	field	2	0.3611111	0.1805556	1.82	0.1651	
	method	2	.1944444	.0972222	.98	.3776	
	diversity	1	.0185185	.0185185	.19	.6664	
	field*method	4	.1944444	.0486111	.49	.7435	
	field*diversity	2	.0648148	.0324074	.33	.722	
	method*diversity	2	.1759259	.087963	.89	.4141	
	field*method*diversity	4	.6574074	.1643519	1.65	.1621	
Aster laevis	field	2	.0092593	.0046296	.5	.6073	
	method	2	.0092593	.0046296	.5	.6073	
	diversity	1	.0185185	.0185185	2	.1589	
	field*method	4	.0462963	.0115741	1.25	.2911	
	field*diversity	2	.0092593	.0046296	.5	.6073	
	method*diversity	2	.0092593	.0046296	.5	.6073	
	field*method*diversity	4	.0462963	.0115741	1.25	.2911	
Echinacea pallida	field	2	4.9259259	2.462963	14.93	<.0001	
	method	2	.1203704	.0601852	.36	.6948	
	diversity	1	.1666667	.1666667	1.01	.3161	
	field*method	4	1.6851852	.4212963	2.55	.0403	fig. 18
	field*diversity	2	.7777778	.3888889	2.36	.0973	
	method*diversity	2	.1944444	.0972222	.59	.5557	
	field*method*diversity	4	.9444444	.2361111	1.43	.225	
Elymus virginicus	field	2	.1759259	.087963	1.05	.3536	
	method	2	.0648148	.0324074	.39	.681	
	diversity	1	35.851852	35.851852	425.92	<.0001	
	field*method	4	.0740741	.0185185	.22	.9271	
	field*diversity	2	.1759259	.087963	1.05	.3536	
	method*diversity	2	.6203704	.3101852	3.69	.0268	fig. 17
	field*method*diversity	4	.3518519	.087963	1.05	.3851	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Iowa: high diversity seed mix—Continued				
Pycnanthemum virginianum	field	2	0.1944444	0.0972222	3	0.0521	
	method	2	.5277778	.2638889	8.14	.0004	
	diversity	1	.2268519	.2268519	7	.0088	
	field*method	4	.6111111	.1527778	4.71	.0012	
	field*diversity	2	.0648148	.0324074	1	.3697	
	method*diversity	2	.287037	.1435185	4.43	.0131	
	field*method*diversity	4	.2962963	.0740741	2.29	.0615	
Ratibida pinnata	field	2	.8425926	.4212963	2.26	.1071	
	method	2	1.787037	.8935185	4.79	.0093	
	diversity	1	10.226852	10.226852	54.85	<.0001	table 3
	field*method	4	2.7685185	.6921296	3.71	.0061	fig. 18
	field*diversity	2	.4537037	.2268519	1.22	.2984	
	method*diversity	2	.0092593	.0046296	.02	.9755	
	field*method*diversity	4	.4351852	.1087963	.58	.6749	
Rudbeckia hirta	field	2	.7777778	.3888889	2.04	.1322	
	method	2	3.0833333	1.5416667	8.1	.0004	
	diversity	1	1.5	1.5	7.88	.0055	
	field*method	4	1.1388889	.2847222	1.5	.2046	
	field*diversity	2	1.4444444	.7222222	3.8	.0241	fig. 16
	method*diversity	2	7.6944444	3.8472222	20.22	<.0001	fig. 17
	field*method*diversity	4	.0277778	.0069444	.04	.9974	
Solidago speciosa	field	2	1.8425926	.9212963	13.77	<.0001	
	method	2	.1481482	.0740741	1.11	.3326	
	diversity	1	.0046296	.0046296	.07	.7928	
	field*method	4	.1296296	.0324074	.48	.7473	
	field*diversity	2	.0648148	.0324074	.48	.6169	
	method*diversity	2	.037037	.0185185	.28	.7586	
	field*method*diversity	4	.1851852	.0462963	.69	.5984	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Iowa: high diversity seed mix—Continued				
Tradescantia ohiensis	field	2	1.3333333	0.6666667	3.74	0.0256	
	method	2	2.1944444	1.0972222	6.15	.0026	table 4
	diversity	1	1.1851852	1.1851852	6.64	.0107	
	field*method	4	.5555556	.1388889	.78	.5405	
	field*diversity	2	1.9259259	.962963	5.4	.0052	fig. 16
	method*diversity	2	.4537037	.2268519	1.27	.2828	
	field*method*diversity	4	.3518519	.087963	.49	.7409	
Tridens flavus	field	2	.1111111	.0555556	1.06	.3469	
	method	2	.1944444	.0972222	1.86	.1579	
	diversity	1	.2962963	.2962963	5.68	.0181	
	field*method	4	.0277778	.0069444	.13	.9701	
	field*diversity	2	.037037	.0185185	.35	.7017	
	method*diversity	2	.287037	.1435185	2.75	.0664	
	field*method*diversity	4	.0462963	.0115741	.22	.9261	
Vernonia fasciculata	field	2	.3425926	.1712963	2.38	.0952	
	method	2	.6203704	.3101852	4.31	.0147	
	diversity	1	.0046296	.0046296	.06	.8	
	field*method	4	.1574074	.0393519	.55	.7016	
	field*diversity	2	.0648148	.0324074	.45	.6381	
	method*diversity	2	.0648148	.0324074	.45	.6381	
	field*method*diversity	4	.1574074	.0393519	.55	.7016	
			Iowa: Extra-high diversity seed mix				
Anemone cylindrica	field	2	0.0740741	0.037037	0.31	0.7374	
	method	2	.6851852	.3425926	2.83	.064	table 4
	field*method	4	.8703704	.2175926	1.8	.1358	
Asclepias tuberosa	field	2	1.4074074	.7037037	3.72	.0278	table 5
	method	2	4.0185185	2.0092593	10.61	<.0001	
	field*method	4	1.7037037	.4259259	2.25	.0692	fig. 18

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Iowa: Extra-high diversity seed mix—Continued				
Astragalus canadensis	field	2	0.3888889	0.1944444	1.38	0.2556	
	method	2	.3888889	.1944444	1.38	.2556	
	field*method	4	2.2222222	.5555556	3.95	.0051	
Baptisia leucantha	field	2	.6851852	.3425926	1.55	.2166	
	method	2	.7962963	.3981482	1.81	.1698	
	field*method	4	1.8703704	.4675926	2.12	.0839	
Cassia fasciculata	field	2	.5185185	.2592593	1.29	.2787	
	method	2	.0185185	.0092593	.05	.9549	
	field*method	4	.3703704	.0925926	.46	.7633	
Delphinium virescens	field	2	2.462963	1.2314815	7.91	.0007	table 5
	method	2	.9074074	.4537037	2.91	.059	
	field*method	4	.4259259	.1064815	.68	.6048	
Desmodium canadense	field	2	1.462963	.7314815	3.64	.0299	table 5
	method	2	2.7962963	1.3981482	6.95	.0015	table 4
	field*method	4	1.2592593	.3148148	1.56	.1896	
Eryngium yuccifolium	field	2	.1296296	.0648148	1.57	.2129	
	method	2	.2407407	.1203704	2.92	.0587	
	field*method	4	.3148148	.0787037	1.91	.115	
Helenium autumnale	field	2	.5185185	.2592593	3.08	.0504	
	method	2	.0740741	.037037	.44	.6453	
	field*method	4	.1481482	.037037	.44	.7794	
Parthenium integrifolium	field	2	.9074074	.4537037	1.92	.1523	
	method	2	1.1851852	.5925926	2.51	.0868	
	field*method	4	1.2592593	.3148148	1.33	.2638	
Penstemon digitalis	field	2	.5740741	.287037	5.25	.0068	
	method	2	.1296296	.0648148	1.18	.3102	
	field*method	4	.4259259	.1064815	1.95	.1087	

Appendix 1. Analysis of variance (ANOVA) tables for statistical tests.—Continued

[DF, degrees of freedom; SS, sums of squares]

Variable	Source	DF	Type III SS	Mean square	F value	P value	Reference table or figure
			Iowa: Extra-high diversity seed mix—Continued				
Ruellia humilis	field	2	0.6666667	0.3333333	3.41	0.0368	
	method	2	.0555556	.0277778	.28	.753	
	field*method	4	.2777778	.0694444	.71	.5862	
Stipa spartea	field	2	2.0185185	1.0092593	6.09	.0032	
	method	2	.2962963	.1481482	.89	.4125	
	field*method	4	2.4814815	.6203704	3.74	.0071	fig. 18
Thalictrum dasycarpum	field	2	4.962963	2.4814815	13.91	<.0001	table 5
	method	2	.5740741	.287037	1.61	.2054	
	field*method	4	.0925926	.0231482	.13	.9713	

Appendix 2. Species in the Minnesota seed mixes.

[N refers to the number of plots in which the species was encountered; proportion refers to the number of plots in which the species was encountered divided by the number of plots in which the species was planted. For all mixes, the maximum number of plots is 648; for medium and high, 432; and for high, 216]

Seed mix diversity	Species	N	Proportion
All	*Andropogon gerardii*	573	0.88
All	*Aster novae-angliae*	277	.43
All	*Bouteloua curtipendula*	531	.82
All	*Dalea purpurea*	279	.43
All	*Elymus canadensis*	646	1.00
All	*Helianthus maximiliani*	523	.81
All	*Monarda fistulosa*	525	.81
All	*Schizachyrium scoparium*	279	.43
All	*Sorghastrum nutans*	159	.25
All	*Verbena stricta*	301	.46
Medium and High	*Artemisia ludoviciana*	252	.58
Medium and High	*Coreopsis palmata*	255	.59
Medium and High	*Dalea candida*	180	.42
Medium and High	*Heliopsis helianthoides*	403	.93
Medium and High	*Lespedeza capitata*	150	.35
Medium and High	*Panicum virgatum*	300	.69
Medium and High	*Potentilla arguta*	114	.26
Medium and High	*Solidago rigida*	218	.50
Medium and High	*Sporobolus asper*	104	.24
Medium and High	*Zizia aurea*	118	.27
High	*Allium stellatum*	27	.13
High	*Asclepias verticillata*	104	.48
High	*Aster laevis*	19	.09
High	*Carex bicknellii*	0	.00
High	*Carex vulpinoidea*	5	.02
High	*Desmodium canadense*	111	.51
High	*Echinacea angustifolia*	77	.36
High	*Elymus trachycaulus*	240	1.11
High	*Liatris aspera*	0	.00
High	*Ratibida columnifera*	180	.83
High	*Rudbeckia hirta*	158	.73
High	*Solidago speciosa*	131	.61
High	*Stipa viridula*	116	.54
High	*Vernonia fasciculata*	14	.06

Appendix 3. Species in the Iowa seed mixes.

[N refers to the number of plots in which the species was encountered; proportion refers to the number of plots in which the species was encountered divided by the number of plots in which the species was planted. For all mixes, the maximum number of plots is 432; for medium to extra-high, 324; for high and extra-high, 216; and for extra-high, 108]

Seed mix diversity	Species	N	Proportion
All	*Andropogon gerardii*	347	0.80
All	*Aster novae-angliae*	11	.03
All	*Bouteloua curtipendula*	344	.80
All	*Dalea purpurea*	68	.16
All	*Elymus canadensis*	404	.94
All	*Helianthus occidentalis*	9	.02
All	*Monarda fistulosa*	224	.52
All	*Schizachyrium scoparium*	146	.34
All	*Sorghastrum nutans*	297	.69
All	*Verbena stricta*	2	.00
Medium to Extra-high	*Artemisia ludoviciana*	12	.04
Medium to Extra-high	*Coreopsis palmata*	8	.02
Medium to Extra-high	*Dalea candida*	92	.28
Medium to Extra-high	*Heliopsis helianthoides*	232	.72
Medium to Extra-high	*Lespedeza capitata*	177	.55
Medium to Extra-high	*Panicum virgatum*	241	.74
Medium to Extra-high	*Potentilla arguta*	34	.10
Medium to Extra-high	*Solidago rigida*	35	.11
Medium to Extra-high	*Sporobolus asper*	162	.50
Medium to Extra-high	*Zizia aurea*	258	.80
High and Extra-high	*Asclepias verticillata*	126	.58
High and Extra-high	*Aster ericoides*	43	.20
High and Extra-high	*Aster laevis*	3	.01
High and Extra-high	*Echinacea pallida*	169	.78
High and Extra-high	*Elymus virgincus*	131	.61
High and Extra-high	*Liatris aspera*	1	.00
High and Extra-high	*Phlox pilosa*	0	.00
High and Extra-high	*Pycnanthemum virginianum*	9	.04
High and Extra-high	*Ratibida pinnata*	130	.60
High and Extra-high	*Rudbeckia hirta*	142	.66
High and Extra-high	*Solidago speciosa*	17	.08
High and Extra-high	*Tradescantia ohiensis*	61	.28
High and Extra-high	*Tridens flavus*	20	.09
High and Extra-high	*Vernonia fasciculata*	19	.09
Extra-high	*Amorpha canescens*	0	.00
Extra-high	*Anemone cylindrica*	23	.21
Extra-high	*Asclepias tuberosa*	47	.44
Extra-high	*Aster azureus*	0	.00
Extra-high	*Astragalus canadensis*	22	.20
Extra-high	*Baptisia leucantha*	75	.69
Extra-high	*Cassia fasciculata*	147	1.36
Extra-high	*Coreopsis tripteris*	0	.00

Appendix 3. Species in the Iowa seed mixes.—Continued

[N refers to the number of plots in which the species was encountered; proportion refers to the number of plots in which the species was encountered divided by the number of plots in which the species was planted. For all mixes, the maximum number of plots is 432; for medium to extra-high, 324; for high and extra-high, 216; and for extra-high, 108]

Seed mix diversity	Species	N	Proportion
Extra-high	*Delphinium virescens*	25	0.23
Extra-high	*Desmodium canadense*	44	.41
Extra-high	*Eryngium yuccifolium*	5	.05
Extra-high	*Gentiana flavida*	0	.00
Extra-high	*Helenium autumnale*	11	.10
Extra-high	*Heuchera richardsonii*	1	.01
Extra-high	*Liatris pycnostachya*	1	.01
Extra-high	*Parthenium integrifolium*	61	.56
Extra-high	*Penstemon digitalis*	7	.06
Extra-high	*Ruellia humilis*	16	.15
Extra-high	*Sporobolus heterolepis*	0	.00
Extra-high	*Stipa spartea*	30	.28
Extra-high	*Thalictrum dasycarpum*	35	.32
Extra-high	*Tradescantia bracteata*	0	.00
Extra-high	*Veronicastrum virginicum*	1	.01
Extra-high	*Viola pedatifida*	2	.02

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