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Effect of Aminocyclopyrachlor on Native Prairie Species in the Northern Great Plains

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Aminocyclopyrachlor (AMCP) will control many invasive broadleaf weeds, but the susceptibility of desirable forbs is not widely known. Native prairie response to AMCP was evaluated near Fargo, ND, and Felton, MN, in the Northern Great Plains. Both sites had high floristic quality prior to treatment, with 33 and 80 different species at Fargo and Felton, respectively. AMCP was applied at 140 g ha^{-1} in July 2014 to coincide with leafy spurge and Canada thistle treatment timing. AMCP altered the plant communities and reduced foliar cover of undesirable species, high seral forbs (undisturbed stable communities), and low seral forbs (early succession in disturbed communities) at both locations at 10 and 14 mo after treatment (MAT). AMCP reduced Canada thistle and leafy spurge in Fargo and eliminated hedge bindweed, prickly lettuce, and black medic in Felton. High seral forb foliar cover was reduced at 10 and 14 MAT from 20% to 2% and 3% in Fargo and from 19% to 1.6% and 2% in Felton, respectively. The high seral forb species birdfoot violet, white panicled aster, northern bedstraw, Canada goldenrod, purple meadowrue, and American vetch were reduced at both locations. Low seral forb cover also decreased at 10 MAT from 22% to 10% in Fargo and from 12% to 1% in Felton, respectively. By 14 MAT, low seral species in Fargo recovered to 16%, but recovery was much slower in Felton and slightly increased to 1.5%. After treatment high and low seral monocot species increased at both sites, likely due to reduced competition from susceptible species. AMCP reduced richness, evenness, and diversity at both locations at 10 and 14 MAT; therefore, floristic quality declined. A decline in diversity is generally undesirable but could have beneficial effects if invasive weeds and other undesirable species are reduced or eliminated.

Nomenclature: Aminocyclopyrachlor; American vetch, *Vicia americana* Muhl. ex Willd.; birdfoot violet, *Viola pedata* L.; black medic, *Medicago lupulina* L.; Canada goldenrod, *Solidago canadensis* L.; Canada thistle, *Cirsium arvense* (L.) Scop.; hedge bindweed, *Calystegia sepium* (L.) R. Br; leafy spurge, *Euphorbia esula* L.; northern bedstraw, *Galium boreale* L.; prickly lettuce, *Lactuca serriola* L.; purple meadowrue, *Thalictrum dasycarpum* Fisch. & Avé-Lall.; white panicled aster, *Aster simplex* Willd.

Key words: Integrated weed management, invasive weed control, native grasses, revegetation.

Native forbs are an essential component of prairie communities. Floristically diverse plant communities including more than 200 species of plants, with a majority being forbs, were once commonly found in the tallgrass prairie ecosystems of the Northern Great Plains (Beran et al. 1999; Jordan et al. 1988; Weaver 1954). Native forbs increase diversity (Hooper et al. 2005) and aesthetic attributes, provide cover and seed for wildlife, and are better adapted to wide variations in temperature and moisture found in the region than introduced species. Native prairie habitat has declined more than any other ecosystem in North America in the past 185 yr (Samson and Knopf 1994), and preservation of remaining native communities is a high-priority goal for many federal and private agencies.

The Prairie Pothole Region (PPR) of North Dakota is composed primarily of short, mixed, and tallgrass prairie. Interspersed with isolated wetlands and river systems, the PPR has tremendous natural resource value; however, the region is also valuable for agricultural production (Gleason et al. 2008). Consequently, tillage associated with agriculture has caused a decline in native prairie and less than 20% remains (North Dakota Parks and Recreation Dept

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Management Implications

Aminocyclopyrachlor (AMCP) has been used to control many invasive broadleaf weeds, but its effect on native forbs is generally unknown. Native forbs are essential components of the prairie communities, and loss of these species reduces both the quality and stability or the population while increasing the susceptibility to invasion by undesirable species. The effect of AMCP on forb species commonly found in the Northern Great Plains was evaluated at two native prairie sites. The sites, located near Fargo, ND, and Felton, MN, supported diverse native flora and had never been farmed or otherwise cultivated. The floristic quality at both sites declined rapidly following application of AMCP at 140 g ha^{-1}, as many forb species were reduced or eliminated. High seral forb cover was reduced from 19.8 to 2.9% in Fargo and from 18.5% to 2% in Felton at 14 mo after treatment (MAT). Low seral forb cover also decreased at both sites by 10 MAT but began to recover by 14 MAT. Both high and low seral monocot species increased at both locations due to reduced competition from AMCP-susceptible species. AMCP also reduced invasive and weedy species such as leafy spurge, Canada thistle, hedge bindweed, and prickly lettuce. A decline in diversity following AMCP application may not always be adverse for a plant community. In a weed-infested community, AMCP could help control unwanted species and shift the population to a more grass-dominated community. However, in high-quality prairie sites, AMCP would likely reduce or eliminate forbs and decrease flora quality. Land managers must consider both the positive of weed removal from a site and the effect on desirable species when using AMCP in a weed control program.

2014). Moreover, remaining fragmented tracts of grasslands and native prairie have been degraded by invasive, nonnative species (Johnson et al. 1994).

Invasive species can have devastating effects on native plant communities and natural wildlands. Herbage production of native species in wildlands, pasture, and range has been reduced 70% to 80% by leafy spurge (*Euphorbia esula* L.) infestations (Lym 2005; Lym and Kirby 1987; Meiners et al. 2001; Selleck et al. 1962). In Theodore Roosevelt National Park in North Dakota, species richness in woodland communities was reduced up to 55%, and several species that were consistently present in noninfested communities were absent in leafy spurge–infested sites (Cogan and Butler 1999). Broad-spectrum herbicides have been used to control noxious and invasive weeds, despite evidence of injury to nontarget (native) plants, especially forb species (U.S. Department of the Interior, National Park Service 2007). For example, picloram was used in Theodore Roosevelt National Park because state noxious weed laws required control of Canada thistle [*Cirsium arvense* (L.) Scop.], and there were no suitable alternatives (Samuel and Lym 2008).

Aminocyclopyrachlor (AMCP), an auxin-mimic herbicide, was developed to control invasive and noxious weeds in non-crop areas (Finkelstein et al. 2008). AMCP will control many annual broadleaf weeds, as well as several invasive and woody plants. Susceptible weed species include absinth wormwood (*Artemisia absinthium* L.) (Conklin 2012; Endres et al. 2012), Canada thistle (Endres et al. 2012; Lindenmayer et al. 2010; Vassios et al. 2010; Westra et al. 2010), and leafy spurge (Lindenmayer et al. 2010; Lym 2014; Westra et al. 2010). However, the effect of AMCP on native forb species has not been widely studied. The purpose of this research was to determine the effect of AMCP on forb species commonly found in the Northern Great Plains. In general, all grass genera are more tolerant than broadleaf species to applications of AMCP, but variance for tolerance to AMCP exists within native plants (Hergert et al. 2015).

Materials and Methods

The effect of AMCP on the native plant community was evaluated at sites near Fargo, ND (46.91792, –96.80284), and Felton, MN (47.07755, –96.41935). Both sites supported diverse native flora and had never been farmed or otherwise cultivated. The Fargo site consisted of a mixed-grass composition, while the Felton site was primarily composed of tall-grass prairie species. Both locations lie within the glaciated Lake Agassiz Plains region of the PPR (Gleason et al. 2008). The soil at the Fargo location is from the Fargo series, which is 5% sand, 45% silt, and 50% clay, with a pH of 7.2 and 7% organic matter. The Fargo location is classified as a clayey ecological site. Clayey ecological sites generally include species such as western wheatgrass [*Pascopyrum smithii* (Rydb.) Á. Löve], green needlegrass [*Nasella viridula* (Trin.) Barkworth], porcupinegrass [*Hesperostipa spartea* (Trin.) Barkworth], American vetch (*Vicia americana* Muhl. ex Willd.), white sage (*Artemisia ludoviciana* Nutt.), white prairie aster (*Aster ericoides* L.), purple prairie clover (*Dalea purpurea* Vent.), and common yarrow (*Achillea millefolium* L.) (U.S. Department of Agriculture, Natural Resources Conservation Service [USDA-NRCS] 2012). However, due to extended nonuse (no haying, grazing, fire, etc.), the plant community at Fargo had shifted to one dominated by Kentucky bluegrass (*Poa pratensis* L.), smooth brome (*Bromus inermis* Leyss.), goldenrods (*Solidago* spp.), white sage, and western snowberry (*Symphoricarpos occidentalis* Hook.).

The soil in Felton is a Lohnes coarse sandy loam or Lohnes sandy loam consisting of 83.1% sand, 11.9% silt, and 5% clay, with a pH of 6.7 and 3.1% organic matter in the A horizon. The Felton location is classified either as a very shallow or sandy ecological site, with the majority of the area classified as very shallow (USDA-NRCS 2012). Very shallow ecological sites include plant species such as needle and thread [*Hesperostipa comata* (Trin. & Rupr.) Barkworth], blue grama [*Bouteloua gracilis* (Willd. ex Knuth) Lag. ex Griffiths], threadleaf sedge (*Carex filifolia* Nutt.), western wheatgrass, tarragon (*Artemisia dracunculus* L.), prairie coneflower [*Ratibida columnifera* (Nutt.) Woot. & Standl.], fringed sage (*Artemisia frigida* Willd.), and prairie rose (*Rosa arkansana* Porter).

The study was a randomized complete block design (RCBD) with nine replicates, treated and untreated, at each location. Each block was 9 by 6 m (29.5 by 20 ft) and was divided into two plots of 4.5 by 6 m. AMCP at 140 g ai ha^{-1} (2 oz ac^{-1}) with a silicone-based nonionic surfactant blend, Dyne-Amic® (Helena Chemical Company, 225 Schilling Boulevard, Suite 300, Collierville, TN 38017), at 0.25% v/v was applied in July 2014 to one random plot in each block with a handheld boom sprayer equipped with four 8002 flat-fan nozzles (TeeJet Spraying Systems, 200 W. North Avenue, Glendale Heights, IL 60139) delivering 160 L ha^{-1} (17 gal ac^{-1}) at 240 kPa (35 psi). The application timing corresponded to regional recommendations for leafy spurge and Canada thistle control with AMCP.

Species composition was determined by visually assessing plant foliar cover in four permanent 1-m^2 quadrats per plot before treatment. Bare ground, litter, and individual plant species cover were visually estimated (totaled to 100%) during peak standing biomass of cool-season species in mid-June (before treatment) and of warm-season species at the end of July (14 d after treatment). Evaluation took 5 to 7 d at each site. Evaluations before treatment and 14 d after treatment were indistinguishable ($P = 0.68$ and $P = 0.62$ at the Fargo and Felton locations, respectively), and were combined and denoted as "0 months after treatment (MAT)" in Tables 1 and 2. The plots were reevaluated at 10 and 14 MAT.

Plant community diversity was calculated using the Shannon-Wiener diversity index. Richness, evenness, and diversity indices for each plot were calculated using PC-Ord v. 6 (Multivariate Analysis of Ecological Data, PC-Ord v. 6, MjM Software, P.O. Box 129, Gleneden Beach, OR 97388); prior to the calculations, cover data were transformed using an arc sine square-root method (McCune and Grace 2002). Change in vegetative components and plant species richness, evenness, and diversity estimated the effect of AMCP on the plant communities.

Scientific nomenclature follows *Flora of the Great Plains* (Great Plains Flora Association 1986), except as amended by the USDA Plants Database (USDA-NRCS 2014). Plant species were separated into high seral and low seral floristic quality categories as defined by the Northern Great Plains Floristic Quality Assessment Panel (2001). High seral species are found in undisturbed and stable plant communities and generally indicate a high-quality plant community. Low seral species are found in areas with high disturbance levels and indicate an early-succession, low-quality prairie.

Data Analysis. The data were analyzed as an RCBD. Changes in individual plant species' percent foliar cover, richness (number of species present in plots), evenness (relative abundance of species within plots), and diversity between treated and untreated communities were analyzed using ANOVA in SAS (Statistical Analysis Software v. 9.3, SAS Institute, 100 SAS Campus Drive, Cary, NC 27513).

Results and Discussion

The floristic quality at two native prairie sites declined following AMCP treatment due to the loss and/or reduction of many high seral forb species (Tables 1 and 2). Both sites had high floristic quality prior to AMCP treatment; there were 33 and 80 different species observed in Fargo and Felton, respectively. However, AMCP reduced or eliminated many forb species from both communities. High seral forb cover was reduced from 19.8% to 2.9% in Fargo and 18.5% to 2% in Felton at 14 MAT with AMCP at 140 g ha^{-1} (Tables 1 and 2). In contrast, cover of high seral forbs in the control was similar at 0 and 14 MAT and averaged 17% and 23% in Fargo and Felton, respectively.

The reduction in floristic quality is exemplified by the species birdfoot violet (*Viola pedata* L.). Birdfoot violet was present at both locations prior to treatment but was absent in treated areas by 10 MAT and did not return at either location by 14 MAT. In addition to birdfoot violet, foliar cover of white panicled aster (*Aster simplex* Willd.), northern bedstraw (*Galium boreale* L.), Canada goldenrod (*Solidago canadensis* L.), purple meadowrue (*Thalictrum dasycarpum* Fisch. & Avé-Lall.), and American vetch (*Vicia americana* Muhl. ex Willd.) were also reduced by AMCP at both locations. Cover of treated white panicled aster decreased from 1.8 to <0.1% by 14 MAT in Fargo, while white panicled aster was eliminated by AMCP by 10 MAT and did not reappear in Felton. Similarly, purple meadowrue was reduced in Fargo and eliminated in Felton.

Many high seral species that were only observed in Felton were also reduced or completely eliminated by AMCP (Table 2). Species that were eliminated included Flodman thistle [*Cirsium flodmanii* (Rydb.) Arthur], green ash (*Fraxinus pennsylvanica* Marshall), fourpoint evening primrose (*Oenothera rhombipetala* Nutt. ex Torr. & A. Gray), stiff goldenrod [*Oligoneuron rigidum* (L.) Small var. *rigidum*], smooth solomon seal [*Polygonatum biflorum* (Walter) Elliott], and common selfheal (*Prunella vulgaris* L.). High seral forb species that were only reduced by AMCP included purple prairie clover (*Dalea purpurea* Vent.), wild strawberry (*Fragaria virginiana* Duchesne), palespike lobelia (*Lobelia spicata* Lam.), meadow zizia [*Zizia aptera* (A. Gray) Fernald], and golden zizia [*Zizia aurea* (L.) W. D. J. Koch]. In a greenhouse study, purple prairie clover had visual injury symptoms for at least 10 wk after an AMCP application at 35 to 105 g ha^{-1} but did not die and was considered to be "moderately susceptible" (Carter

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Table 1. Foliar cover of individual plant species and species richness, evenness, and diversity within the plant community in Fargo, ND, prior to (0 mo after treatment [MAT]) and 10 and 14 MAT with aminocyclopyrachlor at 140 g ha^{-1} .[a]

		0 MAT		10 MAT		14 MAT	
Scientific name[b]	Common name	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl
		% foliar cover[c]					
High seral forbs							
Anemone canadensis L.	Canadian anemone	0.1	0.1	0	0.1	<0.1	0.1
Apocynum androsaemifolium L.	Spreading dogbane	0.1	0.3	0.1	0.2	0.7	1.1
Aster simplex Willd.	White panicled aster	1.8	1.1	0*	1.0	<0.1*	2.8
Cornus sericea L. ssp. *sericea*	Redosier dogwood	0.1	0.1	0.1	<0.1	0.1*	0
Crataegus dissona Sarg.	Northern hawthorn	—	—	—	—	<0.1	<0.1
Galium boreale L.	Northern bedstraw	5.7	4.8	0*	4.4	<0.1*	4.3
Helianthus maximiliani Schrad.	Maximilian sunflower	0.3*	0	—	—	<0.1	<0.1
Lithospermum canescens (Michx.) Lehm.	Hoary puccoon	0.5	0.3	0.6	0.4	0.6	0.4
Lonicera dioica L.	Limber honeysuckle	0.2	<0.1	<0.1	0	0.1	<0.1
Ribes oxyacanthoides L.	Canadian gooseberry	<0.1	0.1	0.1*	0.2	0.1	0.2
Sisyrinchium angustifolium Mill.	Narrowleaf blue-eyed grass	—	—	—	—	0	<0.1
Solidago canadensis L.	Canada goldenrod	6.7	5.1	0*	6.7	0.2*	8.1
Thalictrum dasycarpum Fisch. & Avé-Lall.	Purple meadowrue	3.3*	1.8	1.0*	2.4	0.9*	2.3
Vicia americana Muhl. ex Willd.	American vetch	0.6	0.5	<0.1*	0.7	0.1*	0.7
Viola pedata L.	Birdfoot violet	0.5*	0.1	0*	0.2	0*	0.2
Subtotal[d]		19.8*	13.7	1.9*	16.2	2.9*	20.2
Low seral forbs							
Artemisia ludoviciana Nutt.	White sage	1.2*	0.2	0.3	0.4	0.8	0.4
Asclepias syriaca L.	Common milkweed	0.3*	0.8	0.1	0.2	0.2*	0.6
Aster ericoides L.	White prairie aster	2.6	2.1	0.4*	3.5	1.0*	4.0
Glycyrrhiza lepidota Pursh	American licorice	1.8	2.0	0.1*	0.8	1.5*	5.0
Juniperus virginiana L.	Eastern redcedar	0.1	<0.1	0.1	0	0.1	<0.1
Rosa arkansana Porter	Priarie rose	5.6	5.8	1.6*	5.1	5.3*	8.7
Symphoricarpos occidentalis Hook.	Western snowberry	10.2*	12.9	6.9*	11.5	7.4*	11.6
Taraxacum officinale F. H. Wigg	Common dandelion	0.3	<0.1	0.1*	0.4	0.1*	0.4
Subtotal[d]		22.1*	27.1	9.6*	22.1	16.3*	30.7
High seral monocots							
Carex pellita Muhl. ex Willd.	Woolly sedge	5.9	4.4	1.0	1.2	1.0	1.0
Dichanthelium oligosanthes (Schult.) Gould	Scribner rosette grass	0.4*	0.1	0.3	0.1	1.0	0.3
Hesperostipa spartea (Trin.) Barkworth	Porcupinegrass	2.7	2.4	4.5	3.1	6.6*	2.6
Subtotal[d]		9	6.9	5.8	4.3	8.6*	3.9
Low seral monocots							
Subtotal[d]		—	—	—	—	—	—
Introduced species[e]							
Bromus inermis Leyss.	Smooth brome	0.2	0	2.7	2.9	3.2	2.9
Cirsium arvense (L.) Scop.	Canada thistle	1.1	1.5	0.2*	1.7	1.0*	3.7
Elymus repens (L.) Gould	Quackgrass	4.6	5.1	0.2	0	—	—
Euphorbia esula L.	Leafy spurge	1.9*	3.9	1.0*	6.2	3*	10.0
Poa pratensis L.	Kentucky bluegrass	6.7	6.5	30.7*	14.6	39.1*	15.8
Rhamnus cathartica L.	Common buckthorn	0*	<0.1	0	0.1	<0.1	0.2
Schedonorus pratensis (Huds.) P. Beauv.	Meadow fescue	0.3	0.8	—	—	0.1	<0.1
Subtotal[d]		14.8*	19.1	34.8*	25.5	46.3*	32.5
Total foliar cover		65.7	66.8	52.1*	68.1	74.0*	87.3
Bare ground		0.3	0	0.7	0.1	-	-
Litter		34.0	33.2	47.2*	31.8	26.0*	12.7
Species richness		13	12	9*	13	11*	14
Species evenness		0.94*	0.93	0.85*	0.92	0.88*	0.93
Diversity index[f]		2.3	2.3	1.8*	2.3	2.1*	2.4

[a] Applied July 2014 with a silicone-based nonionic surfactant (Dyne-Amic®, Helena Chemical Company, 225 Schilling Boulevard, Suite 300, Collierville, TN 38017) blend at 0.25% v/v.

[b] Scientific nomenclature follows the *Flora of the Great Plains* (Great Plains Flora Association 1986), except as amended according to the U.S. Department of Agriculture's Natural Resources Conservation Service (USDA-NRCS) Plants Database (2014). Plant categories determined by the Northern Great Plains Floristic Quality Assessment Panel (2001).

[c] Difference ($P < 0.05$) of plant species foliar cover, bare ground, litter, species richness, species evenness, and diversity between aminocyclopyrachlor-treated and control plots within evaluation date is indicated by an asterisk (*). A dash (—) under % foliar cover indicates species not present in any plot within evaluation period.

[d] Total foliar cover within selected category.

[e] Nonnative (introduced) according to the USDA-NRCS Plants Database (2014).

[f] Species diversity is represented by the Shannon-Wiener diversity index.

Table 2. Foliar cover of individual plant species and species richness, evenness, and diversity within the plant community in Felton, MN, prior to (0 mo after treatment [MAT]) and 10 and 14 MAT with aminocyclopyrachlor at 140 g ha^{-1}.[a]

Scientific name[b]	Common name	0 MAT Trt	0 MAT Ctrl	10 MAT Trt	10 MAT Ctrl	14 MAT Trt	14 MAT Ctrl
		% foliar cover[c]					
High seral forbs							
Allium textile A. Nelson & J. F. Macbr.	Textile onion	—	—	—	—	0	0.1
Anemone canadensis L.	Canadian anemone	0.7	1.0	0.2	1	0.3	0.9
Antennaria parvifolia Nutt.	Small-leaf pussytoes	0.6	0	—	—	—	—
Apocynum androsaemifolium L.	Spreading dogbane	0.3	0.3	<0.1*	0.2	0.1	0.3
Arabis hirsuta (L.) Scop.	Hairy rockcress	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Aster simplex Willd.	White panicled aster	0.9	1.1	0*	0.9	0*	1.3
Castilleja coccinea (L.) Spreng	Scarlet Indian paintbrush	<0.1	<0.1	—	—	—	—
Cirsium flodmanii (Rydb.) Arthur	Flodman thistle	0.6	0.3	0*	0.3	0*	0.3
Dalea candida Michx. ex Willd.	White prairie clover	<0.1	<0.1	0	<0.1	<0.1	0.1
Dalea purpurea Vent.	Purple prairie clover	0.3	0.2	0*	0.2	<0.1*	0.3
Equisetum arvense L.	Field horsetail	0.1	<0.1	0.2*	0.1	0.1	0.1
Fragaria virginiana Duchesne	Wild strawberry	1.8	1.9	0.8*	2.0	0.8*	2.1
Fraxinus pennsylvanica Marshall	Green ash	0.1	0.3	0*	0.3	0*	0.4
Galium boreale L.	Northern bedstraw	2.0*	4.6	0*	4.0	0.1*	4.2
Gentiana andrewsii Griseb.	Closed bottle gentian	<0.1	0	0	0.1	0	<0.1
Geum triflorum Pursh	Prairie smoke	0.2	0.1	0	0.1	<0.1	0.1
Helianthus maximiliani Schrad.	Maximilian sunflower	0.9	0	—	—	0	0.1
Hypoxis hirsuta (L.) Coville	Yellow stargrass	0.2	0.1	0	<0.1	0	<0.1
Lithospermum canescens (Michx.) Lehm.	Hoary puccoon	0.1*	0.5	0*	0.4	<0.1*	0.5
Lobelia spicata Lam.	Palespike lobelia	<0.1	0.1	<0.1	0	<0.1*	0.1
Lysimachia ciliata L.	Fringed loosestrife	<0.1	0	0	<0.1	0	<0.1
Lysimachia hybrida Michx.	Lowland yellow loosestrife	—	—	0.1	<0.1	0.1	0.1
Oenothera rhombipetala Nutt. ex Torr. & A. Gray	Fourpoint evening primrose	0	<0.1	0*	0.3	0*	0.3
Oligoneuron rigidum (L.) Small var. *rigidum*	Stiff goldenrod	1.8	2.3	0*	2.4	0*	2.6
Packera paupercula (Michx.) Á. Löve & D. Löve	Balsam groundsel	<0.1	<0.1	0.1	0.1	0.1	0.1
Pedicularis canadensis L.	Canadian lousewort	0	0.1	0	0.1	<0.1	0.1
Polygonatum biflorum (Walter) Elliott	Smooth solomon seal	0.2*	0.8	0*	0.7	0*	0.7
Prunella vulgaris L.	Common selfheal	0.6*	0.2	0*	0.2	0*	0.2
Rudbeckia hirta L.	Blackeyed susan	0	<0.1	—	—	0	<0.1
Solidago canadensis L.	Canada goldenrod	2.5	1.5	<0.1*	1.9	<0.1*	2.7
Thalictrum dasycarpum Fisch. & Avé-Lall.	Purple meadowrue	0.7	0.7	0*	0.9	0*	0.7
Vicia americana Muhl. ex Willd.	American vetch	1.0	0.7	0*	0.7	<0.1*	0.7
Viola pedata L.	Birdfoot violet	0.2	0.5	0*	0.5	0*	0.5
Zigadenus elegans Pursh	Deathcamas	<0.1	<0.1	<0.1	<0.1	0	<0.1
Zizia aptera (A. Gray) Fernald	Meadow zizia	1.2	1.2	0.2*	1.3	0.4*	1.5
Zizia aurea (L.) W. D. J. Koch	Golden zizia	1.6*	3.9	0.1*	3.8	<0.1*	3.0
Subtotal[d]		18.5*	22.4	1.6*	22.4	2.0*	24.1
Low seral forbs							
Acer negundo L.	Boxelder	0.2*	0.3	0.1*	0.2	0.1*	0.2
Achillea millefolium L.	Common yarrow	0.1	0.1	0*	0.1	0*	0.1
Artemisia ludoviciana Nutt.	White sage	0.4	0.4	0*	0.7	0*	0.8
Aster ericoides L.	White prairie aster	0.9	1.0	0*	0.6	0*	0.8
Cerastium arvense L.	Field chickweed	—	—	0	<0.1	0	<0.1
Erigeron annuus (L.) Pers.	Eastern daisy fleabane	<0.1	0	<0.1	0.1	<0.1	0.2
Glycyrrhiza lepidota Pursh	American licorice	0.4	0.6	0	<0.1	0.4*	1.3
Helianthus annuus L.	Common sunflower	<0.1	0	0	<0.1	0.1	0.3
Parthenocissus quinquefolia (L.) Planch.	Virgina creeper	0.2	0.1	0	0.1	0	0.2
Ratibida columnifera (Nutt.) Woot. & Standl.	Prairie coneflower	<0.1	0	—	—	—	—
Rosa arkansana Porter	Prairie rose	2.6	1.2	0.3*	1.1	0.4*	1.3
Salix spp.	Willow	0.1	0.1	0	0.1	0*	0.2
Symphoricarpos occidentalis Hook.	Western snowberry	5.9	6.9	0.6*	6.4	0.6*	6.5
Taraxacum officinale F. H. Wigg	Common dandelion	0.8	0.9	0*	0.7	0*	0.5
Viola sororia Willd.	Common blue violet	0.4	0.4	0*	0.3	0*	0.2
Subtotal[d]		11.4	11.6	0.9*	10.4	1.5*	12.5
High seral monocots							
Andropogon gerardii Vitman	Big bluestem	4.5	3.1	9.4*	3.8	8.9	4.9
Bouteloua curtipendula (Michx.) Torr.	Sideoats grama	—	—	0.2	0	0.2	0.3
Carex inops L.H. Bailey ssp. *heliophila* (Mack.) Crins	Sun sedge	0.8*	1.4	1.6	1.9	2.2	3.2
Carex sartwellii Dewey	Sartwell sedge	0.1	<0.1	<0.1	0.2	0.4	0.3
Dichanthelium oligosanthes (Schult.) Gould	Scribner rosette grass	0.2	0.3	0*	0.2	<0.1*	0.4

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Table 2: (*Continued*)

Scientific name[b]	Common name	0 MAT		10 MAT		14 MAT	
		Trt	Ctrl	Trt	Ctrl	Trt	Ctrl
Eleocharis macrostachya Britton	Pale spikerush	<0.1	<0.1	0.8	<0.1	0.8	0.1
Hierochloe odorata (L.) Beauv.	Sweetgrass	—	—	<0.1	<0.1	<0.1	<0.1
Juncus balticus Willd.	Baltic rush	0	<0.1	0	0.1	0*	0.8
Koeleria macrantha (Ledeb.) Schult.	Prairie Junegrass	0.7	0.5	—	—	—	—
Nasella viridula (Trin.) Barkworth	Green needlegrass	4.2*	2.4	2.1	1.9	1.3	1.4
Panicum virgatum L.	Switchgrass	—	—	—	—	0.2	0.3
Schizachyrium scoparium (Michx.) Nash-Gould	Little bluestem	1.5	1.8	2.5	1.8	4.5	3.3
Sorghastrum nutans (L.) Nash	Indiangrass	9.6	7.7	14.0*	1.8	8.5	4.3
Subtotal[d]		21.5*	17.4	30.6*	11.8	27.1*	19.0
Low seral monocots							
Cyperus spp.	Flatsedge spp.	—	—	0.2	0.3	0.2	0.3
Elymus canadensis L.	Canada wildrye	0.1	<0.1	<0.1	0	0.2	0.2
Pascopyrum smithii (Rydb.) Á. Löve	Western wheatgrass	—	—	0.5	1.3	11.4*	1.8
Phalaris arundinacea L.	Reed canarygrass	<0.1	0.1	<0.1	0.1	0	0.1
Subtotal[d]		0.1	0.1	0.7	1.6	11.7*	2.3
Introduced species[e]							
Agrostis stolonifera L.	Creeping bentgrass	—	—	5.5	4.4	3.4	4.2
Asparagus officinalis L.	Garden asparagus	—	—	<0.1	0	<0.1	0.1
Bromus inermis Leyss.	Smooth brome	1.6	1.8	1.5*	5.3	1.1*	5.3
Calystegia sepium (L.) R. Br.	Hedge bindweed	0.2	0.3	0	0.2	0*	0.4
Elymus repens (L.) Gould	Quackgrass	2.9	3.2	—	—	—	—
Eragrostis cilianensis (All.) Vign. ex Janchen	Stinkgrass	<0.1	<0.1	—	—	—	—
Lactuca serriola L.	Prickly lettuce	0.1	0.1	0	0.1	0*	0.1
Medicago lupulina L.	Black medic	0.3	0.3	0*	0.1	0*	0.1
Melilotus officinalis (L.) Lam.	Yellow sweetclover	<0.1	<0.1	—	—	0	<0.1
Poa pratensis L.	Kentucky bluegrass	12.2*	9.4	20.0*	10.6	22.0*	11.1
Phleum pratense L.	Timothy	0.1	<0.1	—	—	0.5	0.1
Trifolium pratense L.	Red clover	0.1	0.1	0	0.1	0	0.1
Subtotal[d]		17.5	15.2	27.1*	20.8	27.1	21.4
Total foliar cover		68.9	66.8	60.5	67.0	69.5*	79.3
Bare ground		0	<0.1	—	—	—	—
Litter		31.1	33.2	39.5	33	20.5	20.7
Species richness		16	17	7*	16	9*	19
Species evenness		0.93	0.94	0.88*	0.94	0.86*	0.94
Diversity index[f]		2.6	2.6	1.7*	2.6	1.8*	2.7

[a] Applied July 2014 with a silicone-based nonionic surfactant (Dyne-Amic®, Helena Chemical Company, 225 Schilling Boulevard, Suite 300, Collierville, TN 38017) blend at 0.25% v/v.

[b] Scientific nomenclature follows the *Flora of the Great Plains* (Great Plains Flora Association 1986), except as amended according to the U.S. Department of Agriculture's Natural Resources Conservation Service (USDA-NRCS) Plants Database (2014). Plant categories were determined by the Northern Great Plains Floristic Quality Assessment Panel (2001).

[c] Difference ($P < 0.05$) of plant species foliar cover, bare ground, litter, species richness, species evenness, and diversity between aminocyclopyrachlor-treated and control plots within evaluation date is indicated by an asterisk (*). A dash (—) under % foliar cover indicates species not present in any plot within evaluation period.

[d] Total foliar cover within selected category.

[e] Nonnative (introduced) according to the USDA-NRCS Plants Database (2014).

[f] Species diversity is represented by the Shannon-Wiener diversity index.

2016). Plants that were injured but not killed could recover, as AMCP half-life averaged 18 to 20 d in Fargo clay and Barnes loamy (similar to Felton) soils at 18 C and 45% moisture (Conklin and Lym 2013) and likely had completely dissipated by 14 MAT.

Some high seral forbs were tolerant of AMCP, as cover remained similar between treatments (Tables 1 and 2). By 14 MAT, the tolerant species in Fargo included limber honeysuckle (*Lonicera dioica* L.) and Canadian gooseberry (*Ribes ozyacanthoides* L.). Northern hawthorn (*Cratageus dissona* Sarg.) and narrowleaf blue-eyed grass (*Sisyrinchium angustifolium* Mill.) were not observed prior to treatment, but cover was similar between treatments at 10 and 14 MAT. In Felton, hairy rockcress [*Arabis hirsuta* (L.) Scop.], white prairie clover (*Dalea candida* Michcx. ex Willd.), prairie smoke (*Geum triflorum* Pursh), balsam groundsel [*Packera paupercula* (Michx.) Á. Löve & D. Löve], and Canadian lousewort (*Pedicularis canadensis* L.) cover was similar between the treated and control plots after AMCP treatment. Lowland yellow loosestrife (*Lysimachia hybrida* Michx.) was only observed at 10 and 14 MAT in Felton, and cover was similar between treatments.

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AMCP reduced foliar cover of several low seral forb species at both locations, but some species were able to recover by 14 MAT (Tables 1 and 2). Low seral forb cover decreased at 10 MAT with AMCP from 22.1% to 9.6% in Fargo and from 11.4% to 0.9% at 10 MAT in Felton. At both locations, AMCP reduced white prairie aster, American licorice (*Glycyrrhiza lepidota* Pursh), prairie rose, western snowberry, and common dandelion (*Taraxacum officinale* F. H. Wigg). However, species responses and recovery varied between locations, and recovery occurred more slowly in Felton than Fargo. For example, prairie rose cover in Fargo decreased from 5.6% to 1.6% at 10 MAT and recovered to 5.3% at 14 MAT (still lower than the control), but in Felton, cover decreased from 2.6% to 0.3% at 10 MAT and remained at 0.4% at 14 MAT. AMCP eliminated white sage cover in Felton. Common dandelion at Fargo was the only one of the reduced low seral forb species that had not begun to recover by 14 MAT; whereas only American licorice recovered (although slightly) in Felton, increasing from 0% at 10 MAT to 0.4% at 14 MAT. Conversely, common dandelion in an aminopyralid study recovered to near-pretreatment levels by 22 MAT (Almquist and Lym 2010). The prairie rose and American licorice field results in this study were consistent with a greenhouse study in which these species were considered "moderately susceptible" to AMCP (Carter 2016).

Foliar cover of high seral monocots tended to decrease in Fargo from approximately 9% to 5.8% at 10 MAT but nearly recovered to initial levels by 14 MAT (Table 1). Conversely, high seral monocot cover increased in Felton from 22.5 to 27.1% by 14 MAT (Table 2). The only high seral monocot species found at both locations was Scribner rosette grass [*Dichanthelium oligosanthes* (Schult.) Gould]. In Fargo, Scribner rosette grass cover was different between treatments prior to application of AMCP but similar after treatment; while in Felton, AMCP reduced cover from 0.2 to <0.1% at 14 MAT.

The increase in high seral monocot species in Felton was primarily due to big bluestem (*Andropogon gerardii* Vitman) and Indiangrass [*Sorghastrum nutans* (L.) Nash] cover, which increased from 4.5% and 9.6% to 9.4% and 14% at 10 MAT, respectively. Several desirable grasses were not observed in Felton prior to treatment but were recorded at 14 MAT. These species included sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], sweetgrass [*Hierochloe odorata* (L.) Beauv.], and switchgrass (*Panicum virgatum* L.). The presence of these species after treatment was likely due to the decreased competition from susceptible species and germination from the seedbank. The reduction in forb competition provided a niche for grass species to establish and allowed the plant community to shift toward a grass-dominated landscape. The presence of native and perennial grasses in the plant community is important to maintain community stability and to provide resistance against invasion of weedy species (Tilman 1997; Tilman et al. 2001).

Low seral monocot species were not observed in Fargo, while low seral monocot cover in Felton increased from 0.1% to almost 12% at 14 MAT (Tables 1 and 2). Western wheatgrass was not found at Felton prior to treatment, but foliar cover reached 11.4% by 14 MAT. A flatsedge spp. (*Cyperus* spp.) was also observed only after AMCP treatment, and cover was similar to the control. Canada wildrye (*Elymus canadensis* L.) and reed canarygrass (*Phalaris arundinacea* L.) were similar between both communities at every evaluation.

AMCP reduced the cover of introduced forbs at both locations, which could be considered a positive change in the plant community, because several of the forbs were invasive species (Tables 1 and 2). For instance, by 14 MAT at Fargo, foliar cover of both Canada thistle and leafy spurge had increased in the control. Canada thistle foliar cover in the control increased from 1.5% to 3.7% at 14 MAT and leafy spurge increased from 3.9% to 10%. Both invasive species in the treated plots began to recover by 14 MAT, but foliar cover was still lower compared with the controls and averaged 2% cover compared with 7% cover in the control. In Felton, AMCP eliminated hedge bindweed [*Calystegia sepium* (L.) R. Br.], prickly lettuce (*Lactuca serriola* L.), and black medic (*Medicago lupulina* L.) from the treated plant community. The removal of these introduced species could allow high seral forb or perennial grass species to benefit from decreased competition and thus increase the floristic quality and stability of the community.

Kentucky bluegrass was the only introduced species in which foliar cover increased in treated plant communities at both locations. Following AMCP treatment, Kentucky bluegrass cover increased by 14 MAT from 6.7% to 39.1% at Fargo and from 12.2% to 22% at Felton. The increase in Kentucky bluegrass was likely due to decreased competition from AMCP-susceptible species.

AMCP decreased total foliar cover, species richness, evenness, and diversity in treated communities compared with nontreated communities at both Fargo and Felton at 10 and 14 MAT (Tables 1 and 2). Species richness declined due to the elimination of susceptible species, but more species were removed from the plant community in Felton than in Fargo. In Fargo, species richness in treated areas decreased 31% by 10 MAT and 15% by 14 MAT compared with initial levels, whereas richness in Felton declined 56% by 10 MAT and 44% by 14 MAT. Species evenness was decreased at both locations because of the reduction in abundance of species such as prairie rose, western snowberry, and American licorice, which may have allowed nondesirable species to colonize the treated sites. The evenness at which species are distributed within a pasture may be important in reducing weed abundance; for example, species that are evenly distributed in space may use resources more equitably and produce a competitive environment that is difficult for weeds to invade (Lyons and

Schwartz 2001; Tracy and Sanderson 2004; Wilsey and Polley 2002; Wilsey and Potvin 2000).

The Shannon-Wiener diversity index (H′) is a function of both species richness and evenness; as such, diversity in Fargo was reduced by AMCP at both 10 and 14 MAT (Table 1). Diversity declined from 2.3 to 1.8 by 10 MAT but then increased to 2.1 by 14 MAT to reflect the slight recovery of species richness and evenness. Species diversity in Felton followed the same trend and decreased from 2.6 to 1.7 by 10 MAT and then rose to 1.8 14 by MAT (Table 2).

A decline in diversity and shift in dominant species following AMCP treatment could have beneficial and/or adverse effects depending on the initial quality and composition of the site. In an infested community, AMCP could be applied to control unwanted species and shift the plant community toward a more grass-dominated community (Greet et al. 2016). Reducing invasive or undesirable species also decreases diversity, but quality and stability of the plant community may improve overall. A study in an established native plant community determined that identity of dominant species affected local invasibility, and *Andropogon*-dominated communities were the least invasible (Emery and Gross 2006). Thus, a shift toward a grass-dominated community could lead to a more stable, less invasible community. However, in high-quality native prairies with many desirable forb species, AMCP will likely reduce or eliminate forbs and decrease overall flora quality and diversity of the plant community. Based on the theory of fluctuating resource availability, susceptibility to invasion is determined by resource supply rate rather than diversity, and a plant community becomes more susceptible to invasion with an increase in available resources (Davis et al. 2000). Therefore, injury to susceptible forbs should be considered before applying AMCP, as nearly all desirable forbs were removed or at least temporally reduced in this study.

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