Establishing Tallgrass Prairie on Grazed Permanent Pasture in the Upper Midwest

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Abstract

The goal of the study was to learn whether native prairie grasses and, eventually, a diverse mixture of native forbs could be incorporated in permanent pastures by means of rotational grazing by cattle. An experiment was established on a farm in northeastern Iowa on a pasture that had never been plowed but had been grazed since the 1880s. One treatment was protected from grazing to test for the presence of remnant vegetation. *Andropogon gerardii*, *Sorghastrum nutans*, *Panicum virgatum*, and *Desmanthus illinoensis* were introduced in plots first treated with glyphosate; seeds were either drilled (DR) or hand-broadcast and incorporated by controlled cattle trampling (BT). Seedling establishment and aboveground biomass were followed over 3 years. There was no evidence for remnant native plants on uplands, but seven species of native forbs and four native graminoids flowered in exclosures erected within waterways. *D. illinoensis* initially established up to 12 seedlings/m^2 but had disappeared from all but one plot by the third year. Variation in native grass establishment among replicate plots within treatments was very high, ranging initially from 0.2 to 9.9 plants/m^2. In August of the second year, native grasses made up only 8% of the available forage in DR plots and 1% of BT plots. One year later, however, native grasses made up 56% of the available forage in DR plots and 37% of BT plots, and these differences were significant (p = 0.05). A pilot study seeded in late winter (frost seeding) suggested that seeds spread after cattle trampling produced five times more seedlings (2.5/m^2) than seeds spread before cattle trampling (0.5/m^2). Frost seeding had advantages because it did not require herbicide for sod suppression or tractor access to the site. New plantings could be safely grazed in early spring and late fall, before and after most native grass growth, to offset the negative economic impact of protecting new plantings from burning during the growing season. But this practice precluded subsequent prescribed burning. I propose a strategy for incorporating native wildflowers into the pasture over time with minimum cost.

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Introduction

Zea mays (corn) and *Glycine max* (soybeans) dominate the tallgrass prairie biome. In Iowa, less than 0.2% of the former prairie ecosystem remains in a few state preserves and numerous, mostly undocumented and unprotected fragments (Smith 1992). The largest state-owned tallgrass prairie preserve in Iowa is only 97 ha and is surrounded on all sides by row crops. In this intensively managed landscape it is critical that every remnant habitat within the agricultural matrix be recognized and, if possible, restored. Each permanent pasture in the tallgrass prairie region is a degraded remnant of native wetland, prairie, savanna, or woodland. Usually located in areas unsuitable for cultivation such as drainageways with seasonally high water tables, permanent pastures have never been plowed, but they have been subjected to continuous grazing by cattle and other livestock since the time of Euro-American settlement. Their remnant status is cryptic and often overlooked because they are dominated by cool-season European forage grasses and legumes that can tolerate continuous grazing. The area devoted to permanent pasture has declined in the upper midwest of the United States due to agricultural intensification. In northeast Iowa, for instance, permanent pastures occupied 6–9% of land in farms in 1983, down from about 17% in 1940 (Iowa State Department of Agriculture 1940; Iowa Agricultural Statistics 1984).

There is evidence that at one time permanent pastures contained substantial native plant diversity. Pammel et al. (1901) listed 25 species of native grasses and 10 legume species that they considered valuable components of pastures and meadows in Iowa. Pammel and King (1926) listed at least 42 native, perennial forbs that they regarded as weeds in pastures, including *Cicuta maculata* (water hemlock) and *Asclepias speciosa* (showy milkweed). Eilers and Roosa (1994), in contrast, listed the habitat of water hemlock as "marshes and wet prairies" and showy milkweed as "prairies and woodland openings."

It is possible that some permanent pastures in the tallgrass prairie region still contain small populations of native, warm-season grasses and forbs. Rosburg and Glenn-Lewin (1992), using grazing exclosures, fire, and atrazine treatments, found a total of six native grasses and nine native forb species on seven pastures in southcentral Iowa. Samson and Moser (1982) and Waller and Schmidt (1983) found remnant populations of native grasses on permanent pastures in eastern Nebraska, once the pasture grasses were suppressed with herbicide.

Farmers might gain from the restoration of native prairie species to some of their pastures. The common European forage grasses and clovers are cool-season species that produce little forage in July and August, especially in drier years. Native warm-season grasses, in contrast, are drought-tolerant and highly productive in these months. Warm-season native grasses could increase the availability of midsummer forage and provide some protection from drought (Jung et al. 1978; Hall et al. 1982), while legumes could supply much of the nitrogen required for grass growth and improve the protein level of the forage. Some farmers also value increased biological diversity for educational, aesthetic, and ethical reasons. Aldo Leopold explored this idea in his 1939 essay, "The Farmer as Conservationist," which was based in part on numerous contacts with farmers in Wisconsin (Meine 1987).

I wanted to know whether native grasses and, eventually, a diverse mixture of native forbs could be restored in permanent pastures on a diversified farm by means of rotational grazing. Rotational grazing is a method of managing forage and livestock that has become increasingly popular among dairy and beef cattle farmers in the United States. Pastures are divided into several smaller paddocks using low-cost, portable electric fencing and water tanks. The cattle graze one paddock thoroughly and then are moved to the next paddock (Fig. 1). This prevents them from regrazing the plants they have recently defoliated. Under ideal management, plants recover leaf area and carbohydrate reserves before being grazed again, thus preserving species that are less tolerant of grazing (Voisin 1959). Rotational graziers report lower production costs, improved animal health, improved farm working conditions, and higher profit margins (Chan-Muehlbauer et al. 1994).

In contrast, conventionally managed pastures are grazed continuously throughout the growing season. In the upper Midwest these pastures are usually dominated by shallow-rooted, grazing-tolerant species such as *Poa pratensis* (Kentucky bluegrass) and *Trifolium repens* (white clover), with summer weed populations of *Cirsium canadense* (Canada thistle), and *Ambrosia artemisiifolia* (ragweed). Because most native prairie plants have disappeared from continuously grazed permanent pastures, it is not reasonable to attempt restoration of pastures still grazed in this manner. I hypothesize, however, that many prairie species will be able to tolerate a rotational grazing regime once they are reintroduced.

Through the Practical Farmers of Iowa, an organization devoted to on-farm research in sustainable agriculture, I identified farmers with an active interest in restoring native, warm-season grasses to their rotational grazing pastures. Together we obtained financial support that paid rent to the farmer during the years of establishment to minimize the financial risks of these experiments.

Figure 1. Cattle on the research site are moved to a fresh paddock in early July 1996 by means of portable electric fence. Each paddock was grazed for 2–10 days, depending upon size, and then rested for at least 4 weeks before being grazed again. The paddocks, seeded in 1995 with three native grasses and a native legume (*Desmanthus illinoensis*), were still dominated by flowering *Poa pratensis* (Kentucky bluegrass) and *Phleum pratense* (timothy) in early July 1996. The white flower is *Erigeron annuus* (daisy fleabane).

The study was conducted on Michael Natvig's farm, located in Howard County, Iowa. Mr. Natvig's pasture is a remnant *Quercus macrocarpa* (bur oak) savanna dissected by boulder-strewn, intermittent waterways and dominated by Kentucky bluegrass and white clover (Fig. 2). It has been grazed according to rotational methods by a cow-calf herd since 1988. The pasture has several features typical of other permanent pastures in the region. First, any existing native plant species (besides oak) are virtually impossible to locate under normal grazing management due to their small size and low frequency. Second, due to rough and wet ground it is impossible to access many parts of the pasture with tractor-drawn equipment such as a grass seed drill. Third, the early phases of native plant establishment and prescribed burning are in partial conflict with livestock grazing. Finally, it is difficult to justify economically the purchase for a cow pasture of expensive, local ecotype grass seed and a diverse mixture of native forb seed.

The objectives of the study were (1) to determine whether or not there were significant remnant native plant populations on which to build, (2) to compare methods of interseeding native species, one of which

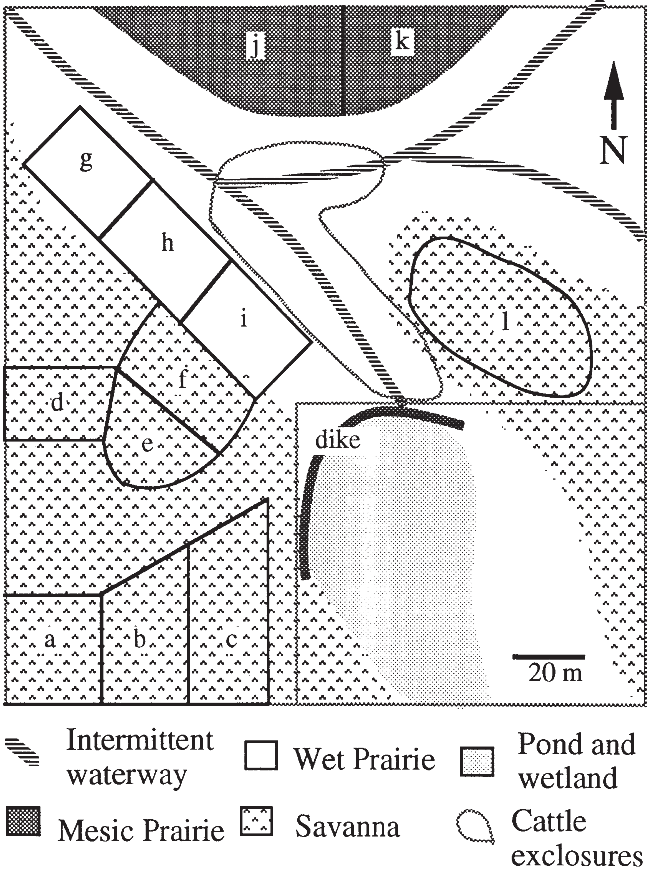

Figure 2. Location of 12 experimental plots, waterways, and cattle exclosures in relation to various potential vegetation types.

was independent of tractor-drawn equipment, and (3) to develop a grazing and burning schedule that optimized conditions for native plant establishment while allowing economic use of the pasture. These are the first steps toward reestablishing native prairie grasses for use as forage, starting with the economically valuable grasses, with the intent of later expanding the research to include a diversity of forbs.

To meet the first two objectives, a replicated field experiment was established in open areas within the pasture, and data were collected on seedling numbers, plant cover, and biomass over three growing seasons. One treatment was not seeded and was excluded from grazing for 3 years to discover potential remnant plant populations. The other two treatments were sprayed with glyphosate to suppress the existing pasture sod, and one was seeded by grass drill with a mixture of three native grass species and a native legume. This treatment required tractor access. The other treatment was the same species mix broadcast by hand, and cattle were used to incorporate the seeds into the ground by trampling. This method did not require tractor access.

To learn how native grass establishment could best be accomplished while allowing some grazing, I consulted regularly with Mr. Natvig concerning the desired location, timing, and intensity of grazing and burning. Grazing and burning decisions were based on frequent observations of pasture plant growth, forage quality, and the progress of native plant establishment, with consideration given to the forage needs of the livestock. The outcome of these decisions was assessed and incorporated into future management plans. Species diversity outside of replicated plots was supplemented by introducing hand-collected forb seed.

Methods

Location

The site is a 4.05-ha permanent pasture in Howard County, Iowa, U.S.A. (43°13′30′′N, 92°11′30′′W), located in an upland drainageway of the Turkey River watershed. The site lies on the northeastern edge of the Iowan Surface, where the once dominant prairie vegetation graded into savanna and woodland (Eilers & Roosa 1994; Prior 1994). General Land Office surveys prior to 1859 describe this area as a combination of "timber," "scattering trees," or "openings" (Anderson 1996). The Howard County Soil Survey (Buckner & Highland 1974) maps this region as a mosaic of aquolls (soils with 6–9% surface organic matter, good crumb structure, developed under water-tolerant grasses and sedges) along drainageways; uplands are dominated by udolls (5–6% surface organic matter, good crumb structure, developed under prairie vegetation) and alfisols (<3.5% surface organic matter, poor crumb structure, usually developed under deciduous forests or mixed grasses and trees) (Brady 1974; Buckner & Highland 1974). Within the study site these areas are referred to as wet prairie, mesic prairie, and savanna soils, respectively (Fig. 2).

The low-lying areas of the site are fairly typical of remaining permanent pastures in the region (Fig. 2). Three broad, boulder-strewn intermittent waterways converge to drain the area. One was excavated and diked in 1994 to create a 0.5-ha pond and wetland. The uplands are dominated by scattered mature bur oaks with diameters at 1.75 m height ranging from 20 cm to 100 cm, with most in the 60–70 cm range. The bur oak canopy within areas of savanna soils is broken by sunny openings ranging from 500 to 5500 m^2, with many smaller areas of intermittent sun 1–2 m in diameter. The pasture, in use by EuroAmericans since the 1880s, has never been plowed or artificially drained.

Both open and shaded areas in the uplands on mesic prairie and savanna soil types contained a similar ground cover assemblage of Kentucky bluegrass, *Phleum pratense* (timothy), white clover, *Taraxacum officinale* (dandelion), *Achillea millefolium* (yarrow), and *Plantago* spp. (plantain species). Broad (>30 m) zones on each side of the waterways (wet prairie soil type) are above the normal high-water flow and remain free of oaks (Fig. 2). These zones consisted of hummocks of Kentucky bluegrass mixed with species of *Carex* (sedge) and grazing-tolerant native perennial forbs such as *Eupatorium perfoliatum* (boneset) and *Verbena hastata* (blue vervain). Bur oaks less than 20 cm in diameter were absent at the beginning of the experiment.

Experimental Design and Treatments

The pasture consisted of large (0.1–1 ha) patches of trees with irregularly shaped openings, making it impossible to establish research plots of uniform size or shape within a single soil type. I identified 12 areas at least 500 m^2 in size within the pasture that were neither waterways nor shaded by trees. Seven of these were located on savanna soils, three were located next to a waterway in wet prairie soils, and two were located on mesic prairie soil (Fig. 2). Treatments were randomly allocated to plots, except that drilled treatments were reassigned if the plot was inaccessible to machinery. Figure 2 shows the timing of herbicide application, seeding, cattle trampling, grazing, burning, and data collection from 1994 to 1997.

The no-seed (NS) treatment was designed to determine if there were remnant prairie species suppressed by grazing. Four replicate plots were not seeded or grazed until the summer of 1997, when two each were grazed or burned (Fig. 3). This treatment also served as a no-herbicide comparison with the seeded treatments during the first year of establishment.

Three additional exclosures were established to supplement the main experiment. In the fall of 1994, the southeast quarter of the pasture surrounding the constructed wetland (Fig. 2) was put into a permanent exclosure. In 1996 Mr. Natvig fenced cattle out of the southernmost waterway near the pond, and in 1997 he extended the fencing north to include waterways in the center of the pasture.

Drilled (DR) and broadcast-trampled (BT) treatments were sprayed with 3.5 liters/ha glyphosate, a systemic herbicide, between 21 and 24 May 1995 to suppress the existing sod (Fig. 3). Drilled plots were seeded with a Truax native seed drill (Minneapolis, Minnesota) on 6–7 June, 1995. Broadcast-trampled plots were hand-broadcast on the same dates. To incorporate broadcast seeds into the soil, twenty-eight 500-kg cows (*Bos taurus*) and their 75-kg calves were introduced to the broadcast-seeded plots for 2–4 days per replicate plot beginning 27 June, immediately after the first substantial (>1 cm) rainfall (Fig. 3). Salt had been withheld from the animals for two weeks. A salt block was placed on a plastic sled attached to a rope and dragged several times from one spot to another. The cows pursued the salt block in a group, creating a pulverized, bare soil surface across the whole plot. A portable water tank was available at all times, and this area was also effectively trampled.

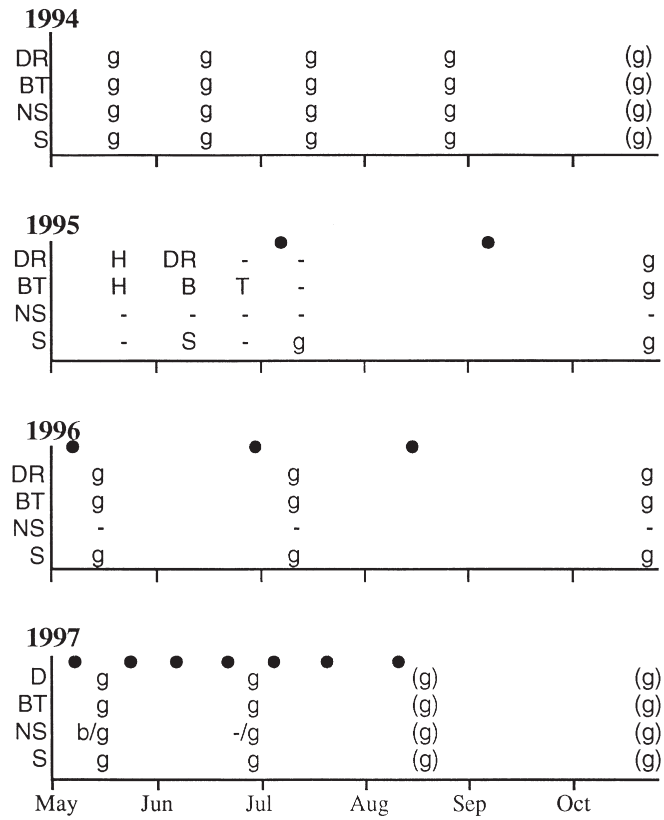

Figure 3. Summary of experimental treatments and first dates of grazing and burning management over 4 years, by treatment. Symbols: DR, drilled; B, broadcast; T, trampled; NS, no seed; S, seeded, either broadcast or drilled depending on access to machinery; H, glyphosate herbicide; g, grazed; (g), grazing deferred; b, burned; b/g, two plots burned and two plots grazed; -/g, two plots deferred and two plots grazed; black dots indicate when data collection for seedling number and percent cover (1995) or biomass (1996, 1997) occurred. Grazing occurred over a 5–9 day period, depending on forage quantity.

Approximately 75% of the pasture (3 ha) was outside of the replicated experiment, primarily under the shade of oaks, near the pond, or within a few meters of the waterways (Fig. 2). These areas (seeded, Fig. 2) were drilled or broadcast (depending on tractor access) directly into the pasture sod, without an herbicide application. In these areas I supplemented the standard seed mix described below with small amounts of wildflower seed collected from remnants in northeast Iowa.

Frost Seeding

In March 1997 one plot from the original experiment (plot j, Fig. 2) was sacrificed in order to establish a new frost-seeding trial. The soil had begun to thaw to about 10 cm below the surface. The 2500-m^2 area was enclosed and divided into two paddocks by electric fence. Forty 500-kg cows plus a 725-kg bull were kept on each paddock for 1.5 days. As in the procedure above, the animals had received no salt for 2 weeks prior to this. A salt block was placed at one end of the plot and hay and a water tank at the other. The cattle walked back and forth across the plots between the water tank and the salt block, creating a muddy surface with 50–75% of the sod inverted. In one paddock, seeds were broadcast before the trampling treatment, and on the other half seeds were broadcast after trampling. In September 1997 I counted all native grasses along two belt transects 2 m wide and 30 m long, one on each side of the trial.

Grazing

Replicated plots were not grazed during the first growing season (1995; Fig. 3). In July the cattle grazed the seeded treatment because there appeared to be no successful native plant establishment there. By the fall of 1995, the pasture had accumulated a large volume of forage, so it was grazed after the first frost, when any native grass seedlings would be dormant. In the second growing season (1996), all areas were grazed three times: in mid-May before emergence of native grasses, in early July when it was judged that native grass seedlings would be sufficiently large and well-rooted to withstand defoliation, and in late October when the native grasses would be dormant (Fig. 3). In the third growing season (1997), all areas were grazed in mid-May and late June. A planned August 1997 grazing was deferred in order to accumulate fuel for a Spring 1998 burn (Fig. 3). Figure 1 illustrates the use of rotational grazing techniques.

Burning

Beginning 1 September 1994, Mr. Natvig deferred grazing from the entire 4.05-ha pasture to accumulate fuel for a planned Fall 1994 or Spring 1995 burn (Fig. 3), but the fuel was not sufficient to carry the fire. In late April 1997 I attempted to burn two of the four NS plots, which had not been grazed since Fall 1994. Despite adequate dry fuel, the bluegrass had already begun to regrow, and the large quantities of green grass restricted the fire to less than 50% of the plot.

Seed Mix and Origin

This seed mix was designed to provide affordable, native, warm-season grass forage for farmers and to include an inexpensive native, nitrogen-fixing legume palatable to livestock. The seed mix consisted of 4.5 kg/ha each of *Andropogon gerardii* (big bluestem), *Sorghastrum nutans* (Indiangrass), and *Desmanthus illinoensis* (Illinois bundleflower), and 0.6 kg/ha of *Panicum virgatum* (switchgrass). Bundleflower seeds were inoculated with the appropriate *Rhizobium* species before seeding. One-quarter of the purchased grass seeds had been collected from remnant stands within a 200-km radius (local ecotype) and three-quarters of it was less costly cultivar seed ("Roundtree" big bluestem, "Rumsee" Indiangrass, and "Cave-in-Rock" switchgrass.) The Illinois bundleflower was from a Kansas seed source; no local ecotype seed was available in 1995. While bundleflower is rare in northeast Iowa, it is within its original published range (Great Plains Flora Association 1986). Bundleflower fixes nitrogen, it has broad habitat requirements, it is readily eaten by livestock, and its seed is less expensive than that of other native legumes (Stubbendiek & Conard 1989).

Measurements

Seedlings of the native species were counted in five to eight 0.5-m^2 circular quadrats per replicate plot on 11–12 July, after native grass seedlings had emerged, and at the end of the growing season on 2 October 1995. Percent cover of bare ground, pasture grasses and forbs, and annual plants were also estimated in these quadrats. Pasture biomass was measured three times in 1996 and seven times in 1997 (Fig. 3) by clipping vegetation to within 5 cm of the surface in four to eight 0.25-m^2 circular quadrats per replicate plot. Clippings were separated by species except for the first and second sampling dates in 1996 and the 23 July 1997 date, when they were separated into pasture plants, native grasses, and bundleflower. Samples were dried at 60°C to constant mass and measured to the nearest 0.01 g.

Statistical Analysis

Pasture species were grouped into five cover categories: perennial pasture grasses, perennial pasture forbs, annual plants (both grasses and forbs), native grasses (all species combined), and bundleflower. Seedling count data were square-root-transformed and biomass data were log-transformed to improve normality in statistical tests; means were back-transformed for presentation. I used the General Linear Models Hypothesis program in SYSTAT (Wilkinson 1989) for analysis of variance (ANOVA) and repeated-measures ANOVA. I used Tukey's protected test for pairwise comparisons to compare means among treatments. I used multiple regression to estimate the effects of cover—perennial pasture grasses, perennial pasture forbs, all annuals, and bare ground—on the number of native grass or bundleflower seedlings in July and October of 1995.

Subsamples within plots were averaged on each date to obtain one value for each replicate plot. The data were analyzed as a one-way ANOVA with three treatments and four replicates (Snedecor & Cochran 1980).

Results

Remnant Species

I had hypothesized that remnant native plant populations would become apparent once grazing was suspended in no-seed plots. No native species appeared, except in August 1997, when a single native grass specimen of *Panicum virgatum* was found in an NS plot. It could, however, have dispersed from neighboring plots. No-seed plots were species-poor compared to seeded plots. Mean species richness for the NS treatment was 3.50 (range 1–6) in August 1996 and 5.0 (range 3–8) in 1997. Mean species richness for drilled and broadcast-trampled plots combined was 9.4 (range 7–12) in August 1996 and 8.6 (range 6–12) in August 1997.

Outside of the replicated NS plots, several native species appeared once cows were excluded. In the waterways, which were fenced in 1996 and 1997, *Lobelia siphilitica* (great blue lobelia), *Spartina pectinata* (prairie cordgrass), *Carex vulpinoidea* (fox sedge), *C. stipitata* (sawbeak sedge), and *Scirpus atrovirens* (dark green rush) became abundant. Blue vervain and boneset increased in abundance and flowered profusely. *Lobelia inflata* (Indian tobacco), *Mimulus ringens* (monkeyflower), *Lysimachia quadriflora* (narrow-leaved loosestrife), and *Helenium autumnale* (sneezeweed) appeared in the constructed wetland and in the waterway exclosures in low numbers in 1997.

Although small amounts of wildflower seed had been scattered in upland and waterway areas throughout the entire 3-ha area outside the experiment, they became established only in the exclosures along waterways. Species introduced as seed in 1995 that flowered in 1997 included *Gentiana andrewsii* (bottle gentian), *Pycnanthemum virginianum* (common mountain mint), *Glyceria grandis* (American manna grass), *G. striata* (fowl manna grass), *Elymus canadensis* (Canada wildrye), *Aster novae-angliae* (New England aster), *Asclepias incarnata* (swamp milkweed), *Vernonia fasciculata* (ironweed), *Monarda fistulosa* (bergamot), and *Silphium perfoliatum* (cup plant). *Caltha palustris* (marsh marigold) and *Calamagrostis canadensis* (bluejoint grass), which were transplanted into the waterway exclosures in 1996 also flowered in 1997. *Zizania aquatica* (wild rice) sown around the edges of the pond formed dense stands over 3 m tall in 1996 and 1997.

Reduction in grazing pressure in 1995 evidently promoted recruitment of bur oak. Mr. Natvig noted that bur oak seedlings older than one growing season were absent from the pasture prior to 1995. In 1996 and 1997 we observed large numbers (>500) of bur oak seedlings with several leaf scars and browsing damage in open areas near oaks in several locations.

Comparison of Seeding Methods

Herbicide application in the drilled and broadcast-trampled treatments succeeded in temporarily reducing the vegetation cover of treated plots, especially of pasture grasses. On the first sampling date, DR and BT plots had significantly more bare ground ($p = 0.003$) and less cover of pasture grasses ($p = 0.005$) than NS plots (Fig. 4). There were no differences between DR and BT treatment in components of vegetation. Variation among replicate plots was high, due in part to the effectiveness of herbicide application and trampling. Plots that were too rough, rocky, or wet to allow even application of the herbicide had a stronger turf, which was then less subject to the shearing and inversion caused by cattle in the BT treatment.

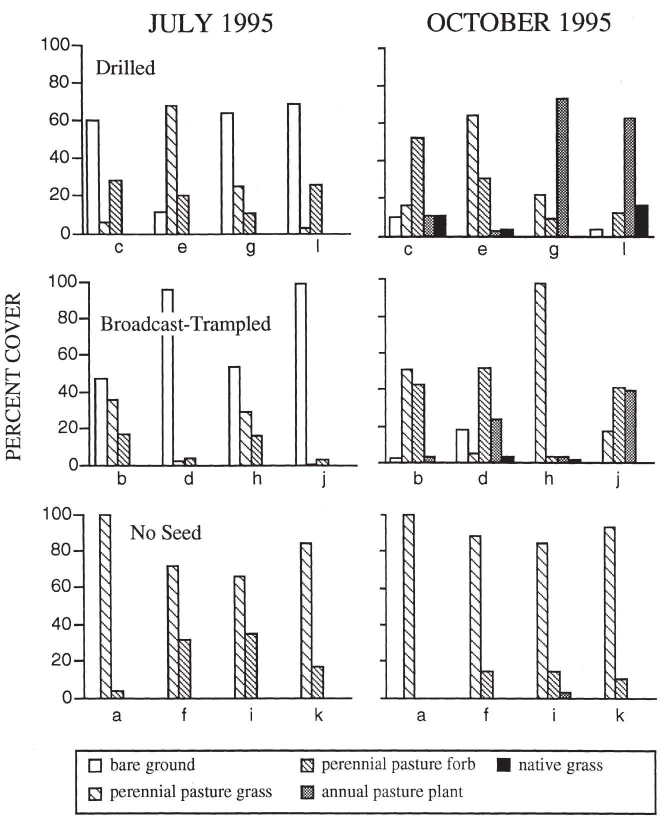

Figure 4. Effect of herbicide, seeding and trampling treatments on percent cover of pasture components (bare ground, perennial pasture grasses, perennial pasture forbs, annual plants, and native grasses) in each replicate plot for July and October 1995. Letters refer to plot designations given in Figure 2. ANOVA results are given in the text.

Seedlings of native grasses, bundleflower, and annual weeds were present in July but were too small and infrequent to be estimated by means of percent cover.

By the end of the first growing season, bare ground in the sprayed plots had been replaced by vegetation, but its composition was highly variable (Fig. 4). Treatment differences were detectable only in the percent cover of perennial pasture grasses, which was significantly higher in the NS treatment than in the DR treatment (p = 0.026). Native grass seedlings occupied an average of 7.8% (range 0–18%) cover in DR versus 1.3% (range 0–5%) in BT treatments; these differences were not significant, again due to substantial variation among replicate plots (Fig. 4).

Drilled plots had significantly greater numbers of native grass and bundleflower seedlings than the BT treatment on the first sampling date (Table 1). This was an artifact of the delay between broadcasting and seed incorporation in the BT treatment (Fig. 3). Some bundleflower seedlings germinated before the trampling treatment and were killed by this treatment. By the end of the first growing season, there were no significant differences between the DR and BT treatments in the number of native grass seedlings; but the three highest numbers of native grass seedlings per square meter were all found in drilled plots (Table 1). Bundleflower numbers dropped to nearly zero in two of the four drilled plots.

In July of the establishment year, multiple regression showed no significant relationship between seedling number and bare ground or any component of vegetation cover within a 0.50-m^2 area (Appendix 1). By October, however, perennial pasture grasses, forbs, and annuals were all negatively correlated with the number of native grass and bundleflower seedlings in each subplot. The regression coefficients were very close to zero, however, and the regression models accounted for only 20–34% of the total variation in seedling number (Appendix 1).

Pasture Development in Year Two

Despite large initial (July 1995) differences in pasture composition among treatments and sites, there was no significant treatment effect on pasture composition at the beginning of the second growing season (Table 2). Native grasses and bundleflower were a very small component of aboveground forage in late June 1996. By August, however, native grass biomass had increased relative to other components of the pasture and was significantly higher in DR than BT plots. The NS treatment began to diverge in total biomass from DR and BT treatments after May 1996, because NS plots were not grazed, while DR and BT plots were grazed twice (Table 2; Fig. 3).

In late June of 1996, native grass density (plants/m^2) was much lower than it was at the sampling dates either before or after (Table 1). Bundleflower, in contrast, maintained levels similar to the October 1995 sampling. Differences in the visibility of the native grasses and bundleflower within the dense pasture may account for these discrepancies.

Pasture Development in Year Three

Cool-season pasture grasses and forbs grew rapidly to a maximum in late June (Fig. 5). Native grasses were present in very small amounts in seeded plots throughout May and June. In late summer, native grasses grew faster than all other components of the pasture, increasing from 22% and 20% native grass biomass on 7 July, to 56% and 37% on 6 August in DR and BT plots, respectively (Table 2; Fig. 5). In August 1997 there was significantly more native grass biomass in DR plots

Table 1. Native grass and bundleflower plants/m^2 by treatment and plot on four census dates, and results of one-way analysis of variance.[1]

	Native Grass				*Bundleflower*			
Plot	*7/95*	*10/95*	*6/96*	*9/97*	*7/95*	*10/95*	*6/96*	*9/97*
Drilled								
c	5.9	8.3	2.9	5.0	8.2	6.4	7.4	0.9
e	3.0	3.0	0.9	1.5	12.4	0.6	0.0	0.0
g	1.4	8.0	2.2	8.8	6.5	0.0	0.9	0.0
l	6.8	9.9	3.6	8.6	3.9	3.9	4.7	0.0
Broadcast-trampled								
b	0.0	0.2	2.2	2.9	0.2	1.0	1.6	0.0
d	0.0	4.4	0.7	3.9	0.6	2.1	0.3	0.0
h	0.0	1.1	1.6	1.7	0.4	0.0	0.5	0.0
j	0.0	0.9	0.4	n/a[2]	0.2	0.0	0.1	n/a[2]
p value	0.005	ns	ns	ns	0.005	ns	ns	ns

[1]Each number is the back-transformed mean of 5–12 subsamples.
[2]This plot was removed from the experiment in 1997 and reseeded.

Table 2. Mean biomass of pasture components in the second growing season (1996, three dates) and the third growing season (1997, one date) by treatment ($n = 4$).

Date	*Pasture Component*	*Drill*	*Broadcast*	*Not Seeded*	p *value*
15 May 1996	pasture grasses	6.91	16.38	21.86	ns
	pasture forbs	21.12	27.83	3.92	ns
	annuals	0.00	0.00	0.00	—
	native grass	0.00	0.00	—	—
	bundleflower	0.00	0.00	—	—
30 June 1996	pasture species	90.10	70.88	176.32	ns
	native grasses	0.80	0.26	—	ns
	bundleflower	0.53	0.10	—	ns
13 August 1996	pasture grasses	12.43*a*	14.03*a*	95.25*b*	0.005
	pasture forbs	7.97*a*	7.02*a*	4.11*b*	0.01
	annuals	5.90	3.62	0.09	ns
	native grass	2.35*a*	0.34*b*	—	0.05
	bundleflower	0.29	0.14	—	ns
8 August 1997	pasture grasses	1.41*a*	1.94*a*	22.86*b*	0.02
	pasture forbs	9.80	5.97	4.37	ns
	annuals	5.22*a*	14.58*b*	0.33*c*	<0.001
	native grass	21.33*a*	13.44*b*	—	0.05
	bundleflower	0.60*a*	0.00*b*	—	<0.001

P values report results of one-way analysis of variance (pasture components) or *t* test (native grasses and bundleflower) of the transformed data. Means on the same line followed by the same letter are not significantly different at $p < 0.05$.

than BT plots ($p = 0.05$; Table 2). Biomass in DR plots did not increase more rapidly than in BT plots (Fig. 5; repeated measures ANOVA, $p = 0.504$).

Between August 1996 and August 1997 there was a significant increase in the absolute biomass of native grasses in all treatments ($T = -2.944$, df = 10, $p = 0.015$) and a decrease in the biomass of other perennial pasture grasses ($T = 3.917$, df = 10, $p = 0.003$) and forbs ($T = 5.203$, df = 10, $p = < 0.001$). Annual weed biomass did not change ($T = -.830$, df = 10, $p = 0.426$).

Big bluestem comprised 64.8% (±5.95 SE); switchgrass 29.0% (±6.83 SE), and Indiangrass 6.2% (±2.01 SE) of the total number of grasses found in transects in September 1997. There were no clear differences in species composition among treatments.

The seeded treatment (no herbicide burn-down) applied to most of the pasture was unsucessful. I first observed native grasses growing in two small (<500 m^2) locations within this treatment in the fall of 1996. Native grass density was about 1.2/m^2 in September 1997 and made up 16% of the available forage.

Frost Seeding Trial

Compared to the summer 1995 BT treatment, the March 1997 frost-seeding trial was more successful in establishing native grasses. We found an average of 0.5 plants/m^2 in the paddock broadcast before trampling, and 2.5 plants/m^2 in the paddock broadcast after trampling. These differences were clearly visible from a distance. Switchgrass was more frequent and big bluestem less frequent than expected in the paddock broadcast before trampling, compared to the paddock in which seeds were broadcast after trampling ($\chi^2 = 23.7$, df = 1, $p < 0.001$). This was consistent with other observations that, where cattle trampling had been especially heavy, switchgrass was more common than observed in other areas.

Burning, Grazing, and Plant Establishment

Burning and grazing interacted in unexpected ways. To carry out a prescribed spring burn, it was necessary to defer fall grazing to accumulate fuel for the burn. Even when grazing was deferred, however, a combination of poor fuel availability, cool and wet weather, and early growth of the cool season grasses prevented successful prescribed fires during 1995 and 1997.

Protecting new seedlings from grazing in their first growing season (1995) started an unforeseen chain of events. Mr. Natvig and I decided to offset the loss of summer forage in the establishment year by allowing grazing after the first frost (October), when native seedlings would be dormant and presumably unharmed. Although forage quality was low at that time because the grasses had gone to seed, the cattle ate a greater proportion of the forage than Mr. Natvig expected, and the strategy was judged a success from the point of view of livestock production. Dormant-season grazing precluded burning the following spring, however, because the fuel was gone.

Midsummer grazing in 1996, the second year of establishment, was judged to be poorly timed (Fig. 3). By

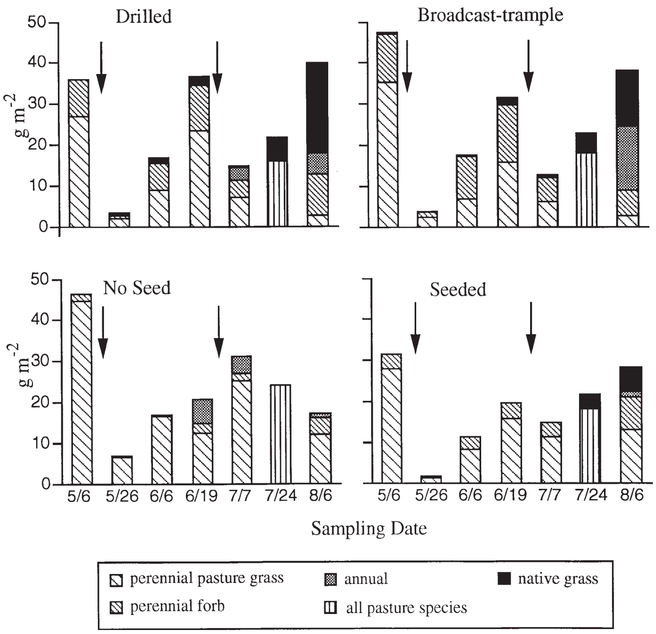

Figure 5. Biomass composition of perennial pasture grasses, perennial pasture forbs, annual plants, and native grasses by treatment on six sampling dates in 1997. Arrows indicate dates of grazing. On July 24, only native grass and total pasture biomass were measured. For the NS treatment, only the means of the two grazed plots are presented. ANOVA results for the final date are shown in Table 2.

delaying the second grazing date until 9 July, we exposed native grass seedlings that were just beginning their rapid phase of growth to competition from a thick, tall stand of Kentucky bluegrass, which had been growing 6 weeks since the last grazing event. In 1997 we shifted the midsummer grazing date up to 23 June. There was very little new bluegrass growth after this date, while native grasses grew rapidly (Fig. 5).

Discussion

Remnant Native Vegetation

Learning the identity and location of native vegetation is an important step in the restoration of degraded habitat, because it can reduce the costs of species introduction and can lead to insights about the character of the former vegetation. In the uplands, bur oak seedlings established in response to one summer's partial protection from grazing. Since then they have withstood several grazings and one fire in 1997–1998. Significantly, this pasture and others in the area have no juvenile oaks, while mature trees continue to die from disease and windthrow, so some oak recruitment is desirable. There were apparently no other remnant native plants in the uplands and in the transition zone between uplands and waterways (Fig. 2). But the response of plants in the waterways to protection from grazing was dramatic. It remains to be seen whether highly palatable species that were introduced into the waterways, such as fowl manna grass and cup plant, will persist under rotational grazing practices.

Samson and Moser (1982) and Waller and Schmidt (1983) used atrazine, a somewhat selective herbicide, to suppress bluegrass sod and locate atrazine-tolerant grass species, primarily big bluestem and switchgrass. The atrazine method would not have succeeded in this study because we wanted to identify all native remnants, including atrazine-sensitive forbs.

The Potential Use of Cattle to Prepare Soil for Pasture Interseeding

Drilling was a more successful method of seeding than broadcasting followed by cattle trampling. Broadcast-trampled plots tended to have fewer numbers of native grass seedlings and less biomass/m^2 than drilled plots; despite large plot-to-plot variation, these trends were occasionally significant (Tables 1 & 2; Fig. 5). Differences between BT and other treatments in 1997 may be artificially small, however, because one BT plot with the lowest native grass establishment (0.1 plants/m^2, Table 1) was excluded from the experiment and reseeded in that year.

Most permanent pastures are not converted to row crops specifically because the ground is too wet or rough for tractor-driven equipment. Thus, a method of native plant seeding was desired which relied on humans and livestock.

Broadcast-trampled seeds may have poorer seed-to-soil contact and more shallow initial rooting depth than drilled seeds. The frost-seeding trial provided evidence that these seeds can be physically damaged by livestock trampling. Five times more seedlings established in the area where cattle trampled before, compared to after, broadcast seeding in March 1997.

Livestock-assisted seeding can create delays and management complications because the cattle must be moved, fenced, watered, and fed during the trampling period. But these inconveniences must be balanced against those of borrowing or renting a special native plant drill. Generally, the more inaccessible the pasture is to tractor-drawn equipment, the greater the incentive will be to use cattle for seed incorporation. The results of the frost-seeding trial were tantalizing. They suggest that in late winter, after the sod has been damaged by severe cattle trampling, broadcast seeds can germinate and establish adequately without herbicide or tractor-drawn equipment.

Seedling Establishment, Burning and Grazing

Grazing was not allowed on experimental plots during the growing season of 1995, because it was anticipated that the combination of defoliation and physical disturbance would harm new grass seedlings. This conservative approach, which forfeited growing-season forage, may in fact have restricted native grass establishment due to competition with the heavy pasture growth. Some restoration practitioners now recommend frequent mowing during the establishment year (C. Kurtz, personal communication). The question of seedling mortality caused by grazing requires a study in which the fates of seedlings are followed in areas with different grazing regimes.

Grazing at the end of June 1997 appeared to remove the competing vegetation and promote the new planting. By the end of June the nonnative pasture grasses and forbs stopped growing, while native grasses grew rapidly (Fig. 5). The mid-July grazing employed in 1996 was probably too late to have this beneficial effect.

Fire management is considered a necessary component of successful prairie restoration and management (Schramm 1992; Packard & Mutel 1997). Burning has a tangible cost, however, because fire and cattle essentially compete for the same biomass. In 1997, for instance, the farmer decided to forego late-summer and fall grazing in favor of a planned burn in the spring of 1998. This was possible only because more pasture ground became available nearby. In addition to the monetary cost, there is a temporal cost. The window of opportunity for spring burning often coincides with the time farmers are planting row crops.

The conflict between burning and grazing serves to highlight the fact that fire and native grazers acted in tandem to shape plant-species composition and recruitment dynamics on the tallgrass prairie. Selective herbivory, as well as wallows, fecal pats, and areas of local aggregation by native grazers (e.g., around shade trees), all created patches of disturbance in which seeds of different species might find a safe site to germinate. Areas of close grazing also would have limited fires the following year. Current literature on the effects of grazing on tallgrass prairie is limited to prairies of the eastern Great Plains (Pfeiffer & Hartnett 1995; Hartnett et al. 1996, 1997), where tallgrass prairie rangelands still exist. These prairies differ greatly in climate and soils from those of the eastern tallgrass prairie. Until the interactions of grazers and fire can be clarified for the Upper Midwest, there will be a large gap in our understanding of the fundamental processes that shaped the tallgrass prairie ecosystem (Williams 1997; Harrington 1998; Henderson 1998).

Adding Forbs to Rotational Grazing Pastures

Due to the economic constraints under which farmers must operate, the present study focused on restoring three warm-season grass species and one nitrogen-fixing legume. Ultimately, a greater number of native species could be introduced which occupy the niche of the European cool-season grasses and forbs, but this will depend upon seed availability, price, forage value, effective seeding methods, and persistence in the pasture.

Illinois bundleflower persisted in only one plot despite initially large numbers of seedlings in all plots (Table 2). Berg (1992) found that bundleflower was selectively grazed by cattle and that it declined over 4 years in a native planting in northwestern Oklahoma. Better candidates for a native pasture legume in this region may be *Desmodium canadense* (showy tick trefoil), which has thrived in pilot study plantings on the Natvig farm, or *Lespedeza capitata* (round-headed bush clover), which is often found in Iowa prairies that have a grazing history. Several other native plant species with known high forage value are untested in rotational grazing systems. These include cup plant and its congeners (*Silphium* spp., Stanford 1990) and the manna grasses (*Glyceria* spp., Pammel et al. 1901).

One scenario for economical establishment of native forbs would be to create a small, temporary (1–2 year) "rest" paddock. Forb seeds collected from prairie remnants or other parts of the pasture could be broadcast in this small area as a fall or late-winter frost seeding after ground preparation by cattle trampling and then managed separately, perhaps with fire, until the desired forbs were firmly established. Then the paddock could be returned to general management practices. The rest paddock could be moved as necessary over different parts of the pasture, spreading the risk of seeding failure over several years and exposing different patches of the pasture to different management histories. Paine et al. (1995) found that the presence of a small rest paddock in the center of a rotational grazing pasture could improve the nesting success of grassland-nesting neotropical migratory birds such as *Dolichonyx oryzivorus* (bobolink), which is declining in the Midwest (Herkert 1991).

Potential for Ecological Restoration on Farms

Contrary to expectations, remnant prairie species were few in this permanent pasture. They could be successfully introduced, however, as long as the farmer was willing to incur some temporary disruption of normal grazing activities. I will continue to monitor the newly established species to determine whether or not they can persist and spread within the grazed pasture.

This study focused on open areas in savanna soils and mesic-to-wet prairie soils along waterways (Buckner & Highland 1974; Fig. 2). Little is known about the potential herbaceous vegetation of savannas on these soils because no intact examples appear to exist in Iowa (DeLong & Hooper 1996). Packard (1997) has suggested that the best time to restore remnant oak savannas is right after livestock have been removed and while European pasture plants still dominate. To keep livestock in the system, it will be important to learn what subset of these species, if any, could tolerate a rotational grazing regime.

Ecological restoration on farms is important in the upper Midwest, because the current system of reserves and remnants is so fragmented. Conservation theory predicts that species within these native habitat islands will lose genetic diversity due to small population sizes, and that the islands will lose species diversity due to the difficulty of recolonizing far-flung remnants once a species has been extirpated from them (Primack 1993). It is the task of conservation biologists to look for restoration opportunities within the agricultural matrix to alleviate these problems.

Rotationally grazed pastures may be such an opportunity. The practice is gaining in popularity and already occupies significant amounts of land, especially when compared to the size of prairie remnants. It may be economically and ecologically compatible with some form of ecological restoration. Furthermore, just as the practice of prescribed burning in restored and reconstructed prairies has helped to advance our understanding of the fundamental role of fire in pre-settlement landscapes, so rotational grazing used as a prairie restoration tool may help us learn more about grazing by large native herbivores on the tallgrass prairie.

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Appendix 1. Regression coefficients to predict the number of native grass (NG) and Illinois bundleflower (IBF) seedlings as a function of nearby cover.[1]

	July 1995		*October 1995*	
	IBF	*NG*	*IBF*	*NG*
Variable				
Bare ground	0.054	−0.060	−0.072*	−0.065
Perennial pasture grasses	0.058	−0.071	−0.063***	−0.066**
Perennial pasture forbs	0.138	−0.023	−0.057***	−0.082**
Annuals	n/a	n/a	−0.059***	−0.087**
Model R^2	0.200*	0.203*	0.345***	0.200*

[1]A significant negative regression coefficient indicates that this variable was negatively correlated with the number of NG or IBF seedlings. Model R^2 indicates the proportion of the variation accounted for by the model. Significance is denoted by $^*p < 0.05$; $^{**}p < 0.005$; $^{***}p < 0.001$.