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Monday, October 4, 2004
PLENARY SESSION

Conservation Genetics of Prairie Grasses

Danny J. Gustafuson, The Citadel

My research interests range from plant conservation genetics to population biology to plant/soil feedback. The conservation genetics research has focused on the distribution of genetic variation of select plant species within a fragmented landscape and ecotypic variation. More recently I have been focusing on feedback between grass species and their biotic soil community as possible mechanism for structuring both the plant and soil microbe communities. Not only does it now appear that the soil biotic community significantly influences plant performance, but plant ecotypic variation (non-local) has the potential to affect this plant/soil feedback.

Monday, October 4, 2004
SESSION I, SECTION A

First-Year Efficacy of Herbicide Treatments for Controlling Fescue and Bermudagrass on a Prairie Site in Mississippi

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Abstract

Herbicidal methodology for eradication of Kentucky tall fescue grass (*Festuca arundinacea*) and establishment of native warm-season grasses (NWSG) is relatively well developed. However, these technologies typically focused on use of glyphosate, imazapic, imazapyr, or combinations thereof. Some relatively new herbicide formulations that might have application for NWSG establishment have become available. The efficacy of these new products and formulations in fescue eradication and NWSG establishment has not been thoroughly evaluated throughout the range of extant conditions. We tested efficacy of several herbicide treatments for eradicating fescue and controlling bermudagrass (*Cynodon dactylon*) on a prairie site in northeast Mississippi. Prior to any treatments, fescue canopy cover was approximately 97%. Prior to herbicidal applications, the field was prescribe-burned in late April 2004 to improve herbicide efficacy and to facilitate use of a native warm-season grass drill. Vegetation was allowed to recover for three weeks following the burn. During this time, a substantial latent bermudagrass component was released in response to reduction in fescue competition associated with the prescribed fire. Herbicide test plots were established in a randomized complete block design. Hillslope positions (n = 6) were treated as a blocking factor with seven 10- x 20-m plots/position. We randomly assigned each treatment to plots within each hillslope position. Blocks (hillslope position) and plots (herbicide treatment plots) were separated by a 5-m buffer strip. During mid-May 2004, we applied varying combinations of the following herbicide treatments: (1) sulfosulfuron; (2) imazapic; (3) imazapyr; and (4) glyphosate. Vegetation structure was evaluated post-treatment in July 2004. We measured total canopy, bermudagrass canopy, fescue grass canopy, forb canopy, legume canopy, annual weed canopy, native warm-season grass canopy cover, bare ground, litter cover, and litter depth. We used mixed model analysis of variance (ANOVA) in a randomized complete block design to evaluate vegetation response to treatments. We blocked on hillslope positions (random effect) and considered treatments as fixed effects. By coincidence, we apparently eliminated most fescue grass with the timing of our prescribed burn. Imazapyr acid applied at 0.500 pounds/acre and imazapic acid applied at 0.188 pounds/acre + glyphosate salt at 2.000 pounds/acre herbicide treatments resulted in the most long-term, overall control of forage grasses and other vegetation. In the context of our study site and herbicide treatments, we suggest the imazapyr and imazapic + glyphosate treatments are most effective in controlling bermudagrass and other competing vegetation prior to NWSG establishment. Given successful restoration of this research site to native grass/forb communities, this site should serve as a valuable public demonstration area for resource managers and private landowners.

Introduction

The conversion of many pastures and other agricultural lands (e.g., row crop fields enrolled in Conservation Reserve Program) to nonnative grasses has generally been detrimental to many early successional habitat-dependent wildlife species. In the Black Belt Prairie region of Mississippi, fescue is a common exotic cool-season grass established for both forage and erosion control. Roseberry and Klimstra (1984) suggested that establishment of coarse-stemmed, sod-forming grasses like fescue on cropland diversion program lands would produce low-quality habitat for grassland bird species such as northern bobwhite (*Colinus virginianus*). Barnes et al. (1995) reported that fescue fields in Kentucky, characterized by dense vegetation, little bare ground, and low plant species diversity, lacked the proper vegetation structure, floristic composition, and food quality to provide bobwhite habitat.

Periodic soil disturbance is required to maintain grasslands in early succession plant communities. Periodic soil disturbance might result in short-term improvements in bobwhite habitat in fescue-dominated fields (Greenfield et al. 2002), but herbicidal conversion of fescue-dominated grasslands might improve long-term bobwhite habitat quality by promoting more desirable, native early successional plants (Madison et al. 1995, Ryan et al. 1995, Greenfield et al. 2001, 2002). The United States Department of Agriculture Farm Services Agency and Natural Resource Conservation Service (NRCS) are increasingly receptive to management practices intended to create and maintain early successional native communities on fields enrolled in the Conservation Reserve Program (CRP). Although accepted practices vary among states, many state NRCS offices throughout the Midwest and Southeast now permit light strip discing, prescribed burning, and herbicide application as wildlife habitat management techniques on CRP fields. The primary purpose of these habitat management practices is to reduce grasses and increase abundance and diversity of forbs, legumes, annual weeds, and invertebrates, thereby enhancing habitat quality for early successional species such as bobwhite. Aside from CRP lands, conversion of fescue-dominated grasslands to native grass/forb communities allows agricultural producers and other landowners to accomplish multiple land-use objectives such as agricultural production and wildlife habitat. There are also potentially large economic values from recreational activities associated with grassland wildlife. Economic impacts associated with bobwhite hunting (e.g., Burger et al. 1999) could produce substantial revenues for landowners and localized economies.

Herbicidal methodology for eradication of fescue and establishment of native warm-season grasses (NWSG) is well developed and has been demonstrated and described in numerous peer-reviewed publications (Barnes et al. 1995, Greenfield et al. 2001, Barnes and Washburn 2002). However, these technologies typically focused on use of glyphosate, imazapic, imazapyr, or combinations thereof. Recently, Plateau® (active ingredient imazapic) herbicide has been removed from the market due to off-label use for peanut production, and relatively new herbicides [Journey® (active ingredient imazapic + glyphosate) and Outrider® (active ingredient sulfosulfuron)] that might have applications for NWSG establishment have become available. The efficacy of these new products in fescue eradication and NWSG establishment needs to be validated.

The focus of this study was on the efficacy of several herbicide treatments for eradicating fescue on a prairie site in northeast Mississippi. We investigated vegetation composition pre-treatment and vegetation composition and response following various herbicide treatments. We also planned to plant test plots with species of warm-season grasses/forbs native to the area. However, planting was delayed during the initial treatment season due to wet field conditions during the planting season that prohibited use of planting equipment. Planting of our test plots was scheduled for the growing season following initial treatments. Given successful restoration of this site to native grass/forb communities, this research site may serve as valuable a public demonstration area for resource managers and private landowners. Such demonstration areas could promote multiple land management strategies incorporating wildlife, soil, and water conservation and agricultural production.

Study Area

Our study was conducted at the Mississippi Agricultural and Forestry Experiment Station located in Prairie, Mississippi (Monroe County). The station is located within the Black Belt Prairie, part of the Blackland Prairie physiographic region of northeast Mississippi (Figure 1). Historically, the Blackland Prairie was a tall grass prairie ecosystem maintained by periodic fires. However, less than 1% of this ecosystem remains; much of the ecosystem presently is in agricultural or livestock production or has succeeded to forest cover due to fire exclusion. Elevation ranges from 62 to 92 m, and soils are chalks, calcareous clays, acid clays, and sediments overlying calcareous materials; hence, soil alkalinity and magnesium levels are low. The field used in this study was formerly a pasture and hay field with substantial fescue canopy cover.

Methods

Treatment Plot Establishment

Our experiments evaluated effects of various herbicide treatments on vegetation structure in a field dominated by fescue canopy cover. Herbicide treatment plots were established within the field in a randomized complete block design. Hillslope position ($n = 6$) was treated as a blocking factor with seven 10- x 20-m plots/position. Slope was approximately 10%, and the greatest elevation was at the east boundary of study plots, while the least elevation was at the west boundary of study plots. We randomly assigned each herbicide treatment to plots within each hillslope position. Blocks (hillslope position) and plots (herbicide treatment plots) were separated by a 5-m mowed strip.

Treatment Application

Prior to any herbicide treatment applications, the field was prescribe-burned to improve herbicide efficacy and to facilitate use of a native warm-season grass drill. The prescribed burn was applied April 19, 2004, and burning conditions followed Mississippi Forestry Commission recommendations (USDA 1989). For maximum herbicide efficacy, vegetation was allowed to recover following the burn for three weeks.

All herbicides were applied along with water at 24 gallons spray solution/acre, 2 feet above foliage. Spraying was conducted with a 3-pt. hitch-mounted, 55 gal., 6-tip boom sprayer with T-jet spray tips at 20" spacing. Herbicides were applied at a velocity of 204 feet/35 seconds. The sprayer (28 PSI) was powered by a PTO-driven pump, running at 540 rpm (2400-rpm engine). Treatments were applied on May 18, 2004, after approximately 4 to 6 inches of vegetation regrowth, winds south to southwest at 0 to 5 mph. Herbicide treatments (rates of actual products applied are documented parenthetically) consisted of:

(1) sulfosulfuron = 0.094 pounds/acre sulfosulfuron (2 ounces/acre Outrider herbicide);

(2) sulfosulfuron 1.5x (1.5 times product label rate) = 0.141 pounds/acre sulfosulfuron (3 ounces/acre Outrider herbicide);

(3) sulfosulfuron 1.5x (1.5 times product label rate) + glyphosate = 0.141 pounds/acre sulfosulfuron + 2.000 pounds/acre glyphosate isopropylamine salt (3 ounces/acre Outrider herbicide + 2 quarts/acre Roundup® Pro herbicide);

(4) imazapic + glyphosateA = 0.188 pounds/acre imazapic acid + 0.500 pounds/acre glyphosate isopropylamine salt (32 ounces/acre Journey herbicide; equivalent to 12 ounces/acre Plateau® herbicide and 1 pint/acre Roundup Pro herbicide);

(5) imazapic + glyphosateB = 0.188 pounds/acre imazapic acid + 2.000 pounds/acre glyphosate isopropylamine salt (32 ounces/acre Journey herbicide + 3 pints/acre Roundup Pro herbicide);

(6) imazapyr = 0.500 pounds/acre imazapyr acid (16 ounces/acre Arsenal® AC herbicide); and

(7) glyphosate = 2.000 pounds/acre glyphosate isopropylamine salt (2 quarts/acre Roundup Pro herbicide).

Evaluation of Vegetation Structure

Vegetation structure was evaluated pre-treatment (April) and post-treatment (in July to evaluate mid-season response). We used a 0.1 m^2 Daubenmire frame to ocularly estimate vegetation structural characteristics (Daubenmire 1959). Canopy cover of various plant life forms was estimated in 5.0% cover classes within the frame. Characteristics measured included total canopy, bermudagrass canopy, fescue grass canopy, forb canopy, legume canopy, annual weed canopy (included annual grasses and forbs), native warm-season grass canopy, bare ground, litter cover, and litter depth. We conducted vegetation sampling in 10 Daubenmire frame plots distributed systematically along the diagonal of each plot. Each frame was oriented relative to hillslope position.

Statistical Analysis

We used mixed model analysis of variance (ANOVA) in a randomized complete block design to evaluate vegetation response to treatments. For each vegetation structural characteristic, we tested the null hypothesis of no difference among herbicide treatments. We blocked on hillslope positions (random effect) and considered herbicide treatments as fixed effects (Petersen 1985, Milliken and Johnson 1992). We used 95% confidence intervals to make inferences about differences in herbicide treatment means.

Results

Prior to prescribed burning and herbicidal application, fescue grass canopy cover was approximately 97%. We apparently killed most fescue, coincidentally, with our spring burn. Post-fire, there was very little fescue present even in untreated buffers between herbicide treatment plots. Mean fescue canopy cover only ranged from about 1 to 13%, with much variation, in our herbicide treatment plots. Thus, we concluded that the timing of our burn eliminated most fescue during the summer of 2004. Given the near elimination of fescue canopy cover prior to herbicide applications, we could not make meaningful inferences about herbicide efficacy for controlling fescue in this study. Regardless of how the fescue was controlled, a significant bermudagrass release occurred after the fescue canopy was removed.

Total canopy cover (Figure 2) was least in the imazapyr and both imazapic + glyphosate treatment plots. Total canopy cover in the glyphosate and sulfosulfuron 1.5x + glyphosate treatment plots was approximately equal and was greater than the imazapyr and imazapic + glyphosate treatment plots. Both sulfosulfuron treatment plots had the greatest total canopy cover.

Annual weed canopy (Figure 3) and forb canopy (Figure 4) cover exhibited similar patterns among herbicide treatments. Both cover classes were similar in the imazapyr, both imazapic + glyphosate, and both sulfosulfuron treatment plots. Both annual weed canopy and forb canopy in the glyphosate and sulfosulfuron 1.5x + glyphosate treatment plots were approximately equal and slightly greater than the other treatments.

Bermudagrass canopy cover (Figure 5) was least in the imazapyr, both imazapic + glyphosate, glyphosate, and sulfosulfuron 1.5x + glyphosate treatment plots. The imazapyr treatment and any treatment with the greater rate of glyphosate provided better control of bermudagrass than imazapic + glyphosateA. Bermudagrass canopy cover in both sulfosulfuron treated plots, regardless of application rate, was much greater than any of the other herbicide treatments evaluated.

Litter cover (Figure 6) was least, and bare ground cover (Figure 7) was greatest in the imazapyr and imazapic + glyphosateB treated plots. Litter and bare ground cover in the remaining treatment plots varied, but in general these plots had greater litter cover and less bare ground cover compared to the imazapyr and imazapic + glyphosateB treated plots. Mean litter depth was similar among all herbicide treatment plots, ranging from 1.05 to 1.50 cm.

There was very little existing NWSG canopy cover present during our vegetation sampling. Mean NWSG, primarily broomsedge (*Andropogon virginicus*), canopy cover ranged from 0 to 3% among our herbicide treatment plots.

Discussion

Imazapyr and any of the herbicide treatments with 2.000 pounds/acre glyphosate yielded the best control of bermudagrass. Imazapyr and imazapic herbicide treatments provided residual soil activity for many annual weeds (annual grasses and forbs). Thus, these plots generally had less total canopy cover and forb and annual weed cover. Glyphosate and sulfosulfuron 1.5x + glyphosate initially controlled bermudagrass and released many annual grasses and forbs. Thus, these plots generally had less bermudagrass cover but greater total canopy cover and forb and annual weed cover. The two sulfosulfuron herbicide treatments released bermudagrass which dominated those treatment plots. We had anticipated a greater johnsongrass (*Sorghum halepense*) component after the fescue was eliminated. Based on previous research in other prairie systems in this region, johnsongrass often became well established after fescue control. We wanted to evaluate sulfosulfuron for fescue and johnsongrass control. Our prescribed burn apparently eliminated most of the existing fescue prior to our herbicide experiments, and johnsongrass was not abundant in the initial year of treatment. Sulfosulfuron is labeled for bermudagrass release, and we did not anticipate the substantial bermudagrass component that was present after removal of the initial fescue-dominate canopy.

The latent bermudagrass cover that quickly dominated the site after fescue canopy elimination was likely a common scenario that land managers may face when trying to control exotic grasses in the Southeast. Thus, it will be important to adequately address both the extant and latent exotic grass problems in order to successfully establish NWSG. For aggressive exotic grasses that are difficult to control, such as bermudagrass, proper monitoring and maintenance (e.g., spot treatments with herbicide) of newly established NWSG stands are essential to ensure exotic vegetation is controlled both prior and after establishment.

In the context of our study site and herbicide treatments, we suggest that the imazapyr and imazapic + glyphosateB treatments are most effective in controlling bermudagrass and other competing vegetation prior to NWSG establishment. However, following applications of imazapyr, sufficient time must be allowed before planting NWSG, as residual soil effects of imazapyr will adversely affect germinating NWSG. Alternatively, application of 2.000 pounds/acre glyphosate prior to NWSG establishment, followed by selective treatment of patches of undesirable vegetation, may be successful for NWSG establishment. Regardless of which herbicide treatments are used, selective treatment of patches of undesirable vegetation may be necessary. We will plant NWSG during the spring of 2005, following additional herbicide treatment test applications to control bermudagrass and other competing vegetation.

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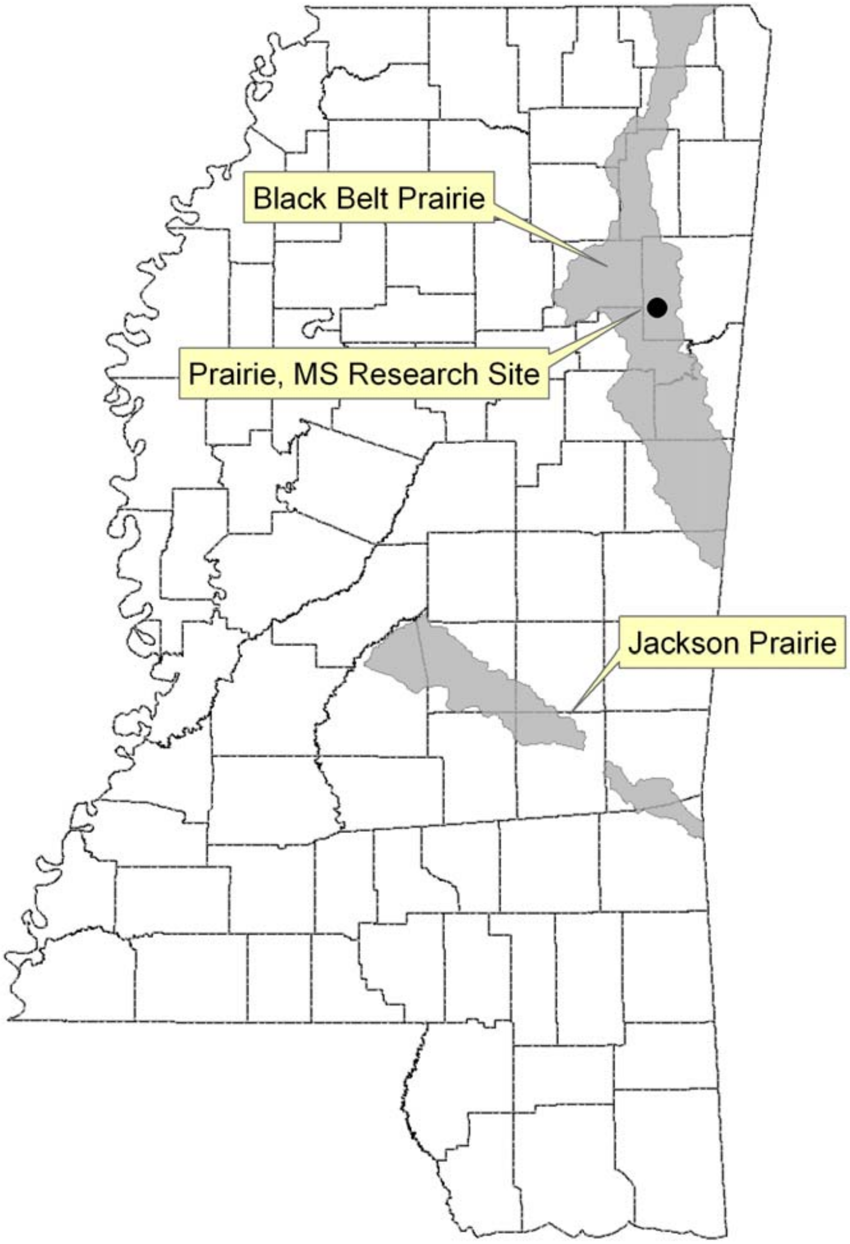

Figure 1. Location of herbicide research plots at Prairie, Mississippi, USA, relative to the two Blackland Prairie physiographic regions in Mississippi.

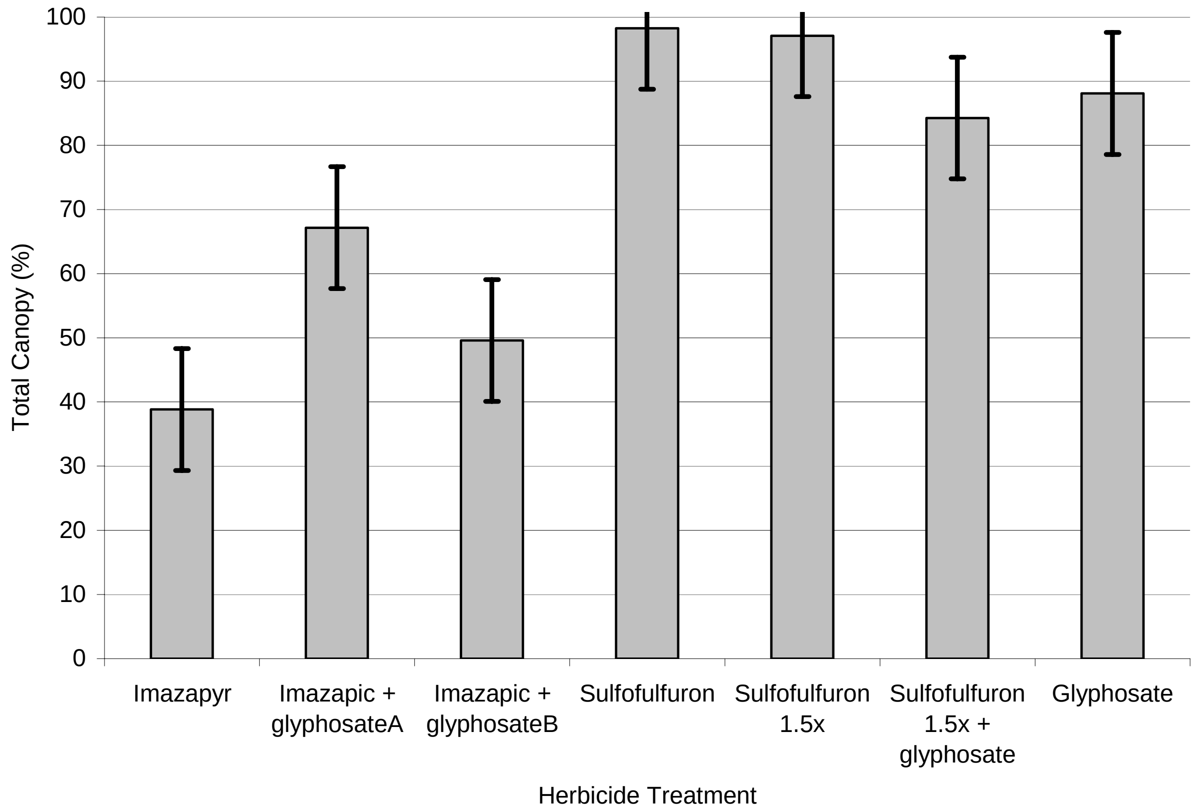

Figure 2. Mean (±95% CI) total canopy cover measured during July 2004 at Prairie, Mississippi, USA. Herbicide treatments (6 replicates) were applied during May 2004. Application rates were: (1) sulfosulfuron = 0.094 pounds/acre sulfosulfuron; (2) sulfosulfuron 1.5x (1.5 times product label rate) = 0.141 pounds/acre sulfosulfuron; (3) sulfosulfuron 1.5x (1.5 times product label rate) + glyphosate = 0.141 pounds/acre sulfosulfuron + 2.000 pounds/acre glyphosate isopropylamine salt; (4) imazapic + glyphosateA = 0.188 pounds/acre imazapic acid + 0.500 pounds/acre glyphosate isopropylamine salt; (5) imazapic + glyphosateB = 0.188 pounds/acre imazapic acid + 2.000 pounds/acre glyphosate isopropylamine salt; (6) imazapyr = 0.500 pounds/acre imazapyr acid; and (7) glyphosate = 2.000 pounds/acre glyphosate isopropylamine salt.

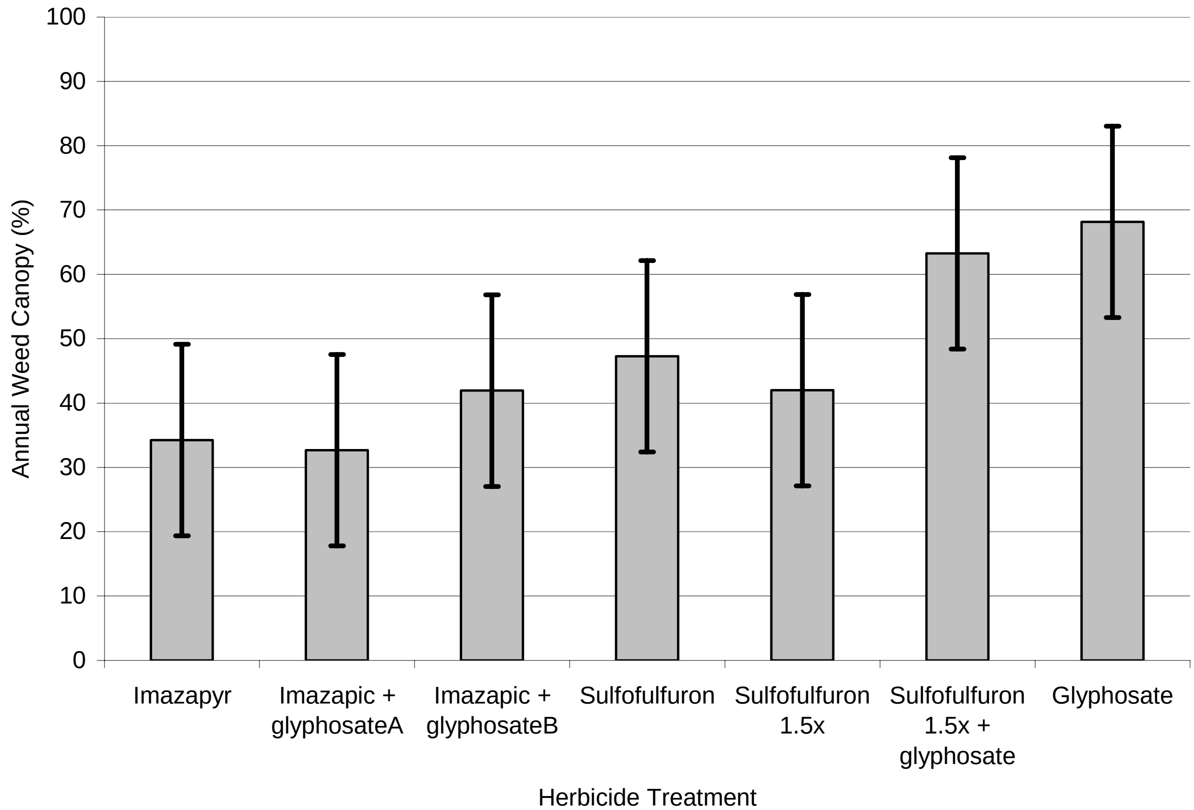

Figure 3. Mean (±95% CI) annual weed canopy cover measured during July 2004 at Prairie, Mississippi, USA. Herbicide treatments (6 replicates) were applied during May 2004. Application rates were: (1) sulfosulfuron = 0.094 pounds/acre sulfosulfuron; (2) sulfosulfuron 1.5x (1.5 times product label rate) = 0.141 pounds/acre sulfosulfuron; (3) sulfosulfuron 1.5x (1.5 times product label rate) + glyphosate = 0.141 pounds/acre sulfosulfuron + 2.000 pounds/acre glyphosate isopropylamine salt; (4) imazapic + glyphosateA = 0.188 pounds/acre imazapic acid + 0.500 pounds/acre glyphosate isopropylamine salt; (5) imazapic + glyphosateB = 0.188 pounds/acre imazapic acid + 2.000 pounds/acre glyphosate isopropylamine salt; (6) imazapyr = 0.500 pounds/acre imazapyr acid; and (7) glyphosate = 2.000 pounds/acre glyphosate isopropylamine salt.

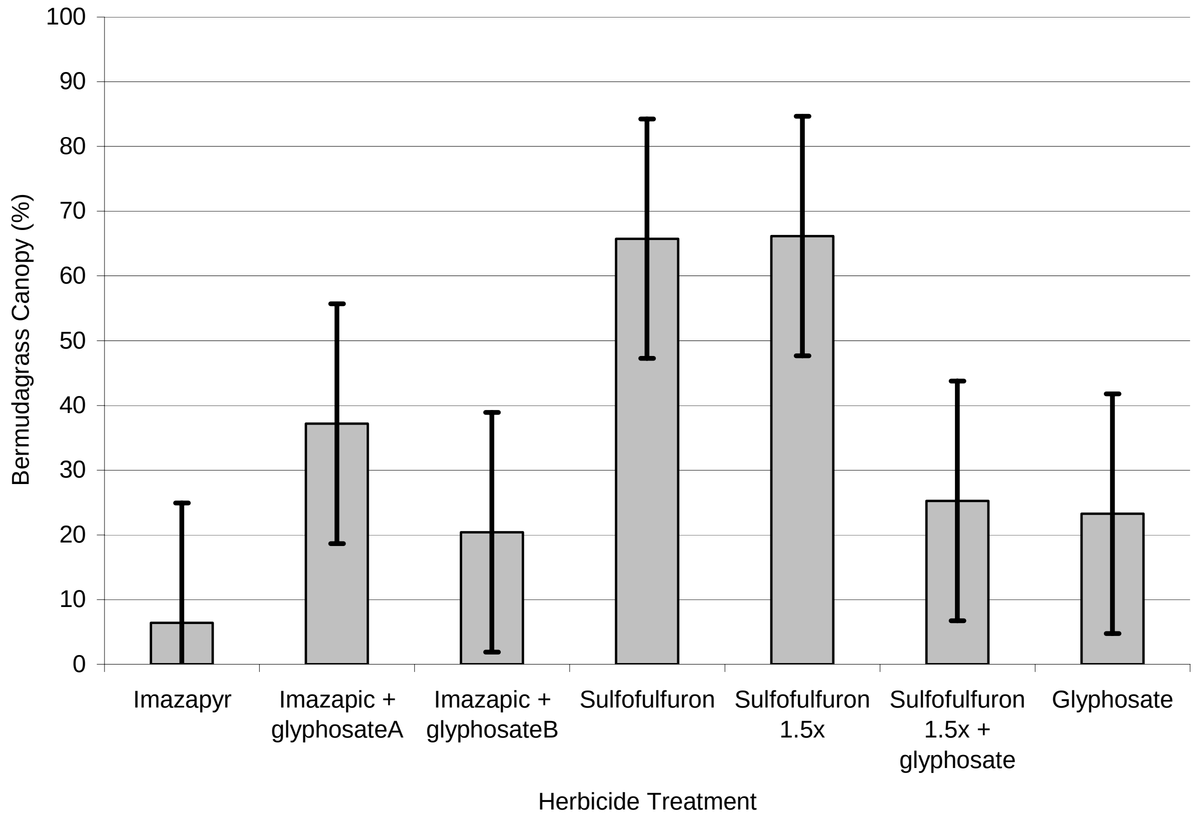

Figure 5. Mean (±95% CI) bermudagrass canopy cover measured during July 2004 at Prairie, Mississippi, USA. Herbicide treatments (6 replicates) were applied during May 2004. Application rates were: (1) sulfosulfuron = 0.094 pounds/acre sulfosulfuron; (2) sulfosulfuron 1.5x (1.5 times product label rate) = 0.141 pounds/acre sulfosulfuron; (3) sulfosulfuron 1.5x (1.5 times product label rate) + glyphosate = 0.141 pounds/acre sulfosulfuron + 2.000 pounds/acre glyphosate isopropylamine salt; (4) imazapic + glyphosateA = 0.188 pounds/acre imazapic acid + 0.500 pounds/acre glyphosate isopropylamine salt; (5) imazapic + glyphosateB = 0.188 pounds/acre imazapic acid + 2.000 pounds/acre glyphosate isopropylamine salt; (6) imazapyr = 0.500 pounds/acre imazapyr acid; and (7) glyphosate = 2.000 pounds/acre glyphosate isopropylamine salt.

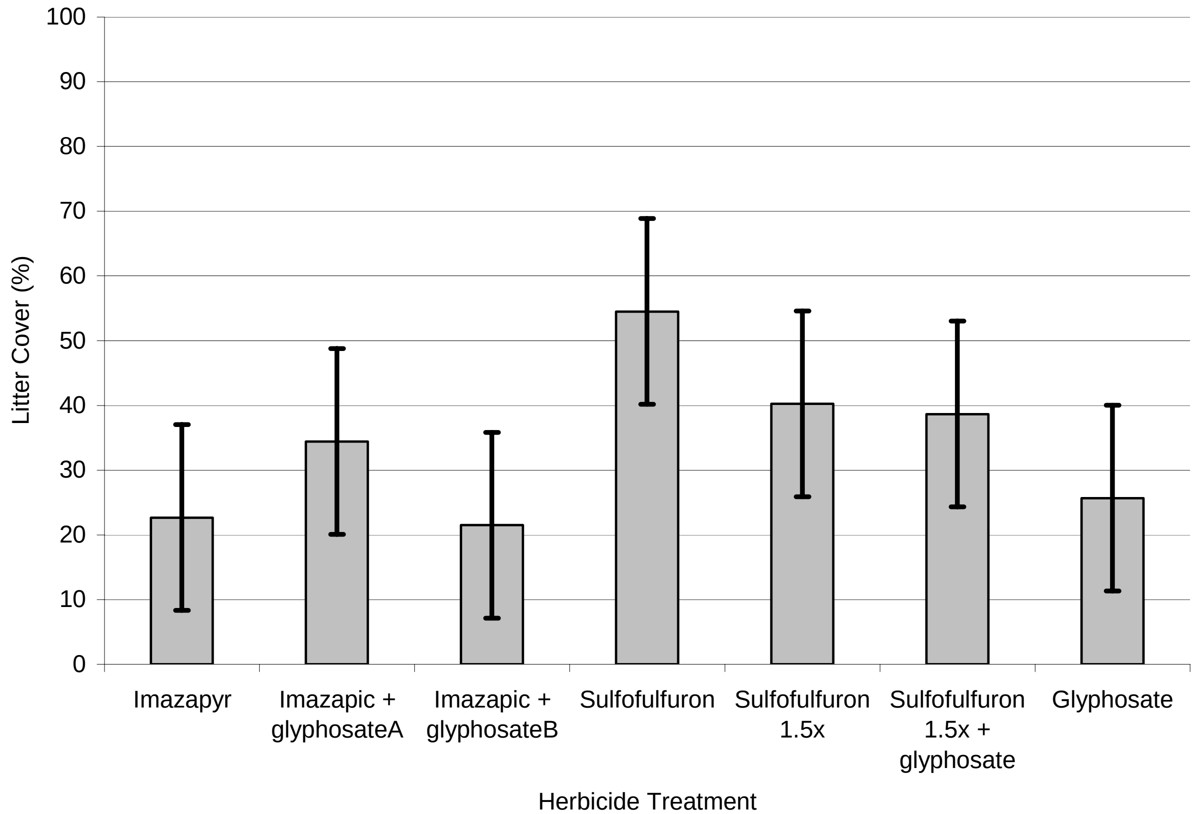

Figure 6. Mean (±95% CI) litter cover measured during July 2004 at Prairie, Mississippi, USA. Herbicide treatments (6 replicates) were applied during May 2004. Application rates were: (1) sulfosulfuron = 0.094 pounds/acre sulfosulfuron; (2) sulfosulfuron 1.5x (1.5 times product label rate) = 0.141 pounds/acre sulfosulfuron; (3) sulfosulfuron 1.5x (1.5 times product label rate) + glyphosate = 0.141 pounds/acre sulfosulfuron + 2.000 pounds/acre glyphosate isopropylamine salt; (4) imazapic + glyphosateA = 0.188 pounds/acre imazapic acid + 0.500 pounds/acre glyphosate isopropylamine salt; (5) imazapic + glyphosateB = 0.188 pounds/acre imazapic acid + 2.000 pounds/acre glyphosate isopropylamine salt; (6) imazapyr = 0.500 pounds/acre imazapyr acid; and (7) glyphosate = 2.000 pounds/acre glyphosate isopropylamine salt.

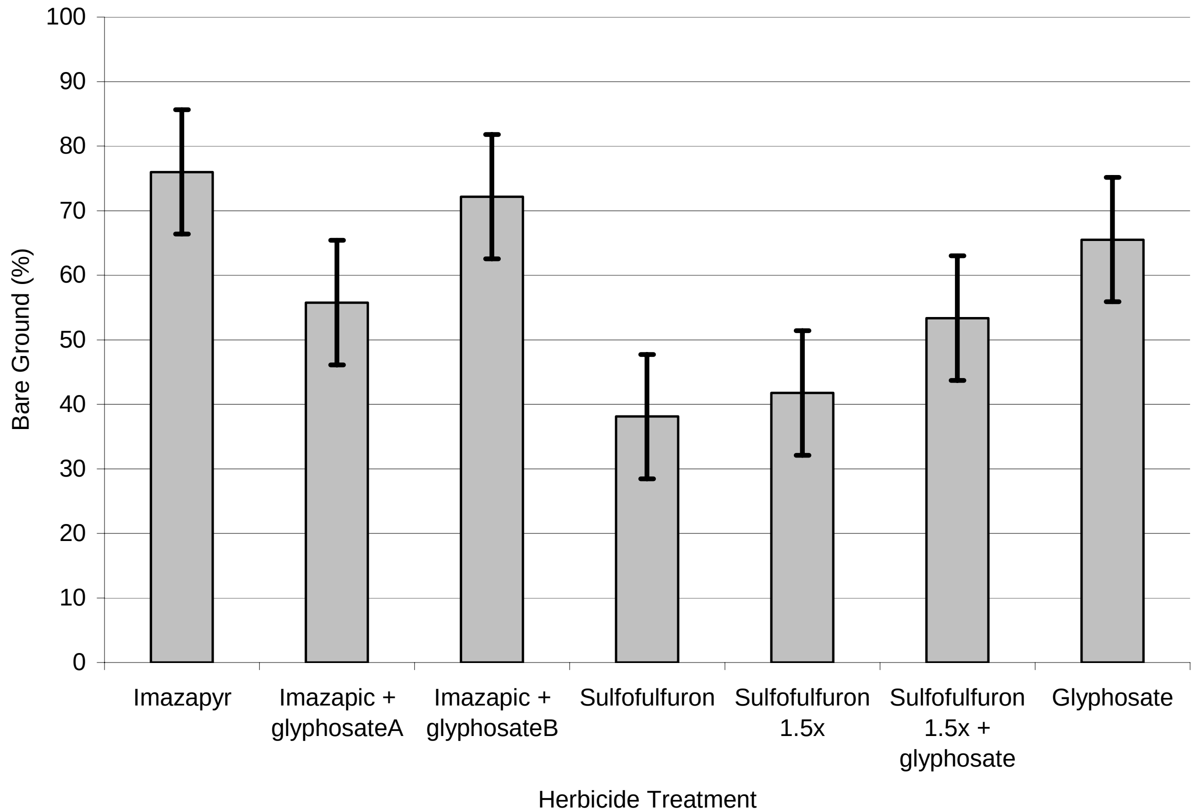

Figure 7. Mean (±95% CI) bare ground cover measured during July 2004 at Prairie, Mississippi, USA. Herbicide treatments (6 replicates) were applied during May 2004. Application rates were: (1) sulfosulfuron = 0.094 pounds/acre sulfosulfuron; (2) sulfosulfuron 1.5x (1.5 times product label rate) = 0.141 pounds/acre sulfosulfuron; (3) sulfosulfuron 1.5x (1.5 times product label rate) + glyphosate = 0.141 pounds/acre sulfosulfuron + 2.000 pounds/acre glyphosate isopropylamine salt; (4) imazapic + glyphosateA = 0.188 pounds/acre imazapic acid + 0.500 pounds/acre glyphosate isopropylamine salt; (5) imazapic + glyphosateB = 0.188 pounds/acre imazapic acid + 2.000 pounds/acre glyphosate isopropylamine salt; (6) imazapyr = 0.500 pounds/acre imazapyr acid; and (7) glyphosate = 2.000 pounds/acre glyphosate isopropylamine salt.

Bermudagrass Conversion to Native Warm-Season Grasses

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I implemented two studies in northern Alabama to determine effective herbicide combinations that would kill common bermudagrass (*Cynodon dactylon*) and replace that community with native warm-season grasses (NWSG). The first study was implemented in spring 1999. The site was burned in April prior to initial herbicide application in May. I implemented the following treatments for the first study: 2.2 kg ai/ha glyphosate, 2.2 kg ai/ha glyphosate plus 0.2 kg ai/ha imazapic at seeding, 2.2 kg glyphosate plus 0.05 kg ai/ha imazapic, 2.2 kg ai/ha glyphosate, 0.28 kg ai/ha imazapyr plus 0.2 kg ai/ha imazapic at seeding, 0.2 kg ai/ha clethodim plus 0.2 kg ai/ha imazapic, and 0.2 kg clethodim plus 0.05 kg ai/ha imazapic at seeding. The NWSG were no-till drilled into the existing sod at a rate of 6.9 kg PLS/ha in early May. The best treatment for killing common bermudagrass consisted of burning in late spring, allowing the grass to regrow to a height of 5 to 8 cm, followed by an application of imazapyr at 0.28 kg ai/ha and glyphosate at 2.2 kg ai/ha with a second application of 0.2 kg ai/ha imazapic a month later. This treatment reduced the vegetative cover of bermudagrass to less than 1%, but it was not the best treatment for establishing NWSG. NWSG cover was less than 2% at the end of the first growing season but was more than 40% by the end of the second growing season. The best treatment for establishing the NWSG was burning followed by an application of 2.2 kg ai/ha glyphosate in April with 0.2 kg ai/ha imazapic at seeding a month later. Bermudagrass cover was reduced to 25% by the end of the first growing season, but the NWSG responded favorably. NWSG cover was 69% at the end of the second growing season. The following treatments were evaluated in the second study: 5.5 kg ai/ha glyphosate, 3.6 kg ai/ha clethodim plus 5.5 kg ai/ha glyphosate, and imazapyr plus 5.5 kg ai/ha glyphosate. All the plots received an application of 0.1 kg ai/ha imazapic at seeding for residual weed control. The imazapyr and clethodim plots reduced the percent cover of bermudagrass to 31.3 and 30.6% respectively compared to the glyphosate (91.9%) and control (98.3%) plots. The number of seedlings also differed by treatment type and ranged from 4.1 seedlings/square meter in the control to 13.3 seedlings/square meter in the clethodim plots. The percent cover by the NWSG was higher in the imazapyr/glyphosate (33% cover) and clethodim/glyphosate (37% cover) plots when compared to the glyphosate (6% cover) and control (1% cover) plots. The results of these studies show common bermudagrass can be converted to NWSG, but it is paramount to kill as much bermudagrass as possible prior to seeding NWSG. Imazapic is also a necessary component to provide residual weed control.

Rate of Increase Among Native Warm-Season Grasses Using Conventional and No-Till Technology with Application of Imazapic Herbicide

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Native warm-season grasses (NWSG) are used to enhance habitat for numerous wildlife species. Over time, habitat quality declines as grass density increases. Of particular concern has been the rate of increase by switchgrass; however, there are no data that compare rate of increase by switchgrass with other species. Plots of NWSG were established in middle Tennessee in 1999 to examine establishment methods, including combinations of conventional tillage, no-till, and application of imazapic herbicide. Density (seedlings/m^2) of big bluestem *(Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*) was measured each April 2001-2004. Rate of increase did not differ among species and treatments. Mean density among species differed within treatments in 2004. Our data support the contention that management practices are necessary to maintain quality habitat when any of these four NWSG are used. Practices including fire during the late growing season, mowing followed by discing, and/or strip herbicide applications should help maintain desirable structure and composition in NWSG stands.

Introduction

Native warm-season grasses (NWSG), such as big and little bluestem, indiangrass, and switchgrass, are commonly recommended to provide quality early successional habitat for a variety of wildlife species (Kenyon 2000). One advantage of these warm-season bunchgrasses over nonnative perennial cool-season grasses, such as tall fescue and orchardgrass, is open space at ground level as opposed to a dense structure at ground level with thatch buildup (Barnes et al. 1995). An open structure at ground level facilitates movement within the field by bobwhites, rabbits, songbirds, and other wildlife (Rosene 1969, Burger 1990). An open structure also enables the seedbank to germinate and allows desired forbs [e.g., ragweed (*Ambrosia artemisiifolia*), beggar's-lice (Desmodium spp.), partridge pea (Chamaecrista spp.), and blackberry (Rubus spp.)] to grow among the grass bunches. These forbs provide quality cover and a critical food source for wildlife.

Fields of NWSG managed for wildlife are allowed to flower and produce seed. Usually, the grasses are left standing through the winter to provide cover. Over time, however, NWSG may increase in density as individual bunches grow larger and as seed produced within the field germinates. Wildlife managers often complain about switchgrass becoming problematic. In fact, many managers are no longer planting switchgrass because they believe it increases in density too quickly. As density of NWSG increases, less space is available for travel, and forb coverage within the field is reduced.

We monitored the rate of increase among four NWSG (big and little bluestem, indiangrass, and switchgrass) in a replicated split-plot design over five years at the Middle Tennessee Experiment Station near Columbia, Tennessee. The initial project investigated establishment success between plots top-sown with conventional tillage and no-till plantings, as well as the effectiveness of imazapic herbicide.

Methods

In June 1999, 64 plots (6 feet by 25 feet each) were planted to big bluestem, little bluestem, indiangrass, and switchgrass at the University of Tennessee Agricultural Experiment Station in Spring Hill, Tennessee. Half the plots were planted using conventional tillage with top-sowing; the other half were planted using a Truax® no-till drill. Half of each block received a pre-emergence imazapic treatment (8 ounces per acre) resulting in four treatment combinations: no-till without imazapic (NoTill/NoPlat), no-till with imazapic (NoTill/Plat), conventional top-sow without imazapic (Till/NoPlat), and conventional top-sow with imazapic (Till/Plat). Four replicates of each grass were sown per treatment at a rate of 8 pounds PLS. All plots were burned annually in March 2001-2004. NWSG "bunches" were counted annually within three randomly located meter-square quadrants in April 2001-2004. More specific details concerning establishment, experimental design, and sampling were outlined in Harper et al. (2002).

Rate of increase of each species was calculated over the four-year period from 2001 to 2004. Grass density (five years post-establishment) was estimated from 2004 data. We tested for across-treatment and within-treatment differences in rate of increase and density using the General Linear Models procedures in SAS (SAS Institute Inc., Cary, N.C.).

Results

Across Treatments

There was no overall difference in rate of increase among grasses ($P = 0.63$). Mean rates were 282%, 195%, 131%, and 126% for switchgrass, big bluestem, little bluestem, and indiangrass, respectively (Table 1).

Within Treatments

With the exception of NoTill/NoPlat plots, rate of increase among grasses did not differ within treatments (Table 2). In NoTill/NoPlat, switchgrass (mean = 104%), indiangrass (mean = 50%), and big bluestem (mean = 33%) had the greatest rates of increase.

Differences in five-year post-establishment density were detected among grasses within all treatments (Table 2). In NoTill/NoPlat, there were more bunches of indiangrass (mean = 18.0), switchgrass (mean = 15.8), and big bluestem (mean = 14.5) than little bluestem (mean = 7.3). In NoTill/Plat, indiangrass (mean = 17.5) had the greatest density, while little bluestem (mean = 7.5) and switchgrass (mean = 7.3) had the lowest density. In Till/NoPlat, the density of indiangrass (mean = 11.8) was higher than that of little bluestem (mean = 6.0). In Till/Plat, the number of indiangrass bunches (mean = 18.3) was higher than that of switchgrass (mean = 4.0).

Discussion

Switchgrass did not show a greater rate of increase than big bluestem, little bluestem, or indiangrass. Further, in the treatment where switchgrass had an apparently high rate of increase (NoTill/Plat), its mean density at five years post-establishment was 7.3 bunches/m^2 compared to 17.5 and 12.0 bunches/m^2 for indiangrass and big bluestem, respectively (Table 2). The apparently high rate of increase by switchgrass in plots established with imazapic is the result of herbicide effects early in establishment. The BASF Plateau® herbicide label states: for switchgrass, stand loss or thinning could occur with application rates of only 2 to 4 ounces per acre. These effects were realized on our plots early in the study. Over time, switchgrass increased in density, although not to the same five-year post-establishment levels as indiangrass and big bluestem. In stands not established with imazapic, five-year post-establishment density of switchgrass was similar to the other three species.

Switchgrass did not increase at a greater rate or create more dense stands than big bluestem, little bluestem, and indiangrass. Therefore, it should not be excluded from NWSG mixes based on rate of increase and density. A better reason for wildlife managers—especially those interested in quail—to exclude switchgrass is leaf structure. Because bobwhites and other species use fine senescent leaves to construct nests at the base of NWSG, species such as little bluestem, broomsedge (*Andropogon virginicus*), sideoats grama (*Bouteloua curtipendula*), and big bluestem are more appropriate.

When considering switchgrass in plantings, managers should be aware 1 pound of switchgrass contains more seed than 1 pound of other species. For example, 8 pounds of big bluestem results in approximately 30 seeds/sq^2 when planted, while 8 pounds of switchgrass results in approximately 70 seeds/sq^2 (Ball et al. 2002). When creating mixes for wildlife habitat, a multi-species mixture that has worked well in providing quality early successional habitat for a variety of wildlife in Tennessee and other areas of the mid-South includes 1.5 pounds big bluestem, 1.5 pounds little bluestem, 1 pound indiangrass, and 0.5 pound of switchgrass. One pound of native legumes, such as partridge pea or native lespedezas (e.g., *Lespedeza virginica* or *L. capitata*), should be added where local seedbanks do not contain a desirable forb component (Harper et al. 2004).

From our data, it is obvious NWSG stands need management after two to three years' growth to maintain desirable conditions for wildlife, regardless of the NWSG species planted. Harper et al. (2002) suggested mature NWSG stands with >10 bunches/m^2 create conditions that preclude forb growth and impede movement of young bobwhite chicks and wild turkey poults. Where wildlife habitat is an objective, NWSG stands should be managed to maintain open structure at ground level. An average stand density of one mature bunch of NWSG per m^2 is sufficient to provide structure for nesting and brood rearing while allowing space for travel and forb growth. Where stands are too dense, grasses can be thinned using growing-season prescribed fire, or mowing followed by discing, or application of a grass-selective herbicide (e.g., Clethodim) with only every third nozzle open on a spray boom (Gruchy unpublished data).

Conclusions

Rate of increase by switchgrass, big bluestem, little bluestem, and indiangrass did not differ among species. However, density did differ. Whether management objectives are wildlife or forage production, density is an important parameter to monitor. Where wildlife habitat is an objective, some form of mid-term management may be necessary as early as three to four years after establishment. Although switchgrass has the reputation of forming more "rank" stands compared to other NWSG, our data did not support this contention.

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Table 1. Overall mean rate of increase of four native warm-season grasses measured on experimental plots in middle Tennessee 2001-2004.

Species	Rate of Increase (%)[a]
Big bluestem	195 A
Indiangrass	126 A
Little bluestem	131 A
Switchgrass	282 A

[a] Means with the same letter are not different (α = 0.05).

Table 2. Within treatment mean rate of increase and mean density (bunches/m^2) of four native warm-season grasses measured on experimental plots in middle Tennessee 2001-2004.

		Year								
		2001		2002		2003		2004		2001-2004
Treatment	Species[a]	Mean[b]	SE	Mean	SE	Mean	SE	Mean	SE	Rate of Increase (%)[c]
No-Till	BB	12.0 AB	2.1	21.3 A	1.8	19.0 A	1.4	14.5 A	1.3	33 AB
	IG	14.0 A	2.5	13.3 B	1.7	15.5 AB	1.2	18.0 A	2.5	50 A
	LB	7.3 B	0.8	12.0 B	0.9	13.5 B	1.8	7.3 B	2.1	-1 B
	SG	8.0 B	0.9	9.5 B	0.9	13.3 B	1.0	15.8 A	1.4	104 A
No-Till + Imazapic	BB	13.8 A	1.5	14.8 A	0.6	15.5 A	1.3	12.0 B	0.9	-7 A
	IG	17.0 A	1.0	11.8 B	1.3	13.8 A	1.7	17.5 A	2.1	4 A
	LB	9.0 B	1.6	11.5 B	0.9	11.5 A	1.0	7.5 BC	1.3	0 A
	SG	3.8 C	1.1	3.5 C	0.6	5.5 B	1.2	7.3 C	1.6	456 A
Conventional	BB	4.8 A	1.2	11.0 A	2.5	10.0 A	2.3	9.0 AB	1.4	134 A
	IG	3.8 AB	0.3	6.8 A	0.6	11.0 A	0.7	11.8 A	1.2	188 A
	LB	2.3 B	0.5	5.3 A	2.3	6.5 A	2.9	6.0 B	2.1	302 A
	SG	3.3 AB	0.3	6.8 A	1.6	10.3 A	2.0	11.0 AB	2.0	286 A
Conventional + Imazapic	BB	2.8 AB	0.9	6.3 AB	1.7	9.3 AB	2.3	8.8 AB	1.8	620 A
	IG	5.3 A	0.6	12.3 B	0.5	16.3 AB	1.0	18.3 A	2.7	260 A
	LB	3.7 A	0.7	17.0 A	5.6	20.7 A	7.5	13.0 AB	3.2	310 A
	SG	0.0 B	NA	2.0 B	NA	4.0 B	NA	4.0 B	NA	400 A

[a] BB = big bluestem, IG = indiangrass, LB = little bluestem, SG = switchgrass.
[b] Means with the same letter are not different (α = 0.05).
[c] Means with the same letter are not different (α = 0.05).

C3—C4 Conversion of Cool-Season Pastures into Warm-Season Grass Prairies on Grazing Lands

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It seems that the popularity of native warm-season grasses continues to increase every year. Increasingly more attention is also being focused on the negative aspects of fescue and cool-season grasses. Some of these negative aspects include endophytic-induced miscarriages in wildlife, limited cover and food values, and susceptibility to cool-season plant community loss resulting from climate changes. Additionally, more people are becoming interested in converting long-term fescue pastures into warm-season grass plant communities that would:

- provide greater wildlife cover, shelter, and feed.
- increase the total carbon sequestration rates of grassed areas.
- provide greater ecological function during and following climate changes.

Some skeptics predicted that the allopathic effects of long-term fescue cover would inhibit or deter the successful establishment of common warm-season grasses. This comprehensive presentation will clearly depict some interestingly successful results realized at the USDA NRCS Cape May Plant Materials Center.

Using Native Little Barley as a Cover Crop

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Abstract

Little barley (*Hordeum pusillum* Nutt.) is a native, annual, cool-season grass that can form dense colonies in some cropland fields in the southeastern United States that are no-tilled or given minimum tillage in the fall. In such areas, little barley functions as a naturally occurring cover crop that does not require reseeding like conventional cover crops such as wheat (*Triticum aestivum* L.). Several NRCS and university agronomists have expressed an interest in developing methods to either manage natural stands of little barley or produce commercial sources of little barley that can be planted as cover crops. We initiated two studies in 2002 at the Jamie L. Whitten Plant Materials Center (PMC), Coffeeville, Mississippi, to evaluate the cover crop potential and management requirements of little barley. In the first study, we compared its ground cover and biomass production to wheat, crimson clover (*Trifolium incarnatum* L.), and hairy vetch (*Vicia villosa* Roth) planted at their recommended cover crop rates (101, 22, and 34 kg ha^{-1}, respectively). Little barley provided close to 95% cover during the winter and early spring, the most of all species tested; however, a considerable amount of seed (807 seeds m^{-2}) was planted to ensure a sufficient stand for testing. Additional research is needed to determine optimum planting rates for little barley. Hairy vetch provided little cover during the winter, but cover increased to more than 95% before the target burndown date of April 15. The other two species provided intermediate ground cover ratings during the winter. In 2003, biomass yields were highest for little barley and crimson clover, but in 2004, dry matter yields of wheat were highest. The second study examined the burndown requirements of little barley. Conventional recommendations are to use either 1.12 kg a.i. ha^{-1} of either glyphosate or paraquat to burn down grass cover crops before planting. We wanted to determine if these rates could be reduced to 0.84, 0.56, and 0.28 kg ai ha^{-1} and still provide control of little barley. Glyphosate rates when reduced to 0.5 kg a.i. ha^{-1} provided adequate burndown of little barley, with a visual rating of more than 80% dead plants at 14 days after treatment. The rate of paraquat could not be decreased below 0.84 kg a.i. ha^{-1} and still provide a comparable level of burndown.

Introduction

Cover crops are vegetation that is planted or managed to reduce soil erosion and improve soil quality. Cover crops can be incorporated into the soil as green manure, or they can be killed prior to planting the main crop. Historically, cover crops were a common component of crop rotations, planted in the period between cash crops, usually the winter, when the soil would normally be fallow, but they fell out of favor in many modern farming systems when the use of inorganic fertilizers and herbicides reduced their importance. However, concerns about the impact of soil erosion on water quality and other environmental factors have led to increased use of conservation tillage systems (i.e., no-till and reduced or low-till) for many agronomic crops. Cover crops can be a useful component in these systems because, in addition to providing plant residue to reduce soil erosion, they can either provide or store nutrients for the main crop, reduce weed competition, increase soil organic matter, and increase water infiltration by preventing soil crusting (Dabney 1998; Hartwig and Ammon 2002). Standing cover crop residue can also protect young crop seedlings from damage by wind (Davis 1994; Daniel et al. 1999) and late frosts (Daniel et al. 1999). However, many growers have not embraced cover crops. The main concern is the annual cost of establishment (Parvin et al. 2004), although another major concern in more arid regions is that cover crops consume soil moisture, making it unavailable for the following crop (Dabney et al. 2001). Growers have also cited management difficulties in harvesting the previous crop and establishing the cover crop, increased insect and disease problems, establishment problems for the subsequent crop (Davis 1994; Dabney et al. 2001), and, in conservation tillage systems, the annual cost of controlling or burning down the cover crops prior to planting the cash crop (Dabney and Griffin 1987).

Plant species used as winter cover crops fall into two major categories: legumes and non-legumes. Legumes, such as clovers and vetches, fix atmospheric nitrogen, a portion of which then becomes available for the subsequent cash crop. Non-legumes do not have this capability, but they can also have a major impact on nutrient availability because they can take up and store excess nutrients left in the soil from the previous crop and then release them to the main crop as they decompose (Dabney 1998; Dabney et al. 2001; Hartwig and Ammon 2002). The most common non-legume cover crops are small grains [e.g., wheat and rye (*Secale cereale* L.)] and annual ryegrass [*olium perenne* ssp. *multiflorum* (Lam.) Husnot)]; these grasses provide better winter ground cover than legumes, seed is cheaper and easier to establish (Davis 1994; Bloodworth 1996), and they are easier to burn down with herbicides prior to crop planting (Davis 1994; Dabney and Griffin 1987). Mixtures of non-legumes and legumes can combine the benefits of both (Daniel et al. 1999; Dabney et al. 2001). Rather than planting a cover crop, growers can also utilize cool-season weeds growing in their fields as cover crops (Hurst 1992, Hartwig and Ammon 2002).

Little barley is a cool-season annual grass that occurs throughout most of the contiguous 48 states (Baum and Bailey 1986). Its culms range from 10 to 60 cm in height. Flowers are produced from April to June in the Southeast. Little barley flowers are arranged in a spike, and each seed unit contains three spikelets, one fertile one in the center and a sterile one on either side. All spikelets have long, stiff awns (Radford et al. 1968). It is considered a troublesome weed in pastures and cropland in the southeastern United States; however, the fact that it germinates readily and occurs in dense populations on some agronomic fields (Fischer et al. 1982; Elmore et al. 1995) indicates that it might make an acceptable cover crop. Also, because little barley flowers early in the spring and seeds have been shown to be capable of germination as soon as 11 d after flowering (Fischer et al. 1982), it also has great potential for reseeding itself in properly managed cropping systems. The PMC (1988) included a single accession of little barley in a study examining a variety of cool-season species for cover crop use and found it had only average vigor; however, herbicide carry-over from previous cotton (*Gossypium hirsutum* L.) crops may have affected vigor of the little barley plants. Growers in Georgia have been utilizing native stands of little barley as a cover crop for more than a decade. They believe that it produces ample residue and the residue decomposes more slowly than that remaining from a rye or wheat crop, providing longer-term soil protection (Jimmy Dean, personal communication).

Little barley also has been shown to possess allelopathic properties (Smith and Martin 1994) which might allow it to suppress weed growth, potentially reducing the need for herbicides in the subsequent crop (Hartwig and Ammon 2002).

To the best of my knowledge, none of the producers who are currently using little barley as a cover crop have conducted head-to-head comparisons with other cool-season species to compare their productivity. Therefore, in order to fully evaluate the cover crop potential of little barley, the PMC initiated a study to compare its ground cover and biomass production to those of wheat, another annual grass, and two legumes, crimson clover and hairy vetch. In our region of the country, we were particularly interested in looking at little barley as a potential cover crop for cotton, a low residue-producing crop (Daniel et al. 1999). We were also interested in possibly using little barley in seed mixes as a nurse crop to provide cover for other native grasses and forbs that do not establish as quickly. Another topic that we wished to address was burndown of this crop. Little barley, being a grass, should burn down more easily than leguminous cover crops (Davis 1994; Dabney and Griffin 1987), and since it is smaller than other grasses like wheat and has less lignified stems, it likely would be even easier to control with chemicals. Therefore, we also initiated a study to examine the efficacy of reduced rates of burndown herbicides on control of little barley.

Materials and Methods

The cover crop potential study was planted at the PMC on 17 October 2002 and 25 September 2003. Evaluations were made in the subsequent calendar year, and plantings will be referenced by their evaluation years throughout this publication. Little barley seeds (seed units) were combine-harvested in May 2002 from fields at the PMC and cleaned using an air-screen cleaner (A.T. Ferrell and Co., Bluffton, IN). The long awns on the little barley seeds made them clump together, limiting seed cleaning efficiency. The seed lot contained inert matter and seeds of other species, especially crimson clover, that could not be removed during the cleaning process. Seeds of the other species were purchased from a local farm supply store. A germination test was conducted on the little barley seed lot to estimate its viability prior to planting, and purity of the lot was determined.

Recommended planting rates for broadcast seeding were used for the standard cover crops. These were wheat, 101 kg ha^{-1}; crimson clover, 22 kg ha^{-1}; and hairy vetch, 34 kg ha^{-1} (Bloodworth 1996). Little barley did not germinate well in the germination test (> 4%), so a high planting rate of 807 seeds m^{-2} (75 seeds per square foot) was used. Each species was planted in a 1.5-m by 3-m plot, and there were three replications of each treatment. Soil type was a Grenada silt loam in the first year and an Oaklimeter silt loam in the second year. The seeds were broadcast by hand over the plot and lightly raked into the soil. The legumes were inoculated with the appropriate *Rhizobium* strain at planting. Nitrogen was applied to the wheat and little barley plots at a rate of 28 kg ha^{-1} after planting. All plots received 67 kg of P and K. The second-year little barley plots were sprayed with 1.1 kg ai ha^{-1} 2, 4-D in November 2003 and March 2004 to control broadleaf weeds.

Ground cover (stand) ratings were made on 9 January, 7 March, and 2 April 2003 and 16 January, 12 March, and 15 April 2004. To take these ratings, a line was positioned diagonally across the plots from one corner to another. Sampling points were located every 15 cm along the line. Each point where a plant was present was counted, and stand percentages were calculated based on the number of points with plants divided by the total number of points, multiplied by 100. Biomass yields were determined by harvesting a 0.28 m^2 sample from the middle of each plot on 18 April 2003 and 15 April 2004. The plants were cut at ground level, air-dried, and weighed to determine their dry matter (DM) production. The little barley plots contained varying amounts of crimson clover as a contaminant, and these plants were removed from the sample when they were harvested to avoid biasing the results.

The study examining reduced burndown rates was planted on October 18, 2002, and September 25, 2003. The target burndown date was April 15, which is a date commonly recommended for cotton planting in Mississippi (Jim Parkman, personal communication). Herbicides used were glyphosate and paraquat, and their recommended application rate for burndown of grass cover crops is 1.12 kg ai ha^{-1} (Al Rankins Jr., personal communication). The full rate (1X) was used as the standard, and the reduced rates were three-quarters (3/4X), half (1/2X), and one-quarter (1/4X) this rate or 1.12 kg ai ha^{-1}, 0.84 kg ai ha^{-1}, 0.56 kg ai ha^{-1}, and 0.28 kg ai ha^{-1} of both herbicides. An untreated control was also included. Plots were planted in the same fields using the same methods as the cover crop comparison study, including plot size, seeding rates, fertilizer, and 2, 4-D applications.

The burndown treatments were applied on 11 April 2003 and 15 April 2004 using a CO_2 backpack plot sprayer calibrated to apply approximately 187 L ha^{-1}. A nonionic surfactant at 0.25% (v/v) was added to the spray solution of the paraquat treatments in 2003 but was inadvertently omitted in 2004. Visual injury ratings were made 7 d and 14 d after treatment (DAT) using a scale of 1 = 100% dead, 3 = 75% dead, 5 = 50% dead, 7 = 25% dead, 9 = slight injury, and 10 = no injury. Also at 14 DAT, a line transect similar to that used for the cover crop comparison study was taken, but in this case it was run the length of the plots, approximately 0.6 m from the edge of the plot, to ensure that plants sampled were in the spray swath. All dead plants at the transect points were counted, and the percentage of dead plants was determined. A small seed sample was collected from the 1X rate plots of both herbicides for germination testing. Seed collected in 2003 was tested on 19 November; the 2004 seed has not been tested as of this publication date. Three replications of 100 seeds were counted from the sample. Only seeds that separated easily from the spike were used because those that adhered tightly to the rachis were most likely immature. The seeds were placed between two blotters in a Petri dish and placed in a germinator (Hoffmann Manufacturing Inc., Albany, OR) maintained at 20°C with 8 hr. of light. Germination counts were made every 7 d for 5 weeks.

Data from both studies were subjected to an analysis of variance using MSTAT-C (Michigan State Univ., 1988), with each year analyzed separately. Significant means were separated using the least significant difference test (LSD) at $P < 0.05$ (Michigan State Univ., 1988). The results presented here are still preliminary because both studies will be repeated for another year to provide additional verification.

Results and Discussion

Temperatures during the first study period were close to seasonal averages (Table 1). Rainfall during this period was well below average in January but exceeded the average in both the prior and subsequent months (Table 1), so there was probably little effect from this reduced rainfall, especially since it occurred in the winter when the plants were not actively growing. Average temperatures during the second year were close to the 30-year average; however, the average minimum temperatures for both January and February were -1°C (data not presented). Average low temperatures for February are generally slightly above freezing at this location. Monthly rainfall totals during the second planting period were fairly close to normal levels (Table 1).

Mean ground cover ratings in January, March, and April for the four cover crops differed in 2003 ($P = 0.0001$, 0.0000, and 0.0107, respectively). Little barley germinated well in both years of the study and because of the high planting rate, stands ranged from 89 to 100% for all evaluation periods (Tables 2 and 3). This level of germination in the field would not have been anticipated from the poor germination in the seed test. The awns on the spikelets prevented good contact with the substrata used in the test and probably allowed the seeds to dry out somewhat, reducing germination. Stands of wheat were poor in 2003 (Table 2) because seed of unknown age that had been stored in the PMC cooler was used, and viability was obviously less than optimal. In the subsequent year, seed was purchased just prior to planting. Stands in 2004 varied for only the January ($P = 0.0074$) and April ($P = 0.0001$) evaluation dates. Wheat stands for the first two rating periods in 2004 were higher than those recorded in the previous year (Table 3). The lower April 2004 rating (Table 3) was simply due to fewer clumps of wheat being contacted at the individual sampling points on the line transect, not to plant mortality. The 2004 data indicate that even with good quality seed, stands of wheat planted at the recommended planting rate did not exceed 76% (Table 3). If little barley is to be planted as a cover crop, research on planting rates needs to be conducted to develop a broadcast seeding recommendation that will provide equivalent erosion protection to that provided by similar cover crops.

Crimson clover stands for the January rating date in 2003 were comparable to those of the reduced stand of wheat in that year but increased markedly at the two later evaluation dates and were not different from those of little barley at the final evaluation date (Table 2). However, in 2004, stands of crimson clover were higher and were comparable to those of little barley at all three evaluation dates (Table 3). Hairy vetch provided less ground cover than the other three species in January of 2003 and less cover than little barley and crimson clover in 2004. Keeley et al. (1992) rated 8-week percent ground coverage of hairy vetch significantly lower than that of annual ryegrass and common barley (*Hordeum vulgare* L.). However, hairy vetch ground cover increased greatly by the April evaluation dates to levels that were comparable with crimson clover in 2003 and with little barley in 2004.

Mean biomass production of the cover crops species varied in 2003 ($P = 0.0068$) and 2004 ($P = 0.0027$). Little barley and crimson clover produced more biomass than the other cover crop species in 2003 (Table 2), but in 2004 wheat was the top biomass-producing crop (Table 3). Poor wheat biomass production in 2003 was the result of the poor stands discussed previously. If stands of the two grass species contained the same number of plants, wheat would always out-produce little barley because it is a larger plant. Although stands of hairy vetch rated high in April ground cover percentage, biomass production was less than little barley and crimson clover in 2003. This also is not unexpected because, as a vine, its long stems cover a large amount of ground, but they are fairly slender and the leaves are also small, resulting in less potential biomass. Stands of crimson clover were high in 2004; however, biomass production was reduced compared to the previous year (Table 3). The plants at the January 2004 evaluation date were visibly damaged by below-freezing temperatures that occurred in January and February (Table 1). They appeared to recover when ratings were made in March, but biomass production must have been reduced. Crimson clover has been shown to be less cold-hardy than hairy vetch (Dabney et al. 2001).

Cover crops that are not burned down effectively or ones burned down too early, allowing a new crop of weeds before planting, can cause management problems in the following crop (Davis 1994). In this study, a visual rating of 1 (100% control) or 2 (slightly over 87% control) would be necessary to prevent further competition from the cover crop.

There were differences between visual injury ratings at 7 DAT and 14 DAT ($P = 0.0000$ for both), and percentage of dead plants at 14 DAT ($P = 0.0007$) for the burndown treatments in 2003. In this year, ratings for glyphosate at 7 DAT were no different from those of the control; however, at 14 DAT, control for the 1X rate was over 87% and 100% for the 3/4X and 1/2X rate (Table 4). Glyphosate needs to be translocated within the plant and is therefore slower-acting than paraquat, which is a contact herbicide (Ashton and Crafts 1981). Dabney and Griffin (1987) rated control of a wheat cover crop at 99% for both the 1/2X and 3/4X rate and 89% for the 1X rate of glyphosate. Percentage of dead plants was similar for 1X, 3/4X, and 1/2X herbicide rates (Table 4). The 1/4X rate of glyphosate provided little control (Table 4). Although not specifically sampled, glyphosate at all rates provided poor control of the crimson clover plants also growing in the plots. As stated previously, legumes are more difficult to control with burndown herbicides (Davis 1994; Dabney and Griffin 1987), which could be a consideration if little barley were interseeded with a legume. It could also mean that higher rates of glyphosate are required if other broadleaf weeds are present (Dabney and Griffin 1987). There were also treatment differences in 7 DAT ($P = 0.0009$) and 14 DAT ($P = 0.0000$) injury ratings and percentage of dead plants ($P = 0.0000$) in 2004. Glyphosate ratings in 2004 (Table 5) followed a similar pattern as in the previous year (Table 4); however, 7 DAT ratings were slightly higher for all herbicide rates. By 14 DAT, ratings for the 1X, 3/4X, and 1/2X treatments were all in the acceptable range (Table 5). Percentages of dead plants for these three rates were also comparable (Table 5).

At 7 DAT, paraquat at 1X, 3/4X, and 1/2X were all rated as acceptable in 2003; however, at 14 DAT, the 1/2X rating increased to 3 (Table 4). There is little translocation of paraquat out of the treated leaves to the meristems when it is applied in daylight (Ashton and Crafts 1981), which can allow plants that are not killed to regrow. Dabney and Griffin (1987) found that wheat was controlled 100% and 99% at the 1X and 1/2X rate used in this study. Possibly control ratings for little barley were lower in this study than they found for wheat because the thick stand prevented thorough plant coverage with the herbicide solution. Spray volume and surfactant concentration can also affect levels of control when using paraquat as a desiccant (Bennett and Shaw 2000). The percentage of dead plants for the 1X and 3/4X rate in 2003 were not different (Table 4); however, fewer dead plants were found in the 1/2X rate. The higher percentage of dead plants at the 1/4X rate was probably due to a similar occurrence as discussed above for the wheat stand, where more live plants happened to be found at the sampling points. The poor visual ratings, where the entire plot was sampled, indicate that this rate is less than satisfactory. Paraquat also provided better control of the crimson clover plants in the plots. Dabney and Griffin (1987) found that weed control in a fallow field, dominated by cutleaf evening primrose (*Oenothera laciniata* Hill.), was better with paraquat than similar rates of glyphosate. In 2004, paraquat ratings were all lower than acceptable levels because surfactant was not added to the spray solution (Table 5).

Germination testing completed for the 2003 seed found that none of the glyphosate-treated seeds germinated, and only one of the paraquat-treated seeds (0.3%) germinated. Little barley has been shown to be capable of germination as quickly as 11 d after flowering (Fischer et al. 1982). Because glyphosate acts more slowly than paraquat, it would allow seeds more time to mature before the parent plant died. Therefore, one would expect germination rates to be higher for the glyphosate-treated seed. However, this was not the case. Both glyphosate and paraquat have been shown to affect seed development and subsequent germination and growth of seedlings when applied to plants in the flowering stage (Bennett and Shaw 2000). Perhaps the poor germination in this test was due to the effect of these chemicals on seed development, or perhaps another temperature regime, such as 20/30, should have been used (Fischer et al. 1982).

Where it is currently being used as a cover crop, little barley has been shown to reseed annually (Jimmy Dean, personal communication); however, whether burndown chemicals were used and what types were used is not known. Reseeding potential of little barley cannot be effectively studied in small plots such as those used here. Large plot demonstrations will be needed to determine its reseeding potential and the possible effects of burndown chemicals. Also, mechanical control methods (Dabney and Griffin 1987; Dabney 1995) that likely would not have a deleterious effect on seed germination should be examined.

Conclusions and Considerations

Little barley provided ample amounts of ground cover and biomass and appears to be an acceptable native replacement for the introduced small grains and annual ryegrass used as non-leguminous cover crops and as nurse crops for slower-establishing species. Currently, the only option that growers have is to manage the little barley stands that exist in their fields. In 2004, the PMC began initial evaluation of more than 50 accessions of little barley from the southeastern United States to potentially develop a germplasm source for commercial release. Further research is also required on planting rates and methods. Investigation of seed conditioning techniques, such as debearding or hammermilling, to remove or decrease the length of the awns should be undertaken to improve seed cleaning and sowing operations. Any potential deleterious effects of little barley on the following crop also need to be examined. Will the allelopathic compounds produced by little barley (Smith and Martin 1994) affect germination of agronomic crops? Also, will using little barley as a cover crop increase insect or disease problems in the main crop? Little barley has been shown to be an alternate host of Russian wheat aphid (*Diuraphis noxia* Mordvilko) (Kindler and Springer 1989), which is not likely to be a problem in the Southeast; however, it has also been found to be susceptible to *Septoria nodorum* (Berk.) (Cunfer and Youmans 1983), a disease that could infect barley and wheat produced in this region.

Although the two higher rates of paraquat provided comparable control to all but the lowest rate of glyphosate in the one year that these could be compared, paraquat is a restricted-use herbicide that carries a greater danger of toxicity to the applicator. Also, prices of paraquat formulations have increased in recent years, whereas prices of glyphosate, due to the advent of generic formulations, have decreased. Therefore, glyphosate would generally be the burndown herbicide of choice unless broadleaf weeds that are more effectively controlled with paraquat are present or if glyphosate is shown to interfere with reseeding potential of little barley.

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Table 1. Rainfall and temperature recorded during the study period.

Month	Average Temperature			Total Rainfall		
	2002/03	2003/04	30-yr. avg.	2002/03	2003/04	30-yr. avg.
	--------------------°C--------------------			---------------------mm---------------------		
Oct.	18	17	17	189	89	99
Nov.	9	13	11	109	120	138
Dec.	NA	7	6	178	112	98
Jan.	3	6	4	37	145	135
Feb.	6	5	7	198	171	156
Mar.	12	14	12	58	81	122
Apr.	17	16	16	72	163	94

Table 2. 2003 stand ratings and biomass production for four cover crop species at the Jamie L. Whitten Plant Materials Center, Coffeeville, Mississippi.

Cover Crop	Stand Rating			DM Yield
	Jan.	Mar.	Apr.	
	-------------------------%-------------------------			------kg ha^{-1}------
Little barley	95	100	100	5 594
Wheat	42	32	52	3 900
Crimson clover	45	72	83	5 425
Hairy vetch	17	30	77	3 052
LSD (0.05)	15	13	22	1 257

Table 3. 2004 stand ratings and biomass production for four cover crop species at the Jamie L. Whitten Plant Materials Center, Coffeeville, Mississippi.

Cover Crop	Stand Ratings			DM Yield
	Jan.	**Mar.**	**Apr.**	
	-------------------------%-------------------------			------kg ha^{-1}------
Little barley	89	94	96	5 594
Wheat	65	76	42	7 459
Crimson clover	80	83	88	3 730
Hairy vetch	47	65	97	5 765
LSD (0.05)	19	NS†	22	1 301

† Not significant at $P < 0.05$.

Table 4. 2003 visual injury ratings and percentage of dead plants for normal and reduced rates of burndown herbicides at the Jamie L. Whitten Plant Materials Center, Coffeeville, Mississippi.

Treatment	Visual Rating[†]		Dead Plant
	7 DAT	14 DAT	14 DAT
			---------%---------
Control	10	10	0
Glyphosate 1X	8	2	98
Glyphosate 3/4X	9	1	72
Glyphosate 1/2X	9	1	72
Glyphosate 1/4X	9	9	32
Paraquat 1X	2	1	86
Paraquat 3/4X	1	2	78
Paraquat 1/2X	2	3	52
Paraquat 1/4X	6	5	83
LSD (0.05)	1	1	36

[†] Visual control ratings 1 = dead; 3 = 75% dead; 5 = 50% dead; 7 = 25% dead; 9 = slight injury; and 10 = no injury.

Table 5. 2004 visual injury ratings and percentage of dead plants for normal and reduced rates of burndown herbicides at the Jamie L. Whitten Plant Materials Center, Coffeeville, Mississippi.

Treatment	Visual Rating[†]		Dead Plant
	7 DAT	14 DAT	14 DAT
			---------%---------
Control	10	10	0
Glyphosate 1X	3	1	100
Glyphosate 3/4X	5	1	98
Glyphosate 1/2X	7	2	92
Glyphosate 1/4X	7	4	47
Paraquat 1X	4	4	43
Paraquat 3/4X	5	5	28
Paraquat 1/2X	6	6	23
Paraquat 1/4X	8	7	20
LSD (0.05)	3	1	17

[†] Visual control ratings 1 = dead; 3 = 75% dead; 5 = 50% dead; 7 = 25% dead; 9 = slight injury; and 10 = no injury.

Monday, October 4, 2004
SESSION I, SECTION B

Managing 'Highlander' Eastern Gamagrass for Sustainable Forage in the Upper Southeastern United States

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'Highlander' eastern gamagrass [*Tripsacum dactyloides* (L.) L.] is a native warm-season perennial bunchgrass with potential for use as a forage crop in the southeastern United States. Sustainable production and stand longevity are influenced by cutting management and N fertilization. The USDA-Natural Resources Conservation Service, Jamie L. Whitten Plant Materials Center, and Mississippi State University conducted studies to determine management recommendations for long-term sustainable production of 'Highlander' eastern gamagrass in the upper southeastern United States. A 45-day clipping frequency produced higher yields with similar quality as a 30-day clipping frequency. Stands declined significantly under a 30-day clipping frequency, while stands of a 45-day clipping frequency persisted and produced a three-year average yield of 6 tons/acre. Nitrogen fertilization experiments on silt loam and clay soils in northern Mississippi found 120 and 240 lb N/acre/season, applied in three equal applications of 40 and 80 lb/acre, produced season total yields of 4 and 6 tons/acre, respectively. Crude protein (CP) ranged from 6 to 10% with 40 lb/acre/application and 7 to 12% with 80 lb/acre/application. 'Highlander' harvested on a 45-day harvest frequency produced higher yields and similar quality as a 'Tifton 44' bermudagrass [*Cynodon dactylon* (L.) Pers.] harvested on a 30-day frequency. Silage yields of 'Highlander' exceeded those of corn (*Zea mays* L.) varieties by 61% (tons/acre = 23 vs.14), but digestibility of corn was 16 percentage units higher (*in vitro* true digestible = 75 vs. 59).

Forage Yield and Quality of Eastern Gamagrass with Increasing Rates of Nitrogen Fertilizer

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Eastern gamagrass, *Tripsacum dactyloides* (L.), requires two growing seasons to achieve good establishment and economic yield. This study investigates the effects of five levels of nitrogen (0 to 224 kg/ha) on forage yield and quality during the establishment period. The study was conducted in Corning, New York, on a Unadilla silt loam soil. The "Pete" eastern gamagrass

was planted on 5/21/91 after a two-month stratification period using a corn planter with a 76 cm row spacing at 3.8 kg/ha pure live seed. There were five nitrogen treatments: 0, 56, 112, 168, and 224 kg/ha nitrogen applied using ammonium nitrate. During the establishment year, the nitrogen was applied at a one-half rate on 8/1/91. The full rates were applied on 5/26/92, 5/24/93, and 5/19/94. The fertilizer treatments were applied to plots 3.0 meters (4 rows) by 3.0 meters with five replications. The dry matter yields were taken from a 1.5 meter section of a center row from each of the plots. In 1992, the average dry matter yields were relatively consistent above the 112 kg/ha nitrogen treatment. In 1992, the yields for the 0, 56, 112, 168, and 224 kg/ha nitrogen rates were 6.0, 6.5, 9.2, 7.8, and 9.4 Mg/ha, respectively, from a single harvest on 9/18/92. In 1993, three harvests were conducted on 6/10/93, 7/27/93, and 10/1/93; there was a yield response for the 224 kg/ha nitrogen rates. The average total yields for the 0, 56, 112, 168, and 224 kg/ha nitrogen rates were 5.5, 6.5, 6.5, 6.5, and 8.3 Mg/ha, respectively. In 1994, two harvests were conducted on 6/17/94 and 8/11/94. The average total yields for the 0, 56, 112, 168, and 224 kg/ha nitrogen rates were 5.1, 6.7, 7.4, 8.4, and 7.6 Mg/ha, respectively. The crude protein (CP), *in vitro* true digestibility, neutral detergent fiber (NDF), digestible NDF, acid detergent fiber (ADF), and lignin were measured for all three cuttings for all fertilizer treatments in 1993. In 1993, the 168 kg/ha nitrogen treatment had the following forage quality. First cutting values were 178, 815, 647, 714, 288, and 26 g/kg, respectively. For the second cut, they were 106, 687, 678, 537, 327, and 39 g/kg, respectively. For the third cut, they were 141, 752, 666, 628, 277, and 32 g/kg, respectively. The first cutting had the highest forage quality. There was a trend for higher digestibility and CP and lower NDF and ADF with increasing rates of nitrogen. For the first cutting, there were significantly higher CP levels at the 168 and 224 kg/ha rates than the 0 and 56 kg/ha nitrogen rate with CP means of 176 g/kg and 155 g/kg, respectively. The forage quality of the second cutting was reduced due to the later-than-optimum harvest interval. The third cutting, although harvested late, had an intermediate forage quality analysis.

Yield of Four Warm-Season Grasses and Post-Frost Losses Due to Weathering

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Abstract

Grasses provide quick carbon accumulation via photosynthesis, without tying up agricultural land for significant periods of time. The biomass produced from grass can be utilized as a biofuel, either through direct combustion or as a precursor to syn-gas. Utilities often fault the use of grass hay in generation facilities because of the high silica and potassium content. Species used in this study were assessed for yield, yield loss post-frost, ash content, and mineral components. The species were *Miscanthus floridulus* (giant maidengrass), *Panicum virgatum* (switchgrass), *Pennisetum purpurea* (elephantgrass), and *Sorghum bicolor* (sorghum-sudangrass). Plants were established by appropriate means and maintained to maximize yield. At the end of each growing season, subplots of the yield trial were cut, dried, and loosely bundled. Bundles were exposed to ambient conditions. At four-week intervals, from December to April, samples were taken for analysis. Yield data indicated that the three perennial species yielded

approximately three times more than sorghum-sudangrass. Of the four species tested, elephantgrass yielded the greatest during the first year of the study, but plots suffered severe damage from single-digit temperatures during the intervening winter. Ash analysis indicated that elephantgrass and sorghum-sudangrass had the greatest total ash and the highest potassium concentrations. Yield losses during the first 30-day period ranged from 30 to 40% depending on species. Most of the yield loss was due to significant loss of leaf material. Of the four species tested, switchgrass would be the best choice because of its relative ease of establishment coupled with its lower innate ash and potassium content.

Introduction

Grasses, especially warm-season C_4 grasses, offer an abundant source of CO_2-neutral energy. Biomass yields of 7 to 12 T/A have been reported from several grass species with a corresponding potential energy value of 185 GJ (175.5 MBtu) for 11 tons of switchgrass (Samson et al., 2004). Frost-killed biomass can be removed from the field without damaging potential spring regrowth. This is part of a larger study looking to utilize cultured biomass to generate ethanol via fermentation of syn-gas from the pyrolysis. In addition to the carbon status, grasses have additional advantages over fossil fuels. Compared to the fossil fuels, grass biomass is lower in ash, heavy metals, and sulfur, and it utilizes land already in production without necessitating the reclamation and restoration of large tracts of mined land (Turn et al., 2002). However, grass is not a panacea. Oil and natural gas are generally low in ash, while coal can have varying ash concentrations but is generally considered to be low in potassium. Here lies one of the biggest problems with biomass, especially grass. Grass hay, relative to fossil fuel, is relatively high in potassium (Turn et al., 2002). Furnaces used to burn biomass typically utilize technology known as a fluidized bed. In this arrangement, ceramic spheres are preheated to a combustion or pyrolysis temperature before the biofuel is introduced. These spheres allow for more uniform consumption of the fuel. Normally, the ash from the fuel would be vibrated through the fluidized bed and out the bottom. Introduction of grass as a fuel introduces a significant source of potassium (or sodium) to the ash composition. The introduction of potassium to an ash composed primarily of silica causes the silica to melt at much lower temperatures than without potassium. Three percent potassium introduced to a primarily silica ash causes the melting point of that ash to go from 1700°C to as low as 600°C (Sander, 1997). Once the ash liquefies, removal is difficult, and if the furnace cools, the slag solidifies into a solid vitreous mass. In an attempt to ameliorate this problem with grass hay, we looked at in-field weathering as an attempt to reduce the potassium concentration in standing hay. Weathering, however, is expected to reduce potential yield as well. This study was undertaken to determine yield of adapted grass species and to determine the effect weathering would have on final yield, ash concentration, and ash composition.

Materials and Methods

Based on a three-year average yield of 10 species grown in Mississippi, we narrowed the species for this test to the four with the highest annual biomass yield. These four were *Miscanthus floridulus* (MISFO, giant maidengrass; sterile exotic perennial), *Panicum virgatum* (PANVI, switchgrass; seeded native perennial), *Pennisetum purpurea* (PESPU, elephantgrass; fertile exotic weak perennial), and *Sorghum bicolor* (SORVU, sorghum-sudangrass; domestic seeded annual). In November of 2002 and 2003, 15 bundles of each of the four species were cut from the field, dried until no further weight loss was measured, and weighed. Weight of each bundle was recorded, and bundles were tagged with an aluminum identifying tag. Each bundle was loosely bound and placed outside in a galvanized steel stand on a concrete pad. In 30-day increments, three bundles (representing replications) of each of the four species were removed from the stand, dried, and re-weighed, and the entire sample was ground for analysis. This process was repeated each month from December through April. Ground samples were analyzed for caloric value and total ash. Ash was analyzed for calcium, magnesium, phosphorous, sulfur, and potassium. Differences were determined by Proc GLM at a significance level of 0.05 (SAS, 1999).

Results and Discussion

Yield Accumulation

The larger study upon which this is based utilized harvest regimes as a factor in its analysis. Yields were obtained from a two-harvest per season regime or a single harvest at the end of the growing season. For all the species mentioned in this test, two 90-day harvests yielded the same or greater than the same species under a single 180-day harvest ($P = 0.046$). Analysis of the yields of the four species over two years indicated an interaction between species and year. In 2002, PESPU had yields from the 180-day harvest of 13.2 T/A; in 2003, the same species yielded only 5.2 T/A under the same harvest regime. Single-digit temperature during the intervening winter caused extensive damage to the crowns, causing the extreme drop in yield in 2003. During the same period of time, winter-hardy MISFO and PANVI expanded their respective crowns as individual crown size increased. Yields of these two species increased dramatically from the prior year. Based on these data, while PESPU may produce exceedingly high yields in some years at Starkville, Mississippi, the potential exists for significant winter-kill. PANVI and MISFO are reliably hardy at this location, producing mean yields of 10.5 and 8 T/A, respectively.

Yield Loss Due to Weathering

Measurements of weight loss in the bundles that were stored outside from November until the following April indicate substantial losses occurring during this time period. Within the first 30-day period, mean yield losses for MISFO and PANVI were 30%, while mean losses for PESPU and SORVU were recorded at 40% during the same time period ($P = 0.019$). Although yield losses continued to accumulate for the remaining months of the weathering study, a 30% loss was considered economically marginal and a 40% loss unacceptable. By April of the following year, losses approached 70% for SORVU, 63% for PESPU, 57% for PANVI, and 49% for MISFO. Based on these findings, it was determined that harvest could not be delayed greater than 30 days past frost.

Percentage Total Ash as Affected by Weathering

After assessing weight loss, entire bundles were hammer-milled, then ground further to be ashed for analysis. The ground samples were used for estimates of total ash, and the ash was further analyzed for its components. We focused on calcium, magnesium, phosphorous, sulfur, and potassium. At harvest, overall ash content appears slightly elevated relative to other reports. This may be attributed to a dirt road in close proximity to the test “dusting” the plants as traffic passed. Samples from the November harvest indicated that the two species that are typified by broad leaves and spongy stalks had the highest ash. November samples from SORVU and PESPU were 10.1 and 9.88% total ash, respectively. Contrastingly, PANVI and MISFO for the same time period had total ash values of 5.1% and 7.5%, respectively. Thirty days of weathering reduced total ash levels in all the species except PESPU, with SORVU showing the greatest reduction during that time period (- 44%). Weathering over time caused all species to lose ash, with three of the four species leveling off by January (60 days after harvest) and PESPU continuing to decrease in total ash until April.

Components of Ash

Calcium, magnesium, phosphorous, sulfur, and potassium were monitored because of their relative significance to plant growth (phosphorous, potassium, calcium, and magnesium), their potential as a pollutant (sulfur), and their ability to cause slagging (potassium). While the components of ash were monitored throughout the five-month duration of the test, the amount of biomass loss that had occurred during the first 30-day weathering period made later (> 30 day) analysis of these minerals moot.

At harvest, MISFO (0.73%) had higher levels of calcium ($P = 0.005$) than the other three species (0.55%) in the test. None of the species lost measurable amounts of calcium nor magnesium during the entire five-month duration of the test. When we look at phosphorous at harvest, PESPU and SORVU have higher levels than MISFO and PANVI (0.29% for both PESPU and SORVU versus 0.12 and 0.11% for MISFO and PANVI, respectively ($P = 0.001$).

Of the four species, only PESPU and PANVI lost measurable quantities of phosphorous during the first 30-day period. PESPU dropped from 0.29 to 0.15%, and PANVI dropped from 0.11 to 0.08%. It should be noted that although phosphorous levels in PESPU dropped by half in the first 30 days of weathering, the final percentage (0.15%) is still higher than the unweathered value for PANVI (0.11%).

The sulfur levels in these species were low with respect to coal. Values for low-sulfur coal typically run at 0.5% (Turn et al. 2002). Sulfur content of these grasses are one-tenth the value of low-sulfur coal. With the exception of PANVI, sulfur percentages did not decrease over the five-month duration of the test. For PANVI, sulfur percentages did decrease, and they did so in the first 30-day weathering period ($P = 0.049$), going from 0.06 to 0.04%.

The effect of potassium levels on slagging and fouling of generation facilities is undisputable. However, the extent to which the potassium levels in grasses are causing this problem can be addressed. Two of the four species, PESPU and SORVU, were relatively high in potassium at harvest (1.0 and 1.2%, respectively), while MISFO and PANVI were lower at harvest (0.4 and 0.3%, respectively; $P = 0.001$). All four species recorded large drops in potassium percentages after 30 days of weathering ($P = 0.005$). During the first 30-day weathering, potassium levels in all species dropped by half or more. However, a 50% drop in SORVU means that the weathered material still contains 0.68% potassium, while the same drop in PANVI results in 0.14% potassium in the ash.

The ash analysis has focused on making the biomass more acceptable to the biofuel facility; however, it must be pointed out that losses of these minerals due to weathering in a field situation reflect a return of these same minerals to the soil profile. Minerals such as phosphorous and potassium are macro-nutrients and fertilizers important for maximizing plant growth. Based on the mean yield of PANVI (13 T/A) in this test and the percentage potassium taken up in the unweathered material, removal of unweathered material to a co-fire facility represents a removal of 78 lb/A of elemental potassium which must be replaced by fertilizer application. For SORVU, this is 140 lb/A, and with maximum yields of PESPU (18 T/A), we are looking at a potential removal of 360 lb/A potassium. A 30-day weathering period means that roughly one half of the potassium can be returned to the soil instead of being shipped to the power plant.

Caloric Value of the Biomass

When we tested the 10 species from the original study, we found that caloric values of all the grasses were relatively close, between 3,800 and 4,150 calories per gram of dry material. Upon closer investigation with these four, there are observable differences in energy potential. Under a single-cut regime, SORVU and PESPU at 3,921 and 3,860 cal/gm, respectively, have lower caloric values when burned than either MISFO or PANVI (4,123 and 4,171 respectively; $P = 0.032$). In looking at the stems of SORVU and PESPU versus those of MISFO and PANVI, one will notice that the stems of the former two are true stalks (filled with spongy pith), while the stems of the latter two are true culms (hollow stems with thickened walls). The differences in energy value probably come from the lignification and increased density of these culms. The caloric differences between the species may seem small, but when they are converted to calories per acre based on tons of dry matter, we see very large differences. In a comparison of SORVU (low caloric value with low tonnage) with PANVI (highest caloric value with moderate tonnage), we see that SORVU has the potential to produce 2.49×10^{10} calories/A and PANVI double that, at 4.92×10^{10} calories/A.

Other Considerations

If biomass/biofuel is to become successful, the fields that produce the crops must be relatively easy to establish using equipment a producer would already have. Propagation of each of these grasses differs. MISFO is sterile, a triploid, so produces no viable seed. Fields of MISFO are established by dividing crowns of existing plants, an extremely labor-intensive process. According to the NRCS (2004), PESPU has variable seed fertility, and most seed that is produced is usually of poor quality. In this study, we established PESPU from a single clone. As most grasses are obligate out-crossers, propagating from a single clone means that seed set will be further reduced. Worldwide, most pastures of PESPU are established from sprigs or cuttings. As with other vegetatively propagated species, establishing large acreage is extremely labor-intensive. Establishment questions coupled with the fact that in north-central Mississippi, PESPU is susceptible to winter-kill makes it an unlikely candidate for continued use in spite of the high tonnages.

Both PANVI and SORVU are propagated via seed, which makes them easier to establish with conventional farm equipment. However, since SORVU is an annual, it would have to be replanted each spring. Even though establishment of PANVI is extremely slow, it does establish. Being perennial in nature means that the field will reestablish year after year. PANVI is native to North America, making it more ecologically desirable than introduced species.

Conclusions

Based on consistent yield potential, winter-hardiness, lower yield losses during weathering, low innate ash content (especially potassium), high energy value, the fact that it is seed propagated, and has a perennial growth habit, PANVI is the clear choice for planting and production of biomass for fuel.

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Yield and Population Density Changes of Switchgrass Established under Sorghum/Sudangrass

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Abstract

Switchgrass (*Panicum virgatum* L.) is a warm-season C_4 perennial grass common to the Great Plains of North America. As a species, switchgrass has been grown for greater than 50 years as forage and also been used in prairie restoration projects. Recent events in the energy markets have forced federal and state governments to look at high-yielding grasses as a source of carbon dioxide-neutral energy. However, many of the native grasses of North America are known to be extremely slow to establish due to low germination rates and slow seedling growth. In this study, switchgrass was established under a nurse-crop of sorghum-sudangrass. The sorghum-sudangrass provides a quick source of biomass during the establishment year, with the switchgrass providing subsequent biomass yields. The field was established as a split-plot. Main plots were sorghum harvest regime. Subplots were sorghum seeding densities. Varying sorghum-sudangrass densities were used to determine their effect on switchgrass establishment. Population counts and yield data were obtained each year. Initial stand counts indicated a strong effect of sorghum-sudangrass density. After the first year, populations of individual switchgrass crowns decreased from their initial levels. Yields and populations are still being monitored. Eighteen months after establishment, there was no observable effect of the sorghum/sudangrass treatment on number of crowns per acre. Regardless of original treatment, mean crown density was 57K/acre. By fall of 2003 (30 months after establishment), differences in yield due to original treatment also disappeared.

Introduction

Gasification and fermentation of syn-gas is being investigated to determine its potential for use as a source of ethanol. In this process, pyrolysis of biomass yields carbon dioxide, carbon monoxide, and hydrogen, which can be converted by anaerobic bacteria to the ethanol. Switchgrass has been shown by researchers in the Great Plains, Texas, and Georgia to be a reliable source of biomass for the gasification process. However, there are some substantial problems with using switchgrass as a crop for biomass. Most notably, switchgrass from seed is notoriously slow to germinate and establish. Baldwin and Cossar (2002) determined that a midsummer planting of switchgrass that was maintained free of other grasses yielded only 100 lb/A of biomass by the end of the season. Because switchgrass typically takes a year to establish, producers who convert to biomass production receive no revenue from land devoted to switchgrass during the first (establishment) year. In addition to financial loss, invasion of weedy grass species during the establishment year affects the overall switchgrass population (Roth and Curran, 1998). That being said, a nurse-crop could provide some revenue during the establishment year (Hintz et al. 1998).

Sorghum-sudangrass was chosen as the nurse-crop because, like switchgrass, it is tolerant to atrazine and simazine. It is also recognized as a biomass crop that establishes well even under adverse conditions. Additionally, because of its annual growth habit, there is a definite termination of growth, meaning switchgrass alone will dominate the field next spring.

The main objectives of this study were to determine how a nurse-crop of sorghum-sudangrass affects the yield and density of a stand of switchgrass plant with it and to optimize the seeding rate of sorghum-sudangrass to minimize its effect on the subsequent crop of switchgrass.

Materials and Methods

This study consisted of three fields, each immediately adjacent to one another. The original field was established August 8, 2001, and irrigated with one inch of water a week until established. Each year in spring and again in fall, population counts were made, and during the fall yields were calculated. This field has been monitored for four years. The two remaining fields were established on April 16, 2003. Soil moisture was sufficient as not to require irrigation. The two new fields were established as a split plot, and each mimicked the original test. Sorghum-sudangrass seed at varying rates was planted with a fixed rate of switchgrass seed. Main plot treatments were the sorghum removal. In one-half of the test, the sorghum was allowed to grow full season and then cut only at the end of the season. In the second half of the test, sorghum was removed twice, once in August and again at the end of the season. Subplots consisted of varying the sorghum seeding rate. This was composed of five treatments: 5, 3, 2, 1, and 0 sorghum-sudangrass per linear foot of row (each with switchgrass 'Alamo' at a fixed planting rate of 10 lb PLS/A).

Before planting, the vegetation in the fields was burned down using 1 qt/A of paraquat, followed by conventional discing and harrowing. Immediately following planting, 1 lb/A of atrazine was applied over-the-top and irrigated in. After germination, the first seedling counts were made. The fall 2003 counts were mistakenly not taken. The following March, winter annuals were burned down with paraquat followed with a 1 qt/A application of pendamethelin to control spring weed germination. At this time, 300 lb/A of ammonium nitrate was applied to stimulate switchgrass growth. As appropriate, the sorghum-sudangrass was cut from the field, sorghum weights were taken, and the number of switchgrass plants counted. All switchgrass seedlings in the 2003 fields were counted the first week in August, which coincides with the first sorghum cut on the two-cut part of the field. The next data collected were taken in spring 2004. During this growing season, there was no sorghum-sudangrass emergence, except for a few sporadic volunteers. The number of switchgrass plants surviving the winter was counted and recorded (spring 2004). After the switchgrass matured, the biomass was harvested from all fields. Yield was calculated, and the number of switchgrass crowns was also counted.

Results and Discussion

Sorghum-Sudangrass Yields

Data from the sorghum harvests of the 2003 fields and in other adjacent fields indicated that yield was unaffected by planting date (spring versus midsummer) or harvest regime (one or two cuts/season). Whether the sorghum-sudangrass was cut once, during midsummer and again at the end of the season, or just at the end of the season, the maximum mean yield of the sorghum-sudangrass was 7.1 to 7.5 T/A ($P = 0.032$). However, seeding rate of the sorghum-sudangrass did affect its yield ($P = 0.047$). Sorghum established at a density of 5 seed/linear foot row had a mean biomass yield of 7.5 T/A; under 3 seed/linear foot row, 7.1 T/A; under 2 seed/linear foot row, 6.1 T/A; and 3.4 T/A with 1 seed/linear foot row. Of course, no sorghum-sudangrass was harvested from the 0 seed plots. With regard to biomass production from sorghum-sudangrass, 5 and 3 seed/linear foot row yielded more that a single seed/linear foot row (with yield from two seed plots falling into both groups).

Switchgrass Yields

In the original test, established during the summer of 2001, yields of the switchgrass plots that established under the 5 sorghum seed/linear foot row treatment show a definite suppression of yield that persists for three years (Table 1). By the fourth year of the test, 2004, there are no observable differences due to the original sorghum seed density treatment ($P = 0.58$). The yield data from 2004 original test (Table 1) would indicate that this field seems to be in decline (especially the yields of the 0 sorghum seed plots). Mean yields from this field are between 3.7 and 5.9 T/A; we expect 8 to 10 T/A. However, this field was flooded three times this summer in flash floods. The adjacent fields (2003 fields) also yielded lower than expected. The reduction in yield may be a function of the year itself. Soil testing is under way to determine if sufficient nitrogen and potassium levels exist after the flooding.

Table 1. Yields of switchgrass from the original field (planted 2001) followed over four years.

Original Sorghum Seed Density (seed/linear ft row)	Yield (Tons/A) 2001	2002	2003	2004
5	2.6	3.6	5.6	5.8
3	5.0	4.9	8.0	4.8
2	7.0	7.0	8.7	4.7
1	5.2	5.2	7.9	5.9
0	10.6	10.6	7.7	3.7

For the new field (established 2003), 2004 represents the first year of switchgrass harvest. Comparing the main plot effect (removal of sorghum-sudangrass), there was a difference in yield between the plots that had the sorghum removed twice during the previous growing season versus the one-time removal at the end of the season. The yield of the switchgrass grown under the twice-removed sorghum-sudangrass was, on average, 0.75 T/A higher than under the other treatment (P = 0.031). Further evaluation showed no difference in switchgrass yield due to sorghum seed density (P = 0.056). As mentioned earlier, yields from this test were lower than expected, even for first-year switchgrass growth.

Table 2. 2004 yields of switchgrass under a one-cut and two-cut removal of sorghum-sudangrass during the establishment year (2003).

	Switchgrass Yield (Tons/A)	
Original Sorghum Seed Density (seed/linear ft row)	**Sorghum Removed Twice During the Growing Season**	**Sorghum Removed Once During the Growing Season**
5	3.1	2.0
3	2.5	2.0
2	3.2	1.8
1	2.8	2.3
0	2.5	2.3

Crown Counts

To determine the number of plants that contributed to the switchgrass yield, crown counts were taken immediately after removal of the biomass. In the original test (established Aug. 2001), after the four weeks of growth, the number of switchgrass seedlings was highest under two sorghum plants per foot (1.02 M plts/A). However, just two months later (fall 2001), the highest numbers of switchgrass seedlings were observed where the sorghum was planted in the lowest densities. In spring 2002, again the greatest number of seedlings was observed under the treatment of 2 sorghum seed, and by fall 2002, the number of switchgrass plants was highest in the 0-seed treatment and lowest in the 5-seed treatment. By fall 2003, differences in plant number observed in the original test due to sorghum seed density had disappeared (P = 0.52). However, with the fall 2004 counts, differences in crown number were observed but only between the 5 and 0 sorghum seed density plots (P = 0.033).

Crown counts from the field established in 2003 taken in August indicate no differences between the switchgrass populations due to sorghum removal regime. The same counts indicate that sorghum seed density affects switchgrass establishment equally in the two halves of this test. We would have expected this because the two halves of the field were treated equally up to this point (when first removal of sorghum was made on the two-cut main plot). Analysis within seeding treatment shows a greater number of switchgrass seedlings under 2, 1, or 0 sorghum seed density as compared to under 5 or 3 seed/linear foot row. The fall 2003 counts were missed, but by the spring of 2004, the populations of the 2003 test were similar to those recorded in 2002 of the original test. This is not surprising, as by this time, the 2003 test had undergone one full year of growth. Comparisons of population numbers between the two halves of the 2003 test made in spring 2004 indicate higher populations of switchgrass established under the sorghum regime that was cut twice (~ 45,000 plants) than under the part that was cut once (~15,000; P = 0.004).

This is not surprising. Twice removal of the sorghum nurse-crop biomass allowed light to reach the ground during the August cut, which subsequently allowed new seedlings to germinate. Counts made in fall of 2004 show that the difference in switchgrass populations observed in spring 2004 had disappeared. Both groups, regardless of sorghum removal regime, had an equal number of plants. It is interesting to note that this result indicates that in the sorghum plots removed once, populations increased from spring 2004 (with the exception of the 0 sorghum plots), and in the sorghum plots removed twice, populations declined. There is significance in the identical behavior of the 0 sorghum seed plots. Such similar behavior verifies the uniformity of the field.

Conclusions

Based on these observations, it may be concluded that sorghum can be used as a nurse-crop for sorghum-sudangrass under a two-cut system since mean yield of the two-cut system is 0.75 T/A greater than the one-cut regime. If the one-cut system is necessary, the recommended seeding rate is two or three sorghum seed/linear foot row. The reason we recommend two to three sorghum seed is to obtain sufficiently high tonnages of sorghum during the establishment year while minimizing the effect on the subsequent switchgrass crop. Switchgrass mortality rates calculated on each test indicate that 10 lb/A seeding rate is too high. Yields of the new test show no differences due to sorghum regime or sorghum seed density. This is not what was found in the original test where high sorghum seed density caused depression of yield in the subsequent switchgrass crop.

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Modeling Greenhouse Gas Emissions from Bioenergy Cropping Systems in Pennsylvania Using DAYCENT

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Abstract

Reducing the net global warming potential (GWP) of energy use is a major factor driving interest in biofuels. Bioenergy cropping systems vary in contribution to the GWP due to the crop yield and resulting quantity of fossil fuels displaced, quantity and quality of C added to the soil, feedstock conversion efficiency, N_2O emissions, N use efficiency, and inputs required for crop production and operation of farm machinery. The objective of the study was to use DAYCENT

to model the net greenhouse gas (GHG) emissions of bioenergy cropping systems (corn, soybeans, alfalfa, switchgrass, and hybrid poplar) in Pennsylvania for inclusion in a full C cycle analysis. The quantity of displaced fossil fuel was the largest GHG sink. Soil C sequestration was the second largest GHG sink. Although crops with higher soil C inputs, such as switchgrass and hybrid poplar, will have higher equilibrium soil C levels, the change in system C will approach zero in the long term. N_2O emissions were the largest GHG source. When the credit for the amount of fossil fuel displaced was not taken into account and soil C storage was assumed to have reached its maximum capacity, switchgrass and hybrid poplar were the only cropping systems to remain a sink for GHGs. Therefore, use of switchgrass and hybrid poplar for production of biofuels has the potential to be GHG neutral and may even be a long-term sink for GHGs.

Introduction

Changes in land use and combustion of fossil fuels have been the largest human impacts on the global C cycle (Janzen 2004). Burning fossil fuels has added tremendous quantities of CO_2 to the atmosphere; > 400 times the Earth's current net primary productivity were required to produce the quantity of fossil fuels burned in 1997 (Dukes 2003). Reducing the net global warming potential (GWP) of energy use is a major factor driving interest in biofuels. The main components of GWP from crop production are N_2O emissions, soil CO_2 fluxes, CO_2–C emissions associated with agricultural inputs and farm equipment operation, and CH_4 fluxes (Del Grosso et al. 2001a; West and Marland 2002). Bioenergy cropping systems vary in contribution to the net greenhouse gas (GHG) production due to the crop yield and resulting quantity of fossil fuels displaced, quantity and quality of C added to the soil, feedstock conversion efficiency, N_2O emissions, N use efficiency, and inputs required for production and operation of farm machinery. Several studies have evaluated the energy balance (Shapouri et al. 2002) and GWP (Heller et al. 2003; McLaughlin et al. 2002; Sheehan et al. 1998; Sheehan et al. 2004; Updegraff et al. 2004) of specific bioenergy crops, but there is limited information comparing a range of crops (Kim and Dale 2004). Cropping system practices, such as tillage, plant life cycle, and N fertilizer use, have a significant impact on GHG emissions and their integrated impact has not been evaluated in previous studies. DAYCENT can integrate climate, soil properties, and land use (Del Grosso et al. 2001a) and can dynamically evaluate the impact of cropping systems on crop production, soil C, and trace gas fluxes, factors critical to conducting a full C cycle analysis of bioenergy cropping systems. Our objective was to use DAYCENT to model the net greenhouse gas fluxes of bioenergy cropping systems in Pennsylvania for inclusion in a full C cycle analysis.

Materials and Methods

DAYCENT is the daily time step version of the CENTURY (Parton et al. 1994) biogeochemical model. DAYCENT (Del Grosso et al. 2001a; Parton et al. 1998) simulates fluxes of carbon (C) and nitrogen (N) between the atmosphere, crops, and soil. From climate (daily maximum and minimum air temperature, precipitation), soil texture class, and land use inputs, DAYCENT simulates crop production, SOM changes, and trace gas fluxes. Key submodels include soil water content and temperature by layer, plant production and allocation of NPP, decomposition of litter and soil organic matter, mineralization of nutrients, N gas emissions from nitrification and denitrification, and CH_4 oxidation in nonsaturated soils. Flows of C and N between the different pools are controlled by the size of the pools, C/N and lignin content of material, and abiotic water/temperature controls. The land surface submodel used in DAYCENT simulates soil water content and temperature by layer (Parton et al. 1998). The ability of DAYCENT to simulate NPP, SOC, N_2O emissions, NO_3 leaching, and CH_4 oxidation has been tested with data from various native and managed systems (Del Grosso et al. 2001b; 2002; in press). Simulated and observed grain yields for major cropping systems in North America agreed well with data at both the site and regional levels (Del Grosso et al. in press). The CH_4 oxidation submodel correctly simulated the high uptake rates observed in deciduous forests, the intermediate rates observed in coniferous and tropical forests and grasslands, and the low uptake rates observed in cultivated soils (Del Gross et al. 2000). N_2O emission data from eight cropped sites and NO_3 leaching data from three cropped sites showed reasonable model performance (Del Grosso et al. in press).

Simulations of net greenhouse gas emissions using DAYCENT were performed for the following bioenergy crops: corn (*Zea mays* L.), soybeans (*Glycine max* Merr.), alfalfa (*Medicago sativa* L.), switchgrass (*Panicum virgatum* L.), and hybrid poplar (*Populus* spp.) grown in Pennsylvania. Four bioenergy cropping systems were compared: 1) switchgrass, 2) corn•soybean rotation (2 years of corn followed by 1 year of soybeans), 3) corn•soybean•alfalfa rotation (3 years of corn, 1 year of soybeans, followed by 4 years of alfalfa), and 4) hybrid poplar. Conventional and no tillage were compared within the corn•soybean and corn•soybean•alfalfa rotations. All simulations were for 24 years except hybrid poplar, which was for 30 years since the harvest cycle is 10 years.

Daily weather and soil properties for Pennsylvania were obtained from the Erosion-Productivity Impact Calculator (EPIC, Sharpley and Williams 1990). Soil physical properties needed for model inputs were calculated from texture class and the hydraulic properties calculator (http://www.bsyse.wsu.edu/saxton/soilwater/) of Saxton et al. (1986). Land use parameters were defined for each crop, including crop growth dynamics, N application rate, harvest schedule, and tillage. DAYCENT was calibrated using 10-year averages from agricultural statistics in Centre County, Pennsylvania, for corn, soybeans, and alfalfa (USDA-National Agricultural Statistics Service. 2004) and switchgrass and hybrid poplar yields from Walsh et al. (2003). To minimize erosion and maintain tolerable soil loss limits (Nelson 2002; Sheehan et al. 2004), only 50% of the corn stover was harvested for biofuel. Production parameters for management of alfalfa as a biofuel were based on Lamb et al. (2003). Only alfalfa stems were used for production of biofuel, while leaves were assumed separated for use as a protein source. The quantity of alfalfa biomass for use as biofuel was calculated by multiplying the yield from DAYCENT by 0.5, since alfalfa stems account for about 50% of total alfalfa biomass when it is managed as a biofuel crop (Lamb et al. 2003). Nitrogen fertilizer application rates were 13 g N m^{-2} yr^{-1} for corn, 10 g N m^{-2} yr^{-1} for switchgrass, and 8.4 g N m^{-2} in years 3, 5, 7, and 9 for hybrid poplar. Corn, soybeans, and switchgrass were harvested in the fall annually. Alfalfa was harvested twice annually in late June and September. Hybrid poplar was harvested once every 10 years.

Model outputs are sensitive to current SOC levels, which in turn are influenced by previous vegetation cover and land management. To acquire reasonable modern SOC levels, 1,700 years of native vegetation followed by plow out and 300 years of cropping were simulated. Native vegetation was assumed to be the potential vegetation from VEMAP (1995) analysis. Plow out was assumed to occur in the year 1700. Historically accurate cropping systems were simulated, and improved cultivars and fertilizer applications were introduced at appropriate times. The simulations of the different biofuel systems all used identical initial conditions that included the legacy effects of 300 years of conventional tillage cropping.

Output from DAYCENT was compiled for above- and belowground net primary productivity and grain yields, SOC changes, and trace gas fluxes. Net greenhouse gas (GHG_{net}) emissions were calculated as: $GHG_{net} = (-C_{displaced\ fossil\ fuel}) + (-\Delta C_{system}) + (\pm C_{feedstock\ conversion}) + C_{N_2O} + C_{N\ fertilizer} + C_{ag.\ machinery}$, where the sinks were the amount of fossil fuel displaced by ethanol or biodiesel ($C_{displaced\ fossil\ fuel}$) and the change in soil organic carbon (SOC) and belowground biomass C (ΔC_{system}), and the sources were the amount of CO_2 equivalents emitted from fossil fuels used in feedstock transport to the biorefinery, conversion to biofuel, and subsequent distribution ($\pm C_{feedstock\ conversion}$; positive or negative values result depending on size of electricity credit at the biorefinery), CO_2 equivalents of N_2O emissions (C_{N_2O}), CO_2 emission from N fertilizer manufacture ($C_{N\ fertilizer}$), and fuel used by agricultural machinery for tillage, planting, fertilizer/pesticide application, harvesting, and drying corn grain ($C_{ag.\ machinery}$).

The parameters for GHG_{net} were either from DAYCENT output or calculated as described below. DAYCENT outputs were used to determine $C_{displaced\ fossil\ fuel}$, ΔC_{system}, and C_{N_2O} for the GHG_{net} calculation. All DAYCENT outputs were presented as annual means over the entire simulation period. The ethanol yield was determined by multiplying the aboveground biomass or grain yield by the theoretical ethanol yield (U.S. Department of Energy 2004). Biodiesel is produced from soybean; biodiesel yield was determined from the product of about 0.6 L biodiesel kg^{-1} biomass C and the soybean grain yield. The quantity of fossil fuel displaced by biofuel ($C_{displaced\ fossil\ fuel}$) was calculated from the product of biofuel yield from the bioenergy crops and the fuel economy ratio of fossil fuel to biofuel [fuel economy values are from Sheehan et al. 2004 (6.75 km L^{-1} ethanol/10.3 km L^{-1} gasoline) and based on Sheehan et al. 1998 (0.146 L diesel bhp-h^{-1}/0.179 L biodiesel bhp-h^{-1})]. The quantity of GHGs from the life cycle of fossil fuel displaced by biofuel was calculated from the product of the quantity of fossil fuel displaced by biofuel and the total emissions of CO_2, CH_4, and N_2O during the fossil fuel life cycle [based on Sheehan et al. 2004 for gasoline (about 671g CO_2-C equivalents will be emitted L^{-1} gasoline consumed or about 440g CO_2-C equivalents will be displaced from gasoline L^{-1} ethanol consumed) and on Sheehan et al. 1998 for diesel (about 864g CO_2-C equivalents will be emitted L^{-1} diesel consumed or about 705g CO_2-C equivalents will be displaced from diesel L^{-1} biodiesel consumed)]. The ΔC_{system} was the sum of change in SOC and belowground biomass C. The $C_{feedstock\ conversion}$ was determined from Sheehan et al. (2004); a value of -135.2 CO_2-C equivalents L^{-1} ethanol produced at the biorefinery was calculated for corn stover and applied to the other biomass sources and 293.3 CO_2-C equivalents L^{-1} biofuel for grain. The C_{N_2O} was the mean sum of annual N_2O emissions over the simulation period. N_2O emissions were converted to CO_2 equivalents by assuming that its global warming potential is 310 times that of CO_2 on a mass basis. The $C_{N\ fertilizer}$ was calculated from the product of N application rate and the C emissions factor from the fossil fuel energy requirement of N fertilizer manufacture (857.54 kg C Mg^{-1} N fertilizer from West and Marland 2002). Using agricultural machinery management data documented in the ASAE Machinery Management Standards (ASAE 2000), the Integrated Farm System Model (IFSM) (Rotz 2004) was used to calculate fuel use for management practices, $C_{ag.\ machinery}$. IFSM allowed comparison of current energy use from agricultural machinery between all farm operations under standardized conditions.

Results and Discussion

Crop Yield

Yields for the individual crops were switchgrass > hybrid poplar > corn grain plus 50% stover > alfalfa stems > soybean grain (Table 1). The model calibration for corn, soybean, and alfalfa yields were based on Pennsylvania agricultural statistics (USDA-National Agricultural Statistics Service 2004) and switchgrass and hybrid poplar on estimates from Walsh et al. (2003), so yield results from DAYCENT were as expected. Yields for cropping systems were switchgrass > hybrid poplar > corn•soybean rotation > corn•soybean•alfalfa rotation (Table 2). Since soybean and alfalfa had lower yields than the other crops, their inclusion in the crop rotation reduced overall yield of the cropping system. Biofuel production is directly related to crop yield and composition. Based on composition, grain has a higher conversion efficiency per unit weight than biomass. Since the composition between biomass sources is similar, ethanol yield differences per unit weight are not great (U.S. Department of Energy 2004), and biomass yield is the most important factor determining biofuel production from a cropping system. Only a portion of biomass C is retained in the biofuel. In an ethanol conversion facility for corn stover, about one-third of the biomass C is converted to ethanol; the remainder of biomass C was emitted as combustion exhaust and fermentation-generated CO_2 (Sheehan et al. 2004). If this CO_2 could be captured, the impact of biofuels on reducing GHG_{net} would be even greater than described below. Similar proportions of biomass C were converted to ethanol in this study. A range of about 1,800 to 3,600L ethanol and biodiesel ha^{-1} yr^{-1} were produced and 1,200 to 2,400L gasoline and diesel displaced (Table 2). The amount of fossil fuel displaced is a measure of the energy security impacts of bioenergy cropping systems since it describes the quantity of fossil fuels that can be replaced by biofuels.

Greenhouse Gas Sinks

The GHG sinks from bioenergy crop production are the amount of fossil fuel (e.g., gasoline and diesel) displaced by the biofuel (e.g., ethanol and biodiesel) produced and C sequestered in the soil (ΔC_{system}). Displaced fossil fuel ($C_{displaced\ fossil\ fuel}$), a function of crop yield and biofuel conversion efficiency of the biomass source, was the largest GHG sink (Figure 1). The quantity of $C_{displaced\ fossil\ fuel}$ basically followed crop yield since there are only small differences in conversion efficiency between biomass sources (U.S. Department of Energy 2004). The largest differences in conversion efficiency are between grain and biomass, > 20% for corn grain and stover. System C (soil plus root C) was the second largest GHG sink (Figure 1). The ΔC_{system} was calculated as the difference between initial and final system C levels. Crops with higher soil C inputs, such as switchgrass and hybrid poplar, had higher equilibrium soil C levels at the end of the simulation. In general, perennial crops are expected to have higher soil C levels, and adding alfalfa to the corn•soybean rotation increased ΔC_{system}. As soil C levels reach equilibrium with the quantity of C input, ΔC_{system} approaches zero. Although ΔC_{system} will approach zero in the long term, differences in soil C concentration between cropping systems will remain. Soil properties also affect the equilibrium soil C level (Six et al. 2002). The amount of CO_2 equivalents emitted from fossil fuels used in feedstock transport to the biorefinery, conversion to biofuel, and subsequent distribution ($C_{feedstock\ conversion}$) was negative for some cropping systems and positive for others (Figure 1). Negative values result from an electricity credit at the conversion facility for combustion of the lignin fraction of biomass. Cropping systems with a smaller electricity credit are net consumers of energy for this component and have positive values. With higher biomass yields in switchgrass and hybrid poplar, more energy could be produced from the by-products than consumed during feedstock conversion.

Greenhouse Gas Sources

There were three sources of greenhouse gases quantified in this study: CO_2–C equivalents of N_2O emissions (C_{N_2O}) determined by DAYCENT, CO_2 emission from N fertilizer manufacture ($C_{N\ fertilizer}$), and fuel used by agricultural machinery for tillage, planting, fertilizer/pesticide application, harvesting, and drying corn grain ($C_{ag.\ machinery}$). The C_{N_2O} was the largest GHG source (Figure 1). The corn•soybean rotation had the highest C_{N_2O} followed by the corn•soybean•alfalfa rotation. Switchgrass had a lower C_{N_2O} than the corn rotations even though it had the highest mean annual N application rate, probably due to higher N use efficiency (see N leaching discussion below). Hybrid poplar had the lowest C_{N_2O}, but it also had the lowest N application rate, about one-third that of switchgrass. The $C_{N\ fertilizer}$ GHG source followed the mean annual N application rate over the simulation period (Figure 1). Although corn had the highest annual N application rate, the corn rotations were second to switchgrass in $C_{N\ fertilizer}$ because N was applied annually in the switchgrass cropping system, but only in two or three years out of the three- or eight-year corn rotation, respectively. The soybean and alfalfa legume crops contributed fixed N in the other years. Reducing synthetic N use is important to decreasing GHG emissions from cropping systems whether through use of legumes in the cropping systems, or more efficient N use strategies or crops. Perennial cropping systems can have lower agricultural machinery inputs than annual systems, thereby reducing $C_{ag.\ machinery}$ as seen in this study (Figure 1). Reducing inputs through reducing tillage and N fertilizer applications significantly reduced net GHG emissions. The relative contribution of management practices to $C_{ag.\ machinery}$ was about 20% for tillage, 30% toward propane for drying the corn grain, and 50% for planting, fertilizer/pesticide application, and harvesting.

The GHG_{net} combined all the GHG sinks and sources considered in this study. The most negative GHG_{net} was for switchgrass and hybrid poplar and less negative for the corn•soybean and then the corn•soybean•alfalfa rotation (Figure 2a). The $C_{displaced\ fossil\ fuel}$ was the dominant factor in determining GHG_{net}. The more negative GHG_{net} is for a biofuel cropping system, the greater the impact on reducing GHGs from fossil fuels. In general, switchgrass and hybrid poplar have higher yields, greater soil C sequestration, reduced GHG emission from feedstock conversion, reduced soil N_2O emissions, and reduced GHG emissions from N fertilizer manufacture and agricultural machinery operation. Carbon sequestration was higher with perennial crops. Even though the yields and consequently $C_{displaced\ fossil\ fuel}$ were lower for the corn•soybean•alfalfa rotation than the corn•soybean rotation, its ΔC_{system} was greater and $C_{feedstock\ conversion}$ lower, leading to lower GHG_{net}. This first scenario considered how using biofuels would reduce GHG_{net} compared to continuing to use fossil fuels (Figure 2a) and found that all cropping systems will reduce production of GHGs compared to continuing to use fossil fuels. But the question remained whether using biofuels will still lead to an increase in concentration of GHGs in the atmosphere. We considered both near-term and long-term scenarios. For the near-term scenario, $C_{displaced\ fossil\ fuel}$ was removed from GHG_{net}. With removal of $C_{displaced\ fossil\ fuel}$ from GHG_{net}, GHG_{net} was positive for crop rotations under conventional tillage but remained negative for all other cropping systems (Figure 2b). Therefore, the concentration of GHGs would still increase when using biofuel from the crop rotations under conventional tillage but would decrease under the other cropping systems. In the long term, when soils are C saturated under a given cropping system and further C sequestration no longer occurs, ΔC_{system} is zero. When both $C_{displaced\ fossil\ fuel}$ and ΔC_{system} were removed from GHG_{net}, GHG_{net} was only negative for the switchgrass and hybrid poplar (Figure 2c). So in the long term, when further storage of C in the soil does not occur, both the switchgrass and hybrid poplar bioenergy cropping systems will lead to lower atmospheric levels of GHGs.

Nitrate Leaching

Nitrate leaching did not correlate with application rate; cropping systems differed in N use efficiency. Although switchgrass has the highest mean annual N application rate over the simulation time, N leaching was similar to hybrid poplar with the lowest N application rate (Figure 3). The N leaching from the corn•soybean rotation was almost twice that from the corn•soybean•alfalfa rotation and more than four times greater than switchgrass and hybrid poplar.

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Table 1. Bioenergy crop yield, biofuel production, and fossil fuel displacement.

Yield	**Switchgrass**	**Corn Grain**†	**Corn Stover**†	**Soybean**†	**Alfalfa Stems**†	**Hybrid Poplar**
	---------- kg C $ha^{-1}yr^{-1}$ ----------					
Cropping system yield	3,943	2,291	923	945	1,088	2,972
	---------- L $ha^{-1}yr^{-1}$ ----------					
Biofuel yield‡	3,600	2,523	819	566	965	2,713
Fossil fuel displaced§	2,359	1,653	537	462	632	1,778

† Data presented were from the corn•soybean•alfalfa rotation (8-year rotation, 3 years corn, 1 year soybean, and 4 years alfalfa) under conventional tillage. Corn stover yield represents 50% of total stover produced. Alfalfa harvest represents 50% of total since only stems were used for biofuel.

‡ Ethanol was the biofuel produced from all crops except soybean, which was converted to biodiesel.

§ The fossil fuel displaced was either gasoline or diesel, depending on whether the biofuel produced was ethanol or biodiesel.

Table 2. Bioenergy cropping system yield, biofuel production, and fossil fuel displacement.

	Conventional Tillage			No-Till		
Yield	**Switchgrass**	**Corn• Soybean**†	**Corn• Soybean• Alfalfa**†	**Corn• Soybean**†	**Corn• Soybean• Alfalfa**†	**Hybrid Poplar**
	----- kg C $ha^{-1}yr^{-1}$ -----					
Cropping system yield	3,943	2,649	1,867	2,637	1,907	2,972
	----- kg C L^{-1} biofuel -----					
Quantity C displaced	0.75	0.33	0.59	0.39	0.61	0.90
	----- L $ha^{-1}yr^{-1}$ -----					
Biofuel yield‡	3,600	2,587	1,806	2,572	1,850	2,713
Fossil fuel displaced§	2,359	1,733	1,195	1,724	1,224	1,778

† The cropping system rotations were defined as follows: corn•soybean (3-year rotation, 2 years corn and 1 year soybean) and corn•soybean•alfalfa (8-year rotation, 3 years corn, 1 year soybean, and 4 years alfalfa). The corn yield included 50% of stover harvested and alfalfa harvest represents 50% of total since only stems were used for biofuel.

‡ Ethanol was the biofuel produced from all crops except soybean, which was converted to biodiesel.

§ The fossil fuel displaced was either gasoline or diesel, depending on whether the biofuel produced was ethanol or biodiesel.

Figure 1. Components of the net greenhouse gas profile from different bioenergy cropping systems.

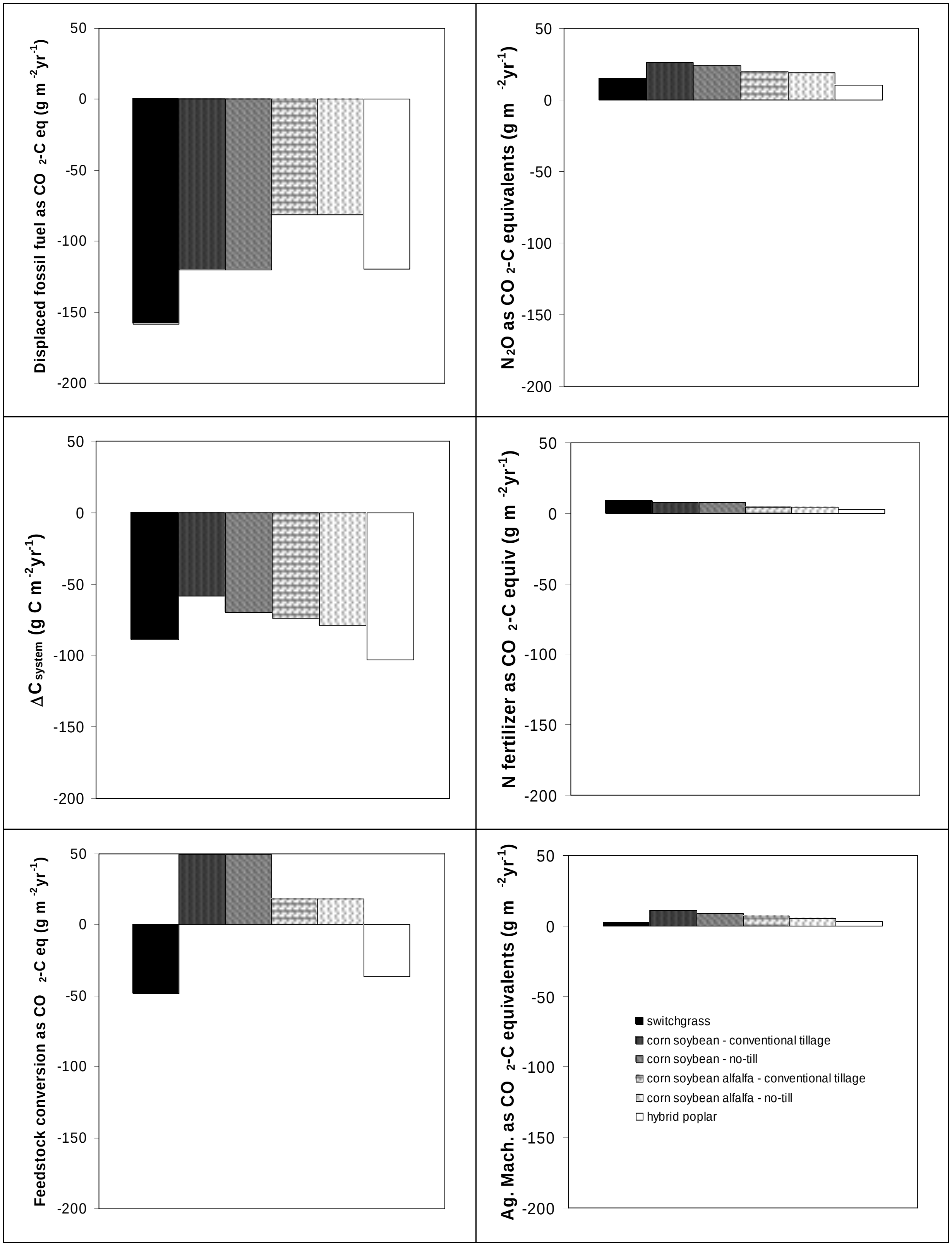
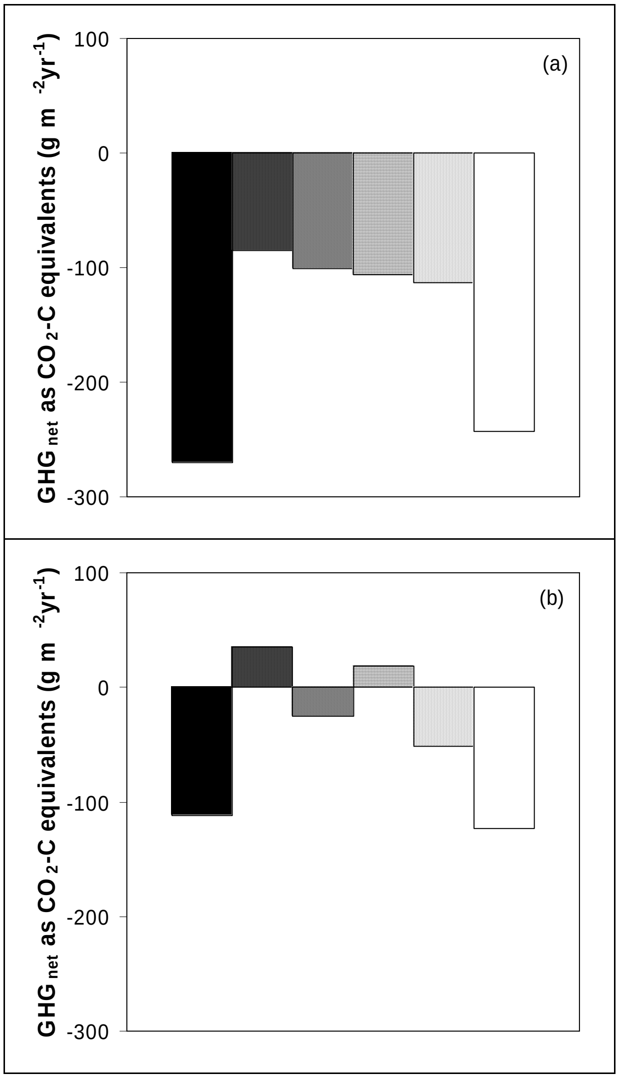


Figure 2. Net greenhouse gas (GHG_{net}) emissions from different bioenergy cropping systems. (a) GHG_{net} is the sum of displaced fossil fuel, Δ system C, feedstock conversion, N_2O emissions, fossil fuel used to produce N fertilizer, and fossil fuel used in agricultural machinery operations (b) GHG_{net} is the sum in (a) except displaced fossil fuels, and (c) GHG_{net} is the sum in (a) except displaced fossil fuels and Δ system C.



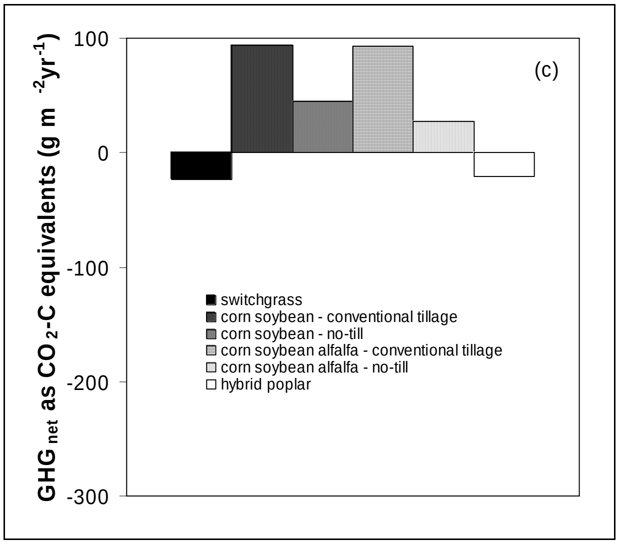
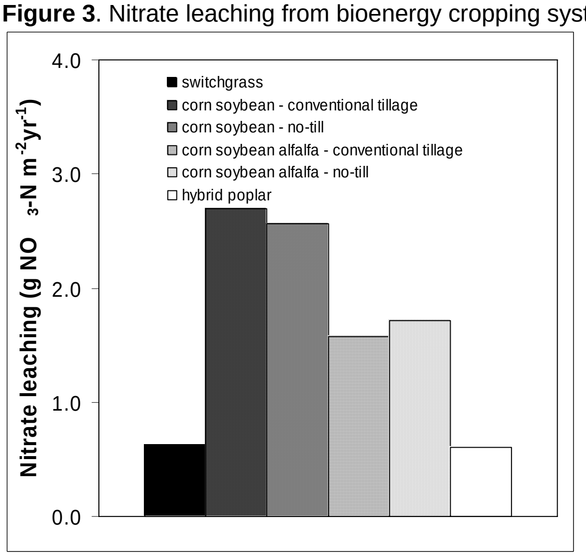


Figure 3. Nitrate leaching from bioenergy cropping systems.



Monday, October 4, 2004
SESSION II, SECTION A

Mine Reclamation to Karner Blue Butterfly Habitat with Warm-Season Grasses and Wildflowers

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Abstract

We are currently involved in the reclamation of a 210+-acre gravel mine to suitable habitat for the introduction of the endangered Karner blue butterfly (*Lycaeides melissa samuelis*) through the planting of warm-season grasses and associated wildflowers, trees, and shrubs. To our knowledge, a gravel mine has not been reclaimed to Karner blue butterfly habitat and a reintroduction attempted in the eastern United States. The ecology and biology of Karner blue butterflies are also amenable to such a reintroduction program. If this project is successful, we believe reclamation of gravel mines in the Karner blue butterfly's former range to warm-season grass savannahs is a way to increase the population of this endangered species, increase the amount of acres of warm-season grass ecosystems in the East, and increase the available habitat for other species that depend on these ecosystems as well.

Introduction

The Karner blue butterfly (*Lycaeides melissa samuelis*) is a federally endangered species that is intricately connected with the warm-season grassland ecosystems it persists in. The Karner blue butterfly differs from many other federally listed species in that it is geographically widespread. The butterfly's former range is within the Great Lakes and New England regions of the United States and Canada, mainly within the glaciated landscape. In many areas, such as the outwash regions, the glaciers left behind infertile, well-drained soils with coarse sands and gravels. Warm-season grasses, wild lupines (*Lupinus perennis*), the sole food source of Karner blue larvae, and other wildflowers colonized the glacial remnants creating unique open grasslands and savannah ecosystems. This led to the rise of endemic ecological communities such as the Pine Barrens of Glacial Lake Albany (Reschke 1990). These grasslands and savannahs were maintained by natural disturbance regimes of fires and tornadoes and also by fires set by Native Americans (Nuzzo 1998).

Similar to many other grassland species, the Karner blue is declining in numbers due to habitat fragmentation and development and by the destruction of its habitat by the cessation of the disturbance that maintained the open canopy needed for the continuance of the warm-season grassland plant community (USFWS 2003). Presently, the Karner blue butterfly is found in only a handful of sites across the Northeast and Midwest (see Figure 1). They have been extirpated in Maine, Vermont, Massachusetts, Pennsylvania, Ohio, Iowa, Illinois, and Ontario (USFWS 2003). Karners were formerly found across New York State, not just in the eastern-central portions where the only populations in New York are currently located. Shapiro (1974) found populations of Karner blue butterflies in Genesee, Jefferson, and Oneida counties in New York that have been extant since 2002. The remaining populations are highly scattered, and colonies rarely exceed 1,000 individuals. There are only a few colonies in the world with significantly more than 1,000 adult butterflies (USFWS 2003). One of these colonies exists at the Saratoga

County Airport near Albany, New York. There are other smaller colonies scattered around Albany, but some only contain as few as 10 individuals (K. O'Brien, NY DEC personal communication June 9, 2004 Wilton, NY; USFWS 2003).

Karner blue butterflies are adapted to living in small isolated colonies. Small populations that are geographically isolated are often considered metapopulations. However, such small and dispersed colonies are highly vulnerable to weather events and other disturbances such as drought, fires, and human activity (Saunders et al. 1991). One perturbation in the environment such as drought, flooding, introduction of a new species, or some other disturbance will eliminate a colony. This shoves the Karner blue closer to the brink of extinction, thus justifying a reintroduction and habitat restoration program throughout the Karner blue butterfly's former range.

Today the glaciated landscape that supported the Karner blue butterfly and its associated ecological communities are economically important. Many glaciated soils contain large amounts of sand and gravel that are an important commodity and component of the mining industry in the Northeast. The disturbance of the landscape by the mining activity leaves behind similar conditions when the glaciers that brought the gravel retreated. Traditionally, former mines are reclaimed to agricultural land or open space seeded with a conservation mix usually containing cool-season grasses and nonnative legumes. These areas serve less benefit to wildlife than warm-season grass species. The warm-season grasses are also better adapted to the site conditions. We believe reclaiming former gravel mines within the Karner blue butterfly's former range to warm-season grass savannahs, coupled with a reintroduction program, can restore the Karner blue butterfly populations to viable numbers within its former range. Restoring the warm-season grasslands will also benefit other grassland-dependent species in the eastern United Sates such as grasshopper sparrows (*Ammodramus savannarum*) and Henslow's sparrows (*Ammodramus henslowii*). This paper will describe the pilot project and rationale for Lafarge North America's Freedom Mine involving the building of a warm-season grass savannah and reintroducing Karner blue butterflies.

Methods

The Freedom Mine owned by Lafarge North America is currently an active gravel mine approximately 210 acres in size and expanding as time goes on. The gravel being harvested was deposited approximately 15,000 years ago during the late Wisconsin Glacial period (Tesmer 1975). Pollen studies of local wetlands reveal the presence of warm-season grasses in this area shortly after this glaciation (Miller 1973). Eaton and Schrot (1987) found numerous species of warm-season grasses that composed the post-glacial prairies throughout Cattaraugus County, New York. This area falls within the former range of the Karner blue as well. The remaining material left on the slopes and floor of the mine is unconsolidated clays, silts, sands, and small gravels with no organic matter and low fertility, and it is well drained. This area is well suited once again for warm-season grasses, wild lupines, and the associated ecological community.

We approached this project as an ecological restoration aimed at recreating an ecosystem that once occupied the region 15,000 years ago. A reference ecosystem was located and selected with a similar climate, regional location, and physical site conditions. This site was the grassland found in the aviation fields at the Saratoga County Airport in Saratoga, New York. This location contains the largest population of Karner blue butterflies in New York (K. O'Brien, NY DEC personal communication June 9, 2004 Wilton, NY; USFWS 2003). Although this site is the closest savannah with a sustainable population of butterflies, there are slight differences in the geomorphology and climate that do not allow for the exact replication of this ecosystem on our site. The Saratoga County Airport is a part of Glacial Lake Albany, a lake formed after the last glaciation which yielded an endemic plant community (Reschke 1990). There are some plants that are an integral part of the grassland found at Saratoga that are not found in western New York around our project site. To overcome this challenge, we studied the plant species composition of the Saratoga County Airport and the ecological role each plant portrayed and compared the occurrence of each species to its occurrence in western New York. If a species did not occur in our project region but in our reference ecosystem, we found a plant species that did occur in our region with the same ecological niche. Table 1 lists the plant species contained within our seed mix. Local ecotypes were selected when available, or suitable ecotypes were substituted when local ones were not.

Not only was the reference ecosystem used to determine species composition but also to establish goals of stem density and coverage. There are current efforts in New York to further describe optimal habitat conditions for Karners including lupine stem densities (K. O'Brien , NY DEC personal communication June 9, 2004 Wilton, NY). These efforts are not complete, but the USFWS final recovery plan for Karner blue butterfly (*Lycaeides melissa samuelis*) (2003) sets the criterion for lupine densities at a minimum of at least 500 stems per 0.25 ha or 0.62 acres. Our objective is to meet and exceed the plan's recommendation for areas larger than 5 hectares or 12.3 acres in size with an average of 0.1 lupine stem per square meter (1,000 per hectare or 405 per acre). Our overall goal is to have at least 85 to 90% ground coverage of the warm-season grasses and associated forbs including lupines. This goal also satisfies New York's Mined Land Reclamation Law as Amended 1991, Article 23, Title 27 of NYS Environmental Conservation Law, which requires a reclaimed mine to have at least 85% vegetative cover. We believe this standard is compatible with the restoration and reintroduction project because the reference ecosystem contains at least 85% vegetative coverage but not 100%. The open ground appears to be a part of the subhabitats the butterflies need. Not only does the bare soil contribute to subhabitats, wild lupine appears to germinate and establish at a higher rate in these areas (K. O'Brien, NY DEC personal communication June 9, 2004 Wilton, NY). The butterflies also need a diversity and abundance of other plants to meet their other biological facets. An extensive literature review of the biology and ecology of Karner blue butterflies was performed also to help in determining a suitable seed mixture, canopy cover, and other needs.

Karner Blue Butterfly Biology and Ecology

The life history of the Karner blue butterfly is quite complex. There are two broods annually, otherwise referred to as bivoltine. Eggs that have overwintered from the previous year hatch in April. Karners are monophagus; the larvae feed only on wild lupines (*Lupinus perennis*). The larvae feed and mature rapidly. Later stage instars and sometimes the eggs are tended by a wide variety of species of ants. The fate of the eggs cared for by ants is unknown (Lane and Andow 2003). Near the end of May, they pupate and the adult butterflies emerge and are in flight for the first two weeks of June when the lupines are in bloom. Adults live an average of five days (Haack 1993). The timing of pupation is correlated to the blooming of spring nectar flowers. Karner blue butterflies are considered nectar generalists, meaning they are not selective when choosing flowers to get nectar from (Grundel et al. 2000). However, they do tend to select flowers that are yellow or white (Grundel et al. 2000). In western New York, these flowers are wild strawberry (*Fragaria virginiana*), clovers (*Trifolium pretense* and *T.repens*), and dewberry (*Rubus flagellaris*). These needed herbs and their flowering times are an important consideration for our restoration and reintroduction project. Quality and quantity of nectar flowers can be a limiting factor for butterflies (Grundel et al. 2000). The females lay their eggs singly on lupine stems and leaves or sometimes on other substrate near lupines and then soon die. The summer eggs hatch in about a week and again are sometimes tended to by ants. The emerging larvae feed on the lupine leaves for about three weeks and pupate, and the second brood of adults emerges the second or third week of July. The nectar flowers available to them at this time in our region are butterfly weed (*Asclepias tubersosa*), beebalm (*Monarda didyma*), and wild bergamot (*Monarda fistulosa*). The summer brood females lay their eggs in the plant litter, on the base of the stems of little and/or big bluestem grasses (*Schizachyrium scoparius, Andropogon gerardii*), near lupines, or on the lupines themselves (Grundel et al. 1998a). The adults soon die, and the eggs overwinter. The success of the generations is highly dependent on their environment.

Butterflies have complex ecology. There are a few main ecological necessities identified by many authors (Lane and Andow 2003; USFWS 2003; Grundel et al. 1998a; Grundel et al. 200). These necessities have been characterized as the quantity and quality of nectar for adults, quantity and quality of forage for larvae, the presence and abundance of mutalistic ants, topography, and shade (Lane and Andow 2003; USFWS 2003). Karner blues require specific heterogeneous patches of canopy cover featuring patches of *Lupinus perennis* (Fabaceae), native warm-season grasses and forbs, and scattered trees and shrubs. The mixture of these plants creates distinctive microtopography and microclimate within the grasslands creating the distinct habitats for mating, oviposition (egg laying or breeding), and foraging or nectaring (Grundel et al. 1998a; Lane and Andow 2003). The interactions of these biotic and abiotic factors are crucial to the survival of the butterfly. Without any of those habitat facets in sufficient size and quality, it cannot maintain a sustainable population over the long term.

Recent research efforts have focused on understanding the Karner blue’s use of its habitat and associated subhabitats in order to set habitat restoration goals (Grundel et al. 1998a; Lane and Andow 2003; Grundel et al. 2000). Subhabitat is defined as a smaller constituent within a habitat. “Microhabitat” is a term also used to describe subhabitats. Lane and Andow (2003) make the case for subhabitat being a more appropriate term because canopy cover, a main subhabitat determinant, does not always occur on a small enough scale to be considered “micro.” For this reason, we are also using the term subhabitat as opposed to microhabitat.

For any reintroduction project to be successful, consideration of the species’ biology and ecology is essential (SER 2002). We needed to further our understanding of how the Karner blue butterfly uses its habitat to ensure we meet all of the butterfly’s needs when designing and building the restoration project. Lupines provide nourishment to growing larvae, while wildflowers provide nectar to the adults. Trees, shrubs, tall grasses, other forbs, and bare ground provide shade and cover to ovipositing females and microtopography for territorial males. Males tend to spend more time in the open canopy areas foraging, mating, and tending to their territories (Grundel et al. 1998a; Grundel 2000). Females tend to spend even amounts of time in closed, open, and partially shaded subhabitats but foraging and ovipositioning more often in partially shaded subhabitats (Grundel et al. 1998a; Lane and Andow 2003). Grundel et al. (1998b) found highest frequency of oviposition on lupine plants grown in areas with partial to full shade. Stem density of lupines was lower in these shaded areas compared to open areas of their study site. The authors also found these shade-grown plants produced lusher, plumper plants with higher water content. The lupines grown in shade or partially shaded habitats reached senescence and flowered at a later date than open-grown lupines. This allowed for higher nutrient and water content of the plants to nourish growing larvae more effectively. The authors speculated a trade-off exists between lupine quality and quantity. Lupines growing in open canopy are found more frequently, but the trade-off is balanced by preferential oviposition in less common, more nutritious shade-growing lupines. Lane and Andow (2003) had similar conclusions to explain their finding of higher larval survival from partially and fully shaded subhabitats.

The Lane and Andow (2003) study focused on the subhabitat use of the Karner blues and how the subhabitats affected the population dynamics of Karner blues. They found the subhabitats created by canopy heterogeneity have significant effects on Karner blue butterfly adult abundance, feeding, oviposition, and larval survival. The number of eggs per stem of lupine was greater in partially open canopied subhabitats than open or closed canopy subhabitats during the first flight. The number of eggs found on the lupine stems did not change with stem density or plant condition. Larval survival was higher in closed canopy subhabitats; however, pupae survival did not differ with subhabitat. This resulted in the greatest number of adults for both flights reared from partially closed canopy subhabitat. The authors concluded from the results of their study all three subhabitat types are critical to the long-term population sustainability of Karner blues. The subhabitat types offer refugium over variable environmental conditions and satisfy all of the biological needs of the butterfly.

To create the subhabitats needed to meet the ecological needs of the Karner blue butterflies, we will plant chinquapin oaks (*Quercus muehlenbergii*), white pines (*Pinus strobus*), sand cherries (*Prunus besseyi*), and viburnums (*Viburnum dentatum, V. lentago, V. trilobum*). These species will be planted so as to achieve a canopy cover of no more than 35%. We will not have sufficient tree and shrub growth for the first years of the restoration to create the optimal sun shade heterogeneity. However, the subhabitats also exist in a smaller scale in the herbaceous layer. The term microhabitat is appropriate at this scale. It may be the key component for continual sustainable population numbers at Saratoga County Airport where the aviation fields are kept free from trees and shrubs by frequent mowing (Andow et al. 1994b; Grundel et al. 1998).

Reintroduction

As of August 2003, there are four reintroduction efforts under way, not including this restoration and reintroduction project (USFWS 2003; S. Bonanno, The Nature Conservancy personal communication, e-mail September 7, 2004). Most of the reintroduction programs involve captive rearing Karner blue butterflies taken from a donor population before releasing them at the reintroduction site (USFWS 2003). We will follow the same protocols developed by VanLuven (1994).

Before we release Karner blue butterflies on our restored site, we will conduct a trial release with frosted elfins (*Callophrys irus*), an associate of Karner blue butterflies. Pending the success of this reintroduction, the Karner blue butterfly reintroduction will proceed. We chose frosted elfins because the larvae also use lupines (*Lupinus perennis*) as a host plant. This butterfly is classified as "threatened" in New York but not federally. It has similar habitat needs and similar lifestyle. Its range is from Maine to Texas. The frosted elfin differs from the Karner blue in that its larva will use other members of the Fabaceae family (*Baptisia tinctoria*, *B. australis*, *Crotalaria sagittalis*) as host plants, and this may be why this butterfly has higher population numbers. The frosted elfins will be taken from a donor site, reared in captivity to gain a significant population number, then released on site. The population will be monitored over approximately three to five years through population surveys. Habitat modifications will be made when appropriate to achieve the population goal. Our goal is to have a sustainable metapopulation of frosted elfins. A success criterion of a minimum of 3,000 individual frosted elfins has been set. This criterion is adopted from the USFWS Karner blue butterfly (*Lycaeides melissa samuelis*) Recovery Plan. The plan defines a viable metapopulation size of a minimum of 3,000 adults from the first brood. The same goal of 3,000 Karner blue butterfly adults to form a viable metapopulation has also been set.

Management

The primary threat to Karner blue butterflies is loss of habitat due to succession and development (USFWS 2003). Lafarge North America has made a commitment not to develop the property and protect it forever. The restored savannah located on the property will be divided into 10-acre habitat units. The mine is expanding every year, and the final mining plan is not complete; however, it is expected to encompass at least 200 acres after the cessation of mining. The 25-acre habitat units will assist in maintenance of the habitat. Different management techniques will be implemented to emulate natural disturbance and maintain early successional habitat. These techniques are periodic mowing as recommended by the NRCS Wildlife Habitat Incentive Program (WHIP) and prescribed burning.

Both techniques have advantages and disadvantages. Mowing a habitat unit every three to five years will impede the encroachment of shrubs and trees closing the canopy more than the desired amount. USFWS (2003) recommends mowing in late October after the first hard frost with the mower blade set 6 to 8 inches above the ground. The second brood adults tend to lay their eggs at the base of little and big bluestem grasses, on leaf litter, or low on lupine stems. Smallidge et al. (1996) did not find any correlation between mechanical mowing or tree removal and lupines or Karner blue butterfly mortalities. The disadvantage to mowing is that it is not a natural disturbance; therefore, it does not promote plant and insect biodiversity or nutrient cycling.

Fire is the preferred method of management because it promotes further integrity of the restored savannah ecosystem. Fire reduces built-up leaf litter, exposes bare soil which lupine regeneration and other associate plants successfully regenerate upon, reduces nitrogen levels in the soils, helps native adapted savannah plants outcompete undesirable species, and encourages higher soil temperatures (USFWS 2003). The Karner blue butterfly (*Lycaeides melissa samuelis*) Recovery Plan recommends prescribed burning of a habitat unit in New York every 6 to 18 years. This fire frequency is based on the historical fire records from the Albany Pine Bush (Givnish et al. 1988). Studies of disturbance frequencies of western New York and northern Pennsylvania are similar with these findings from east-central New York; therefore, we believe the 6 to 18 year burning frequency is appropriate for our site (White 1998). The disadvantages of fire are a socially unpopular management technique, egg mortality and other organism mortality, and a possibility of food reduction in the short term. Karner blue butterflies are adapted to disturbance-dependent ecosystems, and recolonization rates of habitat units are expected to be high due to the proximity of habitat units (within 300 meters) and lack of habitat barriers. Fire will most likely be used as the savannah ages and in alternation of mowing.

Conclusions

The biggest threat to biodiversity is loss of habitat. In the eastern United States, grassland and savannah habitat is rapidly lost to development and succession. Reclamation of former sand and gravel mines to grasslands and savannahs has great potential. In New York alone, there are approximately 119,790 acres of non-hydrocarbon mines (NYDEC 2002). The intentions of mined land reclamation laws are to ensure productive and beneficial end land uses. Reclaiming sand and gravel mines to warm-season grass savannahs is consistent with the spirit of mined lands reclamation laws while providing societal and ecological benefits.

The feasibility of restoring grasslands on former mines is realistic. The harsh physical conditions of the former mines are suited for warm-season grasses and associated wildflowers, trees, and animal communities. Wild lupine and the warm-season grasses can increase the amount of plant-available nitrogen in the soil, encourage mineral cycling, reduce surface runoff and soil erosion, add organic matter to the soil, encourage soil structure, and increase cation exchange capacity (Turvey and Smethhurst 1983). The ecosystem services provided by these plant communities overcome environmental challenges posed by these sites.

Glacial remnant areas contain sought-after mineral resources, consequently producing mine sites. However, the plant communities suitable for habitating these former mine sites are found in glacial remnant areas as well. These areas contain the mineral resource sought after, and mine sites are most likely within the same region. The post-glacial remnant ecosystems such as Glacial Lake Albany can serve as reference ecosystems for reclamation/restoration projects such as ours. Reference ecosystems containing species of concern such as the Karner blue butterfly are a resource of information about species composition and other habitat characteristics.

The Karner blue butterfly has a biology and ecology amenable to reintroduction but not without challenges. The butterfly is adapted to living in small isolated metapopulations. It only flies within a 300-meter radius and is dependent on ecosystem disturbance (Grundel et al. 1998a). The disturbance regime must be maintained in order to preserve the integrity of the savannah ecosystem and to achieve the goals of restoration. However, this is not always an easy task due to the socially unpopular view of fire and the labor and costs of mowing.

The Karner blue butterfly's lifestyle is also complex with many ecological facets. The adult butterflies differ in their preferences for feeding in subhabitat by sex. Females find cover from harassment of males in shaded and partially shaded subhabitats because males prefer to feed and patrol territories in open areas. Females also prefer to lay eggs (oviposition) in somewhat shaded subhabitats, although the only food source for larva, wild lupine, is shade intolerant. Most eggs are oviposited on lupines found in full sun, but this is linked to the increased abundance of lupines in these open areas. Larva survival is also higher in the closed and partially closed subhabitats, possibly explaining the preference of females to oviposition in these areas. The quality of the lupine forage in the closed and partially closed subhabitats is higher than that of the open-grown ones. This is most likely due to the lack of water stress during drought years, and these plants reached senescence and flowered at a later date, providing more nourishment to growing larva. Open, partially closed, and closed subhabitats together make up the essential habitat needed for the persistence of this species.

Changing the paradigm of mine land reclamation in the eastern United States from sloping and seeding with a standard conservation mix to warm-season grassland habitat restoration could yield highly beneficial results. Not only would organisms such as frosted elfins and Karner blue butterflies benefit, but so would other ailing species such as upland sandpipers (*Bartramia longicauda*) and Henslow, grasshopper, and Vesper sparrows (*Ammodramus henslowii, A. savannarum, Pooecetes gramineus*) through the creation of additional habitat. The increased number of these species saves them from peril, further protecting biodiversity.

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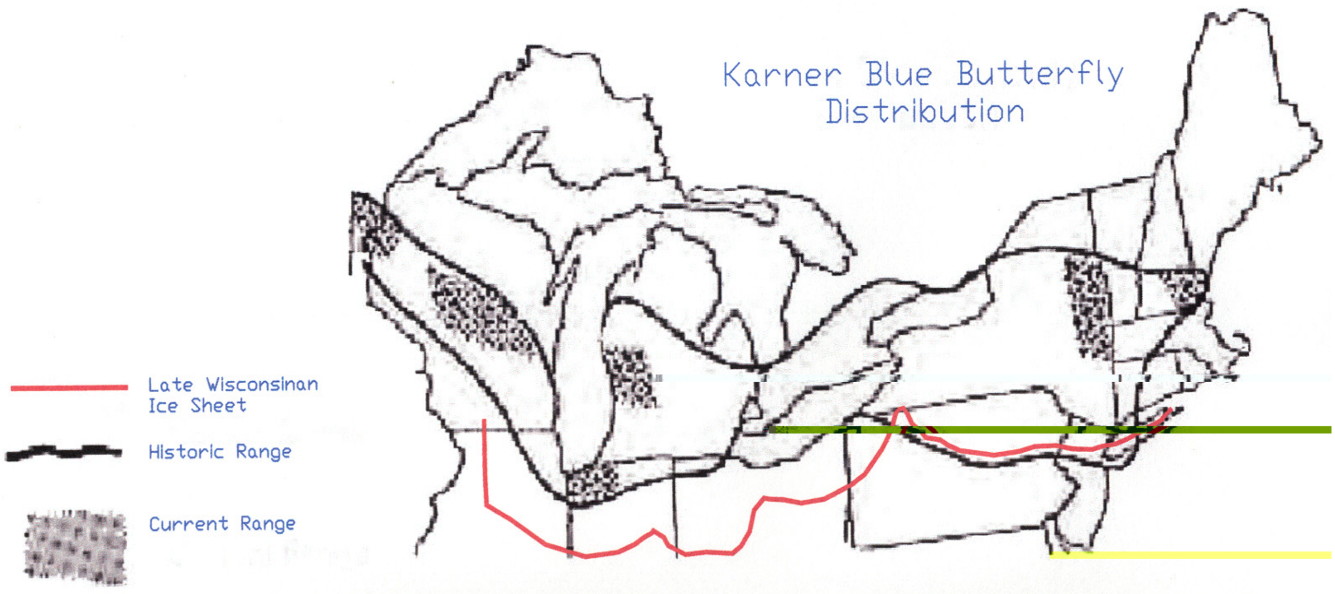
Figure 1



Adapted from Greenfeld and Fried. Date unknown.

Table 1. Freedom savannah restoration seed mixture.

Common Name	Scientific Name
Big bluestem	*Andropogon gerardii*
Little bluestem	*Schizachyrium scoparium*
Indiangrass	*Sorghastrum nutans*
Sideoats grama	*Bouteloua cartipendula*
Eastern gamagrass	*Tripacum dactyloides*
Switchgrass	*Panicum virgatum*
Butterfly milkweed	*Asclepias tuberosa*
Perennial lupine	*Lupinus perennis*
Roundhead lespedeza	*Lespedeza capitata*
Wild bergamot	*Monarda fistulosa*
Black-eyed susan	*Rudbeckia serotina*
Coltsfoot	*Tussilago farfara*
New England aster	*Aster novae-angliae*
Smooth aster	*Aster laevis*
Dogbane	*Apocynum androsaemifloium*
Wild strawberry	*Fragaria virginiana*
Red clover	*Trifolium pretense*
White clover	*Trifolium repens*
Wild indigo	*Baptisia tinctoria*

Breeding Bird Response to Native Warm-Season Grass Reestablishment in the Piedmont of Georgia

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Southeastern early-successional habitat has experienced large-scale conversion to high-intensity agriculture, pine plantations, and exotic grass pastures. Many native grasses have virtually been eliminated. Birds that depend on grassland communities for breeding and/or wintering habitat have experienced precipitous declines in the eastern United States. In order to evaluate native grass reestablishment as a management tool for grassland songbirds, we established 12 plots of 3 to 10 acres in the Piedmont region of Georgia. Six plots were forest openings within a loblolly pine forest landscape. Six plots were fields within an open agricultural landscape. Within each landscape context, three experimental plots were planted with a combination of big bluestem, little bluestem, switchgrass, and indiangrass during spring 2002. Three control plots remained under the current management of annual mowing and periodic burning. Breeding bird use of experimental and control plots was monitored using constant effort mist netting, point counts, and transect surveys during spring 2002-2004. Vegetation measurements were made during spring 2002-2004 to evaluate success of native grass reestablishment and to quantify vegetative differences between control and experimental plots. Avian species richness in experimental and control plots remained similar from 2002-2004. Mist net capture rates were higher in control plots in 2002. In 2003 and 2004, capture rates were much higher in experimental plots. Grass cover increased from 2002-2003 (2004 data pending) in experimental plots but decreased in control plots. Plant species richness was similar in control and experimental plots in 2002 but higher in experimental plots in 2003. Data collected to date indicate that reestablished native grass fields may provide better habitat for breeding birds within the Piedmont of Georgia.

Grassland Breeding Bird Use of Managed Grasslands on the National Wildlife Refuges in the Northeast

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In the northeast United States, grassland breeding birds have experienced significant declines, as agricultural land has reverted to forest or been lost to development. A recent trend in management of the remaining grasslands has focused on restoration by planting warm-season grasses. The Fish and Wildlife Service, with support from NRCS, initiated a three-year study in 2001 to (1) examine what role National Wildlife Refuges could play in providing critical habitat for grassland breeding birds; (2) determine how the choice of dominant grass species (cool-season or warm-season) and management technique (mowing versus burning) affect vegetation structure; and (3) assess how vegetation structure, in turn, affects breeding grassland bird use. Three treatments were investigated: warm-season grass managed through burning and cool-season grass managed through mowing or burning. These treatments were applied to grassland fields of 12 to 16 ha at 13 northeastern refuges (UWFWS Region 5). The fields were monitored for one year pre-treatment and two years post-treatment with independent double-observer point counts and standard vegetation measurements. Preliminary results suggest that planted warm-season grass fields did not attract a demonstrably higher density of obligate grassland birds than their cool-season counterparts and that the burning treatment in warm-season grass fields produced only minor and short-lived beneficial effects, in terms of obligate grassland bird density, vegetation density, and grass cover. However, patterns of response by grassland birds and vegetation variables varied considerably by refuge. Study results will be used to set management priorities and recommend management strategies at northeastern refuges and will also inform NRCS technical specialists administering USDA conservation projects involving grassland restoration on private lands in the region.

Use of Herbicides to Restore Native Grasslands

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We implemented two field research studies throughout Kentucky during the spring of 2001 and 2003 to determine the efficacy of using herbicides to remove tall fescue (*Festuca arundinacea*) from native grasslands dominated by warm-season grasses. The second objective was to evaluate which broadleaf species resisted the effects of 0.2 kg ai/ha imazapic and 0.03 kg ai/ha sulfosulfuron. The first study was a randomized-block experiment implemented at four sites in the outer Bluegrass and Mississippian Plateau region of Kentucky. We evaluated the use of 0.21 kg ai/ha clethodim and 0.21 kg ai/ha imazapic against an untreated control in 0.1 ha treatment plots that were approximately 50% native warm-season grasses and 50% tall fescue. A methylated seed oil surfactant at 2.3L/ha and 28-0-0 liquid fertilizer were included with all herbicides following manufacturer's recommendations. All herbicides were sprayed with a Demco™ spray unit delivering a spray volume of 187 L/ha at 414 kPa through Tee-Jet 8003 flat fan nozzles attached to an all-terrain vehicle driven at a constant speed of 2 to 3 kph. The herbicides were applied at two different time periods, one in late March and the second in mid-April. The second study evaluated the use of 0.2 kg ai/ha clethodim, 0.21 kg imazapic ai/ha, and 0.03 ai/ha sulfosulfuron against an untreated control in a completely randomized experiment at 14 locations representing most of the physiographic regions across Kentucky. Individual treatment plots were 3 x 10 m, and the herbicide was applied with a backpack sprayer delivering 187 L/ha at 414 kPa through Tee-Jet 11002 flat fan nozzles while walking at a constant rate of 2 to 3 kph. In the first study, both the clethodim- and imazapic-treated plots worked at removing the tall fescue irrespective of the spraying date. The amount of tall fescue was reduced from an average of 42.5% to less than 1% in all the treatment plots irrespective of the herbicide used. By the end of the second year, the percent fescue began increasing in the clethodim-treated plots and not the imazapic-treated plots. The NWSG responded to the herbicide treatments and was increased in all plots except the plots sprayed with clethodim in April. The imazapic plots had higher percent NWSG cover than the clethodim plots irrespective of time of herbicide application and averaged 41.8, 25.8, 52.8, and 55% in the early and late clethodim plots and the early and late imazapic plots, respectively. The percent tall fescue in the pre-treatment plots from the second study ranged from 25 to 70%, and the NWSG percent ranged from 40 to 50%. Total vegetative cover averaged across all 14 sites was 92.8%, and tall fescue cover averaged 45.9%. The mean cover by the NWSG was 39.6% with an average species richness of 6.1. As expected, all three herbicides provided substantial efficacy in killing tall fescue. The average percent tall fescue was 7.8, 1.2, and 3.8% in the clethodim, imazapic, and sulfosulfuron plots, respectively. The percent cover in the imazapic and sulfosulfuron plots was higher than the clethodim plots and averaged 74.6, 60.5, and 39.2%, respectively. The amount of bare ground was similar between treatments and averaged between 20.5 to 29.4%. Species richness was also similar, although the clethodim plots had a higher average number of species. Typical groups of broadleaf plants or wildflowers that appeared to resist the effectiveness of the herbicides were typically in the composite or legume family. Managers should proceed with caution because in some cases, invasive exotic species like crown vetch or sweet clover invaded plots where the fescue was eliminated. This information shows that herbicides can be used to restore native grasslands, but more information is needed to determine which additional species of broadleaf plants or wildflowers resist the effects of various herbicides.

Monday, October 4, 2004
SESSION II, SECTION B

Piedmont Prairies and a Partnership: Partners for Fish and Wildlife Program, U.S. Fish and Wildlife Service

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Introduction

In the spring of 2001, conservation professionals met at Pee Dee National Wildlife Refuge, located in Ansonville, North Carolina, to start what is known today as the Piedmont Prairie Partnership. To “jump start” this working group, a $10,000 grant from the U.S. Fish and Wildlife Service’s (Service) Partners for Fish and Wildlife Program was made available to restore native, remnant Piedmont prairies. To accomplish this objective, it was necessary to have an informational/educational meeting and develop a partnership. The purpose of the meeting was to gather working professionals to determine common goals and objectives and to learn where the highest priority areas are for rare species protection and restoration. The Piedmont Prairie Partnership was started.

Today, the partnership has evolved with the help of the following participants: private landowners, North Carolina Plant Conservation Program, North Carolina Botanical Garden, North Carolina Zoo, North Carolina Wildlife Resources Commission, North Carolina Natural Heritage Program, North Carolina Cooperative Extension Service, North Carolina Forest Service, North Carolina Museum of Natural Sciences, The Nature Conservancy, Natural Resources Conservation Service (NRCS), NRCS Plant Materials Program, Quail Unlimited, The Land Trust for Central North Carolina, Catawba Lands Conservancy, Sandhill Area Land Trust, Piedmont Land Conservancy, Environmental Impact RC&D, Mitchell River Coalition, University of North Carolina at Charlotte, North Carolina State University Water Quality Group, Surry Community College, Habitat Assessment and Restoration Program Inc. (HARP Inc.), local Soil and Water Conservation Districts, Town of Troy, Town Creek Indian Mound, Mecklenburg County Park and Recreation Department, Crowders Mountain State Park, Environmental Defense, Southern Environmental Law Center, and the U.S. Fish and Wildlife Service.

In spring of 2004, a common goal and seven of the following objectives were agreed upon. The group also agreed to formalize partnership in a Memorandum of Understanding.

Goal: To restore native, remnant Piedmont prairies within its historic range in North Carolina and South Carolina.

Objectives:
1) Restore, protect, and identify highest priority sites.
2) Strive to down list and recover the federally endangered Schweinitz's sunflower and smooth coneflower; provide refuge for other rare listed flora and fauna.
3) Maintain an educational component and share information on latest restoration techniques.
4) Continue to seek funding sources and work together as a partnership.
5) Encourage and maintain research and monitoring of Piedmont Prairies.
6) Collect, propagate, and maintain local ecotypes of native seed sources in the region for restoration and enhancement.
7) Provide wildlife habitat for priority species of concern.

Piedmont Prairies

"From 1540 to 1750, European explorers and traders in the Piedmont region of North and South Carolina reported many prairie-like openings. These unforested areas, which they called 'prairies,' 'savannahs,' 'plains,' or 'old fields,' ranged up to 40 km across" (Barden, 1997). Dr. Lawrence S. Barden further summarized information from Rostlund (1957) on the historical evidence of Piedmont prairies in the southeast United States and concluded they were ubiquitous. Barden focused on prairie landscapes of the Carolina Piedmont region at the time of European-American exploration and settlement. He revealed by historical and meteorological evidence that these prairies were primarily the products of Native American burning and agriculture. In the 1500s, early explorers Hernando de Soto and Juan Pardo explored the Piedmont region of South and North Carolina. Journals revealed "very large and good plains ... clear land ... beautiful plains" in the Carolina Piedmont, including one just south of the Charlotte area" (Rostlund 1957, Hudson 1990).

"Piedmont Prairie" is a name professionals have used to describe a prairie community that occurs in the physiographic region in the entire U.S. Piedmont, from Virginia to Alabama. They contain similar characteristic vegetative prairie species and impermeable soils. Piedmont prairies have also been called mafic natural areas, grasslands, savannahs, and early successional habitat.

The North Carolina Natural Heritage Program classifies the natural communities Diabase Glades and Xeric Hardpan Forests as "prairie-like" openings or grassy woodlands. Today, Shafale describes Diabase Glades as open communities of mixed physiognomy, with patches of herb, shrub, and stunted tree dominance, sharing species both with other mafic and outcrop rock communities, occurring on level, shallow soils over diabase or gabbro, with some exposure of bedrock kept open by the shallowness of the soil.

A Xeric Hardpan Forest occurs on "…upland flats and gentle slopes with an impermeable clay subsoil but which do not pond water for extended periods. Most commonly occurs on mafic rocks" (Schafale and Weakley, 1990). Schafale further describes, "Under current conditions, they tend to be somewhat open forests of post oak, but with some fire would likely range from open post oak savannahs with grassy herb layers, to nearly treeless prairies." To distinguish these two community types, Schafale explains that Diabase Glades are rock outcrop communities, on extreme sites, versus Xeric Hardpan Forests that are less extreme communities found within shallow soils. Both are fire-dependent ecosystems.

Piedmont Longleaf Pine Forests are also associated with prairie species. This rare community is known only from the eastern Piedmont adjacent to the Sandhills, in Moore, Montgomery, and Anson counties in North Carolina. Also, "Ashe and Pinchot (1897) described a transitional forest of *Pinus palustris* with various dry oaks in Nash, Wake, Montgomery, Northhampton, and Halifax counties that might have been this type" (Schafale and Weakley, 1990). They describe in its natural state that "openings are apparently maintained by the extreme shallowness and dryness of the soils, natural disturbance, particularly fire." The reintroduction of fire or minimal disturbance (creation of openings) into the Uwharrie National Forest in Montgomery County has allowed some rare native plants, including the federally endangered Schweinitz's sunflower (*Helianthus schweinitzii*), to reappear in this ecosystem. The presence of longleaf (*Pinus palustris*) and shortleaf pine (*Pinus echinata*), warm-season grasses, big bluestem (*Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*), sunflowers (Helianthus spp.), huckleberry (Gaylussacia spp.), and blueberry (Vaccinium spp.) shrubs indicate these areas had an open canopies and "flatwoods-like" structure within this fire-adapted community.

Importantly, Shafale and Weakley note that the dynamics of the natural structure of these communities are uncertain and poorly known. Professionals agree prairie-like remnants are rare communities of concern, worthy of protection, and should be targeted for restoration. Example sites to look for would retain prairie herbaceous flora within an undisturbed, old pastured, or cutover Xeric Hardpan Forest. Also look for a Piedmont Longleaf Pine Forest, or open, disturbed, successional woodlands with the same companion flora. Two good tools to search for remnant sites are soil surveys and geologic maps. Diabase glade remnants are associated with diabase and gabbro rocks. The underlying rock formation is mafic (containing minerals with high proportions of magnesium and iron) bedrock forming diabase dikes and sills. Mafic-associated soils are formed from these parent rock materials. Areas may be distinguished and identified within a soil survey with ground-truthing of the community type if possible. In North Carolina, known rare examples are South Butner Diabase Glade and Picture Creek Diabase Barrens in

Granville County, and Penny's Bend/Eno River Bluffs in Durham County. In York County, South Carolina, the State Heritage Trust Program protects the rare Rock Hill Blackjack Heritage Preserve.

Companion Prairie Species

Piedmont prairies contain a whole suite of native rare plants and provide habitat for wildlife such as neotropical migratory songbirds, game birds, and mammals. In 2002, researchers documented results of a five-year study on the vascular flora of six sites, of which two are considered to be remnant. A collection of 548 species was inventoried, and those with no association to Piedmont prairies were discarded: nonnative, woodland, and wetland species (Davis et al. 2002). Davis compiled a list of 277 species of vascular plants representative of the Piedmont prairie community. He noted glades were probably dominated by grasses, forbs such as asters, goldenrods, beggar's-lice, bush clovers, and sunflowers.

Table 1. Listed rare vascular plant species associated with Piedmont prairies and associated communities (not all inclusive).

Common Name	Scientific Name	Status
Schweinitz's sunflower	*Helianthus schweinitzii*	Federally Endangered
Smooth coneflower	*Echinacea laevigata*	Federally Endangered
Georgia aster	*Symphyotrichum georgianum*	Federal Species of Concern
Carolina bird's-foot trefoil	*Lotus helleri*	Federal Species of Concern
Tall larkspur	*Delphinium exaltatum*	Federal Species of Concern
Butner Barbara's buttons	Marshallia sp	Federal Species of Concern
Heller's rabbit tobacco	*Gnaphalium helleri*	Significantly rare–Proposed
Carolina thistle	*Cirsium carolinianus*	Significantly rare–Proposed
Sessile tick-trefoil	*Desmodium sessilifolium*	Significantly rare–Proposed
Carolina thistle	*Cirsium carolinianum*	Significantly rare–Proposed
Thick-pod white wild indigo	*Baptisia alba*	Significantly rare–Proposed
Thin-pod white wild indigo	*Baptisia albescens*	Significantly rare–Proposed
Smooth sunflower	*Helianthus laevigatus*	Significantly rare–Proposed
Earle's blazing star	*Liatris squarrulosa*	Significantly rare–Proposed
Southeastern bold goldenrod	*Solidago rigida ssp glabrata*	Significantly rare–Proposed
Prairie dock	*Silphium terebinthinaceum*	Significantly rare–Proposed
Glade wild quinine	*Parthenium auriculatum*	Significantly rare–Threatened

Other associated species found in prairies are several of the native warm-season grasses. Davis lists 33 grass species. To name a few, you may find indiangrass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), the less common big bluestem (*Andropogon gerardii*), gamagrass (*Tripsacum dactyloides*), switchgrass (*Panicum virgatum*), and broomsedge (*Andropogon virginicus*).

The following is a primary, not complete, forb list of desirable native prairie species to use as a guide and goal for restoration.

Table 2. Desirable native Piedmont Prairie species.

Common Name	*Botanical Name*
Butterfly milk weed	*Asclepias tuberosa*
Purple coneflower	*Echinacea purpurea*
Black-eyed susan	*Rudbeckia hirta*
Blazing stars	*Liatris (spicata, squarrosa, aspera)*
Golden rods	*Solidagos (odora, rigida)*

Table 2. Desirable native Piedmont Prairie species.

Common Name	***Botanical Name***
Swamp sunflower	*Helianthus angustifolius*
Purple-disk sunflower	*Helianthus atrorubens*
Tick seed	*Bidens aristosa*
Late purple aster	*Aster patens*
Toothed rosinweed (Chatham Co.)	*Silphium asteriscus*
Kidneyleaf rosinweed (Chatham Co.)	*Silphium compositum*
Three-leaved rosinweed (Chatham Co.)	*Silphium trifoliatum*
Greater tickseed	*Coreopsis major*
Calliopsis or golden tickseed	*Coreopsis tinctoria*
Whorled coreopsis	*Coreopsis verticillata*
Lance leafed tickseed	*Coreopsis lanceolata*
Joe Pye weed	*Eupatorium fistulosum*
Evening primrose	*Oenothera biennis*
Wild quinine	*Parthenium integrifolium*
Rattlesnake master	*Eryngium yuccifolium*
Cardinal flower	*Lobelia cardinalis*
Atamasco lily	*Zephyranthes atamasco*

The following list of priority bird species supported by prairies is based on the North Carolina Partners in Flight and the Partners in Flight Southern Piedmont Bird Conservation Plan.

Table 3. North Carolina Partners in Flight priority bird species associated with prairie/grassland, shrub-scrub, and savanna habitats (not all inclusive).

Prairie/Grassland	**Shrub-Scrub**	**Pine Savanna**
Henslow's sparrow	Prairie warbler	Red-cockaded woodpecker
Bachman's sparrow	American woodcock	Bachman's sparrow
Northern bobwhite	Northern bobwhite	Brown-headed nuthatch
Loggerhead shrike	Field sparrow	Henslow's sparrow
Short-eared owl (winter)	Eastern towhee	Northern bobwhite
Barn owl	Orchard oriole	Summer tanager
Northern harrier (winter)	Yellow-breasted chat	American kestrel
Grasshopper sparrow	Gray catbird	Red-headed woodpecker
Eastern kingbird	Common yellowthroat	Northern flicker
Eastern meadowlark	Brown thrasher	Chuck will's widow
Sedge wren (winter)	White-eyed vireo	Whip-poor-will
Dickcissel	Willow flycatcher	
Bobolink (migrant)	Vesper sparrow (winter)	
Horned lark (winter)	Loggerhead shrike	
	Barn owl	

Threats

Threats to prairies are development, noncompatible management practices, invasive species, fragmentation, and fire suppression. The I-40 and I-85 highway corridors are known in this region as a corridor of rapid development. Between the 1980 and 1990 censuses, 15 North Carolina and South Carolina counties that comprise the Charlotte region grew by 15.5 percent, and the area's populations expanded to more than 1.6 million people. Between 1990 and 1996, the Charlotte region's population jumped by 10.2 percent or nearly 200,000 residents. Another 5.3 percent growth was estimated between 1996 and 2000 and 10.6 percent between 2000 and 2010 (UNC Charlotte, Urban Institute, 1998).

Noncompatible management practices that threaten prairies are primarily the lack of disturbance, such as burning and mowing. There are certain times in the year disturbance should be done depending on the restoration need, wildlife compatibility, and seed production. Historically, wildfires naturally burned the landscape and fulfilled an important ecological role for prairies and savannahs because of fire dependency. Today, managers must plan and conduct prescribed fire to reintroduce this important component back into the ecosystem. Prescribed fire has become increasingly difficult to accomplish because of wildland-urban interface and liability issues. Invasive, nonnative species are one of the greatest threats to natural ecosystems. Invasive species displace and outcompete native plants.

Conservation Strategies

The Piedmont Prairie Partnership conservation strategies are to identify high-priority sites, support natural heritage inventories of the Southern Piedmont, seek funding for habitat restoration, and provide permanent land protection with conservation easements or fee title land acquisition. High-priority sites are ranked by listed species, recovery goals for listed species, location of the site, and the willingness of the cooperator or landowner to manage the site in some type of agreement.

Restoration, recovery, enhancement, and creation of prairie habitats may be supported through the Service’s Partners for Fish and Wildlife program. The Service also allocates endangered species funding for development of a restoration, management, prescribed burn, and monitoring plans for this rare community. Other programs that offer funding for restoration, enhancement, and creation of prairies are the Natural Resources Conservation Service Farm Bill Programs: Environmental Quality Incentives Program (EQIP), Wildlife Habitat Incentives Program (WHIP), and the new Grasslands Reserve Program. The North Carolina Wildlife Resources Commission offers the Cooperative Upland-Habitat Restoration and Enhancement (CURE) program within focus areas of North Carolina.

One of the objectives of the partnership is to share technical expertise on current restoration and management techniques. They include burning, mowing, thinning, girdling, applying herbicides, and planting or transplanting native species. Other strategies that may benefit Piedmont prairies include developing propagation techniques (establishing production plots), conducting workshops, and sharing research and monitoring information. Currently, the focus has been on acquiring restoration equipment such as grass drills and harvesting equipment. Establishment of native warm-season grasses is more successful if you have the right equipment to do the job, depending on your goals. In addition, the partnership is focusing on utilizing local genotypes and developing a native seed source for North Carolina. For our geographic area, Carthage switchgrass (*Panicum virgatum*) is the only species currently available. Although it was not documented from any of the six sites studied by Davis, switchgrass is native to North Carolina and is generally considered a Piedmont prairie species.

Once restoration has taken place, it is important to maintain the site in a prairie or savannah-like state by prescribed fire (preferably) or by mowing, in order not to quickly lose the site to succession.

Prairie Sites

The North Carolina Natural Heritage Program prepared a “prairie-like Piedmont woodlands” occurrence map in 2001 that includes Piedmont Longleaf Pine Forest, Xeric Hardpan Forest, and Diabase Glades. The Service is working with the North Carolina Natural

Heritage Program to obtain a list of high-priority sites for the partnership to review for restoration, management, and protection. With this information, a status survey may be conducted to determine current land use, presence of rare species, and prioritization for restoration and protection.

A "Status Survey and Protection Prioritization of Schweinitz's Sunflower" was conducted under a Service grant in 2002 by Moni Bates, consulting botanist. This study did not include all known prairie sites that contain other threatened or endangered species. Most protected and unprotected populations of Schweinitz's sunflower in North Carolina and South Carolina were reviewed. The study also included searches for new populations in North Carolina. Seven new populations were located in the following five counties: one in Gaston, two in Rowan, one in Randolph, two in Davidson, and two in Anson.

A total of 98 sites were ranked for protection and restoration potential. A total of 87 sites were ranked for Right-of-Way (R-O-W) management. The R-O-W sites are important to manage because they currently or potentially serve as seed and plant material sources for restoration on adjacent or nearby preserves (Bates, 2003). Her results reveal there are nearly 80 sites in the North Carolina Natural Heritage Program's Biological Conservation Database for Schweinitz's sunflower. Six of these populations occur in natural or semi-natural habitat.

Bates and other biologists in the region have laid the foundation for recovery of Schweinitz's sunflower by protecting and managing 19 sites: 14 in North Carolina and five in South Carolina. In North Carolina, they include Latta Plantation, Shuffletown Prairie, Mineral Springs Prairie, McDowell Nature Preserve, McCoy Road, Pisgah Covered Bridge Road, Caraway Mountain, Purgatory Mountain, Okeewemee Woodland, Island Point, Winget Road, Rankin Farm, N.C. 24/27, and FSR-576 (U.S. Forest Service). In South Carolina, they include Brattonsville Prairie, I-77 (SCDOT), Banks Road, Rock Hill Blackjack Heritage Preserve, and Ann Springs Close Greenway. Of these, the sites that meet the criteria for down-listing the species were indicated.

Prior to the partnership, with the help of partners and the Partners for Fish and Wildlife program, the following sites were restored: Suther Prairie, Mineral Springs Prairie, and Dodge City Prairie. After the partnership formed in 2001, the Service, the North Carolina Plant Conservation Program, and its partners restored the following sites: Richmond County-Sharpe Piedmont Savannah/Grassland—85 acres; Mecklenburg County Park and Recreation Department-McDowell Nature Preserve Grassland Expansion—connecting and expanding small existing fields to a total of 150 acres of contiguous grasslands; Montgomery County-Okeewemee Woodland-North Carolina Plant Conservation Program—phase 1, restore 30 of 60 acres; and Montgomery County-Wysner Mountain—40 acres.

The Partners for Fish and Wildlife program is primarily designed to restore degraded habitats to benefit migratory birds, threatened or endangered species, or anadromous fish. NRCS, through the WHIP program, has helped Mecklenburg County Park and Recreation Department restore the remnants of Shuffletown Prairie, Winget Road, and McCoy Road. This program is designed to reverse decline of farmland-associated wildlife species by helping landowners with wildlife habitat improvements. It has provided funding for many acres of native grass restoration, which also benefits the farmer with hay production, while at the same time restoring prairies and wildlife habitat.

Conclusion

The Piedmont Prairie Partnership is a great working group that continues to grow. As members of the partnership share expertise, ideas, and resources, perhaps recovery goals for Schweinitz's sunflower and smooth coneflower will be met. Ecologically, if the rare communities are protected and managed, then rare flora and fauna indigenous of prairies will also certainly benefit from this cooperative effort. The best opportunities for restoration and management of Piedmont prairies is through a concerted effort with partners and, most importantly, the willingness of landowners to protect, restore, and manage these vanishing communities.

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Native Plants for National Parks: A Cooperative Plant Materials Program Between the USDI-National Park Service and the USDA-Natural Resources Conservation Service

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Since 1989, an interagency agreement between the National Park Service and the Natural Resources Conservation Service has led to an exchange of technical information and the development of park indigenous plant materials, new seed/plant propagation technologies, and revegetation methodologies for revegetation of highway and other construction projects.

The program provides assistance to national parks through NRCS Plant Materials Centers (PMC) to identify plant species needed; collect and process native seed; provide high-quality, custom-grown container plants and field production of native forb and grass seed from site-specific collections; ensure genetic integrity; and provide technical assistance on site preparation, plant establishment, weed control, seed collection, and processing.

In the past 12 years, the program has assisted 45 national parks with nearly 100 projects in cooperation with 12 Plant Materials Centers (PMC); tested more than 1,000 native species/ecotypes and developed successful propagation techniques for more than 700 species and produced approximately 29,000 PLS pounds of grass/forb seed and 720,000 tree/shrub seedlings.

In addition, computer tools such as guides to assist in development of seeding rate/mixtures and revegetation cost estimation have been developed. A manual that summarizes the propagation technology for more than 200 native species was published. These propagation protocols developed from research by the Park Service and PMCs have been placed on an interagency Web site (http://nativeplantnetwork.org) for access by nurseries, seed producers, and the general public.

USDA-NRCS Plant Materials Program's Contribution to Native Grass Technology

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USDA-NRCS Plant Materials Program has a long history of providing native grasses to support conservation needs. From forage production to dune and marsh revegetation to mine reclamation, NRCS has provided the technology to support these programs. This paper will review the accomplishments and benefits of the plant materials within the Eastern Region.

Introduction

Since the beginning of the Natural Resource Conservation Service, plant materials have been an important component of the agency. When the first plant nursery (plant materials centers were formerly called nurseries between 1935 and 1954) was established in the mid-1930s and the first cultivar of sideoats grama was released in 1940, plant materials became the backbone of using vegetative solutions to solve conservation problems.

As the mission of the agency has changed, so too has the plant materials technology supplied to the field. Since the first cultivar was released, more than 210 native grass or grass-like species have been provided as tools for the conservation effort.

Meeting Changing Priorities

In the 1980s, NRCS began to switch from its conventional funding methods to more program-based funding. This led to the Plant Materials Centers expanding from erosion control to plant solutions to improve water quality and wetland restoration. With the 1990s, the Plant Materials Centers continued to evolve, adding technology to aid in agroforestry, local ecotypes, streambank stabilization, the continued emphasis on wetlands, and conservation in urban areas. In addition, outreach to underserved and disadvantaged farmers became more important. In 2000, we are faced with more challenges, including air quality. The Plant Materials Program has risen and succeeded in all of these, even though the overall staff has decreased and emphasis for the conservation programs changes.

The current need in native plants for restoration and conservation often calls for local source ecotypes. This creates many challenges. Based on definition, local source can mean material found on site to material found within several miles or several hundred miles. For many species, finding a sufficient amount of collection material in the local area can be difficult. This can be very important if the restoration project is very large. In the eastern United States, native grasses are often expensive, in limited quantities as seed, and difficult to find. This leads to selections of improved plants to accomplish these functions. Plant Materials Centers and their products seek a middle ground when selecting new native grass releases. Releases must have the potential to be profitable in the commercial market. To accomplish this, PMCs carefully assemble and select plants to meet identified needs of the resource with the viability in the commercial market.

A dilemma in all of this is that NRCS is an agricultural agency. Our job is to produce plant materials that grow faster, with more nutrients, with less insect damage, under a variety of conditions. We also are a natural resources management agency, so we need native ecotypes that accomplish the job and are part of a plant community. We do not want a monoculture. Additionally, we also face the challenge of misuse of plant materials. The program provides seed to the commercial growers, most times explaining where the plant should be used. However, we cannot guarantee that is what happens.

Development of New Releases

Release categories used in the NRCS Plant Materials Program are defined by the Association of Official Seed Certifying Agencies (AOSCA). The traditional type of release is the cultivar. Cultivars are the most developed release material. The material is usually genetically uniform, and performance and adaptation of the cultivar has been well documented. Tested and selected types have had some genetic selection, and the materials may have undergone varying degrees of testing on planting sites. The material usually has greater genetic diversity than the cultivar, but the performance and adaptation of tested and selected classes of releases may not be fully investigated. Source-identified types are typically straight from the field and may have the most genetic diversity within the collection. There is usually no information developed on the performance and adaptation of source-identified releases beyond what can be inferred from the collection site.

When ecological restoration or enhancement is the goal of a planting project, locally collected source-identified plant materials are usually preferred because they are assumed to have a wide variety of genetic material that is adapted to the area around the planting site. For most conservation work, and in particular the stabilization of "highly stressed" critical areas, using source-identified class parent materials may be risky due to the lack of performance information and the material. When critical area stabilization is needed, such as work performed along streambanks and shorelines, it is necessary to stabilize the site so that excessive erosion control does not occur. In this case, cultivars are the best choice. In the case where plant materials are used for forage, cultivars specifically selected for improved nutrition and regrowth may outperform local unselected materials. The usual or middle-of-the-road projects include those for buffers and wildlife plantings.

Usually it is desirable to know that the plant materials are going to achieve the desired results, for example, produce food for wildlife or provide a vegetative buffer between developed land and a wetland. It is often not necessary or desirable to have highly selected materials or to know the entire range of performance and adaptation. In this case, selected and tested class releases are often the best suited. Most importantly, the designer needs to decide what the objective of the planting is and which plant materials are suited to meet that objective.

For years, one of the major challengers for eastern native warm-season grass production has been using material from midwestern sources. Finding local ecotype materials for conservation activities has been challenging. There are also very few species of cool-season native grasses from commercial sources. PMCs in the East, as well as many partners, are currently making collections of both cool-season and warm-season native grass species. Most of these are designed to be used in the general location of the collection point or the center. In that way, the center can release materials that are local to the project. Several of these may not have enough of a market for production by commercial growers but will supply the local conservation or restoration need.

Finding the Need and Filling It

Within the eastern half of the country, there are eight Plant Materials Centers that are working on this need. Let's examine some of the native grass products they have provided to the industry. The Big Flats New York PMC has released 'Niagara' big bluestem (*Andropogon gerardii*), which is superior to midwestern cultivars when grown in the East. It can be used for livestock forage in pastures and hayland. It is persistent, and productivity exceeds other big bluestem varieties. It is excellent for wildlife habitat, critical area seeding, and erosion control.

They have also developed 'Shelter' switchgrass (*Panicum virgatum*), a warm-season native, perennial sod-forming grass. The name "Shelter" reflects the ability of this grass to provide spring nesting cover for ground nesting birds and escape for wildlife. It has an upright form and stiff branches, even under snow. The Plant Materials Center is also evaluating a source-identified release of eastern gammagrass.

The Cape May PMC in New Jersey has released several species including 'Cape' American beachgrass (*Ammophila breviligulata*), which is the industry standard for frontal dune stabilization.

They have also developed 'Bayshore' smooth cordgrass (*Spartina alterniflora*). Smooth cordgrass is the dominant emergent grass species growing along tidal salt marshes of the Atlantic and Gulf coasts.

The center is also evaluating sources of big bluestem, little bluestem, and indiangrass.

The Beltsville PMC in Maryland has released selected species of switchgrass (*Panicum virgatum*) and is in the process of releasing indiangrass (*Sorghastrum nutans*) and bottlebrush grass (*Elymus hystrix*). They are evaluating Canada brome (*Bromus pubescens*), hairy wild rye (*Elymus villosus*), and Virginia wild rye (*Elymus virginicus*) for the mid-Atlantic and Piedmont regions. These are releases for general conservation use and wildlife habitat.

The Michigan PMC has released a source-identified material of big bluestem (*Andropogon gerardii*) for rotational grazing systems, switchgrass (*Panicum virgatum*), indiangrass (*Sorghastrum nutans*), and little bluestem (*Schizachyrium scoparium*). They are also evaluating prairie sandreed (*Calamovilfa longifolia*) for stabilization of Great Lakes Coastal areas, Canada brome (*Bromus pubescens*) for general conservation use and pasture, Canada wild rye (*Elymus canadensis*), bottlebrush grass (*Elymus hystrix*), and junegrass (*Koeleria macrantha*) for general conservation use.

The Georgia PMC has released a cultivar of ‘Americus’ indiangrass (*Sorghastrum nutans),* which is used for wildlife habitat, livestock forage, and conservation needs. This is the only cultivar in the Southeast and is drought tolerant.

The Florida PMC is evaluating releases of blue maidencane (*Amphicarpum purshii*) and chalky bluestem (*Andropogon glomeratus*). Both are recommended for use as forage and wetland restoration and to improve water quality. They are also evaluating lopsided indiangrass (*Sorghastrum secundum*), which is recommended for use in wildlife habitat improvement, rangeland improvement, and native grass community restoration. The Plant Materials Center is also evaluating source-identified switchgrass.

The Coffeeville, Mississippi, PMC has released the cultivar ‘Halifax’ maidencane (*Panicum hemitomon*), which is recommended for shoreline erosion control; a source-identified woolgrass (*Scirpus cyperinus*), which is recommended for constructed wetlands; and a cultivar ‘Highlander’ eastern gamagrass (*Tripsacum dactyloides*), which is recommended for forage and general conservation use.

In addition to native grasses, the Plant Materials Program is also actively producing plant technology for legumes and woody plants.

The scope and uses of plant materials in NRCS keep expanding. Currently we are partnering with the USFS and universities to develop techniques to mitigate air quality concerns. We also have Plant Materials Centers researching biofuels to help decrease our dependence on foreign sources of energy.

An economic analysis of the Plant Materials Program was completed several years ago and determined that for every $1.00 that is invested, there is a benefit of $6.00. All of the previously mentioned native grasses and the technology needed to establish and maintain them have been provided by the Plant Materials Program. In today’s economy, that is a good investment, especially as we continue to expand our mission.

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Native Grass Establishment Using the Farm Bill and Partnership in Kentucky

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Farm bill funding is currently the largest source of private landowner funding available for establishing native grasses. Since 1998, more than 60,000 acres of native grass have been established in Kentucky through farm bill programs. Through partnership, increased financial and technical assistance, staffing, education, and equipment have been key to improving acceptance and utilization of native grass as conservation cover, forage, and wildlife cover through farm bill programs. Active partner participation on the NRCS State Technical Committee and program subcommittees has also facilitated incorporation of native grass into all possible programs. A brief history of native grass use by program will be covered.

Also discussed will be the technical evolution of native grass plantings in Kentucky through farm bill programs. Initially, many plantings were slow to establish, with some failures due to unsuitable planting equipment or equipment operation, poor seedbed preparation, and/or competition control. Through training and improved planting equipment, and with the advent of increased herbicide options, native grass planting success has greatly improved. Today, due to such success in establishing native grasses, we are looking at options to slow grass establishment, improve stand diversity, and set back succession to improve habitat. Prescribed burning, strip discing, herbicide applications, and lower grass seeding rates with increased forb rates are successfully being used to improve stand diversity and set back succession of native grass stands established through farm bill programs.

Monday, October 4, 2004
SESSION III, SECTION A

Reproductive Biology Influences the Partitioning of Genetic Variation Within and Among Populations of Native Grasses

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Genetic variation was surveyed within and between native populations of little bluestem (*Schizachyrium scoparium* (Michx.) Nash [= Andropogon scoparius Michx.]) and Virginia wild rye (*Elymus virginicus* L.), using random amplified polymorphic DNA (RAPD) markers. The native populations of each species included collections from both northeastern and midwestern regions within the United States. Analysis of molecular variance (AMOVA) technique showed that little bluestem populations were highly variable within populations, whereas Virginia wild rye populations were relatively uniform within populations. Furthermore, when the two species were compared, an interesting relationship was observed between the genetic distance among populations and the geographic origin of the populations. Little bluestem exhibited a positive correlation, and thus its populations became more genetically different the further populations were separated by geographical distance. Virginia wild rye populations lacked such correlation, and thus populations between widely separated regions could exhibit genetic relationships that were, in some cases, more similar than populations within a region.

Partitioning of genetic variability within and among populations across regions is, in large part, a function of the breeding system of the species. Little bluestem possesses an open-pollinated, outcrossing breeding system, whereas Virginia wild rye is a self-pollinated, inbreeding species. Thus, the reproductive biology of native plants governs the genetic structure observed among populations within a species. As such, a species' reproductive biology is a vitally important parameter to consider when replenishing or replacing locally adapted gene pools.

Faulty Sexual Reproduction in Big Bluestem Populations in South Carolina

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Big bluestem (*Andropogon gerardii* Vitman) occurs as small, isolated populations in old field edges in the Piedmont of South Carolina. We collected seeds from several of these populations in Oconee County, South Carolina. These seedlots germinated very poorly in field plantings and in standard germination tests. Upon physical examination of seedlots, we discovered that most caryopses contained no filled seeds or severely shriveled seeds. Flowering

These data indicate that unsuccessful seed production in isolated populations arose from lack of outcrossing among the individuals in these populations. Wide genetic differences between isolated populations suggests the opportunity to increase viable seed production by building composite populations with plants from a large number of isolated populations.

Preliminary Progress Toward Reducing Seed Dormancy in Native Grasses

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Abstract

Big bluestem (*Andropogon gerardii* Vitman), indiangrass *(Sorghastrum nutans* [L.] Nash), and switchgrass (*Panicum virgatum* L.) possess seed dormancy contributing to extremely poor field establishment. Two classical breeding techniques, half-sib progeny test (HSPT) and phenotypic recurrent selection (PRS), were used to attempt to enhance germination by reducing seed dormancy in native populations adapted to the humid Southeast. Switchgrass mean germination increased from 4% in cycle 1 to 26% in cycle 2 (14 d totals) by implementing PRS. Big bluestem and indiangrass germination was extremely low (0.2 to 1.2% in 14 d) for all populations. Fungal infestations of the seed may have affected seed viability. In big bluestem, the HSPT resulted in a higher mean germination versus one cycle of PRS ($P = 0.019$). Mean germination percentages of indiangrass were not different from the original population following either breeding method ($P = 0.052$). Hopefully, additional cycles of PRS will improve mean germination. Populations from this research will eventually have potential for use in biomass production and pasture establishment, as well as prairie restoration.

Introduction

Big bluestem (*Andropogon gerardii* Vitman), indiangrass (*Sorghastrum nutans* [L.] Nash), and switchgrass (*Panicum virgatum* L.) are all perennial tall-grass prairie representatives native to North America (Weaver 1968). They have been produced as forage for greater than 50 years and are important in prairie restoration projects (Vogel 2000). A new application for switchgrass is a role in the production of biofuel, where vegetative material is converted into fuel for electricity (Sanderson et al. 1996). Producers interested in establishment of these grasses are typically faced with poor yields initially, as a substantial percentage of the seed fail to germinate. An important contributor to problems in establishment is seed dormancy. To offset the negative effects of dormancy, typically seed are substantially over-planted, stored for extended periods, or stratified. These alternatives vary in overall effectiveness, and a more reliable means of obtaining acceptable stands is required. The objective of this study was to implement traditional breeding techniques to attempt to reduce seed dormancy. Phenotypic recurrent selection (PRS) and half-sib progeny test (HSPT) were used toward creating a more domesticated crop with reliable initial stand yields.

Materials and Methods

Only PRS was used to improve switchgrass populations. The breeding program initiated with 900 kg of switchgrass seed, which were harvested from a crossing block at the Jamie L. Whitten Plant Materials Center (PMC) in the fall of 2001. The crossing block was comprised of 92 accessions collected across Mississippi and west Alabama by Joel Douglas and Janet Grabowski (at PMC). Screening for reduced dormancy began four months after seed harvest. Approximately 30,000 seed were randomly selected to represent each of six subsamples. Each subsample was distributed onto a stainless steel tray between two layers of germination paper and placed in a germinator (GR-371, Percival Scientific Inc., Boone, IA) set at an alternating temperature of 30°C light (16 h)/20°C dark (8 h). Seed were moistened with 590 ml of metylaxyl solution (0.1 ml/L). Germination was defined as radicle and/or coleoptile protrusion of 3 mm or greater. Seed that did not germinate in 4 d were discarded, and additional subsamples of seed were distributed onto the trays. Seedlings that germinated in 4 d or less were considered to possess reduced dormancy, retained, and eventually planted in an isolated crossing block located at the Mississippi State University Plant Science Research Center (Starkville, Mississippi). A total of 49 seedlings were collected as a result of the screening process to represent cycle 1 of PRS. Cycle 1 plants intercrossed via open pollination, seed was collected in November 2003, and seed was screened in the same manner as described above. Sixty seedlings that germinated in 4 d were retained and transplanted in spring 2003 to a second isolated crossing block (cycle 2). The plants comprising cycle 2 intercrossed, and the seed produced was screened to form cycle 3, which was also placed in a different isolated crossing block in March 2004. At least 400 m (0.25 mi) separates each cycle of selection to prevent pollen contamination by wind. This distance was found to be effective in pollen control of maize isolated populations (Luna et al. 2001). Germination tests of PRS cycle 1 and cycle 2 were compared using ANOVA and mean separation test (SAS Institute 1999).

The big bluestem and indiangrass germplasm for the PRS and HSPT breeding program originated from the Jamie L. Whitten Plant Materials Center (PMC) in Coffeeville, Mississippi. The PMC is located within an area of about 6 hectares, maintained as a prairie largely comprised of these native grasses and smaller subpopulations of several others. The seed source of the original planting is unknown. Approximately 160 crown divisions and corresponding OP seed from both indiangrass and big bluestem were transferred from the PMC to the Mississippi State University Animal Science Research Center in Starkville, Mississippi, by fall 2002. This established the mother plant (evaluation) nursery (MPN). Plants were chosen based on a visual estimate of superior biomass production. Seed were collected from each plant prior to crown divisions, maintaining the identity of the mother plant. Seed germination protocol was described previously. When possible, six subsamples of 100 seed represented each mother plant. Each subsample was contained in a Petri dish lined with one layer of germinating paper and moistened with 5 ml of metylaxyl solution (0.1 ml/L). Germination was recorded every 2 d for 14 d. The results of the germination test were used to determine elite parents of the HSPT. Elite parents were chosen based on the performance of the progeny; the plants producing seed with the greatest percent germination in the shortest amount of time were divided as clones from the MPN and placed together in an isolated location. There were 14 elite parents for big bluestem and 13 for indiangrass. Plants were maintained in 3.8 L black plastic pots.

Big bluestem and indiangrass PRS was initiated with the MPN seedlings from the germination test that germinated in ≤14 d. These were placed in an isolated crossing block representing cycle 1 of PRS (adjacent to the cycle 1 switchgrass). There were at least 50 individuals for each species in the PRS cycle 1 crossing block. In 2003, seed were collected and a synthetic composite was formed, with each plant having an equal representation in the combined seed lot.

A 14 d germination test was conducted from progeny of HSPT and PRS cycle 1. Results from germination tests of each of these breeding methods were compared using ANOVA and mean separation tests (SAS Institute 1999). Comparison of the mean germination achieved by each population will serve to measure the progress made toward reduced dormancy and will give an indication of the efficiency of each method. Individuals from cycle 1 intercrossed and the seed was collected in October 2003. Individuals that germinated in ≤14 d were transplanted to an isolated crossing block in March 2004 to represent cycle 2.

Following the initial 14 d germination test, seed from all crossing blocks were stratified to determine the percentage viable but dormant. Immediately following the initial screening, seed were placed in an incubator (SP-1254, Hoffman Manufacturing Co., Albany, OR) set at 4°C for 14 d. After this moist chilling treatment, seed were returned to the germinator (30°C light/20°C dark), and germination was recorded every two days for an additional 14 d. The regime of 14 d in cold treatment followed by 14 d in ideal temperatures was repeated at least four times to determine if extensive cold treatments were required to achieve further germination.

Results and Discussion

For this study, the most important comparison is germination percentage achieved during the first 14 d (pre-stratification). At 25.5%, mean germination of switchgrass PRS cycle 2 differed from 4.2% achieved from PRS cycle 1 ($p < 0.001$, Table 1). This represented a 6-fold increase in germination prior to stratification; PRS was effective in reducing switchgrass seed dormancy. PRS was also effective in reducing dormancy of other grasses, specifically kleingrass (*Panicum coloratum* L.; Tischler and Young 1987) and green needlegrass (*Stipa viridula* Trin.; Schaff and Rogler 1960). Future cycles are being developed with the intent to continue to increase mean germination percentage. Stratification did not improve mean germination for either switchgrass population. Mean germination decreased to 2.8% for PRS cycle 1 and 2.7% for cycle 2 after one stratification period (Table 1). Subsequent stratification did not continue to improve mean germination of new seedlings; new germination ceased following two stratification periods in both PRS cycle 1 and cycle 2. Previous research has shown stratification reduces seed dormancy (Emal and Conard 1973; Beckman et al. 1993). When stratification is ineffective in increasing mean germination, as seen here, it implies a reduction in seed dormancy. If seed dormancy were simply inherited, we would expect the additional individuals that germinate prior to stratification in PRS cycle 2 to be represented in the individuals that germinate following one period of stratification in PRS cycle 1. Based on the limitations of the current testing, it is not possible to determine if there is a shift in the frequency of alleles responsible for seed dormancy.

One cycle of PRS was not effective in reducing seed dormancy in big bluestem as measured by pre-stratification germination. Synthetic composite seed collected from the big bluestem MPN had a mean germination of 0.3%, which was similar to the mean of PRS cycle 1 at 0.2%, but both were lower than the mean of the HSPT at 1.2% ($p = 0.019$, Table 1). Though dormancy was significantly reduced in the HSPT as compared to the pre-stratification mean germination of the MPN, the increase was not great enough to warrant further development into a cultivar. Also, a substantial increase in germination following stratification (41.3%) indicates seed dormancy persists in the population. These findings are consistent with those of Vogel and

Pedersen (1993); although HSPT is useful in developing initial cultivars, it has not been successful in improving quantitative traits such as yield (Vogel and Pedersen 1993).The combined mean germination in the HSPT population before and after stratification was much higher than that of the MPN and PRS, indicating superior viability. This may have been a result of different production conditions; parents of the HSPT were maintained in containers near the greenhouse where it was easier to address water and nutrient requirements. Extended stratification did result in additional germination for both the big bluestem and indiangrass MPN, but germination percentages were extremely low overall (Table 1). Low germination percentages are due at least in part to fungal outbreaks on the leaves (rust, putatively identified as Helminthosporium sp.) and seed (putatively identified as bunt, Tilletia sp.; smut, Ustilago sp.; and ergot, Claviceps sp.).

Indiangrass seed dormancy was not reduced by either breeding method. Mean germination of both populations was similar to the MPN ($p = 0.561$, Table 1). As in big bluestem, there were fungal infestations on the leaves and seed, which contributed to low mean germination. All indiangrass populations showed increases in additional germination following stratification. The MPN had a mean germination of 0.2% prior to stratification, and 8.0% following 14 d of stratification. Additional germination continued to increase even after three periods of stratification. Mean germination from indiangrass PRS cycle 1 was 0.3% prior to stratification, 16.3% following the first period of stratification, and gradually declined with additional stratification periods. This is encouraging because less stratification was necessary to decrease germination of new seedlings versus the MPN. Longer periods of stratification may indicate that a greater degree of dormancy exists in the MPN population. If this is the case, then PRS is shifting the frequency of alleles in the population toward a reduced degree of seed dormancy. Although there was no mean germination prior to stratification in the 2003 indiangrass HSPT, seed did germinate following the first stratification period at 10.5% and following the second stratification period at 7.7%. Viability tests conducted on the seed lot were inconclusive on the extent of live seed present in the population. Flowering was not synchronous, which affected seed production and quality and possibly contributed to the lack of success in decreasing seed dormancy.

Selection for quantitative traits such as seed dormancy using classical breeding techniques is not a rapid process, especially if only one cycle can be completed per year. If initial germination is low and the majority of the seed are not viable, selection is all the more difficult, which was the case for big bluestem and indiangrass. With trace germination percentages, even if dormancy were absent in the population, establishment would still be low for these two species. Production conditions have significant effects on seed quality in these grasses. Although environmental conditions may positively or negatively affect seed production, additional research to attempt to reduce seed dormancy remains important in development of commercial cultivars that do not require a pre-treatment or extended storage. These cultivars would have application in numerous areas, including biomass production, wildlife habitat, and forage production.

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Table 1. Mean germination percentage of selected populations prior to and following stratification. There were six replications of 100 seed tested for all populations. Percentages represent 14 d totals.

	% Germination				
Population	**Pre-Strat.**	**1st Strat**	**2nd Strat**	**3rd Strat**	**4th Strat**
Big bluestem					
MPN	0.3 a*	2.8	2.5	1.0	0.8
Cycle 1 PRS	0.2 a	2.0	2.8	1.0	0.2
HSPT	1.2 b	41.3	18.7	1.0	0.8
Indiangrass					
MPN	0.2 a	8.0	9.0	13.5	0.0
Cycle 1 PRS	0.3 a	16.3	12.2	5.0	0.7
HSPT	0.0 a	10.5	7.7	1.8	0.7
Switchgrass					
Cycle 1 PRS	4.2 a'	2.8	0.3	0.0	0.0
Cycle 2 PRS	25.5 b	2.7	0.7	0.0	0.0

* Within populations, means followed by the same letter are not significantly different (α = 0.05).

Monday, October 4, 2004
SESSION III, SECTION B

Establishing and Maintaining Native Warm-Season Grasses on Mined Lands Dominated by Sericea Lespedeza

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Abstract

The Peabody Wildlife Management Area (PWMA) consists of coal surface mined lands and coal waste disposal sites varying in age from pre-law to current regulations. Established in 1995, the PWMA occupies 73,000 acres in Ohio, Muhlenberg, and Hopkins counties in Kentucky. Located in the physiographic area known as the Shawnee Hills, the PWMA is comprised of eight management units. The Homestead and Ken-Hopewell Units in Ohio County have been the focus of management efforts to change grasslands dominated by sericea lespedeza, Ky 31 fescue, and thistle to native warm-season grasses (NWSG). In 1997, a native grassland landscape restoration goal of 5,000 acres was established. Since that time, 2,754 acres of NWSG have been established. Management techniques have included installation of 20 miles of fire lanes, rotational fall and winter prescribed burning, repetitive multibrand herbicide spraying in spring and fall for two to three successive years, and varied planting rates and methods. Seeding rates have ranged from 6 to 12 lb/ac of pure live seed (PLS) using Truax Flex II no-till drills. Establishment of native forbs has met with marginal success due to reinfestation of NWSG fields by sericea lespedeza when fields are manipulated by ground disturbance such as discing. Broadleaf herbicides such as Garlon and Plateau have not been selective for residual suppression of germinating sericea in the soil bank. Field test plots using Vista and Escort XP herbicides are now being monitored for residual sericea suppression. Garlon and 2-4D mixtures have been very successful in thistle control. Quail Unlimited and U.S. Fish and Wildlife have been major partners in the department’s efforts to establish NWSG on a landscape scale while controlling exotic flora.

Introduction

Landscape-scale conversion of sericea lespedeza (*Lespedeza cuneata*) on reclaimed rangeland has been in progress on the Peabody Wildlife Management Area (PWMA) since 1996. Field practices used by Kentucky Department of Fish and Wildlife Resources (KDFWR) to establish and maintain native warm-season grasses (NWSG) on mine spoil have evolved over the past eight years. The practices involve two operational phases: (1) conversion and (2) maintenance. Both phases use integrated field management consisting of prescribed burning, selective herbicide applications, and conservation tillage methods.

Peabody Wildlife Management Area History

The PWMA was established by KDFWR in 1995 as a result of purchase and lease agreements executed between Peabody Coal Company and Beaver Dam Coal Company. Eight management units spanning Ohio, Muhlenberg, and Hopkins counties comprise the PWMA.

Occupying 70,000 acres in western Kentucky's physiographic province known as Shawnee Hills, the PWMA lies within the Green River watershed. Coal surface mining occurred throughout the area from the 1950s to the 1990s. Twenty thousand acres of sericea lespedeza rangeland occupy the PWMA.

Public Access

Three parkways provide convenient access to the area. The Wendell H. Ford Parkway bisects the southern third. The William M. Natcher Parkway is located along the eastern edge, and the Edward T. Breathitt Parkway is at the western edge. The Kentucky Department of Military Affairs' 10,000-acre Wendell H. Ford Training Center lies geographically in the middle.

Ornithological Rationale for NWSG

Ornithological work in the 1980s and 1990s by biologists at KDFWR and the Kentucky State Nature Preserves and members of the Kentucky Ornithological Society (KOS) revealed that several species of grassland birds experiencing population declines were utilizing reclaimed grasslands. The bird species included Henslow's sparrow, bobolink, grasshopper sparrow, dickcissel, short-eared owl, and northern harrier hawk. During this same time, Quail Unlimited (QU) was also recognizing the unique landscape-scale restoration that could be accomplished for northern bobwhite quail.

Kentucky QU chapters have provided several thousand cash match dollars and equipment purchases for the PWMA since its creation. Public request for and support of native grasslands habitat for resident and migratory grassland birds prompted KDFWR to commit to an ambitious restoration effort. The PWMA was identified as a priority grassland bird demonstration site in conjunction with the North American Bird Conservation Initiative and the Northern Bobwhite Conservation Initiative.

NWSG 15,000-Acre Goal

The Kentucky Department of Fish and Wildlife Resources established a PWMA 15,000-acre NWSG goal. Fieldwork would occur in three 5,000-acre blocks. The first block currently at 2,700 acres is located in Ohio County at the Ken and Homestead Management Units.

By January 2005, NWSG maintenance w

seed bank is laden with 16 million pounds of sericea seed (calculations based on 350,000 seeds per pound and 800 pounds per acre times 20,000 acres). The seed can remain viable for 30 years. Allelopathic tannins of sericea inhibit other plant growth as well as make mature plants unpalatable. While providing good cover, sericea has limited forage value for wildlife.

PWMA Sericea Control Strategy

KDFWR's eight years' field experience with NWSG has evolved into field practices that exploit sericea's few vulnerabilities. Conversion methods focus on:
(1) removal of dormant mature tillers and surface seed accumulation using prescribed winter burning;
(2) killing new germinating seedlings and emerging tiller growth via spring herbicide spraying;
(3) planting twice the normally recommended NWSG seeding rates to compete with sericea stored in the seed bank;
(4) planting soon after spring herbicide spraying; and
(5) using 10-ft. no-till NWSG drills that can handle rocky, rough terrain while minimizing spoil disturbance.

Reduction of new annual seed production from mature plants and suppression of new crown buds is now being evaluated via fall spraying. Aerial spraying of Escort during full flower has just been completed on a 20-acre test site. A helicopter with onboard GPS is essential in tracking treated fields. Aerial application of herbicides is cost effective when attempting to perform treatments on a landscape scale in very rough terrain.

Winter Prescribed Burning for Conversion and Maintenance

Preparation for winter-prescribed burning begins in the previous fall with installation of fire lanes. Fire lanes are installed using AMCO offset and finishing discs. Fire lanes are installed on a permanent-use basis with fall seeding of cool-season legumes and warm-season forbs. ATVs equipped with broadcast seeders are used on fire lanes in addition to tractor-mounted flail seeders. Partridge pea, Illinois bundle flower, Korean lespedeza, and winter wheat are planted in fire lanes. There are 20 miles of permanent fire lanes on the PWMA. Fire is the quickest and most efficient way to remove 40 years of sericea duff. Back firing is used extensively during these burns. Sericea produces a dense black smoke even in its dormant stage.

ATVs equipped with spray guns and tanks are used for ignition and extinguishing tasks. Foam is added to spray tanks for additional fire suppression effectiveness. NWSG maintenance-prescribed burns produce spectacular flame heights and lots of heat. Maintenance burns are performed every three years, and fields are fired later on each rotation to facilitate vegetative diversity. All prescribed burning is timed to avoid grassland bird nesting.

Herbicides Used for Conversion

The "sericea silver bullet" herbicide, which kills the mature plant from tiller to root and has residual carry-over to suppress or abort seed embryo germination, simply does not yet exist. Thus, herbicide mixes are used on the PWMA. Current herbicide choices are limited to four herbicide families: phenoxy, imidazolinone, pyridine, and imidazolidinone. Brand names are 2,4D, Plateau, Reclaim, Garlon, Remedy, and Arsenal. Glyphosate is not categorized within a specific herbicide family but is a cost effective broad-spectrum herbicide marketed as Roundup, Accord, and Glystar. The herbicide mix used for PWMA spring conversion spraying via a pull-behind boom sprayer includes 2 qt/ac Roundup, 1 qt/ac 2,4,D, 12 oz/ac Plateau, and 1 pt/5 ac surfactant. KDFWR policy prohibits use of “restricted” herbicides on WMAs. Test plot conversion spraying in the fall using the boom sprayer has been done using mixtures of 1.5 qt/ac Garlon A, 8 oz/ac Plateau, and 1 pt/5 ac of surfactant. Fall test conversion spraying via rotary wing application was done in September on 20 acres using 1 oz/ac Escort and 1 pt/5 ac surfactant NuFilm.

Herbicides Used for NWSG Maintenance

Maintenance of NWSG requires frequent monitoring and use of selective herbicide mixtures appropriate for the specific situation. Sericea is so persistent in newly established NWSG fields that some spraying is done in the fall of the same planting year. New sericea seedlings, while not mature enough to produce seed their first year, may be so thick that they simply shade out young NWSG shoots.

Thistles, especially musk thistle (C*arduus nutans* burning, selective spring and fall herbicide spraying, no-till conservation tillage, and persistent spot maintenance for at least four years.

Harvest Management of Switchgrass in Pennsylvania for Yield and Biofuel Quality

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Abstract

Harvest management of switchgrass grown for biofuel must consider not only biomass yield but also the fuel quality of the biomass. A three-year study was conducted to determine the effect of fall versus spring harvest on biomass yield and biofuel quality. In winters with low snowfall, delaying harvest from fall to spring did not affect yield. However, in winters with above-average snowfall, biomass losses were 40%. About 25% of the yield reduction during winter resulted from losses in tiller weight with reductions in leaves and the panicles; however, 75% of the yield reduction was due to biomass not picked up by the baler. Although the yield is highest in late summer, mineral element concentration in the biomass decreases after the peak yield through a killing frost and into spring, thereby enhancing biomass quality for combustion. Although the biomass yield decreased over the winter, energy yield from gasification did not decrease on a unit biomass basis, whereas ethanol production decreased about 25%. Switchgrass moisture content needs to be less than 15% for storage but averaged 34% in the fall versus 7% in the spring. Although there was substantial reduction in switchgrass yield with spring harvest, the biofuel quality of spring-harvested biomass was greater than fall biomass.

Introduction

A number of plant species have been considered as possible candidates for dedicated energy crops (Lewandowski et al. 2003b), representing both annual and perennial herbaceous crops and short-rotation trees (Walsh et al. 2003). Perennial grasses have several advantages over annual crops such as lower establishment costs, reduced soil erosion, increased water quality, and enhanced wildlife habitat (McLaughlin et al. 2002). Seasonal time of harvest affects switchgrass yield (Madakadze et al. 1999; Sanderson et al. 1999; Vogel et al. 2002) and biofuel quality of reed canarygrass (Burvall 1997) and Miscanthus (Lewandowski et al. 2003a). Our objective was to examine how seasonal time of harvest affects switchgrass biomass yield and biofuel quality.

Materials and Methods

The experiment was conducted in Rock Springs, Pennsylvania, from fall 2001 to spring 2004. The soil was a Hagerstown silt loam (fine, mixed, mesic Typic Hapludalfs). Switchgrass (*Panicum virgatum* L.) was planted in blocks ranging in size from 0.08 to 1.75 ha. Five switchgrasss varieties, Pathfinder, Trailblazer, NJ-50, Cave-in-Rock, and Shawnee, were planted in seven blocks with Pathfinder and Cave-in-Rock in two blocks each. The blocks were each split in half and randomly assigned harvest in either fall or spring, resulting in a randomized complete block statistical design. Over the three years of the experiment, the actual harvest time ranged from Oct. 31 to Nov. 8 in the fall and Apr. 7 to Apr. 18 in the spring. Nitrogen was applied in the spring annually at the rate of 56 kg N/ha. Before harvest, 100 tillers were collected from each plot and separated into stems, leaf blades, and panicles to identify and quantify change in biomass with plant part. Plots were harvested with standard-sized farm equipment (a John Deere 926 MoCo Discbine with 2.97-m cut and a John Deere model 457 Silage Special Round Baler set at 1.22-m wide by 1.52-m diameter). After cutting the switchgrass, samples were collected from the windrows and dried at 55°C to determine moisture content at harvest. Switchgrass was baled after samples were collected, individual bale weights determined, and yield calculated by dividing the moisture corrected bale weight by the area harvested. After drying, samples collected for moisture content determination were ground in a hammer mill and then ground through a 20-mesh (0.85 mm) screen in a Wiley mill. To determine the quality of the switchgrass as a biofuel in combustion systems, N, P, K, Ca, Mg, S, Cl, and ash were determined at Clemson University Agricultural Service Laboratory using standard methods. Ethanol yield from the fall- and spring-harvested switchgrass, without prior chemical treatment, was predicted by using *in vitro* gas production as a surrogate measure of the fermentability of cellulosic biomass to ethanol (Weimer et al. 2004). Components of gasification (CO, CO_2, CH_4, C_2H_4, C_2H_6, C_3H_8, and C_4H_{10}) were quantified using flash pyrolysis with a pyroprobe (Pyroprobe 2000, CDS Analytical)-gas chromatography (GC) mass spectrometer (MS) (6890N gas chromatograph and HP 5973 mass spectrometer, Agilent Technologies). Char yield (elemental carbon plus ash) was determined gravimetrically. All other gases evolved during pyrolysis that were not quantified were combined together as tar; this included condensable and non-condensable gases with molecular weight greater than C4 and hydrogen. Hence, tar was determined as the difference between the initial biomass and the sum of the measured gas and char.

Results and Discussion

Biomass Yield

The effect of delaying harvest from fall to spring varied depending on snowfall. During the winter of 2001-2002, there was little snowfall, about 56 cm, and switchgrass yields were similar between fall 2001 (6.69 ± 1.45 Mg/ha) and spring 2002 (6.83 ± 1.78 Mg/ha). However, snowfalls were almost three times higher in the following two winters, from fall 2002 to spring 2004, about 153 cm each year, and yields decreased an average of almost 40% (Table 1). The long-term snowfall average is about 117 cm. The decrease in yield occurred from two sources: biomass that was not picked up by the baler either because it was not cut due to lodging or just cut but not picked up by the baler, and a decrease in standing tiller weight. Tiller weight decreased less than 10% during the winter, with weight reductions due to loss of leaves and panicles. In the fall, about 21% of the biomass yield was left in the field as residue not picked up by the baler. Almost twice as much residue was not picked up by the baler in the spring. The largest source of biomass loss at spring harvest resulted from biomass not picked up by the baler, about 42% when expressed on an adjusted yield basis. When these two sources of biomass loss were added back onto the spring yield, fall and spring yields were within 4% of each other. In the midwestern United States, maximum yields occurred in mid-August at the full panicle emergence to post-anthesis developmental stages (Vogel et al. 2002); yields decreased 10 to 20%

with harvests after a killing frost in October. In this study, we show that yields can decrease further over winter, but the magnitude of the decrease depends on snowfall.

Biofuel Quality

The effect of seasonal harvest time on biofuel quality was evaluated for three different energy generation processes: combustion, ethanol fermentation, and gasification. Generally, bioenergy crop production seeks to maximize the concentration of lignocellulose in the feedstock and minimize the N and mineral concentrations. The efficiency and end products of the various conversion processes depend on the chemical composition of biomass. Biomass contains higher concentrations of inorganic elements compared with fossil fuels, resulting in decreased energy density for combustion (Agblevor et al. 1992; Nordin 1994). The concentration of elements usually decreases in forages as they mature (Sanderson and Wolf 1995; Jorgensen 1997; Madakadze et al. 1999); delaying the harvest until late winter/early spring further decreases elements and moisture content in reed canarygrass and Miscanthus at harvest (Lewandowski and Kicherer 1997; Burvall 1997; Lewandowski et al. 2003a). Similar results were found in this study; both the element and moisture content decreased in spring compared with fall-harvested switchgrass biomass. In the spring-harvested switchgrass, all elements did not decrease equally. The concentration of Cl, K, P, and Mg in switchgrass biomass was less than 50% of the fall concentration, while the concentration of Ca, S, and N was greater than 75% of the concentration in fall-harvested biomass (Table 2). The reduced concentration of alkali metals in the switchgrass biomass improved biofuel quality since these can increase the formation of fusible ash, causing slagging and fouling of boilers used for direct combustion (Miles et al. 1996). Time of harvest affects the ability to achieve the desired moisture content of switchgrass for stable storage and burning efficiency. The percent dry weight was 66 ± 9 for fall harvest and 93 ± 3 for spring harvest averaged for three years. To store well, the switchgrass moisture content should be less than 15% (greater than 85% dry weight). Increased moisture leads to an increase in danger of self-ignition during storage and reduced burning efficiency.

Seasonal time of switchgrass harvest did not affect gas production from pyrolysis. Pyrolysis is heating in the absence of oxygen. Products from pyrolysis are the synthetic gases, char, and tar. Total gases (synthetic gas), comprising CO, methane, CO_2, ethane, and propane (H not measured), were about 20% of the total mass from pyrolysis (Figure 1). There were no differences between seasonal harvest times, so data from fall- and spring-harvested switchgrass data were combined. Tar was about 70% of the total mass from pyrolysis (Figure 1). Tars are heavy molecular weight hydrocarbons which at higher temperatures can undergo further pyrolysis to yield lightweight hydrocarbons (tar cracking). Char, which is ash plus elemental carbon, was less than 10% of the total mass from pyrolysis. The synthetic gas yield was temperature dependent; methane, ethane, and propane are produced at higher temperatures than CO and CO_2 (Figure 2). The mass of char tended to be higher in fall-harvested switchgrass (Figure 3). This result is consistent with higher ash concentration measured in fall-harvested switchgrass (Table 2). There is a lower ash content in spring biomass because some elements leach out over the winter. Char mass decreased with temperature due to its pyrolysis at elevated temperatures, thereby decreasing the elemental carbon while ash remains constant.

Fermentation gas production decreased about 25% from 99.2 ± 4.6 ml/g in the fall (harvested after a killing frost) to 73.8 ± 4.7 ml/g in spring-harvested biomass. The decrease in fermentability of the spring-harvested switchgrass (overwintering) is consistent with reports in corn silage that digestibility decreases with multiple frosting events of the corn crop, although the mechanism is not known (St. Pierre et al. 1983; St. Pierre et al. 1987). Presumably this decreased fermentability results either from lower concentrations of sugars and readily fermentable storage carbohydrates or from changes in cell wall structure or composition. In this study, fermentation gas production was used as a surrogate for ethanol production and may provide a more sensitive measure of the effect of seasonal harvest time on carbohydrates, as has been shown for switchgrass and several other forages (Weimer et al. 2004). If future results bear out these early findings, it appears that yields from gasification are not affected by seasonal harvest time, whereas when the biomass is used for ethanol production, a decrease in ethanol yield may result with a spring harvest, although such differences may be reduced by effective biomass pretreatment procedures. Fall-harvested biomass may also be less expensive to ferment, due to its higher concentration of some nutrients that would otherwise have to be added to the fermentation medium to support microbial growth.

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Table 1. Average switchgrass yield of two seasonal harvests times from fall 2002 to spring 2004 at Rock Springs, Pennsylvania (means of 2 years SD).

Harvest Season	Yield (Mg/ha)	Yield Reduction (%)	Residue (Mg/ha)	Tiller Wt. Reduction (%)	Final Yield (Mg/ha)
Fall	6.98 ± 1.13	---	1.91 ± 0.61	---	8.89
Spring	4.38 ± 0.84	37.3	3.59 ± 0.79	6.7	8.54†

† Adjusted for tiller weight loss over winter.

Table 2. Elemental composition of switchgrass harvested in fall 2002 or spring 2003 at Rock Springs, Pennsylvania (means SD).

Element	**Harvest Time**		
	Fall 2002	**Spring 2003**	**Spring/Fall**
	-- % dry wt. --		
Nitrogen	0.51 ± 0.04	0.49 ± 0.05	96
Phosphorus	0.09 ± 0.02	0.04 ± 0.01	44
Potassium	0.26 ± 0.04	0.05 ± 0.00	19
Calcium	0.40 ± 0.05	0.31 ± 0.04	78
Magnesium	0.13 ± 0.02	0.06 ± 0.01	46
Sulfur	0.07 ± 0.01	0.06 ± 0.01	86
Chlorine	0.05 ± 0.02	0.00 ± 0.00[†]	0
Ash	3.26 ± 0.30	2.49 ± 0.32	76

[†] None detected.

Figure 1. The components of pyrolysis are total gas, tar, and char. As the temperature of pyrolysis increases, tar and char are broken down to smaller carbon chemicals and gas. There were no differences in component yields between seasonal time of harvest, so data presented are means of fall and spring samples. Vertical bars denote SD.

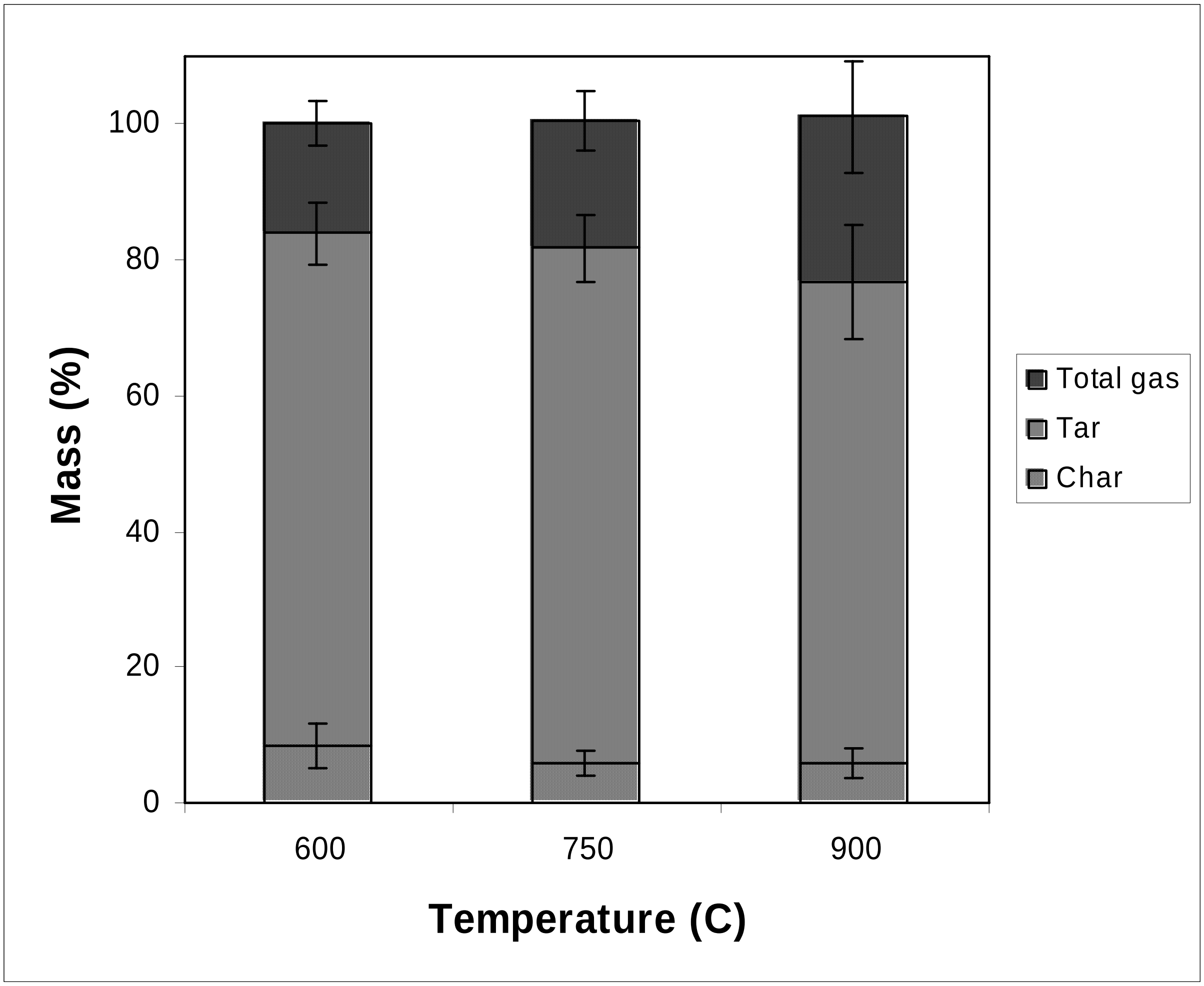


Figure 2. The measured gas components of pyrolysis are CO, methane, CO_2, ethane, and propane. As the temperature of pyrolysis increases, tar and char are broken down to smaller carbon chemicals and gas. There were no differences in component yields between seasonal time of harvest, so data presented are means of fall and spring samples. Vertical bars denote SD.

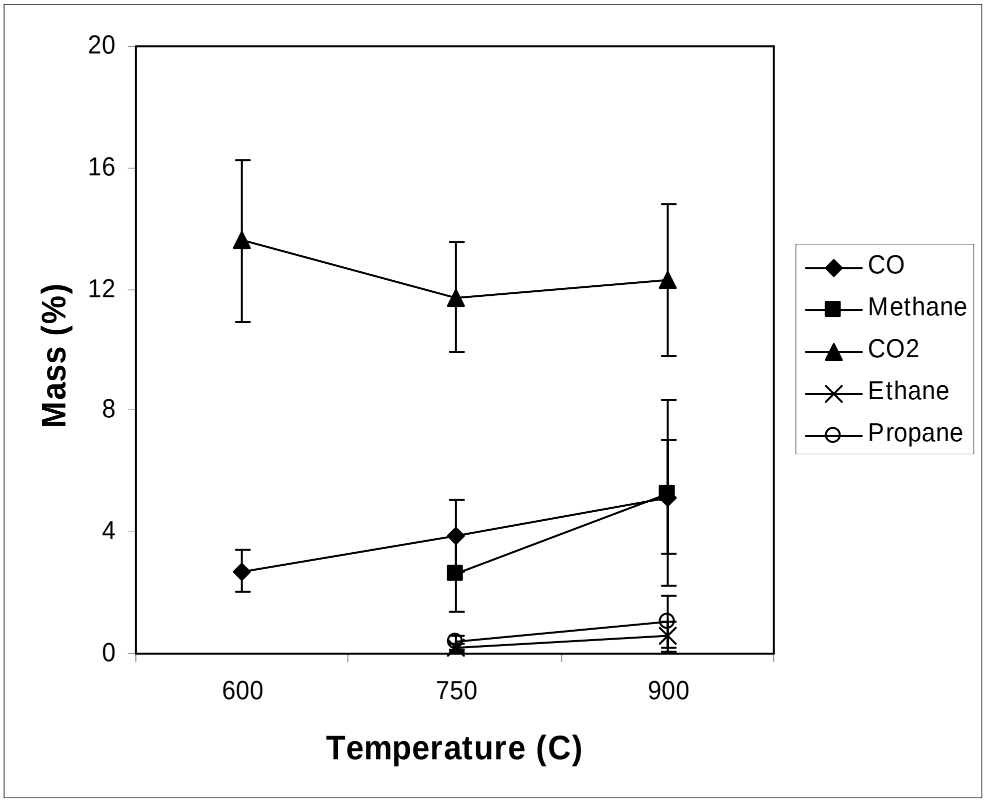
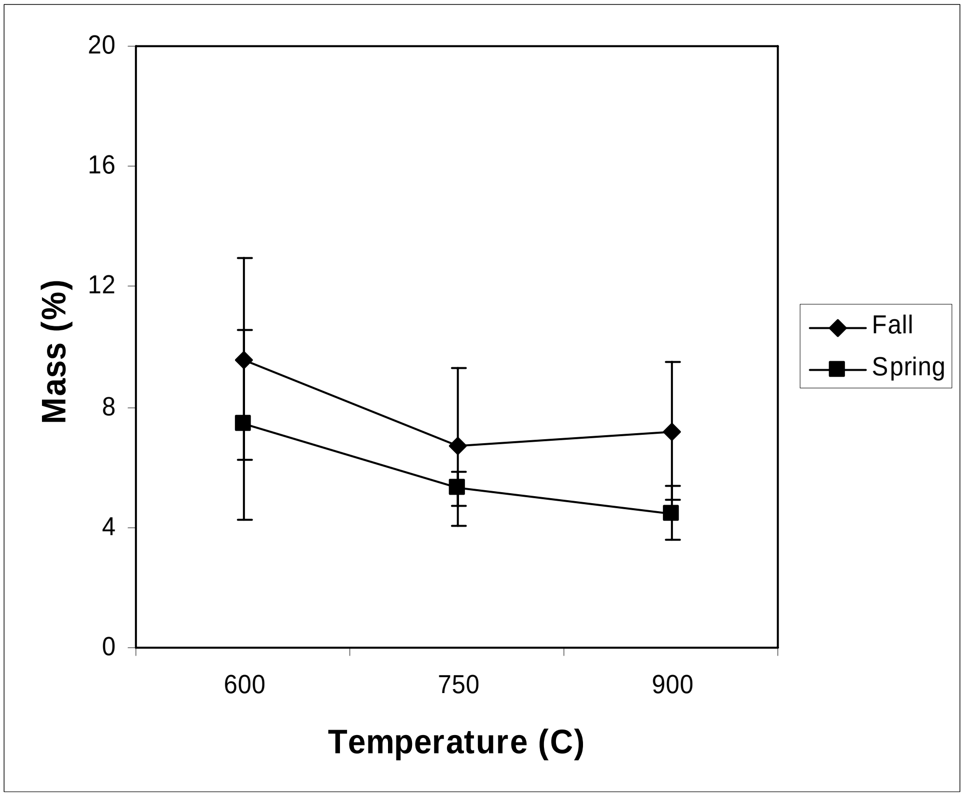


Figure 3. The decrease in char mass (a function of both elemental carbon and ash) with pyrolosis temperature resulted from break down of elemental carbon to smaller carbon chemicals and gas. The greater quantity of char mass in fall-harvested compared to spring-harvested switchgrass was due to higher ash content. Vertical bars denote   SD.



Monday, October 4, 2004
SESSION III, SECTION C

Comparative Ecology of Warm-Season (C_4) versus Cool-Season (C_3) Grass Species in Kentucky, with Special Reference to Bluegrass Woodlands

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Abstract

The distributions of C_4 and C_3 grasses are compared in Kentucky. There is a strong association of C_4 grasses with late summer growth in open, nonforested habitats of Kentucky, including sites maintained by fire. Some 86% of C_3 grasses typically flower between mid-April and late July, whereas 96% of C_4 grasses typically flower between late July and mid-October. Only open habitats that experience much seasonal drying have major concentrations of C_4 grasses: (a) xeric pine/cedar-oak woodlands and associated rocky glades; (b) xeric-tending oak woodlands and associated grasslands, especially on gentle uplands; (c) hydric-tending oak woodlands and associated grasslands, especially on high terraces. A minor concentration also occurs on "shrubby/graminoid streambanks" that experience flooding and other seasonal changes in water level sufficient to maintain a distinct zonation of vegetation between forested banks and the low water levels. Subhydric or hydric sites that experience less seasonal drying appear to have virtually no typical C_4 grasses, but there are a few locally dominant C_3 grasses within these habitats. The few C_4 grasses that occur in deeper shade are all perennials in the genus *Muhlenbergia*.

There is no significant overall trend in numbers of C_4 versus C_3 species along the gradient from acid soils with low fertility to base-rich soils with high fertility. However, locally dominant perennial grasses, especially the few taller species reaching 2 m or more, are mostly C_4 species on low to average soil fertility (e.g., *Andropogon gerardii*), and mostly species C_3 on higher soil fertility (e.g., *Arundinaria gigantea*). Since eutrophic soils support rapid plant growth in general, there is a strong tendency for forest to predominate over the landscape, with rapid recovery from disturbances. Because of this, there may have been relatively little opportunity for selection of grasses that can dominate on sunny, eutrophic soils, especially in phosphatic sections of the Bluegrass region. Moreover, woodlands on eutrophic soils can allow dense grassy ground vegetation with C_3 species to develop in the partial shade, especially in spring before trees are fully leafed out.

This hypothesis is developed further with reference to the literature on the balance of C_4 versus C_3 species. It is suggested that frequent spring fires might maintain openings with C_4 species but at the expense of some native features in Bluegrass Woodlands. In contrast, seasonally intense foraging of ungulates on the nutritious "herbage" is indicated by some historical accounts, and several characteristic native species are associated with moderate ungulate effects in the vegetation. Ungulates may have helped maintain the high proportion of C_3 species due to enhanced nutrient cycling and perhaps overgrazing of incipient C_4 grassland patches along intensely used corridors.

Introduction

Plants with the C_4 photosynthetic system use energy (via ATP) to increase $C0_2$ concentration for enzymatic fixation into carbohydrate (Sage 1999). This process involves shuttling $C0_2$ on 3- to 4-carbon acids from mesophyll to bundle sheath cells, where carbohydrate is produced, stored, and exported from the leaf. It appears to have evolved independently within several lineages of grasses and other plants during the Tertiary era, after about 30 million years ago, probably in response to lower atmospheric $C0_2$ levels and higher O_2 levels—the latter causing wasteful photorespiration of carbon initially fixed in phosphoglyceric acid. In warm sunny habitats, such plants are able to maintain higher rates of photosynthesis and growth than those with the ancestral C_3 system, which are limited by low $C0_2$ levels and photorespiration. Another physiological advantage in certain situations can be higher water-use efficiency, since stomata can remain closed on warm days with $C0_2$ levels accumulated and photosynthesis continuing. Also, higher nitrogen-use efficiency has been estimated, along with lower N concentrations in foliar tissue, which may be allowed by higher rates of CO_2 fixation per unit of photosynthetic enzyme. Moreover, some C_4 species are able to allocate more energy to roots and increase N uptake from infertile soils (Long 1999).

The ecological distribution and apparent adaptation of C_4 species has been widely studied and discussed, but there continue to be uncertainties in the relative importance of various factors that control the balance of C_4 and C_3 species in vegetation (Sage and Munson 1999). The strong association of C_4 species with grasslands and savannas in warmer climates, and their virtual absence in colder climates, is extensively documented. Within temperate climates, there is a more equal balance overall but much variation in time and place. Such variation may have significant consequences for ecosystems, including patterns of herbivory and fire regimes.

This study is a provisional comparison of C_4 and C_3 grass species in Kentucky, prompted partly by the observation that relatively few native C_4 species are common on the eutrophic soils of the Bluegrass region. A database on Kentucky's grasses is being developed, assigning ecological characteristics to each species. Associations between characteristics provide initial hypotheses that can be tested with more detailed analysis of vegetation patterns and experimental studies.

Methods

Some 112 native grasses are included in this study. Rare species (with S1, S2, or S3 rank in the state heritage program) are excluded. Also, alien species are excluded from the analysis, although noted in some comparisons. Taxonomy is based on the author's interpretation of recent literature, together with an attempt to maintain consistency in rather broad generic concepts and rather narrow species concepts. Appendix 1 lists these species, together with values for ecological characteristics. The following sources, definitions, and criteria were used to assign values.

C3/C4 photosynthesis: This is based on data in Kellogg and Campbell (1987), Kellogg (1999), Sage et al. (1999), and associated literature.

Native status: This is based on interpretation of Fernald (1950), Gleason and Cronquist (1991), and other regional floras. The following classes were included in the analysis: N = clearly native; Ns = native to North America south of Kentucky but perhaps only adventive in the state; Nw = native west of Kentucky but possibly only adventive in the state; Nn = reportedly native north of

Kentucky and possibly within the state. Excluded aliens are classed as follows: A = native to East Asia; E = native to Europe; En = native to Europe and reportedly northern North America but probably not Kentucky. Note that native status remains tentative for a few species that are provisionally accepted here, including *Phalaris arundinacea* (see Merigliano and Lesica 1998) and *Poa pratensis* plants that key to *P. angustifolia* (see Fernald 1950).

Flowering month: This is based on general knowledge and interpretation of regional floras. Typical dates are for anthesis and fertilization, not extended to seed maturation. These dates are approximate, with most species ranging over one to two months.

Hydrological habitats: These vegetation classes are based on a general model of habitat gradients in the state (e.g., Campbell 1987), as diagramed in Appendix 2. In most cases there is much intergradation. Most grass species occur in a range of classes; the most typical class is listed first for each species in Appendix 1. Brief outlines of these classes are as follows.

I: Shrubby/graminoid streambanks; heterogeneous shorelines of various substrates that often become exposed and droughty in the summer; locally dominated by *Salix* spp., *Cornus obliqua, Justicia americana*, locally grasses (e.g., *Chasmanthium latifolium, Andropogon gerardii*) or sedges; and locally annuals on exposed areas. This is a somewhat anomalous class within the gradient model, deserving an independent axis for expression.

II: Shrubby/graminoid swamp/marsh/bog; stagnant wetlands too wet for most trees; locally dominated by shrubby species, *Alnus serrulata, Cephalanthus occidentalis, Salix* spp., *Cornus stricta, Forestiera acuminata*; and locally *Polygonum hydropiperoides, Leersia oryzoides, Scirpus* spp., *Carex* spp.

III: Streamside forest, much influenced by frequent flooding; fairly continuous forest, or rapidly recovering from disturbance; typically with *Acer negundo, A. saccharinum, Betula nigra, Platanus occidentalis, Populus deltoides, Salix nigra*.

IV: Deep swamps, lakes, ponds; sometimes drying up at margins into broad zones of marshy vegetation; not developed in most of Kentucky except for artificial impoundments; southern natural areas dominated by *Taxodium distichum, Nyssa aquatica, Gledistia aquatica,* and *Salix nigra*; margins often typified by species of class II or by clonally spreading dominants like *Decodon verticillatus* (rare), *Zizaniopsis miliacea* (rare), *Typha* spp., and *Phragmitis australis*.

V: Mesic forest, on well-drained terraces or cool slopes; fairly continuous forest, rapidly recovering from disturbance; typically dominated by *Acer saccharum, Fagus grandifolia*, or locally *Tsuga canadensis*; locally *Aesculus* spp., *Carya cordiformis, Fraxinus americana, Liriodendron tulipifera, Quercus rubra, Tilia* spp., *Ulmus rubra*, etc.

VI: Subhydric forest, with seasonal flooding or saturation; fairly continuous forest, rapidly recovering from disturbance, or with openings along streams and seeps; typically with *Acer rubrum* var. *trilobum, Fraxinus pensylvanica, Liquidambar styraciflua, Nyssa sylvatica, Ulmus americana*; locally *Quercus michauxii, Q. pagoda*, etc.

VII: Submesic forest, typically on gentle topography with dry and damp seasons; fairly continuous before settlement or somewhat open due to fires and locally intense ungulate use; much now converted to farmland; heterogeneous and often transitional to other classes; typical trees vary but include *Acer rubrum, Aesculus glabra, Celtis occidentalis, Diospyros virginiana, Gleditsia triacanthos, Gymnocladus dioicus, Fraxinus* spp., *Juglans* spp., *Liriodendron tuplipifera, Nyssa sylvatica, Prunus serotina, Sassafras albidum, Ulmus* spp.; various *Carya* spp. and *Quercus* spp.

VIII: Seral thickets, especially with clonal shrubby species; combined here with Class VII but potentially widespread, persistent and distinct under certain disturbance regimes; typical species include *Arundinaria gigantea, Asimina triloba, Cornus* spp., *Prunus* spp., *Rhus* spp., *Rubus* spp., *Symphoricarpos orbiculatus, Viburnum* spp.

IX: Hydric-tending oak woods and grassland, on poorly drained but seasonally drying flats, typically on high terraces or upland swales, potentially flooded by backwaters but without rapid flow; much exposed to fires, ungulates, and recent drainage for farmland; typical trees include *Quercus* spp. and *Carya* spp. but with frequent transitions to Class VI; openings include *Juncus* spp., *Carex* spp., *Rhynchospora* spp., *Scirpus* spp., *Cyperus* spp., *Eleocharis* spp. and many grasses (see Appendix 1).

X: Xeric-tending oak woods and grassland, typically on gentle topography that often dries in summer, above floodplains but sometimes wet where poorly drained; much exposed to frequent fires, intense ungulate use, and recent conversion to farmland; typical trees include *Quercus* spp. (especially *Q. stellata, Q. falcata, Q. marilandica* on poorer soils; *Q. macrocarpa, Q. imbricaria* on richer soils), locally *Pinus* spp., *Juniperus virginiana* or others, depending on disturbance regime; native grassland or open grassy woodland widespread in some regions before settlement.

XI: Subxeric forest, typically on slopes; fairly continuous forest, generally recovering from disturbance but with openings on rocky ground; less exposed than Class X to frequent fires, ungulates, and conversion to farmland; typical trees include *Quercus* spp. (especially *Q. alba, Q. velutina, Q. montana, Q. coccinea, Q. muhlenbergii, Q. shumardii*), *Carya* spp., *Fraxinus* spp, *Castanea dentata* (before blight).

XII: Xeric pine/cedar-oak woods and glades; on thin rocky soils where droughts maintain open conditions and slow succession to oaks or other forest trees; exposed to fires but fuels often thin and interrupted by outcrops; ungulate use varied (from little along clifftops to intense at mineral licks); much less converted to farmland; typical species include *Juniperus virginiana, Pinus virginiana*, scattered other trees, and many distinctive shrubs, herbs, and grasses on more rocky ground.

Sun/shade gradient: Typical position on this gradient is based on general knowledge, including much vegetation survey and discussion among plant ecologists; 1 = clearly most abundant in full sun; 2 = abundant in full sun but also common in thin woods with partial canopy; 3 = most common in the partial shade of thin woods or at edges; 4 = somewhat shade tolerant, growing best in somewhat sunny conditions but clearly persisting into shady forest at lower vigor; 5 = clearly shade-tolerant, and tending to be outcompeted in more sunny conditions.

Soil pH/fertility gradient: Typical position is assigned from general knowledge and interpretation of regional floras; the soil gradient in Kentucky's forests has been revealed by ordination studies (e.g., Campbell 1987), but much more detailed work is needed, especially to examine associations of N and P levels with soil pH; it is generally accepted that soils with pH 6-7 have high natural levels of N and P, especially in the Bluegrass region, but raw data have not been mapped. In addition to direct experience with vegetation and soil data, some initial distributional guidelines are as follows:
A. Association with low fertility is indicated by concentration on relatively acid shales and sandstones in the Knobs and Appalachian regions, coupled with virtual absence in the Bluegrass region or other calcareous regions.
B. Transition, mixed, or uncertain assignment between A and B.
C. Association with average fertility is indicated by widely scattered distribution over the state, including parts of the Bluegrass region as well as the Knobs and Appalachian hills.
D. Transition, mixed, or uncertain assignment; widespread species that are common on farmland or alluvial soils with high fertility are generally assigned here.
E. Association with high fertility is indicated by higher frequency in the Bluegrass region or other calcareous regions, and typically lower frequency in the Knobs and Appalachian hills (except in rich valleys and other unusual sites).

Tables were developed to compare the distribution of C_4 and C_3 species among these ecological classes. Tests of independence were used to estimate probabilities that differences could have arisen by random assortment of the species, using the Pearson chi-square statistic with Model I (Sokal and Rohlf 1969, 16.4). It has been argued that an individual species is not an independent observation, when searching for statistical associations among characters because a character may have only evolved once in a phylogenetic group of species (Freckleton et al. 2002). Alternatively, it can be argued that each species should be weighted according to its abundance. This provisional study is concerned only with overall patterns among species; further analysis will have to involve deeper examination of phylogenetic associations and distribution of abundance, together with appropriate statistics that examine phylogenetic correlation. However, for some provisional consideration, the tables include the number of genera provided in parentheses after each species total. Chi-square tests are run with these numbers of genera, in addition to the usually higher numbers of species, but this is still an arbitrary level of analysis.

Results

Flowering month: Table 1 shows the distribution of C_4 and C_3 species in relation to typical flowering month. There is a highly significant difference ($P < 0.0005$), with 55 of the 64 C_3 species typically flowering from mid-April to late July, and 46 of the 48 C_4 species typically flowering from late July to mid-October. Within C_3 species, inspection of the data indicates that early flowering species tend to occur mostly in somewhat wooded habitats on well-drained soils, while later species tend to occur in sunny, dry, or wet habitats. Within C_4 species, there is no suggested association with habitat.

Hydrological habitats: Table 2 compares the distribution of C_4 and C_3 species with respect to typical habitat, as defined from a hydrological perspective. These habitat classes are arranged to form a simple two-gradient model, from relatively mesic conditions to the center left (in mesic forest and streamside forest), xeric to upper right, and hydric to lower right. Note that the typical habitat assignments of many species are provisional, pending more quantitative analysis of vegetation data, and most species range over several classes. Nevertheless, there is a highly significant difference in distribution between C_4 and C_3 species among the 10 classes where they typically occur (P = 0.002).The percentage of C_4 species is consistently higher, at 61 to 64% within the three major habitat classes that have extensive grassland or grassy open woodland: (a) xeric pine/cedar-oak woodland/glades; (b) xeric-tending oak woodland/grassland; and (c) hydric-tending oak woodland/grassland.

The latter, "hydric-tending" class is defined to include sites that frequently dry out in summer. On wetter ground, in transitions to the "deep swamp" class, C_4 species are virtually absent, except on unstable or seasonally exposed shorelines. Instead, a few C_3 species are locally dominant, although these are rare (*Zizaniopsis milacea*) or generally considered alien (*Phragmitis australis*), except perhaps *Phalaris arundinacea* and *Leersia* spp. in various terrestrial transitions. This trend is enhanced through consideration of the sedge family, Cyperaceae (Kellogg 1999), which contains C_4 taxa typical of hydric-tending woodland/grassland and marshy transitions to swamps (most *Cyperus* spp., all *Rhynchospora, Eleocharis, Kyllingia, Fimbristylis, Bulbostylis*). The C_3 taxa in this family are more widespread, extending either into forests or into deeper swamps, marshes, and seeps with more permanent water supply (*Carex, Scleria, Scirpus, Dulichium, Eriophorum*). Moreover, other graminoid taxa of more permanently flooded habitats are also C_3—in Sparganiaceae (*Typha, Sparganium*).

In other habitat classes, with one minor anomalous exception, the percentage of typical C_4 species is much lower, with 0% in subhydric or hydric habitats, and 17 to 33% in typically forested mesic, submesic, or subxeric habitats. The exception is the "shrubby/graminoid streambank" class. This is rather heterogeneous, on various substrates, but it is united by the tendency for floods and other seasonal changes in water level to maintain a zonation from forest, through shrubs, graminoids, and herbs, to truly aquatic habitat in the stream (see "Methods"). There are only a few grass species strongly concentrated in this habitat within Kentucky, but most (5 of 6) are C_4 (*Eragrostis hypnoides, E. frankii, Paspalum fluitans, Panicum virgatum, Cenchrus longispinus*); others will be added when rare species are considered (e.g., *Sporobolus cryptandrus* and *Triplasis purpurea* along the Mississippi River sandbars). In addition to specialists, more widespread or weedy grasses are often present (e.g., C_4 *Andropogon gerardii* in full sun on rocky banks and C_3 *Chasmanthium latifolium* at upper edges).

Sun/shade gradient: Table 3 shows that the percentage of C_4 species is much higher (76%) among those typical of full sun conditions, with high significance given the model of random assortment (P < 0.0005). There is virtually no trend with increasing shade concentration (divisions 2-5 in Table 3), where the percentage of C_4 species averages ca. 10 to 20%. The few C_4 species in more shady conditions are largely restricted to the "closed/non-drying" habitats. Moreover, in partial or deeper shade (divisions 3-4; none at 5), the only genus represented is *Muhlenbergia*.

Soil pH/fertility gradient: Table 4 shows that there is no overall trend in the proportion of C_4 to C_3 species along this gradient of increasing base-status and presumed overall fertility. There may a somewhat higher percentage at intermediate positions (with ca. 49% at both "average/C" and "slightly above-average/D" fertility), but this will deserve proper analysis only when more data are included in the analysis, with addition of rarer species, real vegetation data, and a broader regional context. For example, there are several rare but locally abundant C_4 species in Kentucky that are typical of higher pH (especially western species such as *Bouteloua curtipendula* and *Muhlenbergia cuspidata*) and lower pH (especially southern species such as *Gymnopogon ambiguus* and *Panicum longifolium*). But there are also several locally abundant C_3 species with northern geographic ranges at these extremes (e.g., *Schizachne purpurascens* at higher pH, *Deschampsia flexuosa* at lower pH).

As a first step toward deeper analysis, Table 5 selects only species that are fairly widespread, locally abundant perennials in native vegetation on relatively undisturbed ground, without much soil exposure, frequent flooding, or trampling. This selection is based on general knowledge of the vegetation in Kentucky and can be supported by many individual observations, but a comprehensive synthesis of vegetation data will be needed eventually. Although the simple statistical test employed here does not show clear significance, there does appear to be a trend that will deserve deeper analysis. Within the C_3 group, there are increases in the number of species from five typical on lower fertility soils (coded A/B), to seven on average soils (C), to 17 on higher fertility soils (D/E). Moreover, the only really tall species, commonly reaching 2 m or more, are *Arundinaria gigantea* and *Phalaris arundinacea*, both typical of above-average fertility (D). Within the C_4 group, there is an increase from two species typical of lower fertility, to 10 on average, but then a decrease to six on higher fertility. Moreover, taller species (reaching at least 2 m), are mostly on lower fertility (*Saccharum* spp.) or average fertility (*Tripsacum dactyloides*, *Andropogon gerardii*, *Sorghastrum nutans*), with only one (*Panicum virgatum*) on higher fertility. The latter species is relatively uncommon in Kentucky, being largely restricted to rocky riverbanks, but it has been successfully planted in many old fields.

Finally, Table 6 lists widespread, locally abundant alien grasses, either perennial or annual, in relation to this soil gradient. There are increases in numbers of both C_4 and C_3 species on higher soil fertility. Moreover, there are two additional tall perennial C_4 species that can exceed 2 m: *Miscanthus sinensis* on average soils and *Sorghum halepense* (plus the annual *S. bicolor*) on above-average fertility. The only alien C_3 species that reach such stature already have native races on above-average soils in North America: *Phalaris arundinacea* and *Phragmitis australis*. Clearly, the invasive C_4 species from the Old World are able to colonize farmland, urban land, and other disturbed sites in Kentucky. It appears that some of these species are adapted to rapid growth in full sun on relatively fertile upland soils, a niche that is occupied by relatively few native C_4 species.

Discussion

The strong association of C_4 grasses with late summer growth in open, nonforested habitats of Kentucky, including sites maintained by fire, accords with many other studies of C_4 versus C_3 distribution (Sage and Monson 1999). In Kentucky, 86% of C_3 grasses flower between mid-April and late July, when average daily maximum temperatures are ca. 15 to 20°C; in contrast, 96% of C_4 grasses flower between mid-July and mid-October, when average daily maximum temperatures are ca. 20° to 30°C.

Further detail is provided here, indicating that only open habitats that experience much seasonal drying have the association with C_4 grasses. The three major habitats with these species are: (a) xeric pine/cedar-oak woodlands and associated rocky glades; (b) xeric-tending oak woodlands and associated grasslands, especially on gentle uplands; (c) hydric-tending oak woodlands and associated grasslands, especially on high terraces. The latter can experience significant drought stress in summer but are often wet in winter. A fourth minor habitat class dominated by C_4 species is defined as "shrubby/graminoid streambanks" that experience flooding and other seasonal changes in water level sufficient to maintain a distinct zonation of vegetation between forested banks and the low water levels. Similar patterns have been observed in other regions of the world (Sage et al. 1999). Further study of shoreline vegetation along different kinds of water-body is needed to examine the fine spatial scale at which C_4 grasses can concentrate within such zonations.

Subhydric or hydric sites that experience less seasonal drying appear to have virtually no typical C_4 grasses, but there are a few locally abundant C_3 grasses within these habitats. A parallel trend exists within the sedge family (Cyperaceae). The dominance of C_3 species on more permanently hydric sites, even in full sun, is a global trend (Sage and Monson 1999).

The few native C_4 grasses that occur in deeper shade are all perennials in the genus *Muhlenbergia*. However, the weedy invasive Asian C_4 annual, *Microstegium vimineum*, has now spread widely into Kentucky's forests, especially along streambanks, trails, grazed areas, and other sites with disturbed soil (sometimes including woods burned in the spring before germination).

There is no significant overall trend in C_4 versus C_3 species along the gradient from acid soils with low fertility to base-rich soils with high fertility. However, locally dominant perennial grasses, especially the few taller species that reach 2 m or more, are mostly C_4 species on low to average soil fertility (e.g., *Andropogon gerardii*), and mostly species C_3 on higher soil fertility (e.g., *Arundinaria gigantea*). In contrast, alien grasses of both C_3 and C_4 groups increase in numbers on higher fertility.

High N levels have been shown experimentally to increase the ratio of C_3 to C_4 grasses in cooler regions (e.g., Tilman 1988, Wedin and Tilman 1993, 1996), in accord with the approximately doubled N requirement for photosynthesis that is typically estimated in C_3 species (Long 1999). For physiological reasons, this effect is probably stronger when temperatures and light levels are lower. However, enhancement of N level in warmer climates or later in the growing season may allow "aggressive eutrophiles" in the C_4 group to increase, including invasive aliens such as *Digitaria* spp. that appear adapted to anthropogenic ecosystems with higher fertility (Kretschmer and Pitman 1995, Sage et al. 1999).

A Developing Hypothesis

Since eutrophic soils support rapid plant growth in general, there is a strong tendency for forest to predominate, with rapid recovery from disturbances. Because of this, there may have been relatively little opportunity for selection of tall, potentially dominant C_4 grasses on sunny, eutrophic sites in eastern North America. Moreover, within the predominantly deciduous woods on eutrophic soils, there is more potential for dense grassy ground vegetation with C_3 species to develop, especially in spring when nutrient and light levels are highest. Global trends would support this hypothesis (Archibold 1995, Sage et al. 1999).

The dense, diverse aspect of ground vegetation in eutrophic woods is a generally observed trend in Kentucky, especially when comparing the rich limestone soils of the Bluegrass region with the relatively acid, infertile soils of the surrounding Knobs region. *Elymus* spp. are particularly common in the partial shade of eutrophic woods, including the recently described, early flowering *E. macgregorii* J. Camp. & R. Brooks (Campbell 2000). The local dominance of *Arundinaria gigantea* (cane) in more open woods before settlement on eutrophic uplands in Kentucky may be interpreted as a response to anthropogenic fires, or perhaps intense ungulate effects.

There are many historical indications that herbivores, probably promoted by high productivity and mineral nutrition, played at least a partial role in maintaining features of Bluegrass Woodlands before settlement. Also, several characteristic species of Bluegrass Woodlands have chemical or mechanical defenses that suggest coevolution with large ungulates (Campbell 1984). Bison, cattle, horses, elk, and sometimes deer are known to relish cane forage in certain seasons, but the extensive rhizome system of cane allows rapid regrowth after disturbance. It is likely that canebrakes were frequented by such animals for food and shelter during the winter (Campbell 1984, Platt et al. 2001; and continuing review of historical literature). Passenger pigeons are also reputed to have been associated with canebrakes. Nutrient cycling through such animals could have enhanced regrowth of C_3 species into the summer when the ungulates probably ranged into other habitats, including C_4 grasslands. If small areas of C_4 grassland developed within the Bluegrass Woodlands, it is possible that the intense use of the region by ungulates would have kept such grasslands overgrazed, unless fires were frequent enough to promote regrowth. At least in the summer, there is growing evidence in Kentucky that C_4 grasses are typically preferred by ungulates, due in part to healthier C:N ratios (e.g., ongoing research by the University of Kentucky's forage programs). Such patterns would accord with results of Knapp and Medina (1999) at Konza Prairie and the global review of Heckathorn et al. (1999).

The role of fire in Bluegrass Woodlands is more speculative. Initial research could focus usefully on fuel behavior and its relationship to nutrient cycling. Much potential C_3 fuel may experience relatively rapid consumption, compaction, or decomposition, in contrast to the relatively flammable, upright fuel of dominant C_4 grasses (Sage et al. 1999). Probably due to this factor and the greening-up of ground vegetation through the winter and spring, the woods are generally difficult to burn, especially in the spring. Old fields can easily burn in dry periods, but it is unclear what disturbance regime could have allowed similar habitats to develop before settlement. It is possible that large animal trails, followed by Native American burning and local clearing for campsites and villages, could have caused such openings. But early accounts at the time of settlement indicate that full openings were much less extensive than the typically noted "forests'" "thin woods" with "dense herbage of wild-rye, clover & peavine" and "canebreaks" (Campbell 1984, 1988, 1989). It is possible that there were relatively intense fires at longer intervals, perhaps during low points in the ca. 11-year or ca. 22-year periodicities of precipitation (Elam 1973; see also the Kentucky Climate Center Web site for recent data), or after the occasionally intense ice-storms that create abundant woody litter (as experienced in this region during February 2003, 1994, 1951), or after die-back of cane plants following flowering (Campbell 1985).

Within the central Bluegrass region, there is no evidence that C_4 grasslands occurred before settlement, except along rocky banks of major rivers and on the thin shaley soils of the Blue Licks area. However, in transitional areas outside this region, there are extensive remnants of C_4 grassland on dolomitic material, acid shales, old sandy river terraces, glacial deposits, and other soils with lower fertility (Campbell 1984). The only abundant native C_4 grass in old fields of the central Bluegrass region is *Tridens flavus*; minor species include *Andropogon virginicus* (on "worn-out" soils with lower calcium and other nutrients), *Paspalum pubiflorum* (in sunny grazed/mowed sites), and *Muhlenbergia schreberi* (in shady grazed/mowed sites). It is of course possible to plant and maintain the taller C_4 grasses on these soils; *Panicum virgatum* is especially amenable to this. But without mowing, if there are intermixed competitive, root-suckering native woody plants such as *Robinia pseudoacacia, Campsis radicans, Prunus americana, Cornus* *drummondii,* and *Arundinaria gigantea*, even frequent burning may be insufficient to prevent the decline of C_4 grasses to a minor proportion. Frequent fires, especially in the spring, may favor C_4 grasses by keeping N levels low (Knapp and Medina 1999), as well as reducing woody vegetation. But such treatment will probably not provide the best overall balance of native species in the vegetation, which includes diverse sedges, wild ryes, winter annuals, and running buffalo clover that grow mostly in the spring (Campbell et al. 1988). Such predictions can be now be tested at the Griffith Farm and other sites for research on native vegetation in the region.

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This paper is dedicated to the memory of Willem Meijer, who knew the global trends in his bones, provoked us for the better, and rediscovered mesophytic beauties in woodland remnants of the Lexington area. Also, I thank Bill Cohen for still being there 25 years later to answer questions about photosynthesis. And I am particularly grateful to Jeff Hohman, Joe Settles, and others at East Kentucky Power Cooperative for financial support of this work.

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Table 1. Comparison of typical flowering months for C_4 versus C_3 grass species.

	Typical Flowering Months						
	Apr-May 4-5	**May-Jun 5,5-6**	**Jun-Jul 6,6-7,5-8**	**Jul-Aug 7,6-8; 7-8**	**Aug-Sep 8,8-9**	**Sep-Oct 9,9-10**	**Total Species**
C4 species	0	0	1(1)	18(9) 1(1); 17(9)	23(10)	6(2)	48
C3 species	4(3)	15(10)	25(11)	19(11) 11(3); 8(7)	1(1)	0	64
Total species	4	15	26	37	24	6	112
C4 percent	0%	0%	4%	49% 8%; 68%	96%	100%	43%

Notes: In Jul-Aug, a tentative subdivision is presented below the number for the whole month. Numbers in parentheses are genera represented in each class. There is a highly significant difference between the distribution of C_4 and C_3 species among the six seasonal divisions; chi-square = 66.4, d.f. = 5, $P < 0.0005$. The difference between numbers of genera, in parentheses, remains highly significant; chi-square = 29.2, d.f. = 5, $P < 0.0005$.

Table 2. Comparison of typical hydrological habitat classes for C_4 versus C_3 grass species.

[Cliffs] [no typical grasses]	XI: Subxeric forest C_4 = 2(1); C_3 = 8(6) **20%**	XII: Xeric pine/cedar-oak woodlands and glades C_4 = 8(5); C_3 = 5(2) **62%**
V: Mesic forest C_4 = 1(1); C_3 = 2(2) **33%**	VII: Submesic forest, VIII: Thickets, edges, old fields C_4 = 4(4); C_3 = 20(10) **17%**	X: Xeric-tending oak woods and grassland C_4 = 17(10); C_3 = 11(8) **61%**
III: Streamside forest C_4 = 2(2); C_3 = 6(5) **25%**	VI: Subhydric forest; and shrubby seeps C_4 = 0; C_3 = 4(4) **0%**	IX: Hydric-tending oak woods and grassland C_4 = 9(8); C_3 = 5(3) **64%**
I: Shrubby/graminoid streambanks C_4 = 5(5); C_3 = 1(1) **84%**	II: Shrubby/graminoid swamp/marsh/bog C_4 = 0; C_3 = 2(2) **0%**	[IV: Deep swamps] [*Phragmites, Zizaniopsis*, etc.] [rare/alien species only] **0%?**

Notes: Note that most species range widely, but the most typical habitat class is assigned here. "C_4 =" and "C_3 =" show numbers of modal species in each class; numbers in parentheses are genera represented. The bottom line in each class is the percentage of C_4 species. There is a highly significant difference between C_4 and C_3 species among the 10 habitat classes where they typically occur (excluding Cliffs and Deep Swamps); chi-square = 26.6, d.f. = 9, P = 0.002. The difference between numbers of genera remains significant; chi-square = 19.7, d.f. = 9, P = 0.02.

Table 3. Comparison of typical sun-shade distribution for C_4 versus C_3 grass species.

		Typical Position along Sun-Shade Gradient					
C4/C3 Group	**Habitat Classes**	**Full Shade (code 5)**	**Transition (code 4)**	**Thin Shade (code 3)**	**Transition (code 2)**	**Full Sun (code 1)**	**Total Species**
C4 species	open drying	0	0	0	3(3)	36(13)	39
	closed/ non-drying	0	3(1)	2(1)	2(2)	2(2)	9
C3 species	open drying	0	0	0	10(7)	12(7)	22
	closed/ non-drying	4(4)	10(6)	13(12)	15(7)	0	42
C4 percent		0%	23%	13%	17%	76%	43%

Notes: Within groups, species are separated further according to "open drying" habitats (classes I, IX, X, and XII in Table 2) versus "closed/non-drying" habitats (all other classes in Table 2). Numbers in parentheses are the genera represented in each case. There is a highly significant difference between C_4 and C_3 species among the five sun-shade divisions; chi-square = 41.2, d.f. = 4, P < 0.0005. The difference between numbers of genera remains highly significant; chi-square = 19.3, d.f. = 4, P = 0.001.

Table 4. Comparison of typical soil gradient positions of C_4 versus C_3 grass species.

		Typical Position along Soil Gradient					
C4/C3 Group	**Habitat Classes**	**Infertile pH 4-5 (code A)**	**Transition or Varied (code B)**	**Average pH 5-6 (code C)**	**Transition or Varied (code D)**	**Fertile pH 6-7 (code E)**	**Total Species**
C4 species	open drying	1(1)	2(2)	14(8)	22(11)	0	39
	closed/ non-drying	0	2(2)	3(3)	1(1)	3(1)	9
C3 species	open drying	2(2)	7(3)	5(4)	6(6)	2(2)	22
	closed/ non-drying	0	8(6)	13(7)	18(12)	3(3)	42
C4 percent		33%	21%	49%	49%	38%	43%

Notes: Within each group, species are separated further according to “open/drying” habitats (classes I, IX, X, and XII in Table 2) versus “closed/non-drying” habitats (all other classes in Table 2). Numbers in parentheses are genera represented in each category. The difference in distribution between C_4 and C_3 species is not significant, given the model of random assortment; chi-square = 5.1, d.f. = 4, P = 0.28.

Table 5. Locally abundant perennial grasses of relatively undisturbed native vegetation; in full sun (1/2), partial sun (3), or shade (4/5); taller species (often > 2 m) in bold.

	Low Fertility (A/B)	**Average Fertility (C)**	**High Fertility (D/E)**
C4 species	*Saccharum giganteum (1)* ***Saccharum alopecurioides*** *(2)*	**Sorghastrum nutans** (1) **Andropogon gerardii** (1) **Tripsacum dactyloides** (1) *Panicum anceps (1)* *Panicum rigidulum (1)* *Aristida purpurascens (1)* *Andropogon virginicus (1)* *Andropogon glomeratus (1)* *Andropogon ternarius (1)* *Andropogon scoparius (2)*	***Panicum virgatum*** *(1)* *Setaria parviflora (1)* *Andropogon gyrans (1)* *Sporobolus compositus (1)* *Tridens flavus (2)* *Muhlenbergia sobolifera (4)*
C3 species	*Poa alsodes (2)* *Danthonia sericea (2)* *Danthonia compressa (2)* *Chasmanthium laxum (2)* *Piptochaetium avenaceum (3)*	*Panicum scoparium (2)* *Panicum microcarpon (2)* *Danthonia spicata (2)* *Elymus riparius (2)* *Cinna arundinacea (3)* *Panicum boscii (5)* *Brachyelytrum erectum (5)*	***Phalaris arundinacea*** *(1)* ***Arundinaria gigantea*** *(3)* *Leersia oryzoides (2)* *Leersia lenticularis (2)* *?Poa angustifolia (2)* *Elymus glabriflorus (2)* *Elymus v.var. intermedius (2)* *Elymus virginicus (3)* *Chasmanthium latifolium (3)* *Glyceria striata (3)* *Elymus macgregorii (4)* *Elymus villosus (4)* *Elymus hystrix (4)* *Festuca subverticillata (4)* *Muhlenbergia frondosa (4)* *Poa sylvestris (4)* *Diarrhena americana (5)*

Notes: This provisional table is based on general knowledge of Kentucky vegetation; it will need further support from vegetation data. Although C_3 species are about twice as frequent as C_4 species in the high fertility class while about equal in average and low fertility classes, this difference is only marginally significant, given the model of random assortment; chi-square = 4.76, d.f. = 2, P = 0.09.

Table 6. Abundant alien C_4 and C_3 grasses listed in relation to typical soil fertility.

	Locally abundant alien species; in full sun (1/2), partial sun (3), or shade (4/5); taller species (often > 2 m) in bold.		
	Low Fertility (A/B)	**Average Fertility (C)**	**High Fertility (D/E)**
C4 species		***Miscanthus sinensis*** *(1)* *Arthraxon hispidus (2)* *Microstegium vimineum (4)*	***Sorghum spp.*** *(1)* *Cynodon dactylon (1)* *Eragrostis spp. (1)* *Digitaria spp. (1)* *Setaria spp. (1)* *Echinochloa crus-galli (1)*
C3 species		*Holcus lanatus (1)* *Anthoxanthum odoratum (1)*	***Phragmitis australis*** *(1)* *?**Phalaris arundinacea*** *(1)* *Bromus spp. (1)* *Festuca arundinacea (1)* *Phleum pratense (1)* *Dactylis glomerata (2)* *Poa spp. (2)*

Notes: This provisional table is based on general knowledge of Kentucky vegetation; it will need further support from vegetation data.

Appendix 1. Printout from database on Kentucky grasses. (See "Methods" on page 97 for explanation of these codes.)

Scientific Name	C3/C4	Native Status	Vegetation Class	Acid/Basic Soils	Sun/ Shade	Flw Month
Agrostis gigantea Roth	C3	E	X; IX; VII; VI	D	1	6-7
Agrostis hyemalis (Walt.) B.S.P.	C3	N	X; XII	C	1	4-5
Agrostis perennans (Walt.) Tuckerman	C3	N	VII; XII; V	CB	3	7-8
Alopecurus carolinianus Walt.	C3	N	X; VII	D	1	5-6
Anthoxanthum odoratum L.	C3	E	X	C	1	6-7
Arrhenatherum elatius (L.) Beauv. ex J.& K. Presl	C3	E	VII; X	D	1	6-7
Arundinaria gigantea (Walt.) Muhl.	C3	N	VII; VI; III; V	D	3	5
Brachyelytrum erectum (Schreb. ex Spreng.) Beauv.	C3	N	V; XI; VII	C	5	6-7
Bromus inermis Leyss.	C3	E	X	E	1	6-7
Bromus japonicus Thunb. ex Murr.	C3	A	X	D	1	6-7
Bromus pubescens Muhl. ex Willd.	C3	N	VII; XI; V	D	4	6-7
Bromus racemosus L.	C3	E	X	D	1	6-7
Bromus secalinus L.	C3	E	X; XII	E	1	6-7
Bromus sterilis L.	C3	E	X; XII	E	1	6-7
Bromus tectorum L.	C3	E	X; XII	E	1	6-7
Calamagrostis coarctata (Torr.) Eat.	C3	N	VI; IX	B	2	7-8
Chasmanthium latifolium (Michx.) Yates	C3	N	VII; III; I	D	3	7-8
Chasmanthium laxum (L.) Yates	C3	N	IX; VI	B	2	7-8

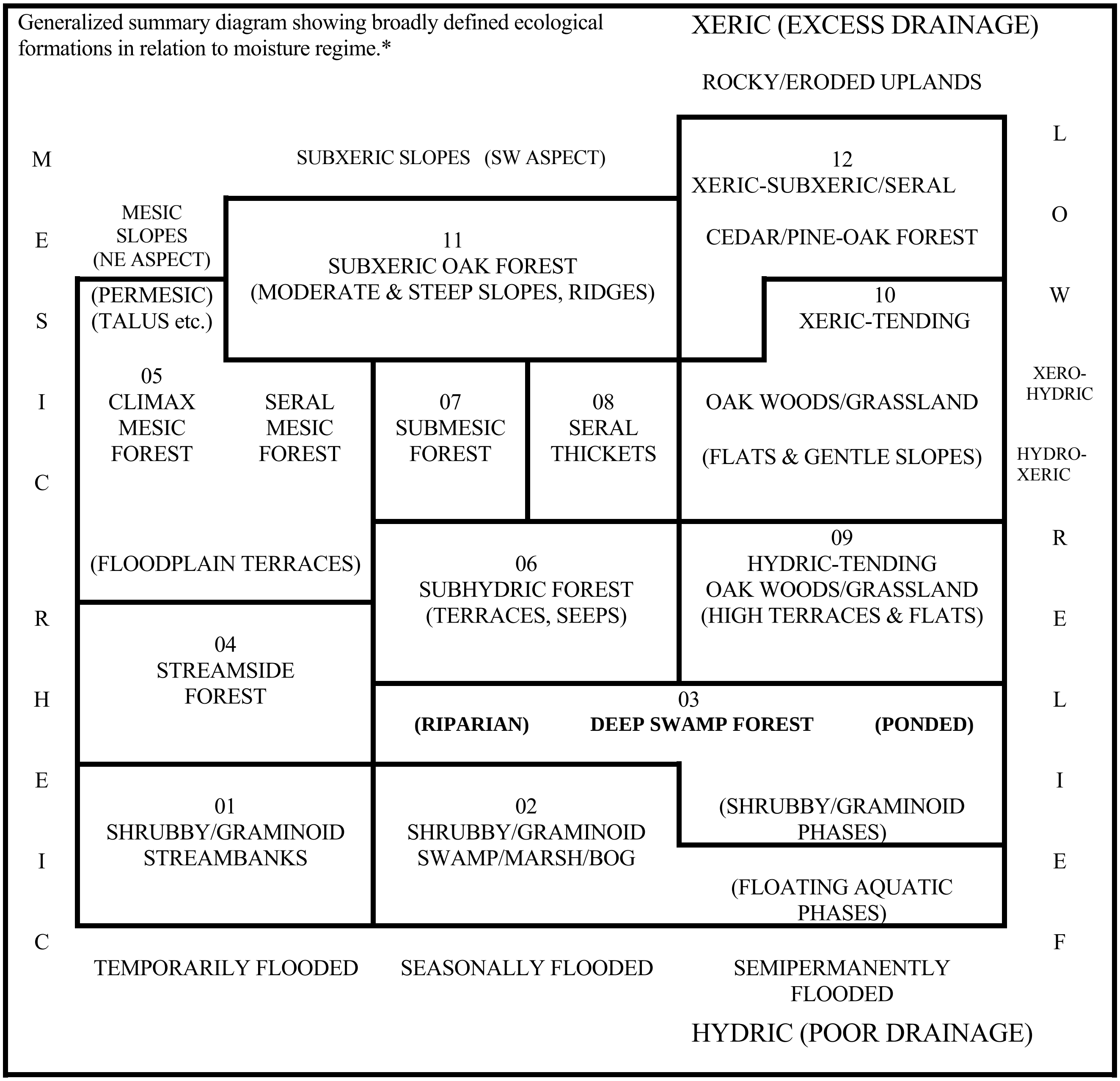
Scientific Name	C3/C4	Native Status	Vegetation Class	Acid/Basic Soils	Sun/ Shade	Flw Month
Cinna arundinacea L.	C3	N	III; VI	C	3	7-8
Dactylis glomerata L.	C3	E	VII; X	D	2	6-7
Danthonia compressa Austin ex Peck	C3	N	VII; X; V	B	2	6-7
Danthonia sericea Nutt.	C3	N	XII; X	A	2	5-6
Danthonia spicata (L.) Beauv. ex Roemer & J.A. Schultes	C3	N	VII; XI; XII	C	3	5-6
Diarrhena americana Beauv.	C3	N	XI; V	E	5	7-8
Elymus glabriflorus (Vasey) Scribn. & Ball	C3	N	VII; X	D	2	6-7
Elymus hystrix L.	C3	N	XI; VII; V	D	4	6
Elymus macgregorii J. Camp. & R. Brooks	C3	N	VII; III; X	E	4	5-6
Elymus repens (L.) Gould	C3	E	VII; IV; X	E	1	7
Elymus riparius Wieg.	C3	N	III; I; VII	C	2	7
Elymus villosus Muhl. ex Willd.	C3	N	VII; XI; V	D	4	6
Elymus virginicus L. var. intermedius (Vasey) Bush	C3	N	III; X*	D	2	7-8
Elymus virginicus L. var. virginicus	C3	N	VII;VI; X	D	3	6-7
Festuca arundinacea Schreb.	C3	E	X; VII	D	1	6-7
Festuca octoflora Walt.	C3	N	X; XII	C	1	5-6
Festuca paradoxa Desv.	C3	Nw	X	D	2	6-7
Festuca pratensis Huds.	C3	E	X; VII; VI	D	1	6-7
Festuca rubra L.	C3	En	X; VII; XI	D	2	6-7
Festuca subverticillata (Pers.) Alexeev	C3	N	V; VII; III	D	4	6-7
Glyceria septentrionalis A.S. Hitchc.	C3	N	II; IV; IX	D	2	6
Glyceria striata (Lam.) A.S. Hitchc.	C3	N	III; IV	D	3	6-7
Holcus lanatus L.	C3	E	VII; VI; X	C	1	5-6
Hordeum jubatum L.	C3	S	X; IX	D	1	7-8
Hordeum pusillum Nutt.	C3	Nw	X; XII; IX	E	1	5-6
Leersia lenticularis Michx.	C3	N	VI; IV; IX	D	2	8
Leersia oryzoides (L.) Sw.	C3	N	II; I; IV	D	2	7-8
Leersia virginica Willd.	C3	N	III; VII; VI	D	3	7
Lolium multiflorum Lam.	C3	E	VII; X	D	2	6-7
Melica mutica Walt.	C3	N	XI; VII; X	D	4	5
Panicum acuminatum Sw. var. fasciculatum (Torr.) Lelong	C3	N	VII; X; XII	C	2	6-8
Panicum ashei Pearson ex Ashe	C3	N	XI	B	3	5-8
Panicum boscii Poir.	C3	N	XI; VII; V	C	5	5-8
Panicum clandestinum L.	C3	N	VII; VI; X; III	D	2	5-8

Scientific Name	C3/C4	Native Status	Vegetation Class	Acid/Basic Soils	Sun/ Shade	Flw Month
Panicum columbianum Scribn.	C3	N	XII; X	B	2	6-8
Panicum commutatum J.A. Schultes	C3	N	VII; XI; V	C	3	5-8
Panicum depauperatum Muhl.	C3	N	XII; X	B	1	6-8
Panicum dichotomum L.	C3	N	XI; VII; V	C	4	6-8
Panicum joorii Vasey	C3	N	VI; III C		4	5-8
Panicum laxiflorum Lam.	C3	N	VII; X	C	2	5-8
Panicum lindheimeri Nash	C3	N	IX; X; VI; VII	C	2	6-8
Panicum linearifolium Scribn. ex Nash	C3	N	XII; X	D	1	5-8
Panicum microcarpon Muhl. ex Ell., non Muhl.	C3	N	IX; VI	B	2	5-8
Panicum oligosanthes J.A. Schultes	C3	N	XII; X	E	1	6-8
Panicum polyanthes J.A. Schultes	C3	N	VI; IX; III	B	2	6-9
Panicum ravenelii Scribn. & Merr.	C3	N	X; VII	B	2	5-8
Panicum scoparium Lam.	C3	N	IX; VI; X	B	1	6-8
Panicum sphaerocarpon Ell.	C3	N	VII; X; XII; XI	B	2	6-8
Panicum villosissimum Nash	C3	N	X; XII	A	1	5-8
Panicum yadkinense Ashe	C3	N	I; VI*	C	2	5-8
Phalaris arundinacea L.	C3	Nn	IX; VI; II	D	1	6-7
Phalaris caroliniana Walt.	C3	N	X; VII	C	1	5-6
Phleum pratense L.	C3	E	X; VII	D	1	7
Phragmites australis (Cav.) Trin. ex Steud.	C3	En	II; IX	D	1	8
Piptochaetium avenaceum (L.) Parodi	C3	N	VII; X; XI; XII	B	3	4-5
Poa alsodes Gray	C3	N	VII; V; III	B	2	5
Poa annua L.	C3	E	VII; X	D	1	4-7
Poa autumnalis Muhl. ex Ell.	C3	N	VII; V; XI	C	4	4-5
Poa cf. angustifolia L.	C3	Nn	X; VII	D	2	5-6
Poa chapmaniana Scribn.	C3	N	X; VII	B	1	5-6
Poa compressa L.	C3	E	VII; X; XI; XII	D	2	5-6
Poa cuspidata Nutt.	C3	N	XI; V	C	5	4-5
Poa pratensis L.	C3	En	VII; X; III	D	2	5-6
Poa sylvestris Gray	C3	N	VII; V; III	D	4	5
Poa trivialis L.	C3	Nn	III; VI; VII	E	2	6-7
Sphenopholis intermedia (Rydb.) Rydb.	C3	N	VII; VI; III; V	D	3	6-7
Sphenopholis nitida (Biehler) Scribn.	C3	N	XI; VII; V	B	3	5-6
Sphenopholis obtusata (Michx.) Scribn.	C3	Nw	X; VII	D	2	5-6

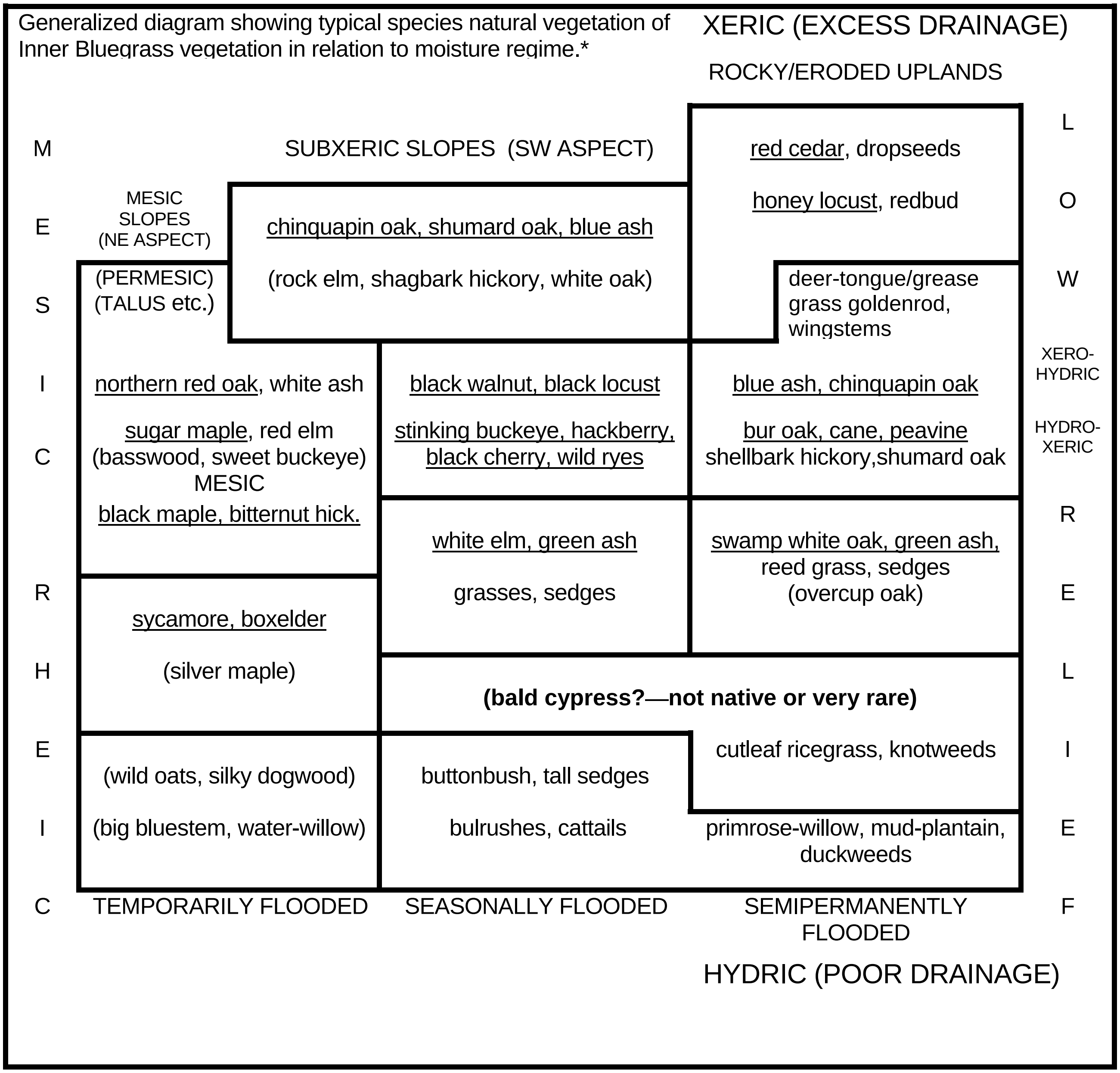
Scientific Name	C3/C4	Native Status	Vegetation Class	Acid/Basic Soils	Sun/ Shade	Flw Month
Andropogon gerardii Vitman	C4	N	X; XII; I*	C	1	7-8
Andropogon glomeratus (Walt.) B.S.P.	C4	N	IX; XI	C	1	9
Andropogon gyrans Ashe	C4	N	X; XII	D	1	9-10
Andropogon saccharoides Sw. var. torreyanus (Steud.) Hack.	C4	W	X	D	1	8-9
Andropogon scoparius Michx.	C4	N	XII; X	C	2	9
Andropogon ternarius Michx.	C4	N	X; XII	CB	1	8-9
Andropogon virginicus L.	C4	N	X; IX	C	1	9-10
Aristida dichotoma Michx.	C4	N	XII; X	B	1	8-9
Aristida longispica Poir.	C4	N	XII; X	D	1	8-9
Aristida oligantha Michx.	C4	N	X	C	1	8-9
Aristida purpurascens Poir.	C4	N	XII; X	C	1	8-9
Aristida ramosissima Engelm. ex Gray	C4	N	XII; X	C	1	7-8
Arthraxon hispidus (Thunb.) Makino	C4	A	VI; IX; III	C	2	9-10
Brachiaria platyphylla (Munro ex Wright) Nash	C4	Ns	III	D	2	8-9
Cenchrus longispinus (Hack.) Fern.	C4	N	I; X*	C	1	7-8
Cynodon dactylon (L.) Pers.	C4	S	X; VII	D	1	7-8
Digitaria ischaemum (Schreb.) Schreb. ex Muhl.	C4	E	X; IX	D	1	7-8
Digitaria sanguinalis (L.) Scop.	C4	E	X; VII	D	1	7-8
Echinochloa crus-galli (L.) Beauv.	C4	E	IX; X; IV; VII	D	1	6-8
Echinochloa muricata (Beauv.) Fern.	C4	N	IX; II*	D	1	7-8
Eleusine indica (L.) Gaertn.	C4	E	VII; X	E	1	7-8
Eragrostis cilianensis (All.) Vign. ex Janchen	C4	E	X; VII	D	1	7-8
Eragrostis frankii C.A. Mey. ex Steud.	C4	N	I; VII; X*	D	1	8
Eragrostis hypnoides (Lam.) B.S.P.	C4	N	I; II*	D	1	8-9
Eragrostis minor Host	C4	E	X; XII	D	1	7-8
Eragrostis pectinacea (Michx.) Nees ex Steud.	C4	E	X; VII; I	D	1	7-8
Eragrostis spectabilis (Pursh) Steud.	C4	N	X	C	1	7-8
Leptochloa brachiata Steudl.	C4	Ns	X; IX; VI	D	1	7-8
Leptochloa fascicularis Lam.	C4	Ns	IX; X	D	1	7-8
Microstegium vimineum (Trin.) A. Camus	C4	A	III; VII; IX; V	C	4	9-10
Miscanthus sinensis Anderss.	C4	A	VII; X	C	1	9
Muhlenbergia frondosa (Poir.) Fern.	C4	N	III; I; VI	E	3	8-9
Muhlenbergia schreberi J.F. Gmel.	C4	N	VII; X; III	E	3	8-9
Muhlenbergia sobolifera (Muhl. ex Willd.) Trin.	C4	N	XI; XII; V	E	4	8-9
Muhlenbergia sylvatica Torr. ex Gray	C4	N	V; III; VII	C	4	8-9

Scientific Name	C3/C4	Native Status	Vegetation Class	Acid/Basic Soils	Sun/ Shade	Flw Month
Muhlenbergia tenuifolia (Kunth) Trin.	C4	N	XI; V	B	4	8
Panicum anceps Michx.	C4	N	X; VII	C	1	7-8
Panicum capillare L.	C4	N	X; VII	D	1	7-8
Panicum dichotomiflorum Michx.	C4	N	X; IX; VI; I	D	1	7-8
Panicum flexile (Gattinger) Scribn.	C4	N	XII; X	D	1	7-8
Panicum gattingeri Nash	C4	N	X; XII; VII	D	1	8-9
Panicum philadelphicum Bernh. ex Trin.	C4	N	VII; X	C	1	7-8
Panicum rigidulum Bosc ex Nees	C4	N	IX; II*	C	2	7-8
Panicum verrucosum Muhl.	C4	N	IX; VI	A	1	8-9
Panicum virgatum L.	C4	N	I; IX*	D	1	7-8
Paspalum dilatatum Poir.	C4	S	VI; IX; X	D	1	7-8
Paspalum floridanum Michx.	C4	Ns	IX; VI; I*	D	1	8
Paspalum fluitans (Ell.) Kunth	C4	N	I; II*	D	1	8-9
Paspalum laeve Michx.	C4	N	VII; X	C	1	7-8
Paspalum pubiflorum Rupr. ex Fourn. var. glabrum Vasey	C4	N	IX; X; VI; VII	D	1	7
Paspalum setaceum Michx. var. muehlenbergii (Nash) Banks	C4	N	X; VII	D	1	7-8
Saccharum alopecuroidum (L.) Nutt.	C4	N	VII; X	B	2	9
Saccharum giganteum (Walt.) Pers.	C4	N	IX; VI; X	B	1	9
Setaria faberi Herrm.	C4	A	X; VII	D	1	7-8
Setaria parviflora (Poir.) Kerguélen	C4	Ns	X; VII; IX; VI	D	1	7-8
Setaria pumila (Poir.) Roemer & J.A. Schultes	C4	E	X; VII; XII	D	1	6-8
Setaria viridis (L.) Beauv.	C4	E	X; VII; XII	D	1	6-8
Sorghastrum nutans (L.) Nash	C4	N	X; VII	C	1	8-9
Sorghum bicolor (L.) Moench	C4	E	X; VII	D	1	7-8
Sorghum halepense (L.) Pers.	C4	E	X; VII; VI	D	1	7-8
Sporobolus clandestinus (Biehler) A.S. Hitchc.	C4	N	XII; X; XI	D	1	8-9
Sporobolus compositus (Poir.) Merr.	C4	N	X; XII; VII	D	1	8-9
Sporobolus neglectus Nash	C4	N	X; VII	D	1	8-9
Sporobolus vaginiflorus (Torr. ex Gray) Wood	C4	N	XII; X	D	1	8-9
Tridens flavus (L.) A.S. Hitchc.	C4	N	X; VII; XII	D	2	8-9
Tripsacum dactyloides (L.) L.	C4	N	IX; X; I*	C	1	6-7

Appendix 2. Explanatory Diagrams for the Model of Habitat Gradients



* See text for more description of these 12 basic classes, as indicated by the number at top center within each box.



Generalized diagram showing typical species natural vegetation of Inner Bluegrass vegetation in relation to moisture regime.*

* Underlined species are locally dominant trees in more natural vegetation; others are a selection of typical associates (generally in more open or successional habitats); species in parentheses are generally uncommon in the region but typical of special habitats.

Cluster Fescue (*Festuca paradoxa* Desv.): A Multipurpose Native Cool-Season Grass

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Native cool-season grasses (NCSG) are adapted to a wide range of habitats and environmental conditions, and cluster fescue (*Festuca paradoxa* Desv.) is no exception. Cluster fescue can be found in unplowed upland prairies, prairie draws, savannas, forest openings, and glades (Aiken et al. 1996). Although its range includes 23 states in the continental United States (Figure 1), it is rarely abundant in natural stands. Cluster fescue is found scattered in some states such as Arkansas and Missouri (Yaskievych 1999); however, it occurs less frequently in Iowa, is listed of special concern in Tennessee, and is listed as endangered in Indiana, Maryland, and Pennsylvania (Natural Resources Conservation Service 2004).

NCSG are C3 grasses that utilize the Calvin cycle for CO_2 fixation in contrast to the more efficient warm-season grasses (WSG) that utilize both the Calvin cycle and the C4 pathway during photosynthesis. NCSG typically exhibit rapid vegetative growth in the fall and early spring and flower in mid- to late spring. The seed matures in early summer before plants become dormant during the hottest part of summer (Navarrete-Tindall et al. 2003, Yatskievych 1999). The growth season of NCSG can be extended when grown under shade in moist soils (Navarrete-Tindall et al. 2003). On the other hand, WSG start growing in late spring or early summer, bloom in the summer, and produce mature seed in late fall before becoming dormant. Many CSG such as tall fescue (*Festuca arundinacea*) are known to be infected by fungal endophyte. The relationship between endophytes and host grasses is a mutualistic relationship (Christiansen and Bennett 2003), beneficial for both grasses and fungi. Cluster fescue samples tested for the presence of endophyte in southern Illinois were found 100% infected (Spyreas et al. 2001).

Limited information is available on the ecological, physiological, and agronomic aspects or wildlife value of cluster fescue probably because it is not well known throughout its range. Yatskievych (1999) and Hitchcock (1971) indicate that cluster fescue lacks rhizomes and produces leaves 10 to 40 cm long with inflorescence panicles 12 to 20 cm long that droop at maturity. Cluster fescue is easily confused with the more shade-tolerant nodding fescue (*F. subverticillata*) (Aiken and Leptovitch 1993, Aiken et al. 1996). We have observed that cluster fescue seed is 3 to 4 mm long or slightly smaller than the seed of tall fescue with approximately 1,000 seed per gram (Navarrete-Tindall et al. 2003). Although the seed matures from June to July, harvest can be extended to October or later as seed remains in the panicles into the winter. Mechlin (1999) reported that cluster fescue produces more vigorous growth after summer burns than after spring burns in trials done at Tucker Prairie. Landowners and conservationists are interested in including NCSG for pasture restoration with native warm-season grasses to provide forage in the spring and fall when WSG are dormant. When seed is readily available, cluster fescue along with other NCSG such as manna grass (*Glyceria striata*), bottlebrush grass (*Elymus hystrix*), or Virginia wild rye (*E. virginica*) need to be planted in pastures with WSG to determine their competitive ability and suitability for wildlife habitat, conservation cover, and livestock forage (V.R. Shelton and W. Vassar personal communications).

The main goal of our studies has been to evaluate the ecological, physiological, and agronomic aspects of cluster fescue and other NCSG to promote their inclusion in natural areas and native plantings. Our main objective for this paper includes developing information on the effects of different planting times and plant spacing on seed production using seed collected from natural populations within several Missouri ecoregions. A second objective is to examine the persistence and effects of different light levels on growth of cluster fescue and other NCSG in replicated studies and demonstration areas in Missouri.

Natural Stands Identification, Seed Collection, and Seed Germination

Initially, we visited sites within the four ecoregions of Missouri where cluster fescue had been previously reported based on the Nomenclature Database of the Missouri Botanical Garden (Missouri Botanical Garden 2004) to study the natural history of cluster fescue and to collect seed (Erickson and Navarrete-Tindall 2004). We also visited several natural areas including prairies, state parks, back roads, and private properties to collect seed in collaboration with the Missouri Ecotype Program, the Plant Materials Center in Elsberry, and the Iowa Department of Natural Resources. We visited several sites and found that private sites had been developed and no longer maintained native vegetation or were not accessible. During the first year of the study, we found cluster fescue at Paintbrush Prairie in Pettis County and at Tucker Prairie in Callaway County. At the end of the second year, we had seed from a total of seven sites, two from Ecoregion 1, one from Ecoregion 2, and two from Ecoregion 3 of Missouri and two sites from southern Iowa.

In one experiment, we tested for the presence of hard and dormant seed of two seed sources collected in Ecoregions 1 and 2 of Missouri. The Missouri Seed Improvement Association in Columbia conducted the seed germination trials by first exposing seed to a moist-chilled environment for three days at 20°C and then placing on moist germination paper in growth chambers at 30°C. Seedling emergence was counted four times over the next 35 days without a purity analyses. Untreated, one-year old seed from Tucker Prairie produced 62% germination with 26% dormant seed. Freshly collected seed from Tucker Prairie and Paintbrush Prairie produced 1 and 2% germination with 89 and 88% dormant seed, respectively. This suggested that cold-moist stratification may be necessary for good seed germination.

Subsequently, we examined the effect of cold-moist stratification on germination of four seed sources in a greenhouse experiment. Initially seed was sown into 12 plastic 38-plug trays. The 5-cm by 7-cm tall plugs were filled with ProMix® 200 growing media. After watering, half of the trays were stored at 5°C in a walk-in cooler, and the second half were set in the greenhouse at 30°C. After 21 days, trays stored in the cooler were set in the greenhouse with the rest of the trays. Seed germination was determined every 10 days for 40 days. Percent seed germination varied depending on the source (Table 1). Average percent germination was slightly higher for stratified seed compared to nonstratified seed. Also seed collected from plants grown at the Horticulture and Agroforestry Research Center (HARC) in New Franklin from seed originally collected at Tucker Prairie had higher percent germination than freshly collected seed from Paintbrush Prairie.

Seed Production Plots

In 2002, we established a study to determine the effect of planting time and plant spacing on growth and seed yield of cluster fescue. Trays from the seed germination experiment were set on wire-top tables for four months to allow the root system to develop (B. Erickson, personal communication). Half of the four-month-old seedlings were planted in the fall of 2002 into plots seeded with perennial ryegrass at the Horticulture and Agroforestry Research Center. Seedlings were planted in rows spaced 90 cm apart with plugs planted 30, 60, or 90 cm apart. Remaining seedlings were overwintered in a walk-in cooler and planted the following spring in plots adjacent to the fall-planted seedlings. Analysis of results from this experiment established as a split plot design with three replications show no differences for tiller number or height or foliage biomass when seedlings were planted 30, 60, or 90 cm apart. Seedlings established in the fall were larger and produced more seed than those planted the following spring (Table 2). Seed yields were approximately 119 kg/ha for seedlings planted in the fall and only 20 kg/ha for seedlings established the same year in the spring. Only seedlings established in the spring with little or no seed production persisted into a second year when they yielded a heavy crop of seed and then died.

Cluster Fescue Natural Regeneration

Because plants may not persist after heavy seed yields, we decided to determine if plant populations persist through natural regeneration and if cluster fescue could effectively suppress other competition from the seed bank. To do this, we placed four 40 by 40 cm Anderson® trays filled with ProMix® 200 medium in each of the seed production plots. We left trays in the field during the fall and winter and brought them to the greenhouse in early spring to observe germination. Trays were watered three times a week. Three months later, we counted the number of seedlings of cluster fescue and other vegetation. We found the number of cluster fescue seedlings per m^2 was higher for trays set in seed production plots when plants were 30 cm apart than for seed production plots when seedlings were established 60 or 90 cm apart (Table 3). Total number of seedlings of perennial rye, other grasses, and forbs was 178, 158, and 250 seedlings per m^2 for plants planted 30, 60, and 90 cm apart, respectively. Our results are similar to results from other studies done at Tucker Prairie, where yearly environmental fluctuations had little effect on cluster fescue reproduction over a nine-year period (Rabinowitz et al. 1989).

Shade Tolerance Trials in Field Conditions and Demonstration Plots

Because NCSG are well adapted to light to moderate shade, we examined productivity of cluster fescue to that of seven other NCSG under artificial and natural shading. In summer 2003, four-month-old seedlings of cluster and nodding fescue, river oats (*Chasmanthium latifolium*), Canada wild rye, Virginia wild rye, bottlebrush grass, prairie junegrass (*Koeleria macrantha*), and fowl manna grass were established as row plots in 5 x 10 m irrigated plots covered with 2 m tall frames. Frames were left uncovered or covered with 30% or 50% shade cloth. This split plot experiment with three replications is being repeated because of poor survival when in competition with perennial ryegrass at the Horticulture and Agroforestry Research Center. In summer 2003, seedlings of the same eight species were also established under the shade of a thinned 15-year-old sweetgum planting at the Turf Research Center near Columbia. Crown cover and light were measured to determine shade levels. We plan to evaluate survival, forage and seed production, and forage quality in both experiments for three years. It is anticipated our findings will help us to make future recommendations for inclusion of NCSG in several agroforestry practices, the restoration of savanna and woodlands, and the creation of native wildlife habitat and landscapes.

Demonstration Plantings

Additional test and demonstration plots for cluster fescue and other NCSG have been established in Columbia, New Franklin, and Sedalia (Table 4). The purposes of our demonstration plots are to increase public awareness of the importance of including NCSG in restoration and wildlife projects and to make seed available to other researchers, conservationists, and seed producers. These plots are used for field days and open to the public. We continue to monitor ease of establishment, persistence, plant growth, and seed production at each of these demonstration plantings.

Acknowledgments

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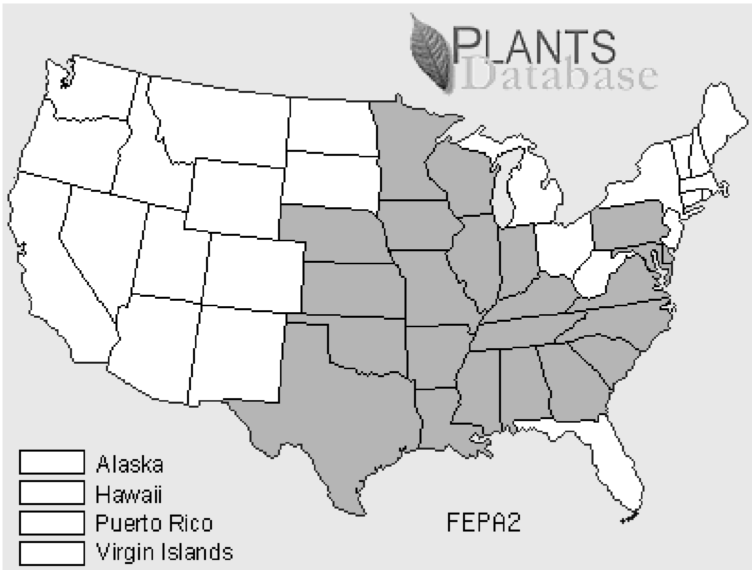

Figure 1. States where cluster fescue (*Festuca paradoxa* Desv.) is naturally found. (Syn: *Festuca nutans* Biehler and *Festuca shortii* Kunth ex Wood)
Source: Adapted from USDA NRCS 2004 Web site:http://plants.usda.gov/.

Alabama	Illinois	Kentucky	Mississippi	Oklahoma	Texas
Arkansas	Indiana	Louisiana	Missouri	Pennsylvania	Virginia
Delaware	Iowa	Maryland	Nebraska	South Carolina	Wisconsin
Georgia	Kansas	Minnesota	North Carolina	Tennessee	

Table 1. Mean percent germination of six 38-plug trays 40 days after sowing of cluster fescue seed collected in 2003 from four locations in Missouri.

Stratification	Tucker	New Franklin*	Cosmo Park*	Paintbrush
	----------------------------- % ------------------------------			
No	37	42	36	10
Yes	38	52	39	12

* Second generation of seed originally collected at Tucker Prairie in 2002.

Table 2. Average tiller number and height for cluster fescue seedlings field-planted in fall 2002 or spring 2003 and average foliage and seed dry weight when harvested in July 2003.

Planting Time	Tiller Number*	Tiller Height*	-----Plant Dry Weight---- Foliage*	Seed*
	-no.-	-cm-	-g/plant	-g/plant-
Fall '02	15	77	7.6	2.7
Spring '03	6	58	1.4	0.9

* Values in columns are significantly different at the 0.05 level of probability according to Duncan's multiple range test.

Table 3. *Festuca paradoxa* seedling regeneration in the presence of a seed bank of perennial rye and other volunteer vegetation.

Stock Plant Spacing	***Festuca paradoxa***	***Perennial Rye***	***Other Grasses***	***Horse Weed***	***Other Forbs***
	---------- no. seedlings/m² -----------				
30 cm (1 ft)	*184*	*20*	*20*	*105*	*31*
60 cm (2 ft)	*59*	*26*	*7*	*118*	*7*
90 cm (3 ft)	*53*	*39*	*59*	*138*	*13*

Values are averages from 12 trays.

Table 4. *Location, NCSG species, establishment year, and purpose of demonstration plots established in Missouri to evaluate growth and seed production of cluster fescue.*

Cosmo City Park, Columbia	*Cluster fescue*	*2002*	*Planted with other native species for ornamental purposes*
UMC-South Farm, Columbia	*Cluster fescue and manna grass*	*2003*	*To show plant competition with two invasive introduced grasses*
UMC-South Farm, Columbia	*Cluster fescue*	*2003*	*Weed control with and without weed barrier fabrics to protected plants*
Horticulture and Agroforestry Research Center (HARC), New Franklin	*Several NCSG, NWSG, and native legumes and forbs*	*2003*	*Established in the Plant Hardiness Zone 5 arboretum*
Bradford Research and Extension Center (BREC), Columbia	*Cluster fescue, other NCSG, NWSG, and native forbs and shrubs*	*2004*	*Established seed production plots for several Missouri and Iowa seed collections*
Recently upgraded intersection right-of-way near Sedalia	*Cluster fescue*	*2004*	*Hydroseeding of cluster fescue seed at 0.5 lb per 1000 ft² (24 kg/ha)*

Sandhill Restoration: Structure and Process

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Abstract

The Nature Conservancy's Northwest Florida Program is involved in an ambitious sandhill community restoration at the Apalachicola Bluffs and Ravines Preserve, Liberty County, Florida. In the late 1950s, the St. Joe Paper Company clear cut longleaf pines (*Pinus palustris*) and pushed remaining vegetation and topsoil into windrows to establish a slash pine (*Pinus*

elliottii) plantation. The Conservancy began its restoration in the 1980s by harvesting the off-site slash pines and replanting longleaf. In the late 1980s, native groundcover restoration began. Initially, wiregrass plugs (*Aristida stricta*) were nursery-grown from hand-collected seed and planted. This limited groundcover establishment to one species was slow and costly. Direct seeding with a mix of native groundcover seed in the field allowed for greater acreage to be sown annually with a much higher number of species and at a much lower cost. However, for sandhill restoration to move in the appropriate direction, there must be the ability to apply the process (fire) that shapes the community. When only longleaf was planted, restoration by fire was limited due to the lack of fine fuels. The addition of wiregrass plugs allows fire to be used more frequently and under more variable climate conditions. Direct seeding allows for an even greater flexibility using fire. After the late April burns of 1999 and May 2000, wiregrass that had been direct seeded in 1996 and 1998, respectively, produced viable seed and established new seedlings. Direct seeding in conjunction with removal of the windrows has been utilized to restore native groundcover to more than 300 acres in the past few years. The Northwest Florida Program is continually working to establish and improve the structure and process for maintaining the sandhill community.

The longleaf pine (*Pinus palustris*) ecosystem once covered a substantial majority of the southeastern United States, between 60 and 90 million acres, perhaps the greatest expanse dominated by a single-tree species in the country (Frost 1991, Johnson and Gjerstad 1998). The longleaf forests have declined by an astonishing 98% from their historical range, mostly due to human settlement. It is estimated that in the late 1800s, Florida had 6.5 billion board feet of virgin longleaf pine, but within four decades, practically none remained. Numerous human activities, including cattle grazing, turpentining, timbering, and clearing for agriculture, have left only scattered remnants of virgin longleaf and its associated groundcover in the Southeast. The largest remaining virgin longleaf stand, approximately 200 acres, is located in southwest Georgia (Johnson and Gjerstad 1998). Today numerous agencies, conservation groups, consultants, and private individuals are interested in restoring longleaf pine communities.

The Nature Conservancy (TNC) owns and manages the 6,300-acre Apalachicola Bluffs and Ravines Preserve (ABRP) in Liberty County, Florida. The preserve contains a mixture of slope forest, floodplain forest, and sandhill upland. Except for a few intact remnants, ABRP's sandhills today by no means resemble the original longleaf pine/wiregrass (*Aristida stricta*)-dominated sandhill community that once existed. Past practices of severe soil disturbance, poor silvicultural applications, and vigorous fire suppression have significantly impacted this system, altering its structure and function. Even within the areas with remnant longleaf pines, fire suppression limited the availability of clear seed beds for the remaining longleaf seed sources.

Clearcutting of the remnant longleaf pines at ABRP began in the 1950s, followed by the mechanical removal of all remaining vegetation. The vegetation, logging debris, and topsoil were pushed into linear heaps or windrows (Seamon 1998). By 1958, the majority of the preserve's uplands had been clearcut and windrowed by private timber companies. At the time, foresters thought that pines would grow easily in almost any soil condition if given enough water and no competition; hence, the mechanical removal, or windrowing, of all other vegetation. The windrows became the havens for much of the remaining natural groundcover, particularly wiregrass. These disturbed areas were then planted in off-site slash pine (*Pinus elliottii*), which are much less fire-tolerant than longleaf pine. Fire was excluded from the system. Active fire suppression allowed invading or sparse mid-story hardwoods to proliferate and further alter the character of the sandhill community. Myers (1990) states that the "abundance and stature of deciduous oaks may be proportional to mean length of fire return: the longer the interval, the more prevalent the oaks." The interwindrow area became dominated by slash pine, turkey oak (*Quercus laevis*), and other hardwoods, and windrows and ravine edges became dominated by mesic hardwoods. Windrows were often pushed to the upper slopes of a ravine, hastening the encroachment of the mesic species into the sandhill by providing a good medium for establishment and by stopping fire from creeping downslope into the ravines.

In 1985, The Nature Conservancy initiated a program to reestablish the longleaf pine/wiregrass sandhills at ABRP on 3,200 acres of disturbed uplands on the preserve. Reforestation of longleaf pine began as the 30+-year-old slash pines were harvested for sale. Originally, it was thought that if 30 trees per acre were left, the needle drop from these trees would help carry fire through the system; however, this density proved too sparse. Since 1996, all off-site pines have been removed during any timber operations. Funds from the sale of the slash pines helped purchase longleaf pine tubelings. To date, more than 1.4 million longleaf pines have been planted, all by hand, at a density of 200 to 500 trees per acre. Survival and establishment have varied among the individual plantings. No attempt has been made to use a local seed source, and there is no genetic information on the origin of most of the planted pines.

Restoring the diverse groundcover, including wiregrass, presents the greatest challenge to sandhill restoration. The overall management goal of ABRP is to enhance the biological diversity within the natural communities. To accomplish this, a prescribed fire program is essential. The longleaf pine/wiregrass community is maintained by frequent, low-intensity fires (Chapman 1932, Myers 1990). Those low-intensity fires will not carry on severely degraded, scarified sandhill sites unless the ground layer is reestablished. Wiregrass is the dominant groundcover in natural sandhill communities and serves as the major fuel source (Platt et al. 1988, Clewell 1989, Myers 1990, Seamon 1998). However, most of ABRP's natural groundcover had been pushed into the windrows and replaced by other grasses and herbs, such as blackberry (*Rubus cuneifolius*) and dog fennel (*Eupatorium compositifolium*) that do not carry fire well.

It was formerly thought that wiregrass could not reestablish through seed as its flowers were rarely perfect and almost never produced seed (Clewell 1989). It was generally surmised that sexual reproduction required certain conditions, but these conditions were unknown. Research by TNC's Fire Management and Research Program and Northwest Florida Program verified that it was feasible to produce viable wiregrass seed, that wiregrass needs growing-season fire to induce flowering, and that fires occurring during the early growing season (April-July) produced the greatest flowering response and the highest viable seed (Seamon et al. 1989, Seamon 1998). Fires that occurred later in the season (September-November) scarcely flowered and produced no viable seed (Seamon 1998). In response to these results, surviving intact wiregrass sites at ABRP have been burned during the early growing season (preferably late April through early July) on a two- to three-year rotation to produce viable seed for harvest.

Early efforts showed that it was possible to germinate seed in the nursery and in the field and that nursery-grown plugs could establish and thrive after outplanting (Seamon and Myers 1992, Seamon 1998). Beginning in 1989, the Conservancy began harvesting seed by hand, and a nursery was built to produce wiregrass plugs from seed (Seamon 1998). All the seed harvested this way since 1989 has come from ABRP or adjacent state-owned Torreya State Park. This is labor-intensive, but it yields the clean seed needed for the nursery. The nursery was built at ABRP that today can produce about 90,000 native groundcover plugs per season; one growing season can provide enough plants to restore approximately six acres. Through September 2004, 894,000 plugs have been propagated and planted on the preserve, restoring approximately 70 acres of groundcover. With approximately 2,700 acres of uplands that have little or no wiregrass, this restoration technique is slow and highly expensive. By approximating labor costs and depreciation of equipment, it has been estimated to cost $8,000 to $12,000 per acre to restore groundcover using nursery-grown wiregrass plugs.

To increase the area restored with native groundcover and the number of species restored in the groundcover and to decrease the costs of the restoration, TNC began looking for a mechanical way to collect seed. Beginning in 1993, mechanical collection was first tried using a Grin Reaper (Mahler 1988), which attaches to a weed trimmer and feeds cut stalks into a bag. This method was successful but put undue strain on the operator: the height of the seed stalks (averaging about 1 m) required the operator to either push down on the back of the machine or lift the front. The second machine proved much more successful, a Woodward Flail-Vac seed stripper, which attaches to the front of a four-wheel all-terrain vehicle (ATV). This machine, made by Ag-Renewal of Weatherford, Oklahoma, grabs the seed stalks with a brush and feeds them into a hopper behind the brush as the ATV drives across the site. TNC now operates two of these seed strippers during the five- to six-week collection period (mid-November/late December). During peak collection times, the seed stripper can collect enough seed to fill a 33-gallon paper yard trash bag in 20 minutes. The machine collects more than just wiregrass seed; therefore, the seed is not clean enough to use in the nursery, but it is fine for direct seeding. To date, 59 additional groundcover species have been identified from collections. Additionally, stems, leaves, sticks, and soil can be collected. The percentage of seed by weight has varied from 15 to 30% of the total weight collected. About half of that weight is wiregrass seed.

The next challenge was effective mechanical sowing of the seed mix. Initially, two different types of fertilizer spreaders were used with less than favorable results. The awns on several species' seeds clumped together and remained as a ball of seed in the bottom of the spreader. Another method attempted was to feed seed into the air intake of a hand-held leaf blower. The leaf blower spread the seed effectively but was slow and labor intensive. However, a commercial hay blower in the bed of a pickup truck proved effective, rapid, and much less labor intensive.

In early 1996, TNC sowed six 15 m x 45 m plots with 20 pounds of seed mix/plot. The year was below average for rainfall, and wiregrass establishment was very low, 100 to 300 plants per plot. However, close to average precipitation in 1997 resulted in a 10-fold increase in wiregrass establishment. This effort was one of the first documented instances of successful wiregrass seedbanking (Seamon 1998, Mulligan and Kirkman 2002).

In 1996 and 1998, TNC received two contracts, respectively, from the Florida Department of Transportation (FDOT) to research the possibility of establishing native groundcover outside the clear zone along new roadway construction (Gordon et al. 2000, Gordon et al. 2001). The first contract (FDOT 1) established 51 15 m x 30 m plots on old windrows that had been knocked down and spread with a bulldozer. Nine pounds of seed mix was sown on 48 of the plots. A factorial design was set up to allow for a number of combinations of treatments. On half of those plots (24), the seed mix was rolled into the soil after sowing with a landscape aerator pulled behind an ATV. On half the plots, a cover crop of annual rye was added to the seed mix, and on half the plots, the plot was watered once for every three days without rain during February and March and once for every four days without rain during April and May (Gordon et al. 2000). At the end of two years of monitoring, it was determined that none of the treatments had resulted in a significant difference in the establishment of native groundcover or, specifically, wiregrass (Gordon et al. 2000). These plots were burned in 2000 and again in 2004. The wiregrass seed collected from the FDOT 1 plots in 2000 contained the highest percentage of viable seed of any seed collected on ABRP that year.

For the FDOT 2 contract, three types of seeding equipment were tried over several types of site preparation. Part of the area was singly chopped with a roller-chopper pulled behind a farm tractor, part of the area was burned, and another part was burned and then chopped. Additionally some plots received supplemental water, and some did not. The seeding equipment included a modified fertilizer spreader on the back of a pickup truck, a commercial hay blower, and a commercial hydroseeder. Results of this restoration indicated that sites that were not mechanically disturbed could establish groundcover if burned prior to sowing and watered post-sowing. If fire and irrigation were not used, lightly roller-chopping the site allowed good establishment of species such as wiregrass but not as successfully as fire and irrigation management (Gordon et al. 2001, Cox et al. 2004). Although the greatest number of wiregrass plants per square meter were established using the fertilizer spreader on the back of the pickup truck, this success may be attributed to the number of times the truck drove over the site spreading seed and pushing the seed into the ground than to the greater efficacy of the fertilizer spreader. The second most effective sowing equipment was the hay blower, which, due to its relative speed and ease of use, is the equipment now being utilized by TNC to restore the groundcover (Gordon et al. 2001, Cox et al. 2004).

Following these two studies, TNC has continued to knock down and spread windrows when funds were available. Additionally, areas between the spread windrows have been lightly harrowed prior to seeding. All seed is rolled in after sowing to maximize seed/soil contact. Sowing rates have been varied in an attempt to find the best proportion. The FDOT 1 plots were sown with a rate of 80 pounds of mix per acre. This produced a dense establishment (7 to 14 wiregrass plants/m^2) greater than the intact relict longleaf areas at ABRP (3 to 5/m^2). The next two years, areas were sown at 23 and 29 pounds/acre, respectively. These rates resulted in 100 acres/year sown with seed, but the open establishment of seedlings could not carry fire for three years following sowing. In 2001, 40 pounds/acre was the sowing rate. Only 35 acres were sown in 2001 due to lower seed collection because fewer areas were burned for seed production during the early growing season. This was caused by a continuation of the dry weather in Florida from 1998 that produced a high fire danger resulting in local and statewide burn bans. Since 2001, approximately 2,400 pounds of seed mix have been collected each year and about 60 acres of groundcover sown each year.

The estimated cost to restore groundcover with direct seeding is between $400 and $800 per acre. This is considerably less than nursery-grown plug restoration and covers a much larger expanse annually. Furthermore, a much higher diversity of species (somewhere between 50 and 100) can be attained with direct seeding than by planting one species of plug. With both methods, as the areas that have been restored become well-established, the areas available to be burned for seed production will increase, allowing more seed to be collected and more acreage to be sown each year.

The goal of these restoration efforts is a functioning sandhill community, one that sustains the main process, fire, in all its variation, and supports a diverse groundcover. The restored sandhill community may not harbor all the elements present before the destructive practices of the late 1950s, but the goal of restoring functions and processes has been proven attainable and remains the objective of the ongoing restoration efforts.

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Tuesday, October 5, 2004
PLENARY SESSION

The Big Barrens Region of Kentucky and Tennessee, An Historical Perspective and Current Conditions

Ed Chester

Tuesday, October 5, 2004
POSTER SESSION

25 Years of Wild Ones

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Having successfully initiated a ban on DDT throughout the United States, Lorrie Otto and her followers set about to heal the Earth through the people they met through their workshops and speaking engagements. As a result of one of these workshops in Milwaukee, Wisconsin, nine people came together to form an informal native garden club which became the Wild Ones. Formerly organized as Wild Ones Natural Landscapers in July 1979 with nine members, it grew to 65 in 1983, and from there to the present 3,000 member households with 42 chapters. Along the way, Wild Ones has successfully achieved many accomplishments and is honored to be able to consider Otto as an honorary director.

Big Bluestem (*Andropogon gerardii*) Selection for Improved Forage Quality—Great Lakes States

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Abstract

To address the identified need for varieties of big bluestem, adapted to the Great Lakes states for improved forage quality, a research project was conducted to develop and release a cultivar or cultivars with superior forage characteristics. Big bluestem plant samples were collected from 103 sites across Indiana, Michigan, and Wisconsin in 1992. Those samples were assigned accession numbers and planted in an initial evaluation test at the Rose Lake Plant Materials Center in 1993 to evaluate plant growth characteristics and potential for forage production. Thirty accessions were selected from that test for evaluation in advanced testing

studies. Ten accessions from the southern region, central region, or northern region of the collection area were placed in advanced tests located in Indiana, Michigan, or Wisconsin, respectively. Commercially available varieties were included in each advanced test as standards. At least two accessions in each advanced test had higher forage quality characteristics than did the standards in those tests. Dry matter production, protein production, and total digestible nutrient (TDN) production of the best-performing selected accessions were 1.4 to 2.5 times higher than the most productive standard in each test.

Future work on this project will include palatability testing, seedling vigor evaluations, and area of adaptation testing. The Rose Lake Plant Materials Center has the potential to release at least three of the accessions tested in this project, based on needs and market potential.

Introduction

Grass species have been used as forage sources for grazing animals for many years. Pastures in the Great Lakes region of the United States consist predominantly of cool-season grasses and legumes. However, cool-season grasses and legumes in the Great Lakes region usually go through a slow growth period in July and August because of the warm temperatures and low precipitation. Warm-season grasses, such as big bluestem, have a growth pattern that can fill the forage needs of grazing animals during those warm summer months when cool-season grasses are not productive.

The Plant Materials Committees that advise the Rose Lake Plant Materials Center identified the need for varieties of big bluestem adapted to the Great Lakes states that have superior forage quality characteristics. A successful variety candidate should demonstrate good adaptability, high forage yield, and superior forage quality characteristics such as crude protein (CP) yield and total digestible nutrient (TDN) yield.

The Rose Lake Plant Materials Center developed a research project to address the need for a big bluestem variety with superior forage characteristics. The objective of the project was to assemble, evaluate, develop, and release a superior native cultivar or cultivars of big bluestem for forage production that is well adapted to the Great Lakes region.

Materials and Methods

Plant Materials Collection and Initial Evaluation

Big bluestem plant samples were collected from 103 sites across Indiana, Michigan, and Wisconsin in 1992. The samples were collected by Natural Resource Conservation Service and Conservation District personnel and were sent to the Rose Lake Plant Materials Center as plants. The samples were assigned accession numbers and planted in an initial evaluation test at the Rose Lake Plant Materials Center in 1993. Plants in that test were evaluated over three years for growth characteristics and potential for forage production.

Initial Plant Selection and Advanced Testing

Thirty accessions were selected from the initial evaluation test and placed in an advanced testing program. Ten accessions from the southern region, central region, or northern region of the collection area were placed in advanced tests located in Indiana, Michigan, or Wisconsin, respectively. Commercially available big bluestem varieties were included in each advanced test as standards. The standards chosen for each test were selected based on adaptation to test site and varied by location. Each test was conducted in a randomized complete block design with three replicates of each accession.

Plant growth measurements such as survival, early season vigor, lodging incidence, and pest incidence were taken for two or three years. Forage harvest was taken for two or three years from those tests, and forage quality characteristics such as crude protein (CP) percentage and acid detergent fiber (ADF) percentage were determined for each plot. Total digestible nutrient (TDN) content and protein yield were calculated for each plot.

Small seed increase or breeder fields have been established for candidate accessions in the states where the accessions were tested. Each field is separated by at least 0.25 miles from each other or other big bluestem plantings to maintain genetic purity of the accession. Seed from those fields were harvested from 1999-2003 and are in storage at the Rose Lake Plant Materials Center.

Results from Advanced Testing

At least two accessions in each advanced test had better forage quality characteristics than did the standards used in those tests. Relative performance of selected accessions compared to the standards was consistent across years for each location.

Indiana: Accessions 9070144 and 9070170 had dry matter yield 1.1 to 1.4 times higher than ‘Niagara’ in the Indiana advanced test for southern accessions. Protein yield and TDN yield for those accessions were also higher than Niagara in that test (Table 1).

Michigan: Three accessions in the Michigan advanced test for central accessions, 9070139, 9070162, and 9070197, had dry matter yield 2.0 to 2.5 times higher than ‘Bonilla’. Protein yield and TDN yield for those accessions were higher than for Bonilla in the Michigan test (Table 1).

Wisconsin: Accessions 9069074 and 9070190 outperformed ‘Sunnyview’ in the Wisconsin advanced trial for northern accessions. Dry matter yield, protein yield, and TDN yield for those accessions were 1.5 to 1.8 times higher than for Sunnyview in that test (Table 1).

Summary

Two selected accessions from the Indiana and Wisconsin advanced tests and three accessions from the Michigan test demonstrated superior yield and forage quality characteristics compared to the standard varieties used in those tests. The selected accessions appear to be adapted to the geography in which they were tested, and they all have produced viable seed in both the advanced tests and seed increase plots.

Future work on this project may include palatability testing, seedling vigor evaluations, and area of adaptation testing. The Rose Lake Plant Materials Center has the potential to release at least three of the accessions tested in this project, based on needs and market potential.

Table 1. Forage quality of accessions in advanced test, by location.

Accession	Dry Matter (kg/plot)	Crude Protein (kg/plot)	TDN (kg/plot)
Indiana (three-year average)			
9070144	1.2	0.08	0.7
9070170	1.0	0.07	0.5
Niagara	0.9	0.05	0.4
Roundtree	0.4	0.02	0.23
Michigan (three-year average)			
9070197	1.5	0.12	0.8
9070162	1.9	0.14	1.0
9070139	1.9	0.14	1.0
Champ	0.7	0.05	0.4
Bonilla	0.7	0.06	0.5
Wisconsin (two-year average)			
9069074	1.7	0.14	0.9
9070190	2.0	0.15	0.9
Bison	0.7	0.06	0.3
Sunnyview	1.1	0.08	0.5

Cattle Grazing and Vegetative Changes at Sabine National Wildlife Refuge

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This observational study was conducted throughout the 1993-98 grazing seasons. Cattle have grazed the Sabine National Wildlife Refuge since its inception in 1937. The 124,511-acre refuge was established to provide wintering habitat for migratory waterfowl. Grazing has been traditional on the refuge as a socioeconomic practice and may produce or maintain habitat conditions that are favorable to waterfowl and other wildlife. Grazing areas consist of natural ridges and their adjoining slopes and the surrounding marshes. The highest natural ridge on the refuge is only slightly over a foot above the surrounding marsh. Long growing seasons facilitated by a subtropical climate allow a thatch to quickly develop. This older plant material can inhibit growth of new vegetation by blocking out sunlight. Thatch has the potential of being removed by grazing animals and fire. During the 1991-1993 grazing seasons, concern developed as to whether grazing was adding to deterioration of the marsh. During this three-year period, rainfall was abundant, muskrats were causing local eat-outs, and cattle grazed within areas that became wet, muddy, and deprived of vegetation. Starting in 1994, 10 sites were monitored for changes in vegetation. Sites were selected based on soil and vegetation type and current cattle use. Data from both grazed and ungrazed sites were collected during May 1994 and compared to similar data gathered in May 1998. This study only looked for changes in species composition and production. Comparisons of foliar cover revealed differences in species composition. This poster documents the methodology used and summarizes the observational data.

Coastal Native Grass Garden at the Pea Island National Wildlife Refuge

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Abstract

The U.S. Fish and Wildlife Service at the Pea Island National Wildlife Refuge in Dare County, North Carolina, has established a native plant garden at its visitor center. The garden demonstrates the species of native grasses indigenous to the coastal dunes of the refuge. It also features the forbs commonly found in association with the grasses. It includes trailing wild bean, the "pea" after which the Service named the refuge. Each species is labeled to teach visitors the identity of each plant. There is a brochure available in the visitor center that describes each species, where they occur in the coastal dune vegetative community, and how to propagate them and establish them in a landscape.

American Beachgrass (*Ammophila breviligulata*)
Ecological function: quick erosion control on frontal dunes with active erosion and sand accumulation, declines when there is no sand deposition
Landscape use: planting along building foundations, as background to shorter plantings
Geographic range: North and Mid-Atlantic Coast, Great Lakes
Propagation: division of plant (breaking apart plant into smaller pieces each with stems and roots) in the dormant season (first frost until last frost)
Field establishment: primarily bareroot planting of divided culms (two culms per planting hole), also containerized (potted) plants in the dormant season (first frost until last frost)
Spacing of planting: 12 to 36 inches between plants and rows, typically 18 inches
Cultivars (date cultivar was released for commercial production)—adaptation:
Cape (1970)—North Atlantic and Great Lakes Coasts
Hatteras (1969)—Mid-Atlantic Coast

Bitter Panicum (*Panicum amarum* var. *amarum*)
Ecological function: quick erosion control on frontal dunes with active erosion and sand accumulation, persists when there is no sand deposition
Landscape use: planting along building foundations, as background to shorter plantings
Geographic range: North, Middle, and South Atlantic Coast, Gulf Coast

Propagation: cuttings of stolons (seed stalks cut into sections with two nodes in the fall after seed matures, treated with hormone, and planted in pots with irrigation), division of plant (breaking apart plant into smaller pieces each with stems and roots) in the dormant season (first frost until last frost)
Field establishment: primarily containerized plants, also bareroot planting in the dormant season (first frost until last frost) and stolons planting horizontally in the fall
Spacing of planting: 12 to 36 inches between plants and rows, typically 18 inches
Cultivars (date cultivar was released for commercial production)—adaptation:
Northpa (1992)—Mid-Atlantic Coast
Southpa (1992)—South Atlantic and Eastern Gulf Coast
Fourchon (1998)—Western Gulf Coast

Coastal Panicgrass (*Panicum amarum* var. *amarulum*)
Function: quick erosion control on frontal dunes with active erosion and sand accumulation, persists when there is no sand deposition
Landscape use: specimen planting, planting along building foundations, as background to shorter plantings
Geographic range: North, Middle, and South Atlantic Coast
Propagation: primarily seed, also division of plant (breaking apart plant into smaller pieces each with stems and roots) in the dormant season (first frost until last frost)
Field establishment: primarily containerized plants, also bareroot planting and seeding in the dormant season (first frost until last frost)
Spacing of planting: seed at 15 pounds of pure live seed per acre, plants 12 to 36 inches between plants and rows, typically 18 inches
Cultivars (date cultivar was released for commercial production)—adaptation:
Atlantic (1981)—North, Middle, and South Atlantic Coast

Seaoats (*Uniola paniculata*)
Ecological function: long-term dune stabilization, persists when there is no sand deposition
Landscape use: planting along building foundations, as background to shorter plantings
Geographic range: Middle and South Atlantic Coast, Gulf Coast
Propagation: primarily seed, also division of plant (breaking apart plant into smaller pieces each with stems and roots) in the dormant season (first frost until last frost)
Field establishment: primarily containerized plants, also bareroot planting in the dormant season (first frost until last frost)
Spacing of planting: 12 to 36 inches between plants and rows, typically 18 inches
Cultivars (date cultivar was released for commercial production)—adaptation:
Caminada (2001)—Western Gulf Coast

Saltmeadow or Marsh Hay Cordgrass (*Spartina patens*)
Ecological function: long-term stabilization of back dunes and salt marshes above high tide line, persists when there is no sand deposition
Landscape use: planting along building foundations, as background to shorter plantings
Geographic range: North, Middle, and South Atlantic Coast, Gulf Coast
Propagation: division of plant (breaking apart plant into smaller pieces each with stems and roots) in the dormant season (first frost until last frost)

Field establishment: primarily containerized plants, also bareroot planting in the dormant season (first frost until last frost)
Spacing of planting: 12 to 36 inches between plants and rows, typically 18 inches
Cultivars (date cultivar was released for commercial production)—adaptation:

Avalon (1986)—North Atlantic Coast
Flageo (1990)—Middle and South Atlantic Coast, Gulf Coast
Sharp (1994)—South Atlantic Coast, Gulf Coast
Gulf Coast (2003)—Western Gulf Coast

Trailing Wild Bean or Beach Pea (*Strophostyles helvula*)
(This is the plant for which Pea Island is named.)
Ecological function: annual stabilization of back dunes, depends on unvegetated areas in which seed can germinate without competition, seed eaten by birds and small mammals
Landscape use: planting on fences or trellises, trailing plant across ground
Geographic range: North, Middle, and South Atlantic Coast, Gulf Coast
Propagation: seed
Field establishment: seed and containerized plants in the early spring (within a month after the last frost)
Spacing of planting: seeds sown 2 inches apart in rows 3 feet apart, 12 to 36 inches between plants and rows, typically 18 inches
Cultivars: no coastal cultivars, but 'Hopefield' was released for the lower Mississippi Valley

Indian Blanket (*Gallardia pulchella*)
Ecological function: annual stabilization of back dunes, depends on unvegetated areas in which seed can germinate without competition, seed eaten by birds and small mammals
Landscape use: planting in beds
Geographic range: North, Middle, and South Atlantic Coast, Gulf Coast
Propagation: seed
Field establishment: seed and containerized plants in the early spring (within a month after the last frost)
Spacing of planting: seeds sown 2 inches apart in rows 3 feet apart, 12 to 36 inches between plants and rows, typically 18 inches
Cultivars: numerous horticultural cultivars

Trumpet Honeysuckle (*Lonicera sempervirens*)
Ecological function: nectar for hummingbirds from trumpet-shaped flowers on back dunes
Landscape use: planting on fences and trellises, trailing plant across ground
Geographic range: North, Middle, and South Atlantic Coast, Gulf Coast
Propagation: seed and cuttings
Field establishment: containerized plants in the early spring (within a month after the last frost)
Spacing of planting: 12 to 36 inches between plants and rows, typically 18 inches
Cultivars: numerous horticultural cultivars

Yaupon Holly (*Ilex vomitoria*)
Ecological function: cover from evergreen foliage and food from berries on back dunes

Landscape use: planting along building foundations and in back of shorter plants, hedges, screens, specimen
Geographic range: North, Middle, and South Atlantic Coast, Gulf Coast
Propagation: seed and cuttings
Field establishment: containerized plants in the early spring (within a month after the last frost)
Spacing of planting: 48 to 96 plants and rows
Cultivars: Numerous horticultural cultivars including dwarfs

Eastern Red Cedar (*Juniperus virginiana*)
Ecological function: cover from evergreen foliage and food from berries on back dunes
Landscape use: planting in back of shorter plants, as hedges, screens, specimen
Geographic range: North, Middle, and South Atlantic Coast, Gulf Coast
Propagation: seed and cuttings
Field establishment: containerized plants in the early spring (within a month after the last frost)
Spacing of planting: 72 to 96 plants and rows
Cultivars: Numerous horticultural cultivars

Figure 1. Native Plant Garden at the Pea Island National Wildlife Refuge Visitor Center

Trumpet Honeysuckle (*Lonicera sempervirens*) | R | Coastal Panicgrass (*Panicum amarulum)*

| A |

Bitter Panicum (*Panicum amarum*) | M | Yaupon Holly (*Ilex vomitoria*)

| P |

American beachgrass (*Ammophila*) | | Seaoats (*Uniola paniculata*)

| |

Eastern Red Cedar (*Juniperus virginiana*) | | American Beachgrass (*Ammophila*)

| |

Coastal Panicgrass (*Panicum amarulum*) | | Bitter Panicum (*Panicum amarum*)

| |

American Beachgrass (*Ammophila*) | | Saltmeadow Cordgrass (*Spartina patens*)

| |

Saltmeadow Cordgrass (*Spartina patens*) | |

____| |

| R ______________________________________ |

| A | Indian Blanket

| M | Coastal Panicgrass (*Panicum amarulum*)

| P | Trailing Wild Bean

Coastal Native Grass Technology Development

Robert J. Glennon[1]

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Abstract

The USDA, Natural Resources Conservation Service, and its cooperators have developed native grass technology for restoring coastal dune and marsh communities over the past 40 years. This technology includes methods for propagating the grasses in cultivation, processing vegetative plant material and seed, and establishing them on restoration sites in the field. It also includes the development of regional cultivars capable of tolerating environmental extremes and producing dependable quantities of quality seed and vegetative plant material. The establishment techniques and cultivars vary from north to south with different species and cultivars playing different roles in the different regions.

American Beachgrass (*Ammophila breviligulata*)
Function: quick erosion control on frontal dunes with active erosion and sand accumulation, declines when there is no sand deposition
Geographic range: North and Mid-Atlantic Coast, Great Lakes
Propagation: division of plant
Field establishment: primarily bareroot planting of divided culms (two culms per planting hole), also containerized plants
Spacing of planting: 12 to 36 inches between plants and rows, typically 18 inches
Cultivars (date cultivar was released for commercial production):
Cape (1970)—North Atlantic and Great Lakes Coasts
Hatteras (1969)—Mid-Atlantic Coast

Bitter Panicum (*Panicum amarum* var. *amarum*)
Function: quick erosion control on frontal dunes with active erosion and sand accumulation, persists when there is no sand deposition
Geographic range: North, Middle, and South Atlantic Coast, Gulf Coast
Propagation: cuttings of stolons (seed stalks), division of plant
Field establishment: primarily containerized plants, also bareroot planting and stolon planting
Spacing of planting: 12 to 36 inches between plants and rows, typically 18 inches
Cultivars: Northpa (1992)—Mid-Atlantic Coast
Southpa (1992)—South Atlantic and Eastern Gulf Coast
Fourchon (1998)—Western Gulf Coast

Coastal Panicgrass (*Panicum amarum* var. *amarulum*)
Function: quick erosion control on frontal dunes with active erosion and sand accumulation, persists when there is no sand deposition
Geographic range: North, Middle, and South Atlantic Coast
Propagation: primarily seed, also division of plant
Field establishment: primarily containerized plants, also bareroot planting and seeding

Spacing of planting: seed at 15 pounds of pure live seed per acre, plants 12 to 36 inches between plants and rows, typically 18 inches
Cultivars (date cultivar was released for commercial production):
Atlantic (1981)—North, Middle, and South Atlantic Coast

Seaoats (*Uniola paniculata*)
Function: long-term dune stabilization, persists when there is no sand deposition
Geographic range: Middle and South Atlantic Coast, Gulf Coast
Propagation: primarily seed, also division of plant
Field establishment: primarily containerized plants, also bareroot planting
Spacing of planting: 12 to 36 inches between plants and rows, typically 18 inches
Cultivars (date cultivar was released for commercial production):
Caminada (2001)—Western Gulf Coast

Saltmeadow or Marsh Hay Cordgrass (*Spartina patens*)
Function: long-term stabilization of back dunes and salt marshes above high tide line, persists when there is no sand deposition
Geographic range: North, Middle, and South Atlantic Coast, Gulf Coast
Propagation: division of plant
Field establishment: primarily containerized plants, also bareroot planting
Spacing of planting: 12 to 36 inches between plants and rows, typically 18 inches
Cultivars (date cultivar was released for commercial production):
Avalon (1986)—North Atlantic Coast
Flageo (1990)—Middle and South Atlantic Coast, Gulf Coast
Sharp (1994)—South Atlantic Coast, Gulf Coast
Gulf Coast (2003)—Western Gulf Coast

Seashore Saltgrass (*Distichlis spicata*)
Function: long-term stabilization of back dunes and salt marshes above high tide line, persists when there is no sand deposition
Geographic range: North, Middle, and South Atlantic Coast, Gulf Coast
Propagation: division of plant, creeping stolons
Field establishment: primarily containerized plants, also bareroot planting
Spacing of planting: 12 to 36 inches between plants and rows, typically 18 inches
Cultivars (date cultivar was released for commercial production):
Brazoria (1999)—Western Gulf Coast

Smooth Cordgrass (*Spartina alterniflora*)
Function: long-term stabilization of salt marshes below high tide line
Geographic range: North, Middle, and South Atlantic Coast, Gulf Coast
Propagation: primarily seeds, division of plant
Field establishment: primarily containerized plants, also bareroot planting
Spacing of planting: 12 to 36 inches between plants and rows, typically 18 inches
Cultivars (date cultivar was released for commercial production):
Bayshore (1992)—North Atlantic Coast
Vermilion (1989)—Western Gulf Coast

Giant Cutgrass (*Zizaniopsis miliacea*)
Function: long-term stabilization of freshwater marshes and shorelines with water up to three feet deep
Geographic range: Middle and South Atlantic Coast, Gulf Coast
Propagation: stolons (seed stalks), division of plant
Field establishment: stolons, containerized plants, bareroot planting
Spacing of planting: 12 to 36 inches between plants and rows, typically 18 inches
Cultivars (date cultivar was released for commercial production):
Wetlander (1993)—South Atlantic and Gulf Coast

Maidencane (*Panicum hemitomon*)
Function: long-term stabilization of freshwater marshes and shorelines with water up to a foot deep
Geographic range: Middle and South Atlantic Coast, Gulf Coast
Propagation: rhizomes (underground runners), division of plant
Field establishment: rhizomes, containerized plants, bareroot planting
Spacing of planting: rhizomes in continuous trenches 1 inch deep and 1 foot apart, plants 12 to 36 inches between plants and rows, typically 18 inches
Cultivars (date cultivar was released for commercial production):
Halifax (1974)—Middle and South Atlantic Coast
Citrus (1998)—South Atlantic and Gulf Coast

Control of Marestail in a Dormant Season Planting of Native Grasses

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Marestail (*Conyza canadensis*) is a common invasive plant of no-tillage crop systems and can potentially cause crop losses. Infestations of marestail could also have negative effects on the establishment of native grasslands. I evaluated the effectiveness of post-emergence applications of 2,4-D amine, triclopyr, and mowing to marestail in a dormant season planting to establish native warm-season grasses (NWSG) at Key Cave National Wildlife Refuge in northwest Alabama. The entire study area, including the control plot, was treated with imazapic at 0.07 kg ai/ha (4 oz/ac) during April. Marestail control treatments (2,4-D at 0.28 kg ai/ha [16 oz/ac]; triclopyr at 0.28 kg ai/ha [16 oz/ac]) and mowing (0.46 m [18 inches] above ground surface) were applied to 2.02 ha (5 ac) treatment plots during July 2000. Five 1-m^2 plots were sampled at the time of treatment, fall 2000, and during summer and fall 2001 to determine marestail control and establishment of NWSG. ANOVA and Fisher's Protected LSD Test were used to detect differences in total vegetative canopy cover (%), plant cover by species (%), planted NWSG cover (%), bare ground (%), and plant species richness (species/m^2) among treatments. All treatments provided some degree of marestail control during the study. Marestail coverage was

less (P = 0.0004) in the triclopyr plot than all other plots during fall 2000. During July 2001, marestail coverage was reduced (P = 0.054) in the mowing and 2,4-D amine plots. By fall 2001, marestail coverage was reduced in all plots, including the control plot, indicating that as NWSG became established, they quickly became the dominant vegetation in the study plots. This dormant season planting established NWSG in one to two growing seasons.

Dormant Seeding of Warm-Season Grasses in the Northeast

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There has been an increase in the use of warm-season grasses for wildlife habitat in the Northeast. There is an interest in dormant seeding of warm-season grasses to allow for another opportunity during the year to seed and to improve establishment by natural stratification. Lighter and less expensive broadcast pendulum spreaders have been used with some success, allowing for seeding at times not feasible for drilling.

A study was conducted at the USDA-NRCS Big Flats Plant Materials Center in Corning, New York, to compare dormant conventionally fall seeded plots, frost seedings with and without oat residue to conventionally seeded spring seedings. The use of oats as a cover crop was investigated to provide warm-season grasses the opportunity for seed soil contact while providing soil erosion protection over winter. The conventionally seeded plots were rototilled; then the seed was hand broadcast, raked, and packed. The plot size was 1.5 x 3.0 meters with four replications. The warm-season grasses included ‘Shelter’ switchgrass, ‘Blaze’ little bluestem, ‘Niagara’ big bluestem, and ‘Holt’ indiangrass at seeding rates to estimate 43 seeds/1000 cm^2. In 2001-2002, the plots were rototilled on 10/19/01. The treatments included a conventional dormant seeding on 10/19/01, and frost or snow seedings surface broadcast on 2/4/02, 3/1/02, and 4/2/02. On 4/2/02, the seed was also broadcast in residue from oats planted on 9/2/01. A conventional spring seeding was conducted on 5/10/02. In 2002-2003, the plots were rototilled on 10/22/02. The treatments included a conventional dormant seeding on 10/22/02 and frost or snow seedings on 3/4/03, 3/31/03, and 4/7/03 on both bare soil and in residue from oats planted on 9/4/02. Conventional spring seedings were conducted on 4/29/03 and 5/29/03.

The 2002 seeding study was evaluated for seedlings/929 cm^2 (1ft^2) on 10/21/02. The incorporated seeding in May did significantly better than all other treatments with 14.8 seedlings. The dormant seeding on 10/19/01 resulted in fewer seedlings with 2.0 seedlings. The seedings in the oat cover crop resulted in 5.0 seedlings, while those surface broadcast without the oats averaged 3.2 seedlings. The average seedling counts for all of the seeding dates were 7.0, 6.5, 4.0, and 3.4 for the indiangrass, big bluestem, switchgrass, and little bluestem, respectively. The 2003 seeding study was evaluated for seedlings/929 cm^2 on 7/14/03. The incorporated seedings on 4/29/03 and 5/29/03 did the best with 8.8 and 21.5 seedlings, respectively. The dormant seeding on 10/22/02 resulted in the fewest seedlings with 1.7 seedlings. The seedings in the oat cover crop averaged 1.9 seedlings, which performed similarly to those surface broadcast without the oats with 2.6 seedlings. The average seedling counts for all of the seeding dates were 7.9, 8.1, 5.4, and 5.1 for the indiangrass, big bluestem, switchgrass, and little bluestem, respectively.

In conclusion, spring incorporated seedings had significantly more seedlings than dormant and frost seedings with seedling counts averaged for both years of 15.0 compared to 2.3 for dormant seedings and 2.7 for frost seedings. Dormant seedings were not significantly different from frost seedings for seedling counts. There were no significant differences between frost seeding dates for seedling counts. Oats did not interfere with frost seedings with an average of 3.4 seedlings with oats and 2.9 seedlings without oats for both years. There were no significant differences for seedling counts between species except for in the spring conventional seedings. All treatments exceeded 1 plant/929 cm^2, considered adequate for wildlife habitat but would require more management and weed control to maintain stands or a much higher seeding rate.

Establishment of Sustainable Native Wildflower and Grass Meadows for Maryland Highway Roadsides

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A cooperative project with the Maryland State Highway Administration was initiated in 1999 and continued through 2003 to study the establishment and maintenance of native meadows comprised of diverse grasses and wildflowers native to Maryland. The objective of this study was to develop practical methods of establishing mixes of native wildflowers and grasses, taking into consideration time of year, seedbed preparation, equipment needed, and post-planting treatments. Native grass (13 species) and wildflowers (30 species) including currently underutilized but commercially available species were assessed for suitability of use along highway roadsides. Seeding mixes were developed using appropriate species of wildflowers and grasses to provide a primary matrix for cover and provide a sustainable wildflower display. Maintenance requirements were also assessed that would be required to keep the meadow sustainable. Based on the results of plot trials, meadow areas were established along the I-95 corridor of Maryland. From the results, standards and guidelines were developed that may be used by Maryland State Highway Administration and others for seeding roadside wildflower mixes.

Plots were seeded in June 2000, May 2001, and November 2001 and were evaluated in 2001, 2002, and 2003. Of the 43 native species tested, 29 proved reliable and cost effective for direct seeding along the highway. Among those species most suitable for highway seeding included *Andropogon virginicus, Bouteloua curtipendula, Dichanthelium clandestinum, Elymus virginicus, Schizachyrium scoparium, Sporobolus cryptandrus, Tridens flavus, Asclepias tuberosa, Aster novae-angliae, Aster prenanthoides, Chamaecrista fasciculata, Eupatorium perfoliatum, Heliopsis helianthoides, Lespedeza capitata, Monarda fistulosa, Penstemon digitalis, Rudbeckia hirta*, and *Rudbeckia triloba*. The seed mix which included tall warm-season grasses was not suitable for the display of wildflowers. Of the 10 establishment treatments, only the dormant seeded plots resulted in poor establishment due to extreme weed pressure. No-till treatment provided better control of weeds and greater control of seeding depth. A few plots located in wetter soil experienced moderate weed pressure along with aggressive competition from *Agrostis alba*, which was included in several mixes as a nurse crop. Excellent weed control prior to seeding was attained in all other plots, which resulted in relatively few weeds and quick establishment in the first year. Mowing, in the maintenance trials, was beneficial when weed pressure was significant. A 4 oz per acre post-emergent Plateau® treatment did not control established weeds but also did not significantly harm the established native species. A 4 oz per acre pre-emergent Plateau® treatment was very effective in controlling establishment of weeds but prevented the establishment of some of the seeded species.

Despite a variety of initial site conditions, the seeding of diverse mixes resulted in successful meadow establishment with a variable species composition that was affected primarily by the initial site conditions and timing of seeding. The most significant factor contributing to successful establishment was the excellent weed control prior to seeding, achieved by several properly timed treatments of glyphosate in the months prior to seeding and another treatment within four days prior to or after seeding. Late spring planting was ideal, allowing adequate time for weed control and for rapid germination and establishment immediately following seeding.

Evaluation of Wild Ryes for Wildlife, Soil Conservation, and Livestock Use

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Virginia wild rye (*Elymus virginicus*) and riverbank wild rye (*Elymus riparius*) plantings were evaluated for suitability for wildlife habitat, conservation cover, and possibly livestock forage.

Both *Elymus virginicus* and *Elymus riparius* have benefits for conservation use, greening up early and providing good cover. Being cool-season, it also has a fall flush. Both species have a fair to good filtering capacity compared to tall fescue. *E. virginicus* has the most biomass and provides better cover for conservation uses. *E. riparius* is better suited for shaded areas and might actually be the best for wildlife in some situations because of the extra structure and increased openness. *E. riparius* planted in the open at the same rate as *E. virginicus* produces a more open and still yet bunchy pattern. This character lends itself well to interseeding of forbs. Established stands average 2.5 plants per square foot. This planting of *E. virginicus* was no-till drilled at 4 pounds per acre and averaged 36 to 60 inches in height. Winter structure as shown in the picture at the right is very impressive.

Virginia wild rye (*Elymus virginicus)*, a cool-season native grass, is traditionally considered a woodland species. *E. virginicus* tolerates both moist and dry conditions and is adapted for shady locations or full sun. The species responds quite differently depending on location and condition. The versatility exhibited by *E. virginicus* makes it an excellent wildlife plant.

The picture to the left is in full sun and, with a high seeding rate, is too thick for optimum wildlife usage. Grazing could be used on this site to open the field interior and provide access to infield edge. Grazing intensity has to be managed to maintain wildlife benefits. Excessive grazing is detrimental to wildlife and to stands of *Elymus*.

The picture to the right is shaded and at a much lower population than the open site. Note the presence of broadleaves which co-exist with the rye. Broadleaf plants are good insect producers. Insects are a necessary protein source for many upland and woodland birds. The beneficial upright bunching growth also provides cover for the same as well as other wildlife species.

This tree line corridor actually runs into the river. The canopy tree is primarily osage orange (*Maclura pomifera*). You might think the understory vegetation is *E. riparius* due to the somewhat nodding head, but it is *E. virginicus*. Being shaded, it does not grow as robustly as it does in full sun, but it does grow and quite well. But, regardless of the shaded condition, it is an excellent wildlife groundcover on this site. Although not readily discernable by looking at the picture, wildlife sign was everywhere one looked—from deer bedding, raccoon loafing, squirrel feeding, rabbit roosting, to just plain wallowing around in the shade. From the eye of a biologist, this is indeed eye candy!

So, where did this rye come from? I am sure it backwatered in and settled out because, from where I am standing, I am sure I could hear the torrents of the river in times of high water, and backwater floods these entire bottoms.

The significant site for *E. virginicus* is in floodplains such as along rivers, as shown in these pictures, serving as a buffer strip and cover for a tree planting. This site has endured several floods and also has native *E. virginicus* growing next to the planted stand all along the river edge in open ground. River water tends to run over fescue and other cool-season grass species and really does not do much filtering. *E. virginicus* on riparian sites actually filters sediment from the water. The rye, because of its rooting structure, i.e., culms, continues to grow through the filtered sediment and still maintains its bunching growth. The bunching characteristic of *E. virginicus* and *E. riparius* makes them desirable from a wildlife management standpoint.

The optimum seeding rate that will maintain the bunch phenomenon as well as the filtering aspect has not been found as yet, but according to this writer (R. Montgomery), it is going to be less than 4 pounds per acre, probably closer to 2 pounds.

An interesting observation is the possible allelopathic effect on giant ragweed (*Ambrosia trifida*) where the *E. virginicus* was planted as compared to the tree planting/buffer where it was not planted. There is practically no *A. trifida* where the *E. virginicus* is present and a significantly high population where the *E. virginicus* was not planted.

Shown below is *E. riparius* on a reclaimed mine site. This stand was no-till drilled at 4 pounds per acre. It also has white clover and bird's-foot trefoil planted with it. The average stand of the *E. riparius* in this field is 0.3 plants per square foot. The plants are an average mature height of approximately 70 inches. This stand is about 5 acres in size.

The growth pattern of *E. riparius* provides many wildlife management options. In the above pictures, the pronounced interbunch characteristic provides access, interseeding locations, bare dirt possibilities for dusting, natural succession opportunity, and bugging sites. When a manager can employ all of these management practices and do it all in the same field, benefits

per effort are really maximized. Throw in some heavy structure (brush pile) and a water bottle, and you have it done.

This *E. riparius* site is partially upland and creek bottom. This site had quite a mixture of other grasses mixed in, but the dominant species was the wild rye. The stand on this site is 0.5 plants per square foot. The plants are an average mature height of approximately 48 to72 inches. This stand is about 2 acres in size.

The picture to the right is a winter picture! The legumes (ladino and bird's-foot trefoil) are frost covered. This is acceptable forage for this time of year in close proximity to the late winter nonlodging upright structure provided by *E. riparius*.

With livestock, we are continuing to search for quality forage species that, first of all, provides nutritious forage for grazing livestock but also provides quality habitat and food for several wildlife species. If these species can help to extend the grazing season for livestock and/or wildlife, then that is an additional benefit. When quality livestock forage is present, it is usually of high value to wildlife also. Many improved forages lack structure and openness needed for many wildlife species. Livestock, especially on rotated systems, are ideal tools for enhancing/maintaining quality wildlife areas.

Rotational grazing can be used as a wildlife management tool. Planned placement of mineral and watering facilities can be used to facilitate opening up the field interior where needed simply by cattle movement.

Stocking rates, flash grazing, and the time of grazing can also be used to manipulate grass structure. Flash grazing only, in some areas, will increase bunchiness, vary the vegetative structure, and also promote new growth. Maintaining openness within a stand of Elymus species in a grazing system should be easier to accomplish because of its structure.

Goals for future evaluation include:
• finding best grazing periods for *E. virginicus* with livestock, best management practices associated with grazing it (grazing heights, fertility including best application periods, yield goals, monocultures or mixes, grazing tolerance, forage quality—crude protein, energy, digestibility), and how to achieve good wildlife value and grazing value at the same time.
• evaluating any problems associated with Elymus species such as ergot (*Claviceps purpurea*) with grazing livestock.
• evaluating different seeding mixtures including increasing use of *E. virginicus* and possibly *E. riparius* as a component with warm-season grasses for wildlife and livestock.
• evaluating the use of *E. virginicus* and *E. riparius* for other conservation practices such as incorporating these native grasses into the Conservation Reserve Program (CRP) land acres and utilizing them instead of traditional conservation cover.

Influence of Nitrogen Fertilization on Seed Production of 'Highlander' Eastern Gamagrass in Northern Mississippi

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Abstract

Eastern gamagrass [*Tripsacum dactyloides* (L.) L.] is a native warm-season perennial bunchgrass with potential for use as forage in the southeastern United States. Large acreages are required for seed production due to low seed yields. Nitrogen fertilization has been shown to increase seed yields of perennial grasses; however, nothing is reported on the effects of N fertilization on seed production of eastern gamagrass. The objective of this study was to compare N rates on production of fertile and vegetative tillers, seed yield, seed fill, grain weight, and germination of 'Highlander' eastern gamagrass. Nitrogen was applied as ammonium nitrate in single and split applications of 0, 112, and 224 kg ha^{-1} to replicated plots at Coffeeville, Prairie, and Starkville, Mississippi, in 2001-2003. The single application and first split application of 0, 56, and 112 kg ha^{-1} were applied when spring regrowth reached 15 to 25 cm, and the second application was applied when 50% of the fertile tillers were in the boot stage. Nitrogen increased vegetative tillers 24% and fertile tillers 28%, but the increase in fertile tiller numbers did not correspondingly show an increased seed yield, likely due to environmental influences and seed shattering prior to harvest. Nitrogen had minimal effect on seed yield, grain weight, percent seed fill, and germination. There was no advantage in splitting the N on seed production parameters. Results of this study suggest that seed producers of Highlander eastern gamagrass in the upper southeastern states should apply N fertilizer in a single application of 56 to 84 kg ha^{-1} when spring regrowth reaches 15 cm. Environmental influences and timing of harvest are critical factors impacting seed yield and quality of eastern gamagrass.

Introduction

Nitrogen fertilizer is a key nutrient for improving seed production of perennial grass crops such as tall fescue (*Lolium arundinaceum* Schreb.) (Buckner 1985). A timely application of N fertilizer can initiate more fertile culms for higher seed yields and improve seed quality (Wheeler and Hill 1957). In North Carolina, N rates of 0, 112, 224, and 448 kg ha^{-1} were applied to tall fescue in equal applications in May, August, October, and January. Maximum seed yield of 404 kg ha^{-1} occurred at 224 kg·ha^{-1} compared to 102 kg·ha^{-1} for the 0 rate (Wheeler and Hill 1957). Young (1997) showed a positive increase in seed yields of two cultivars of perennial ryegrass (*Lolium perenne* L.) with increased rates of N fertilizer (0, 60, 90, 120 kg N ha^{-1}), but timing of N application did not affect seed yields of either cultivar. Kassel et al. (1985) reported an increase in seed yields of 'Cave-in-Rock' switchgrass (*Panicum virgatum* L.) with increased rates of N fertilization of 0, 90, and 180 kg N ha^{-1} on varied row spacing. 'Blackwell' and 'Pathfinder' switchgrass showed no response to N rates.

Eastern gamagrass [*Tripsacum dactyloides* (L.) L.] is a native warm-season perennial bunchgrass with potential for livestock forage and conservation buffers in the southeastern

United States (Dewald et al. 1996; Ball et al. 2002). Low seed yields hinder widespread commercial production of this species. Blan (1990) reported bulk seed yields of 328 kg ha^{-1} for ‘Pete’ eastern gamagrass with a long-term average yield of 182 kg ha^{-1} at the USDA-Natural Resources Conservation Service (NRCS) Plant Materials Center (PMC) in Manhattan, Kansas.

The USDA-NRCS, Jamie L. Whitten PMC in Coffeeville, Mississippi, selected a superior eastern gamagrass for cultivar release for livestock forage and other conservation uses in the southeastern United States. (Snider 1995). It was tested under NRCS accession 9062680 and released as Highlander with the Mississippi Agricultural and Forestry Experiment Station and the USDA, NRCS Jimmy Carter PMC in Americus, Georgia, in 2003. There is no information about the influence of N fertilization on seed production of this selection or any other eastern gamagrass cultivars. The objective of this study was to evaluate the response of Highlander eastern gamagrass to varying rates of N fertilizer applied in single and split applications on tiller and seed production parameters.

Materials and Methods

The study was conducted at three locations: USDA-NRCS, Jamie L. Whitten Plant Materials Center in Coffeeville, Mississippi; Mississippi Agricultural and Forestry Experiment Station, Prairie, Mississippi; and the South Farm at Mississippi State University, Mississippi State, Mississippi, in 2001-2003. Soil type at Coffeeville was an Oaklimeter silt loam; at Prairie, Houston Black clay; and at Starkville, a Marietta loam. Plots of Highlander were vegetatively established in 2.7 m x 3.6 m plots at each location in April 2000. The experimental design was a randomized complete block with three replications. Nitrogen rates of 0, 112, and 224 kg N ha^{-1} were broadcast applied in single applications when spring regrowth reached approximately 15 to 25 cm. A second N treatment of 112 and 224 kg N ha^{-1} was applied to separate plots in split amounts of 56 and 112 kg N ha^{-1} with the first application applied at the same time and in the same manner as the single application. The second split application was broadcast applied when 50% of the fertile tillers reached the boot stage. Ammonium nitrate was used as the N source. Phosphorus and potash were maintained at a moderate to high level, and soil pH was maintained at a 6.0 according to soil tests. Plots were burned annually in late February or early March.

Numbers of reproductive and vegetative tillers were determined annually in May from an average of three randomly selected plants from each plot. Plots were harvested when approximately 75% of the staminate portion had shed from the axillary inflorescences (Table 1). Reproductive seed stalks were hand-harvested from the center (0.9 m x 1.8 m) of each plot and air dried. Plots at Prairie were not harvested in 2003 due to damage (71%) that appeared to be caused by rabbits (Oryctolagus spp.) foraging on the reproductive tillers. Seed units (seed unit is defined as the cupulate fruitcase plus the caryopsis or grain) were detached from other seed units and inert matter with a belt separator (Almaco Model No. BT-14, Nevada, IA). An air-fractionating aspirator (Carter-Day Model No. CF 21, Minneapolis, MN) was used to separate each seed lot into light and heavy fractions. Only the first fraction, which was the heaviest, was used to determine seed yield, percent filled seed, percent germination, and grain weight (Douglas et al. 2000). Percent filled seed was determined by hand-dissecting two replicates of 5% of the seed units from each plot to determine the condition of the grain. Grain weight was determined by weight of three random subsamples of 10 grains each. Seed units were placed in plastic zip-lock bags and soaked in tap water for 24 hours. Water was drained from the bags and the bags placed in a refrigerator maintained at 5°C for six weeks. At the end of six weeks, three replications of 100 seed units were planted in 17.5 cm x 13.3 cm x 5.9 cm plastic flats filled with a commercial potting medium. Flats were placed in a greenhouse environment in April 2002-2004 with a night temperature of 22°C ± 5°C and a day temperature of 32°C ± 5°C. Flats were watered regularly to maintain optimum moisture for germination and subsequent seedling growth. Germination counts were made weekly for 28 days.

Tillers and seed production parameters were combined over years and locations using the Mixed Procedure in SAS (SAS Institute 1996). Analysis of variance was conducted using orthogonal contrasts. Pairwise comparisons were conducted between single or split applications of N fertilizer and the control using least square means.

Results and Discussion

Tiller Production

There was no significant N rate x year interaction effect on fertile or reproductive tillers. There was a decrease (~50 %) in the number of fertile tillers in 2003 ($P = 0.009$) (data not shown); however, it did not negatively affect seed yield (Tables 3 and 4). In studying the organic reserves in eastern gamagrass shoots, Dewald and Sims (1980) found that reproductive tiller development and rooting of new tillers occurred from April through October for the following growing season. Below-average rainfall in early 2002 at Starkville and Prairie (Table 2) may have reduced fertile tiller production and rooting of new tillers, which may explain low fertile tiller numbers when counts were made in 2003.

Increasing rates of N fertilizer increased the number of vegetative tillers when applied in single ($P = 0.0006$) or split applications ($P = 0.0007$) (Tables 3 and 4). This response to N fertilizer agrees with other researchers who have shown an increase in biomass production of eastern gamagrass with N fertilization (Brejda et al. 1996; Brakie 1998; Douglas et al. 2002). There was an increase in number of fertile tillers with increased rates of N, but the increase was not significant. Timely application of N has been reported to increase the number of fertile tillers in tall fescue (Wheeler and Hill 1957). There was no advantage in splitting the N on fertile or vegetative tiller production. The greatest increase in vegetative and fertile tillers occurred from 0 to 112 kg N ha^{-1}, which resulted in a 24 and 28% increase, respectively. Douglas et al. (2002) showed a 25% increase in total forage production of Highlander (in this study, it was referred to as 680) when N fertilizer was increased from 0 to 134 kg ha^{-1}. There was an increase in tiller numbers with an additional 112 kg N ha^{-1} (total 268 kg N ha^{-1}), but the increase was only minimal (10%) and would not justify the added production expense.

Seed Production Parameters

There were no significant N rate, year, or interaction effects for yield, percent filled seed and germination, or grain weight. Excessive N promotes vegetative growth, resulting in lodging and prolonging maturity of grass crops (Wheeler and Hill 1957). This inclination was visually observed in the 224 kg N ha^{-1} plots. In contrast, seed maturity in the 0 rate plots tended to be more uniform. Under unfavorable growing conditions (i.e., low nutrients, drought, and insect pressure) different grain crops will terminate vegetative growth and exhort effort to seed production as a mechanism for species survival (Martin et al. 1976). This may explain the reason for the more uniform ripening of Highlander in the unfertilized plots as compared to the fertilized plots over the three-year study. Plant vigor was notably lacking in the unfertilized plots at the end of 2002 and 2003 growing season. This observation suggests N is needed for sustainable plant health and productivity. Although N increased fertile tiller production, it had little to no effect on seed yield whether applied in a single or split application (Tables 3 and 4).

Kassel et al. (1985) reported no response in seed yields of Blackwell and Pathfinder switchgrass with increased rates of N. Young (1997) reported that perennial ryegrass seed yields were not affected by timing of N fertilizer or growth stage when N was applied. Seed production in 2002 and 2003 at Coffeeville was greatly reduced due to afternoon thunderstorms with heavy rainfall that caused excessive seed shattering shortly before the plots were harvested. This was also encountered in 2002 at Prairie. Eastern gamagrass is indeterminate in its seed maturity and notorious for seed shattering (Jackson 1990). Harvesting too early reduces seed quality, and harvesting too late decreases yield; therefore, correct timing of harvest is critical for optimizing seed yield and quality. Yields reported in this study were less than annual yields from foundation fields of Highlander at Coffeeville, Mississippi (3-yr. avg. of 200 kg ha^{-1}), and for the cultivar Pete in Manhattan, Kansas (Blan 1990).

Seed quality parameters such as percentage or number of filled seed and seed weight of various grain crops are influenced by N fertilization (Wheeler and Hill 1957; Martin et al. 1976). Wells and Turner (1984) showed a direct correlation in the number of filled seed and seed weight of cultivated rice (*Oryza sativa* L.) with varying rates of N fertilizer. In this study, N fertilization did not affect grain weight or percent filled seed when applied in single or split applications (Tables 3 and 4). Indeterminate seed maturity is another factor that directly affects percent filled seed. A typical harvest of eastern gamagrass consists of complete seed units (cupulate fruitcase with filled grain), incomplete seed units (cupulate fruitcase with unfilled grain), and other non-viable inert matter. Inability to adequately separate filled seeds from unfilled seeds may lead to poor stand establishment (Ahring and Franks 1968). Douglas et al. (2000) reported a significant increase in the ratio of percent filled seed within a seed lot of eastern gamagrass processed with an air fractionating aspirator compared to the control processed with an air-screen cleaner (93 versus 47%). In this study, the ratio of percent filled seed averaged approximately 67%, which suggests that additional air flow adjustments on the fractionating aspirator may increase the ratio of percent filled seed, resulting in seed units with heavier grains and higher germination potential.

Seed germination averaged approximately 50% even though the average percent filled seed exceeded 65% (Table 3 and 4). These lower germination percentages may be due to seed dormancy imposed by the cupulate fruitcase that encases the seed or grain in eastern gamagrass (Galiant 1956). Germination can be improved with cold-moist stratification for 45 to 60 days followed by exposure to temperature of at least 30°C (Anderson 1990). Evidently the six-week cold-moist stratification period and exposure to ambient temperatures in the greenhouse may not have been conducive for germinating all of the seed units with germination potential (Tian et al. 2002).

Conclusions

Nitrogen rates of 0, 112 , and 224 kg N ha^{-1} were applied in single and split applications to Highlander eastern gamagrass to determine if N fertilization was beneficial for increasing seed production. Nitrogen was effective in increasing the number of vegetative and fertile tillers, but the increase in fertile tillers did not result in higher seed yields. Seed production parameters of seed yield, seed fill, germination, and grain weights were not significantly influenced by N fertilization. There was no advantage to applying N in split applications on tiller or seed production parameters. Results of this study suggest that 56 to 84 kg N ha^{-1} should be applied in a single application in the spring when regrowth reaches 25 cm. In addition to fertilizer management, moisture and timing of harvest are critical factors that impact seed yield and quality.

Table 1. Harvest dates by location and year.

	Year		
Location	**2001**	**2002**	**2003**
Prairie	18 July	17 July	*
Coffeeville	19 July	22 July	July 17
Starkville	18 July	24 July	July 22

* Plots not harvested.

Table 2. Monthly rainfall totals for Prairie, Starkville, and Coffeeville, Mississippi, from April through July 2001-2003 and 30-year average.

	Year			
Prairie	**2001**	**2002**	**2003**	**30-yr. avg.**
	----------------------mm--------------------------------------			
April	170	95	113	140
May	162	199	267	135
June	145	75	143	100
July	60	70	132	110
August	141	117	111	83
September	101	212	145	94
October	98	135	86	95
Total	877	903	997	757
Starkville				
April	53	70	144	142
May	120	65	158	124
June	121	26	195	103
July	110	100	133	110
August	212	67	172	85
September	103	235	64	88
October	157	164	83	83
Total	876	727	949	735
Coffeeville				
April	200	210	72	150
May	105	225	284	145
June	120	65	130	100
July	95	155	140	110
August	138	136	130	89
September	130	282	99	103
October	121	189	89	104
Total	909	1262	944	801

Table 3. Tiller and seed production parameters of Highlander eastern gamagrass as influenced by N fertilization applied in a single application.

N Rate (kg ha^{-1})[1]	VT[2]	FT[3]	Yield[4]	Grain Wt.[5]	Fill[6]	Germ.[7]
	--number/plant--		--kg ha^{-1}--	-----mg-----	-------------%------------	
0	42	10	152	52	67	50
112	55	14	149	51	65	50
224	61	14	166	52	66	46
N Linear ($P < 0.05$)	0.0006	NS[8]	NS	NS	NS	NS

[1] N fertilizer applied in the spring when regrowth reached 15-25 cm.
[2] Vegetative tillers per plant (avg. of three plants per plot).
[3] Fertile tillers per plant (avg. of three plants per plot).
[4] Seed yield.
[5] Grain weights of three replicates of 10 grains.
[6] Percent filled seed determined by dissecting two replicates of 5% of the seed units in the first fraction of each lot to examine the condition of the grain.
[7] Seed germination consisted of three replicates of 100 stratified seed units.
[8] Not significant.

Table 4. Tiller and seed production parameters of Highlander eastern gamagrass as influenced by N fertilization applied in a split application.

N Rate (kg ha^{-1}) [1/]	VT[2]	FT[3]	Yield[4]	Grain Wt.[5]	Fill[6]	Germ.[7]
	--number/plant--		--kg ha^{-1}--	-----mg------	-------------%------------	
0	42	10	152	52	67	50
112 (56)	59	14	147	51	67	52
224 (112)	61	15	140	52	71	48
N Linear ($P < 0.05$)	0.0007	NS[8]	NS	NS	NS	NS

[1] N fertilizer applied in split application when spring regrowth reached 15-25 cm, and the second application when 50%of the fertile tillers reached the boot stage.
[2] Vegetative tillers (avg. of three plants per plot).
[3] Fertile tillers (avg. of three plants per plot).
[4] Seed yield.
[5] Grain weights of three replicates of 10 grains.
[6] Percent filled seed determined by dissecting two replicates of 5% of the seed units in the first fraction of each lot to examine the condition of the grain.
[7] Seed germination consisted of three replicates of 100 stratified seed units.
[8] Not significant.

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Late-Season Harvest Forage Quality of Native Warm-Season Grasses

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Abstract

We examined the late-season forage quality of six native warm-season grasses and one mixed stand. All seven grasses/mixes experienced higher levels of relative food value (RFV), crude protein, and total digestible nutrients (TDN) and lower values of acid detergent fiber (ADF) and neutral detergent fiber (NDF) between first and second cuttings. We were able to recapture lost quality since the first cutting in part through fertilization and release for new growth (Rector 1994). Managers and producers who want both wildlife/livestock benefits may want to delay haying of native warm-season grasses until August and September for the benefit of grassland songbird and game species.

Introduction

In Kentucky, we have planted 92,500 acres in native warm-season grasses over the last five years: 75,000 acres with federal farm bill programs and 17,500 acres with state-funded habitat improvement programs. Planting fields in herbaceous cover could increase the core area of grasslands and potentially benefit area-sensitive species (Weber, Roseberry, and Woolf 2002). The Kentucky Department of Fish and Wildlife Resources (KDFWR) has made the conversion of fescue into native warm-season grasses the highest priority habitat improvement practice. Ninety percent of fescue fields in Kentucky are infected with the endophyte fungus, causing a wide variety of problems for both wildlife and livestock, such as excessive body temperatures, elevated respiratory rates, loss of appetite, reduction in weight gain, lowered milk production, lowered fertility, and higher mortality (Fescue Eradication, Habitat How-To's, KDFWR). Many farmers and managers want the benefits of both wildlife and livestock production on their property. Delaying grazing/haying for six weeks in some paddocks during the nesting season can nearly double the number of successful nests on a grass farm and results in slightly lower forage quality (Paine and Undersander 1999). The cottontail (*Sylvilagus floridanus*) experiences lower mortality in herbaceous grasses where management strategies decrease movement rates and hence predation risks while increasing foraging efficiency (Bond, Burger, Godwin, and Leopold 2001).

Methods

All samples where taken from mature stands of native warm-season grasses at the Barren River Lake Wildlife Management Area in Barren County, Kentucky. The first hay samples and cutting were done on August 3, 2004, and the second sample was taken 48 days later on September 20, 2004. Although yields where not part of the study, they would be near maximum for the first cutting we did (personal observation). By October 27, there is a 20% probability of the first freezing temperature, 28° Fahrenheit or lower (Mitchell and Latham 1970). Higher yields resulted in six-week rather than four-week harvest intervals in eastern gamagrass (Brejda, Brown, Lorenz, Henry, and Lowry 1997) A quarter-acre plot was randomly placed inside each native warm-season grass stand, and the addition of 98-24-24 pounds of N-P-K was applied after the first cutting. The law of diminishing returns happens around 100 pounds of nitrogen per acre in both yield output and crude protein percent in native warm-season grasses (Barnhart 1981). All grass was collected using “good sampling testing” protocol from Debra Day with the Kentucky Department of Agriculture Forage Testing Program and Paul Salon with the Big Flats, New York, Experimental Station, USDA. Three types of eastern gamagrass (*Tripsacum dactyloides*) were used in the study: Pete, Native (local genotype), and Tetraploid. A local genotype of indiangrass (*Sorghastrum nutans*) was used, and variety Roundtree big bluestem (*Andropogon gerardii*) and variety Cave-in-Rock switchgrass (*Panicum virgatum*) were used in the study.

Results

Big bluestem had the highest species increase in RFV of 32.6 points and 54.3 percent rate of change from first cut to second cut values. An RFV value of 100 represents mature alfalfa hay containing 41% ADF and 53% NDF; the higher the RFV, the better quality of forage. RFV is not used to balance diets but is used to compare one forage to another on an energy basis and is the most important price determinant factor in hay (Ball, Hoveland, and Lacefield 1996). Native gamagrass had the highest RFV in both the first and second cuttings. Crude protein increased the most in Pete gamagrass, 8.7 percent increase, and the 50/50 mix had a 204.8% rate of increase from first to second harvest. CP indicates the capacity of the forage to meet an animal’s protein needs. Again, native gamagrass scored highest in both the first and second cuttings. Acid detergent fiber (ADF) is the portion of hay that is highly indigestible; the lower the ADF, the better. Big bluestem had the largest decrease in ADF of negative 14.2% and also had the largest rate of decrease of negative 41.9% between the first and second tests. All second cut forage was in a tight ADF range of between 33.5 and 36.9%. NDF is the portion of hay that is only partially digestible and limits intake. The lower the NDF, the more an animal will eat; thus, a low NDF is desirable. Native gamagrass scored the best in both first and second cuttings, 71.8 and 60.7 NDF%, respectively. TDN is the digestible components of fiber, protein, fat, and nitrogen-free extract in the diet; the higher the number, the better. All grasses/mix fell within a tight range of 53.7 and 58.2 TDN on the second cutting. The first cuttings would be similar to fair quality cuttings in the spring of fescue; the second cuttings would compare to good quality alfalfa/grass/clover mixtures taken during the spring and early summer of the year (www.kyagr.com Hay Sales Directory).

Management Implications

Late-season harvest of native warm-season grasses should be an option for those managers and producers who want both wildlife and livestock benefits. We were able to recapture lost quality in the second cutting of late harvesting native warm-season followed by fertilization and release. The results were significant and improved in all treatments, and every variable of quality improved across the board. On average, RFV increased 26.1 points, CP increased 6.9 percentage points, ADF and NDF decreased by 10.4 and 14.2 percentage points, respectively, and TDN increased 13.5 points. The rate of change on average was also dramatic: RFV 41.1%, CP increased 131.7%, ADF decreased 31.0%, NDF decreased 22.3%, and TDN increased by 32.7%.

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Prescribed Burning on National Wildlife Refuges in Northeastern North Carolina

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Abstract

The U.S. Fish and Wildlife Service manages 11 national wildlife refuges covering 500,000 acres in northeastern North Carolina and southeastern Virginia. The refuges have 80,000 acres of fire-dependent vegetative communities with natural fire frequencies of one to three years. Brackish marshes cover 50,000 acres; pine savannas, 14,000 acres; managed wetlands, 8,000 acres; and managed inland grasslands, 8,000 acres. Maintenance of wildlife populations in those communities depends on mimicking natural fire frequencies. Research by Cecil Frost of the North Carolina Plant Conservation Program has documented the fire frequency. The Service manages those communities by conducting prescribed fires on a three-year rotation. The Service has assembled a fire management crew located strategically at the different refuges and has trained and equipped them to maintain their efficiency. The fire crew conducts the prescribed burning within stringent guidelines established by the state to protect air quality. These guidelines limit the acreage of each fire depending on the type of fuel, wind atmospheric conditions, and distance from populated areas. The prescribed burning also protects local communities from damage by wildfires and highways from a loss of visibility from smoke.

Introduction

The U.S. Fish and Wildlife Service manages national wildlife refuges throughout the country with a "wildlife first" mission. It also manages for "trust" species, those species with which it is entrusted: migratory birds (waterfowl, shorebirds, wading birds, and neotropical songbirds), threatened and endangered species, and interjurisdictional fish (anadromous and catadromous). In northeastern North Carolina and southeastern Virginia, 80,000 acres of the 500,000 acres of refuge habitat evolved under fire frequencies of one to six years and is dependent on fire of that frequency to retain its character and support the wildlife that have evolved with the habitat. On the refuges involved, the wildlife species of concern are waterfowl, wading birds, and songbirds that prefer a diverse herbaceous plant community in marshes; red-cockaded woodpeckers that prefer pine stands with herbaceous understories; and upland songbirds that prefer grasslands with open stands that are not too dense.

Cecil Frost, a plant ecologist with the North Carolina Department of Agriculture, has documented the frequency. The refuge staff uses those frequencies in planning and conducting a prescribed burning program that mimics natural fire cycles. The state of North Carolina has set limits on the amount of fuel that can be burned in any one fire event. The refuge staff uses those limits to plan each prescribed burn.

Response of Vegetation to Fire Frequency

Moisture Extreme	Fire Frequency	Scientific Name	Common Name	Plant Type
Salt marsh (30-40 ppt salt) vegetation				
Wet	Any	*Spartina alterniflora*	Smooth cordgrass	Grass
Dry	1-12 years	*Juncus roemerianus*	Black needle rush	Grasslike
		Distichlis spicata	Seashore saltgrass	Grass
	>12 years	*Juncus roemerianus*	Black needle rush	Grasslike
Brackish marsh (5-30 ppt salt) vegetation				
Wet to Dry	1-3 years	*Spartina patens*	Saltmeadow cordgrass	Grass
		Distichlis spicata	Seashore saltgrass	Grass
		Juncus roemerianus	Black needle rush	Grasslike
		Diverse salt marsh herbs		Herbaceous
	4-6 years	*Spartina patens*	Saltmeadow cordgrass	Grass
		Distichlis spicata	Seashore saltgrass	Grass
		Juncus roemerianus	Black needle rush	Grasslike
		Mixed salt marsh herbs		Herbaceous
Wet	7-12 years	*Distichlis spicata*	Seashore saltgrass	Grass
		Juncus roemerianus	Black needle rush	Grasslike
	>12 years	*Juncus roemerianus*	*Black needle rush*	Grasslike
Dry	7-25 years	*Cladium jamaicense*	Sawgrass	Grass
		Phragmites australis	Common reed	Grass
		Myrica cerifera	Waxmyrtle	Shrub
		Iva frutescens	Marsh elder	Shrub
		Baccharis halimifolia	Groundsel tree	Shrub
	26+ years	*Cladium jamaicense*	Sawgrass	Grass
		Phragmites australis	Common reed	Grass
		Myrica cerifera	Waxmyrtle	Shrub
		Iva frutescens	Marsh elder	Shrub
		Baccharis halimifolia	Groundsel tree	Shrub
		Juniperus virginiana	Eastern red cedar	Tree
Oligohaline marsh (0.3-5 ppt salt) vegetation				
Wet to Dry	1-6 years	Diverse mixed vegetation		
	7-12 years	*Juncus roemerianus*	Black needle rush	Grasslike
		Myrica cerifera	Waxmyrtle	Shrub

Response of Vegetation to Fire Frequency

Moisture Extreme	Fire Frequency	Scientific Name	Common Name	Plant Type
	13-25 years	*Juncus roemerianus*	Black needle rush	Grasslike
		Spartina cynosuroides	Big cordgrass	Grass
		Phragmites australis	Common reed	Grass
		Cladium jamaicense	Sawgrass	Grass
		Scirpus americanus	American threesquare	Grasslike
		Typha angustifolia	Narrow-leaved cattail	Grasslike
		Typha latifolia	Broad-leaved cattail	Grasslike
		Myrica cerifera	Waxmyrtle	Shrub
		Persea palustris	Red bay	Shrub
Wet	26-100 years	*Spartina cynosuroides*	Big cordgrass	Grass
		Phragmites australis	Common reed	Grass
		Cladium jamaicense	Sawgrass	Grass
Dry	26-100 years	*Acer rubrum*	Red maple	Tree
		Pinus taeda	Loblolly pine	Tree
		Nyssa biflora	Swamp black gum	Tree
		Taxodium distichum	Baldcypress	Tree
		Myrica cerifera	Waxmyrtle	Shrub
		Persea palustris	Red bay	Shrub
Wet or Dry	100+ years	*Acer rubrum*	Red maple	Tree
		Nyssa biflora	Swamp black gum	Tree
		Taxodium distichum	Baldcypress	Tree
Fresh marsh (<0.3 ppt salt) vegetation				
Wet or Dry	1-6 years	Diverse mixture of grasses and herbs		
	7-12 years	Diverse mixture of grasses and herbs		
		Cladium jamaicense	Sawgrass	Grass
		Myrica cerifera	Waxmyrtle	Shrub
		Acer rubrum	Red maple	Tree
	13-25 years	Diverse mixture herbs		
		Cladium jamaicense	Sawgrass	Grass
		Myrica cerifera	Waxmyrtle	Shrub
		Acer rubrum	Red maple	Tree
		Nyssa biflora	Swamp black gum	Tree
		Taxodium distichum	Baldcypress	Tree
	26+ years	*Acer rubrum*	Red maple	Tree
		Nyssa biflora	Swamp black gum	Tree
		Taxodium distichum	Baldcypress	Tree

Natural Fire Frequencies of Various Ecosystems in the Southeastern United States

Ecosystem	Fire Frequency
Low pocosin/bog	1 years
Wet pine savannas	1-2 years
Longleaf pine savanna	1-3 years
Oligohaline marsh	1-5 years
Peatland canebrakes	1-5 years
Brackish marsh	4-6 years
Peatland baldcypress	50-300 years
Peatland Atlantic white cedar	25-300 years

North Carolina Forest Service Smoke Management Guidelines for Prescribed Burning

Distance to Smoke-Sensitive Area (Miles)	Permissible Tonnages of Fuel per Burn				
	Daytime Burning Category				
	1	2	3	4	5
	Nighttime Dispersion Poor to Very Poor				
0.0-0.5	0	0	0	0	0
0.5-5.0	0	360	450	720	900
5.0-10.0	0	720	900	1400	1800
10.0-20.0	0	1080	1350	2160	2700
20.0-30.0	0	1200	1600	2500	3000
30.0+	0	1440	1800	2880	3600
	Nighttime Dispersion Fair to Good				
0.0-0.5	0	0	0	1030	1350
0.5-5.0	0	360	450	1440	1800
5.0-10.0	0	720	900	1880	3600
10.0-20.0	0	1080	1350	4320	5400
20.0-30.0	0	1200	1600	5000	6000
30.0+	0	1440	1800	5760	7200

In the best situation with good nighttime dispersion, more than 30 miles to the closest smoke-sensitive area, a daytime burning category of 5, and 3 tons of fuel per acre of marsh, the maximum permissible acreage is 7200/3 = 2400 acres.

Available Tons of Fuel per Acre for Various Fuel Types and Conditions

Fuel Type	Available Tons per Acre		
	Fuel Condition		
	Low	Medium	High
Marsh/tall grass/broomsedge	3	6	8
Short grass/wiregrass	2	5	7
Pine litter	3	6	12

Daytime Burning Category

Category	Weather	Meaning
1	Low level inversion and stagnant air the entire day	No burning
2	Inversion until early afternoon and very light transport wind	Mid-afternoon burning only, inversion temperature will be given
3	Inversion until late morning and light transport wind	Daytime burning when burn-off temperature is reached
4	Little or no inversion and moderate transport wind	Burning anytime
5	No inversion, strong and gusty transport wind	Burning with caution and good smoke dispersion

Fire Staffing for National Wildlife Refuges in Eastern North Carolina for Prescribed Burning and Wild Fire Suppression (20 Total)

Alligator River National Wildlife Refuge, Manteo, North Carolina

Fire Management Officer
Fire Management Specialist
Wildlife Biologist (Wildland Urban Interface)
4 Forestry Technicians
2 Engineering Equipment Operators

Pocosin Lakes National Wildlife Refuges, Columbia, North Carolina

Fire Management Specialist
4 Forestry Technicians
3 Engineering Equipment Operators

Mackay Island National Wildlife Refuge, Knotts Island, North Carolina

2 Forestry Technicians

Mattamuskeet National Wildlife Refuge, Swan Quarter, North Carolina

1 Forestry Technician

Native Cool-Season Grass Evaluation for the Northeast

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Native cool-season grass development has received little attention in the past. This changed with the passage of the 1996 Farm Bill Program and a growing desire by agencies and resource managers to have native cool-season grasses available for conservation plantings. There are virtually no commercially grown cultivars or tested selections available for the Northeast. The plant materials program of the USDA, Natural Resources Conservation Service initiated a study in 1999 to collect, evaluate, select, and release native cool-season grasses with known origin to be commercially produced with seed available for use in the Northeast. The three plant material centers (PMCs) in the Northeast (the National PMC in Maryland, the Cape May PMC in

New Jersey, and the Big Flats PMC in New York) are interested in the following grasses: Canada bluejoint (*Calamagrostis canadensis*), stout woodreed (*Cinna arundinacea*), drooping woodreed (*Cinna latifolia*), poverty oatgrass (*Danthonia spicata*), crinkled hairgrass (*Deschampsia flexuosa*), Canada wild rye (*Elymus canadensis*), hairy wild rye (*Elymus villosus*), Virginia wild rye (*Elymus virginicus*), red fescue (*Festuca rubra*), little barley (*Hordeum pusillum*), bottlebrush grass (*Elymus hystrix*), and junegrass (*Koeleria cristata*). Field collection of these species was made from 1999 to 2003, and they are currently being evaluated at each plant materials center. At the conclusion of the evaluation process, plants will be released as cultivars or tested/selected source-identified releases. With these new plant releases in the near future, resource managers will have the opportunity to incorporate native cool-season grasses in their conservation seedings. For more information on conservation plantings, see our Web site at http://plant-materials.nrcs.usda.gov.

Native Forage Grass Establishment and Use in Southwest Georgia

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In 1993, the Jimmy Carter Plant Materials Center (PMC), in cooperation with Natural Resources Conservation Service (NRCS) grazing land specialists, established long-term grazing demonstrations of ‘Pete’ eastern gamagrass (*Tripsacum dactyloides* (L.) L.) and ‘Alamo’ switchgrass (*Panicum virgatum* L.) at the PMC in Americus, Georgia. Both native grass pastures were divided into 10 paddocks, and cattle were rotationally stocked through each set of paddocks. Heifers on ‘Pete’ eastern gamagrass achieved 1 pound average daily gain (ADG), and steers obtained between 1.5 and 1.75 ADG. Heifers on ‘Alamo’ switchgrass produced an ADG of 0.7 to 1.0 pound. In 1997, the PMC began a study in cooperation with Auburn University to follow establishment success and invasive plant species control in introduced and native forage grasses under different burn regimes. Six blocks of six 50 by 50 foot plots were sown with native and introduced forages at the PMC. Half of the blocks were burned every year, and half were burned every other year. Percent canopy cover was estimated each fall (1998-2002) and analyzed as a split plot design with year after establishment the main plot and burn frequency the subplot. In mixture with the native grasses, big bluestem (*Andropogon gerardii* Vitman ‘Earl’), switchgrass (*Panicum virgatum* L. ‘Cave-in-Rock’), and indiangrass (*Sorghastrum nutans* (L.) Nash ‘Americus’), little bluestem (*Schizachyrium scoparium* (Michx.) Nash ‘Knox City PMC’) cover was not different in year 1 (13%) versus year 5 (17%) after establishment if the mixture was burned every year. However, when burned every other year, little bluestem cover was higher in year 5 (38%) versus year 1 (16%). In mixture with sericea lespedeza (*Lespedeza cuneata* L. ‘Serala’), little bluestem cover was higher ($P = 0.010$) after year 5 when burned every year (32%) versus every other year (16%). Initially, bahiagrass (*Paspalum notatum* L. ‘Pensacola’) was the dominant invasive species in the native grass mix. Regardless of burn frequency, bahiagrass cover was reduced (*P <.001*) after year 5 (3%) compared to year 1 (26%), while cover of blackberry (*Rubus cuneifolius* Link) increased (*P = 0.024*) between year 1 (2%) and year 5 (14%).

Native Grass Cultivars, Ecotypes, and Germplasm and Their Adaptation for the Eastern United States

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Abstract

The widespread use of native grasses depends on an inexpensive, reliable supply of seed with dependable growers and known ranges of adaptation. Over the past 60 years, the USDA, Natural Resources Conservation Service, USDA, Agricultural Research Service, State Agricultural Experiment Stations, and private seed companies have developed cultivars of grasses to restore ecosystems and produce forage and wildlife habitat. Each cultivar has a known production capability in the nursery and seed production field as well as the situation into which it is established. Each cultivar has a known range of adaptation to climate, soil characteristics, hydrology, and stress such as grazing within which it will perform. Knowledge of these adaptations has allowed the effective use of these cultivars beyond the area in which they were originally collected. Since the largest market for the tall prairie grasses is in the Midwest, much of the cultivar development has occurred in the states from Texas to North Dakota. Knowledge of the cultivars' adaptations has allowed their use in the eastern part of the United States until more local origins are developed. Recently, ecotypes and germplasm have been released for use in very localized areas.

Table 1. Released cultivars, source-identified material, and germplasm; their intended uses; and range of adaptation.

Cultivar	Origin		Adaptation		Special Characteristics
	State	Plant Hardiness Zone	Plant Hardiness Zones	Major Land Resource Areas	
Switchgrass (*Panicum virgatum*)					
Miami	Fla.	10b	10b	U	Local ecotype
Stuart	Fla.	9b	9b	U	Local ecotype
Wabasso	Fla.	9b	9b	U	Local ecotype
Alamo	Texas	9a	7a – 10b	H,I,J,M,N,O,P.T,U	Lowland type, stiff-stemmed
Kanlow	S. Okla.	7a	5a – 8b	H,J,M,N,O,P,S	Lowland type, stiff-stemmed
Carthage	N.C.	7a	6a – 8b	N,O,P,S,T	Adapted to eastern coastal plain
Dirham	N.C.	7a	6a – 8b	N,P,T	Adapted to southeastern Piedmont
Blackwell	N. Okla.	6b	5a – 7b	D,G,H,J,L,M,N,O,P, R,S	Low fertility and water requirement
Shelter	W.Va.	6a	4a – 7a	L,M,N,O,P,R,S,T	Stiff-stemmed
Southlow Michigan	Mich.	5b	4a – 5b	K,L,M	Local ecotype

Table 1. Released cultivars, source-identified material, and germplasm; their intended uses; and range of adaptation.

Cultivar	Origin		Adaptation		Special Characteristics
	State	Plant Hardiness Zone	Plant Hardiness Zones	Major Land Resource Areas	
Cave-in-Rock	Ill.	5b	4b – 6b	H,M,N,O,P,S	Forage quality, grazing persistence
Pathfinder	Kan./Neb.	5a	4a – 6a	H,G,M,N,R,S	Late maturing
Trailblazer	Kan/Neb	5a	4a – 6a	H,G,M,N,R,S	Forage quality
Nebraska 28	Neb.	4b	4a – 5b	H,G,M,N,R,S	Early maturing Sandhill type
Central Iowa	Iowa	4b	4b	M	Local ecotype
Big Bluestem (*Andropogon gerardii*)					
Suther	*N.C.*	*7b*	*7b*	P	Local ecotype
Earl	*Texas*	*7a*	*7a – 10b*	H,I,J,N,O,P.T,U	Long growing season
OH370	*Mo., Ark., Ill., Okla.*	*6a & 6b*	*5a – 7b*	M,N,O,P	Adapted to Ozarks
Niagara	*N.Y.*	*6a*	*4a – 7b*	L,M,N,O,P,S	Adapted to humid east
Southlow Michigan	*Mich.*	*5b*	*4a – 5b*	K,L,M	Local ecotype
Kaw	*Kan.*	*5b*	*4a – 6b*	H,J,M,N,O,P,S	Lowland type, stiff-stemmed
Roundtree	*Iowa*	*5a*	*4b – 6a*	M,N,P,S,R	Forage and seed production
Pawnee	*Neb.*	*5a*	*5a – 6b*	D,G,H,J,L,M,N,O,P,R,S	Earlier seed maturity than Champ
Northern Missouri	*Mo.*	*5a*	*5a*	M	Local ecotype
Southern Iowa	*Iowa*	*5a*	*5a*	M	Local ecotype
Central Iowa	*Iowa*	*4b*	*4b*	M	Local ecotype
Northern Iowa	*Iowa*	*4b*	*4b*	M	Local ecotype
Champ	*Neb.*	*4b*	*4a – 5b*	G,H,L,M,N,R,S	Later seed maturity than Pawnee
Indiangrass (Sorghastrum nutans)					
Lometa	Texas	7b	7a – 10b	H,I,J,M,N,O,P.T,U	Best forage production in Texas
Newberry	S.C.	7b	7b	P	Adapted to southeastern Piedmont
Suther	N.C.	7b	7b	P	Adapted to southeastern Piedmont
Cheyenne	Okla.	6b	5b – 7b	H,M,N,O,P,R,S	Earliest release
Osage	Okla.	6b	4a – 7b	H,M,N,O,P,R,S	Late maturing
Rumsey	Iowa	6a	4a – 7a	H,M,N,O,P,R,S	Forage production and quality
Southlow Michigan	Mich.	5b	4a – 5b	K,L,M	Local ecotype
Oto	Kan./Neb.	5a	5a – 6a	H,M,N,O,P,R,S	Earlier seed maturity than Champ
Nebraska 54	Neb.	5a	4a – 5b	H,L,M,N,R,S	Later seed maturity than Holt
Northern Missouri	Mo.	5a	5a	M	Local ecotype
Southern Iowa	Iowa	5a	5a	M	Local ecotype
Central Iowa	Iowa	4b	4b	M	Local ecotype

Table 1. Released cultivars, source-identified material, and germplasm; their intended uses; and range of adaptation.

Cultivar	Origin		Adaptation		Special Characteristics
	State	Plant Hardiness Zone	Plant Hardiness Zones	Major Land Resource Areas	
Northern Iowa	Iowa	4b	4b	M	Local ecotype
Holt	Neb.	4b	4a – 5b	H,L,M,N,R,S	Earlier seed maturity than Ne-54
Little Bluestem (*Schizycharium scoparium*)					
Suther	N.C.	7b	7b	P	Local ecotype
Cimarron	Okla./Kan.	6a	4b – 7a	E,G,H,N,O,P,R,S	Most recent release
Southlow Michigan	Mich.	5b	4a – 5b	K,L,M,	Local ecotype
Pastura	N. Mex.	5b	4a – 6b	G,H,M,N,O,P,R,S	Excellent seedling vigor
Aldous	Kan.	5b	4a – 6b	F,G,H,M,N,O,P,R,S,T	Medium to late maturity
Blaze	Kan./Neb.	5a	4a – 6a	G,H,M,N,R,S	Late maturing
Camper	Kan./Neb.	5a	4a – 6a	G,H,M,N,R,S	Better establishment and forage
Northern Missouri	Mo.	5a	5a	M	Local ecotype
Southern Iowa	Iowa	5a	5a	M	Local ecotype
Central Iowa	Iowa	4b	4b	M	Local ecotype
Northern Iowa	Iowa	4b	4b	M	Local ecotype
Sideoats Grama (*Bouteloua curtipendula*)					
Haskell	*Texas*	*7b*	*7a – 9a*	H,I,J,N,O,P	Good rhizome production
Niner	*N. Mex.*	*7a*	*4a – 8b*	D,G,H,N,O,P	Even seed maturity
El Reno	*Okla.*	*6b*	*5a – 7b*	D,G,H,J,M,N,O,P	Outstanding forage
Vaughn	*N. Mex.*	*6a*	*4a – 7a*	D,E,G,H,N,O,P	Good drought tolerance
Southern Iowa	*Iowa*	*5a*	*5a*	M	Local ecotype
Central Iowa	*Iowa*	*4b*	*4b*	M	Local ecotype
Northern Iowa	*Iowa*	*4b*	*4b*	M	Local ecotype
Butte	*Neb.*	*4b*	*4a – 5b*	F,G,M,N,R,S	Early maturing
Trailway	*Neb.*	*4b*	*4a – 5b*	H,M,N,R,S	Late maturing
Eastern Gamagrass (Tripsacum dactyloides)					
Martin	*Fla.*	*9b*	*9a - 9b*	U	Local ecotype
St. Lucie	*Fla.*	*9b*	*9a - 9b*	U	Local ecotype
Jackson	*Texas*	*9a*	*8a – 9b*	J,N,O,P,T	South-central adaptation
Medina	*Texas*	*8b*	*8a – 9b*	J,N,O,P,T	South-central adaptation
Iuka	*Okla.*	*7a*	*6a – 8a*	H,N,O,P,R,S	Multi-clone synthetic
Highlander	*Tenn.*	*6b*	*6a – 8a*	N,O,P,R	Southeastern-wide adaptation
Pete	*Kan.*	*6a*	*5b – 7a*	H,M,N,O,P,R,S	First release
SG4X-1	*Synthetic*	*5b*	*5a – 7a*	N,P,R,S	Tetraploid
Deertongue (Dichanthelium clandestinum)					
Tioga	*Pa.*	*5a*	*4a – 7a*	L,M,N,R,S	*Tolerates pH of 4.0, and toxic Al and Mn*
Virginia Wild Rye (Elymus virginicus)					
Kinchafoonee	*Texas*	*8a*	*7a – 8b*	P	*Adapted to southern Piedmont*
Northern Missouri	*Mo.*	*5a*	*5a*	M	*Local ecotype*

Table 1. Released cultivars, source-identified material, and germplasm; their intended uses; and range of adaptation.

Cultivar	Origin		Adaptation		Special Characteristics
	State	**Plant Hardiness Zone**	**Plant Hardiness Zones**	**Major Land Resource Areas**	
Cuivre River	*Mo.*	*5b*	*5b*	M	Local ecotype
Omaha	*Neb.*	*5b*	*4b – 6b*	H,L,M,N,R,S	Shade tolerant
American Beachgrass (Ammophila breviligulata)					
Aterras	*N.C.*	*8a*	*7a – 9a*	T	Better adapted to South Atlantic
Cape	*Mass.*	*7a*	*5a – 8b*	R,S,T	First release
Coastal Panicgrass (Panicum amarum* var. *amarulum)					
Atlantic	Va.	7b	5a – 8b	R,S,T	Suitable for inland and coastal use
Bitter Panicgrass (*Panicum amarum*)					
Southpa	Fla.	10a	8a – 10a	T,U	Better adapted to S. Atlantic & Gulf
Fourchon	La.	9a	8a – 10a	T	Better adapted to western Gulf Coast
Northpa	N.C.	7a	6a – 8a	T	Better adapted to mid-Atlantic Coast
Seaoats (*Uniola paniculata*)					
Caminada	La.	9a	9a	T	Local ecotype
Saltmeadow Cordgrass (*Spartina patens*)					
Gulf Coast	*La.*	*9a*	*8a - 10a*	T	Better adapted to western Gulf Coast
Sharp	*La.*	*9a*	*8a - 10a*	T,U	Better adapted to S. Atlantic & Gulf
Flageo	*N.C.*	*8a*	*7a - 9a*	T	Better adapted to mid-Atlantic
Avalon	*N.J.*	*7a*	*6a - 8a*	R,S,T	First release
Smooth Cordgrass (Spartina alterniflora)					
Vermillion	La.	9a	8a - 10a	T,U	Better adapted to S. Atlantic & Gulf
Bayshore	Md.	7a	6a – 9b	T	Better adapted to N. & mid-Atlantic
Seashore Paspalum (*Paspalum vaginatum*)					
Brazoria	*Texas*	*9a*	*9a*	T	Local ecotype
Maidencane (Panicum hemitomon)					
Citrus	Fla.	9a	8b – 9b	T,U	Local ecotype
Halifax	N.C.	7b	7b – 8a	P,T	First cultivar
Giant Cutgrass (*Zizaniopsis miliacea*)					
Wetlander	La.	9a	8b – 9b	P,T,U	First cultivar
Tall Dropseed (*Sporobolus compositus*)					
Northern Missouri	*Mo.*	*5a*	*5a*	M	Local ecotype
Southern Iowa	*Iowa*	*5a*	*5a*	M	Local ecotype
Central Iowa	*Iowa*	*4b*	*4b*	M	Local ecotype
Northern Iowa	*Iowa*	*4b*	*4b*	M	Local ecotype

Table 1. Released cultivars, source-identified material, and germplasm; their intended uses; and range of adaptation.

Cultivar	Origin State	Origin Plant Hardiness Zone	Adaptation Plant Hardiness Zones	Adaptation Major Land Resource Areas	Special Characteristics
***Florida Paspalum (Paspalum floridanum*)**					
Harrison	Texas	8a	8a	P	Local ecotype

Native Grass Diversity in an Eastern West Virginia Riverine Floritic Community

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Approximately eight river miles of the Cacapon River were surveyed in 2002 to determine the extent and diversity of native grasses. Native grasses proved to be the predominant vegetative component in all of the riparian areas surveyed, with *Andropogon gerardii,* big bluestem, and *Tripsacum dactyloides,* eastern gamagrass, comprising approximately 90% of the total population. *Andropogon gerardii* was visually estimated to compose 70% and *Tripsacum dactyloides* 20% of the total stand population. Other species identified were *Panicum virgatum,* switchgrass; *Elymus virginicus,* Virginia wild rye; *Elymus riparius,* riverbank wild rye; *Schizachyrium scoparium,* little bluestem; *Chasmanthium latifolium,* Indian wood oats; *Chasmanthium laxum,* slender wood oats; *Hystrix patula,* bottlebrush grass; *Spartina pectinata,* prairie cordgrass; and *Sorghastrum nutans*, indiangrass. By visual estimates, these species did not compose more than 10% of the total population. Native grass communities within the survey area are extensive, diverse, and stable. With additional rigorous evaluation, the germplasm of one or more species from the Cacapon River may prove to be locally and/or regionally important ecotypes. Additional study of the native species from the Cacapon River is warranted.

Native Plant Restoration at Stones River National Battlefield

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Stones River National Battlefield, located in Middle Tennessee on the northwestern edge of Murfreesboro, is the site of one of the significant battles of the Civil War. The Battle of Stones River, fought between December 31, 1862, and January 2, 1863, marked the beginning of the Union Army's "March to the Sea," which resulted in Union control of agricultural land and supply networks and prevented further attempts by the Confederate Army to push northward.

Stones River National Battlefield was established in 1927 to preserve this significant historic site. The original property consisted of 344 of the 4,000 acres over which the battle was fought. The park currently encompasses approximately 700 acres.

Vegetation and terrain played an important role in the outcome of the Battle of Stones River. Limestone outcroppings, cedar brakes, and cedar woods dominated the majority of the original park property at the time of the battle. During the battle, the rock outcrops and thick cedar woods significantly slowed troop progress and impeded rapid movement of artillery pieces. However, the battlefield's vegetation has not only historical but also botanical and ecological significance. The site is host to a number of rare and endemic plant species and unique plant communities.

Today, introduced and exotic plant species have encroached onto many areas of the battlefield. Park managers have identified restoration of native plant communities as a high priority for maintenance of the park's circa 1862 authenticity. National Park Service personnel have completed a thorough assessment of the vascular flora inhabiting the battlefield property and have targeted approximately 20 native plant species having high priority for use in restoration of plant communities. Those high priority native species are *Andropogon ternarius, Andropogon gyrans, Bouteloua curtipendula, Carex* spp. *(C. amphibola, C. blanda, C. cherokeensis, C. complanata, C. oxylepis), Chasmanthium latifolium, Dichanthelium spp. (D. dichotomum, D. laxiflorum, D. malacophyllum, D. villosissimum),Eragrostis spectabilis, Leersia virginica, Melica mutica, Schizachyrium scoparium, Asclepias tuberosa, Aster* spp., *Eupatorium altissimum, Eupatorium coelestinum, Eupatorium serotinum, Lespedeza violacea, Rudbeckia* spp., *Solidago* spp., and *Forestiera ligustrina.*

The Alderson Plant Materials Center and the National Park Service at Stones River National Battlefield began implementation of a native plant restoration project within the park during 2003. The primary objective of this project is to maintain and/or improve the native plant communities of Stones River National Battlefield.

In 2003, Plant Materials Center personnel traveled to Stones River National Battlefield to become familiar with the park's ecological communities, identify prime seed collection locations for the species of interest, and assess appropriate seed collection techniques and optimum harvest times. Several late summer seed collection trips netted small (less than 0.5 pounds) quantities of seeds from 12 species. All seed was collected by hand-stripping methods. The 12 species represented in the 2003 seed harvest were *Andropogon ternarius, Andropogon gyrans, Chasmanthium latifolium, Dichanthelium* spp., *Eragrostis spectabilis, Leersia virginica, Schizachyrium scoparium, Symphyotrichum drummondii*, *Lespedeza violacea, Lespedeza hirta, Rudbeckia triloba,* and *Solidago nemoralis.* All seed harvested was transported to the Alderson Plant Materials Center, where it was conditioned and placed in appropriate seed storage until planting in 2004.

In 2004, the Alderson Plant Materials Center produced approximately 20,000 seedlings from the 2003 seed harvest. The seedlings were mechanically transplanted into tilled fields at Stones River National Battlefield to establish seed production fields. Ecologists at Stones River National Battlefield will harvest and use seed from these fields to restore and maintain this historic site's circa 1862 floristic authenticity.

Native Warm-Season Grass Forage Project

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During the planting season of 2001, Kentucky Department of Fish and Wildlife (KDFWR), Green River Region, started a native warm-season grass forage program in partnership with the Natural Resources Conservation Service (NRCS) Monroe County Office. A presentation of foraging and wildlife virtues of native warm-season grass was made to the local cattle producers in Monroe County prior to the 2001 planting season. During the 2001-2003 planting seasons, an average of 70 acres per year were established in Monroe County. Todd County Conservation District and NRCS office investigated the Monroe County plantings during the 2001 establishment period and, based on their observations, requested to participate in the forage project. Monroe and Todd counties have established approximately 300 acres of native warm-season grass forage since 2001 and plan to establish approximately 110 acres during 2004. Eastern gamagrass was the grass of choice with the exception of big bluestem being planted in a 10-acre tract in Monroe County. In Monroe County, one producer implemented a weight gain analysis which showed a 2-pound per day gain in beef cattle grazing eastern gamagrass in paddocks designed for weekly rotation. In Todd County during the month of July, one herd of dairy cattle was grazed on eastern gamagrass. The dairy herd showed no reduction in milk production with the grass used as a partial replacement for alfalfa hay. There has been an overall acceptance of the eastern gamagrass as a forage with the participating producers. One pacesetter producer planted eight acres in 2002 and 18 acres in 2003 and plans to establish 30 additional acres in 2004. We are currently attempting to document the response of eastern cottontail rabbit to the native grass plantings. Anecdotal observations from the producers haying the native grass stands indicate an increase in rabbit sightings. Weed control was an ongoing problem during the establishment period. Several techniques were used in controlling the weed invasion. On the site with paddocks set up for weekly grazing rotation, crabgrass was a major encroachment weed. When the gamagrass was between 4 and 8 inches tall, the cattle were turned into the paddocks to graze the crabgrass. Because the cattle were familiar with crabgrass, it was reasoned that they would graze it before the gamagrass. This proved to be the case, causing the crabgrass to be grazed down to ground level. Once the cattle showed an interest in the gamagrass, they were pulled back off the paddocks and put in cool-season pasture. Traditional methods of herbicide treatment were implemented in the majority of the native forage sites. The sites that had two herbicide applications and then followed up with vigorous spot spraying during the establishment period had excellent results. Going into the 2004 planting season, Monroe and Todd counties have approximately 150 acres scheduled to plant.

Native Warm-Season Grass Restoration on a Piedmont North Carolina Landscape

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The North Carolina Wildlife Resources Commission worked with 24 landowners on a 5,000-acre area in the western Piedmont to restore wildlife populations dependent on tall grass and early succession habitat. Habitat was established on narrow field borders (10 to 12 feet wide), wide field borders (24 to 60 feet wide), habitat blocks (0.21 to 4.45 acres), and forage blocks (1.0 to 10 acres). Habitat was established by killing existing vegetation with herbicide and seeding with a no-till drill or allowing volunteer vegetation to become established on former cropland. We have been successful in establishing high-quality habitat on wide field borders, habitat blocks, and forage plots. Narrow field borders, which were offered by landowners at no cost, have suffered from shading, competition with other nonnative grasses and encroachment from adjacent woodlands and farming operations. Our experiences indicate that efforts expended on private lands to establish native grass and early succession habitat are sustainable and have the potential to be adopted by additional landowners. Success has been greater with wide borders and large habitat blocks that are clearly delineated on the ground and that include economic incentives such as rental payments or forage production in addition to wildlife benefits. Challenges of landscape-scale grassland restoration on privately owned Piedmont landscapes include small parcel size (working with multiple landowners), lack of appreciation for the aesthetics of early succession habitats, and development of the rural landscape.

PLANTS: A Database for Plant Information on the World Wide Web

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The PLANTS World Wide Web site provides basic botanical information about all of the plant species that occur in the United States and its territories. The PLANTS site also provides more detailed information about plants that are in the following groups: conservation plants, noxious and invasive plants, threatened and endangered plants, and culturally significant plants. PLANTS provides the following assets: checklists of species by state and by either family or genus; NWI Wetland Indicator Status of plants that occur in wetlands; classification reports that enable users to search for closely related species; 300 plant fact sheets; 4,360 photographs of plants; one-click links to further information on the Internet; an advanced query function that enables users to search and download PLANTS information using any plant attribute or

combination of attributes in the database; access to information about alternative crops and cover crops and to NRCS Plant Materials publications. The PLANTS URL is http://plants.usda.gov.

Reintroduction of *Arundinaria gigantea* Canebrakes Through Improved Propagation and Establishment

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The *Arundinaria gigantea* (Walt.) Muhl. canebrake was once a dominant ecosystem throughout the southeastern United States, providing habitat for a number of animal species. There has been a greater than 98% decline in the *A. gigantea* population resulting in a critically endangered ecosystem. Historical accounts suggest loss of canebrake habitat has resulted in the extirpation (and perhaps extinction) of many animal species. Thus, canebrake restoration is necessary for maintaining and enhancing biodiversity in the southeastern United States. However, transplantation attempts to reintroduce cane have met with limited success. Efficient propagation methods and a greater understanding of environmental factors critical to establishment success could improve necessary restoration efforts. The environmental factors critical to success, and the focus of this research, are competition, light levels, and soil moisture and nutrients with emphasis on establishment and management. The goal of this study is to facilitate reestablishment of *A. gigantea* canebrakes by comparing propagation methods and examining environmental parameters critical to establishment.

There are several characteristics of *A. gigantea* that make propagation difficult. Since cane flowers infrequently and seed production is inconsistent, a source of seed is unreliable. The more successful transplantations have been with vegetative propagation, using mature culms and rhizomes, thus requiring an abundant source of mature plants. Methods adapted from Platt and Brantley are being used for transplantation, and field studies with transplants are being used to determine conditions necessary for establishment and growth. Additionally, macropropagation methods, used extensively in nursery applications, are being examined for use as source plants for laboratory and field studies. More recently, for large-scale propagation projects, such as the proposed canebrake restoration, micropropagation methods have been developed.

Micropropagation requires relatively little plant material to establish, is a continual source of propagules, and is thereby a feasible method for reestablishment of *A. gigantea* canebrakes. Micropropagation methodology for *A. gigantea* is currently being developed as a continual supply of propagules for canebrake establishment. The focus for both macro- and micropropagation experiments will be determining concentrations of plant growth regulators, auxins and cytokinins, which will result in the greatest amount of plant growth.

Propagation research to date has determined the axillary bud to be a feasible source of micropropagation and macropropagation explant material. Shoot initiation, the first step in the micropropagation method, occurs readily using explants (4 to 6 mm in diameter size range) placed on Murashige and Skoog medium with 3% sucrose, 0.1 μM thidiazuron and 0.1 μM indole-3-butyric acid, 0.6% agar, pH 5.8. Shoot multiplication and root development methodologies are currently under investigation. Macropropagation methods are also being conducted using sand as support medium under misted conditions. Culm segments approximately 42 centimeters in length are treated with auxin and placed in trays containing sand. Propagules from both methods will be acclimatized in the greenhouse for transfer to the field, providing a continual and adequate source for canebrake reintroduction.

Once a source of plants for the field has been developed, it will be necessary to have established environmental parameters favorable for survival and continued expansion. Experiments conducted in laboratory conditions have shown river cane produces the greatest growth in full sun in moist, well-drained soil. Field studies indicate reduction of competition results in increased new shoot growth. Research will continue to determine nutrient requirements, as well as additional data on shading effects on existing river cane populations.

Reintroducing Native Plants on Eroded Sites in the Sumter National Forest in South Carolina

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The Sumter National Forest was acquired in the early 1930s under the Weeks Law of 1911 to provide sustained timber and water resources. Most areas were logged, overfarmed, eroded, and nutrient depleted to the extent that soil productivity was impaired. The practices accelerated surface erosion and gully formation and removed many native grasses from the area. Watershed characteristics were improved on many barren lands by planting loblolly pine trees. Recovery from erosion was slow until the needle cast from pine trees provided ground cover. In intermediate pine stands, needle cast provided ample soil cover and erosion control, but the needles limited the development of understory vegetation and surface soil.

Revegetation with grasses has been a regular part of treating actively eroding and barren lands. Until recently, the less expensive and effective nonnative species were commonly used. Commonly used grasses have included sericea lespedeza, fescue, bahia, orchard, and bermuda. Clover, brown top millet, oats, wheat, and other plants provide variety in the seed mixture for wildlife habitat purposes. Some of the grasses used in the past are nonnative species with some invasive or persistent characteristics. Recent and ongoing efforts have encouraged the development of native plant species for erosion control and soil-building purposes. From the limited field trials, the native plants thrived through several years of drought, while nonnative grass cover had substantial mortality.

Recent forest activities are focusing on the thinning of forest stands to improve forest health and habitats. Opening the forest stands to sunlight and low- to moderate-intensity prescribed fire encourages the reintroduction of native grasses. Native plants with their greater root densities are desirable for soil improvement based on their resiliency to drought, nutrient-deficient soils, and fire. These conditions are common within the Piedmont forest.

The National Forest has cooperated with USDA Natural Resources Conservation Service, South Carolina Native Plant Society, South Carolina Department of Natural Resources, and Clemson University to implement the needed seed collection of local ecotypes and testing and planting fields for future harvests of several native plant species including little bluestem, big bluestem, splitbeard bluestem, bushy beard bluestem, purpletop, indiangrass, beggarweed, and partridge pea. Initial planting of some of the native grasses has shown some difficulty with individual species such as big bluestem in regeneration, but generally we have found good results under greenhouse, plug planting, and broadcast sowing in selected areas.

Restoration of Glade and Grassland Communities at Crooked Creek Barrens State Nature Preserve, Lewis County, Kentucky

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Crooked Creek Barrens State Nature Preserve is a 351-acre nature preserve in Lewis County, Kentucky. The preserve has 10 state-listed plant species and some small examples of high-quality glade and prairie communities. There are also large areas of degraded and anthropogenically derived communities. The goals of the restoration work are to enhance community quality and rare species populations. Restoration work on the degraded communities began in 1999. Restoration methods include prescribed fire, brush removal, invasive species control, and Plateau® applications. Management units where restoration work has been done are relatively small, but the results have been successful. Woody plant removal, prescribed burns, and Plateau treatments have converted fescue- and brush-dominated areas into recovering grasslands and bolstered the populations of several rare plant species.

Switchgrass Filter Strips in Cropland for Wildlife Habitat at the Alligator River National Wildlife Refuge

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Abstract

Switchgrass filter strips were established in cropland on the Alligator River National Wildlife Refuge in Dare County, North Carolina. They were planted to filter nutrients and sediment from the prior converted cropland. The filter strips were 75 feet wide on either side of 300-feet wide cropland strips with surface ditches separating the strips. They were seeded with a mixture of switchgrass, lespedeza, clover, and oats broadcast with regard to the cropland. After four years, the filter strips were dominated by perennial native forbs. The seeded species never established a stand due to poor species and cultivar selection for the poor soil drainage, late seeding date, and poor establishment practices. The native forbs provide habitat for grassland songbird species and raptors that prey on rodents living in the filter strips.

Introduction

The U.S. Fish and Wildlife Service manages cropland at the Alligator River National Wildlife Refuge to provide grain for migratory geese and swans that rest in the adjacent impoundments. The cropland is located on prior converted hydric soils with surface ditches every 300 feet. The cropland is "re-crowned" every few years to promote drainage of the cropland toward the ditches. Before establishment of the filter strips, the cooperating farmers who operate the cropland tilled the fields down to the ditches without any buffers.

In 2000, the cooperating farmers enrolled in the Conservation Reserve Program and installed the filter strip practice. After "re-crowning" the fields late in the spring of 2000, the farmers broadcasted the recommended upland seed mix on the outer 75 feet of each field. The seeding was not cultipacked. The stands have been burned by prescription every year to control the invasion of woody plants.

Seeded Species and Cultivars (Filter Strip Site in Plant Hardiness Zone 8a)

Common Name	Scientific Name	Cultivar	Origin		Seeding Rate Lbs PLS/AC
			State	Plant Hardiness Zone	
Switchgrass	*Panicum virgatum*	Cave-in-Rock	Ill.	5b	3
Switchgrass	*Panicum virgatum*	Pathfinder	Neb.	5a	3
Switchgrass	*Panicum virgatum*	Trailblazer	Neb.	5a	3
Sericea Lespedeza	*Lespedeza cuneata*	Common	Not known	Not known	5
Red clover	*Trifolium pratense*	Common	Not known	Not known	5
Oats	*Avena sativa*	Common	Not known	Not known	60

Stand Composition of Filter Strips

Common Name	Scientific Name [Perennial(P)/Annual(A)] [Native(N)/Introduced(I)]	Percent Cover	Location
Canada goldenrod	*Solidago canadensis (P)(N)*	50	Throughout
Slender goldenrod	*Euthamia tenuifolia (P)(N)*	10	Throughout
Switchgrass	*Panicum virgatum (P)(N)*	10	Dry ends
Dallisgrass	*Paspalum dilatatum (P)(I)*	10	Bottom edges
Sericea lespedeza	*Lespedeza cuneata (P)(I)*	5	Top edges
Partridge pea	*Cassia fasciculate (A)(N)*	5	Top edges
Bushy bluestem	*Andropogon glomeratus (P)(N)*	5	Bottom edges
Various hydrophytic vegetative species (P)(N)		5	Bottom edges

Summary

The seeded species have germinated and persisted poorly. Poor species and cultivar selection, poor seeding technique, and the late seeding date contributed to the poor stands of seeded species. Perennial, native goldenrods have germinated and persisted well on 60% of the filter strips. The cover has provided good food for songbirds late in the year as seed matures and harbors small mammals on which raptors and red wolves feed.

Recommendations for Future Seedings

Seeding date: Before March 1 (the average date of last frost)—to get natural stratification (moist prechill at or below 40°F)

Seeding method: Cultipack before sowing, sow switchgrass and forbs with a drill at ¼-inch depth, sow oats with a drill at 1-inch depth, cultipack after sowing.

Recommended Species, Cultivars, and Origins

Common Name	**Scientific Name**	**Cultivar**	**Origin**		**Seeding Rate, Lbs PLS/AC**
			State	**Plant Hardiness Zone**	
Switchgrass	*Panicum virgatum*	Alamo or Kanlow	Texas or Oklahoma	9a or 7a	4-6
Tickseed sunflower	*Bidens* spp.	Common	Southeast	7-9	1
Narrowleaf sunflower	*Panicum virgatum*	Common	Southeast	7-9	1
Oats	*Avena sativa*	Common	N/A	N/A	60

Switchgrass Yield, Persistence, and Nutritive Value Under Grazing and Clipping

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Abstract

New cultivars of switchgrass have been released in recent years, but information on their performance and nutritive value in the northeastern United States is needed for producer recommendations. Our objective was to determine the performance and nutritive value of switchgrass cultivars under grazing and clipping management. In 1999, Cave-in-Rock, Trailblazer, and Shawnee switchgrass were established in replicated plots at Rock Springs, Pennsylvania, and in replicated pastures on a farm in southeastern Pennsylvania. In 2000 and 2001, two-cut and three-cut clipping treatments were imposed at Rock Springs. At the southeast Pennsylvania farm, the switchgrass pastures were grazed three or four times per year during 2000 to 2004. Forage yield was determined before each grazing. Crude protein, neutral detergent fiber, and digestible neutral detergent fiber were determined on samples from each harvest. There were small and inconsistent differences among cultivars in yield and nutritive value. There was much more variation among years and management treatments than among switchgrass cultivars in forage yield and nutritive value. The Trailblazer cultivar appeared to suffer from leaf diseases and lodging during wet years. Cave-in-Rock and Shawnee are equally suited for Pennsylvania and similar areas in the Northeast.

Introduction

Warm-season perennial grasses, such as switchgrass, can provide valuable forage during the summer and complement cool-season grass pastures. Switchgrass and other warm-season grasses are also useful for wildlife habitat. Information on the performance of newer switchgrass cultivars is needed for producer recommendations in the northeastern United States.

Cave-in-Rock, a commonly recommended switchgrass variety in the Northeast, was developed from plant material collected in Illinois and released in 1973 (Alderson and Sharp 1995). Trailblazer, a switchgrass cultivar selected for improved whole-plant *in vitro* dry matter digestibility (IVDMD), was released in 1984 (Vogel et al. 1991). Studies indicated greater ADG for steers grazing Trailblazer in Nebraska trials (Anderson et al. 1988). Shawnee, released in 1995, is a selection out of Cave-in-Rock and has improved dry matter digestibility (Vogel et al. 1996). There are no published data on the yield or nutritive value of Shawnee in the northeastern United States.

Our objective was to determine the performance and nutritive value of switchgrass cultivars under grazing and clipping management.

Materials and Methods

Clipping Experiment

The clipping experiment was conducted at the Russell E. Larson Agricultural Research Center at Rock Springs, Pennsylvania. Soil at the site is a Hagerstown silt loam (fine, mixed, semiactive, mesic, Typic Hapludalfs). Soil tests in 1999 indicated a pH of 6.4, 78 kg ha^{-1} of available P, and 124 kg ha^{-1} of available K to a 15-cm depth. No additional P or K fertilizer was applied during the experiment.

The switchgrass cultivars Cave-in-Rock, Shawnee, and Trailblazer were seeded at 11 kg pure live seed ha^{-1} with a plot drill in 9- by 15-m plots in a clean-tilled seedbed on 29 April, 1999. Each cultivar was planted in six randomized complete blocks. Plots were not harvested in 1999. Nitrogen fertilizer was applied at 120 lb $acre^{-1}$ in May 2000 and 2001. Plots were split in 2000 and 2001 with one-half harvested on a two-cut schedule and one-half harvested on a three-cut schedule (Table 1). At each harvest, a 1-m by 5-m strip was cut to a 15-cm stubble height with a sickle-bar mower. The fresh weight of herbage was recorded, and a 400-g subsample of herbage was dried at 55°C for 48 hours to determine dry matter yield. Plots were cleared of the previous year's residue in April each year.

Grazing Experiment

Two 0.4-ha pastures of Cave-in-Rock, Shawnee, and Trailblazer were no-till planted on a southeastern Pennsylvania farm in April 1999. In March 1999, existing vegetation at the site was killed with glyphosate herbicide. Seeding rate was 11 kg pure live seed ha^{-1}. Soil tests in 1999 indicated a pH of 5.9, 29 kg $ha^{-1}$of available P, and 131 kg ha^{-1} of available K. Pastures were not cut or grazed during the establishment year. The experiment was a randomized complete block design with two replicates.

The switchgrass pastures were grazed by 25 cow-calf pairs on four dates in 2000 and three dates in 2001 to 2004 (Table 2). The producer grazed the 2.4-ha area in rotation with cool-season grass pastures. The 2.4-ha area of switchgrass was subdivided across the cultivar pastures into five 0.48-ha paddocks for grazing. Thus, the cattle grazed all cultivars at once. Grazing time in each paddock was 2 d.

No nitrogen fertilizer was applied in 2000; however, 112 kg of N ha^{-1} was applied in two split applications of 56 kg each during 2001 to 2004. The first application occurred in late May before the first grazing and the second application in mid-June after the first grazing during 2000-2002. In 2003, the second application of N was delayed until August because frequent rain and flooding precluded machine access to the pastures. In 2004, the N applications were delayed until mid-June and mid-July because of heavy rains. Urea was the source of fertilizer N at each application except in May 2003 when 26-5-21 fertilizer was applied to supply 56 kg N, 12 kg P, and 48 kg K ha^{-1}. Lime was applied in 2001 at 2.5 Mg ha^{-1}.

Dicamba and 2,4-D were applied in June 2001 to control broadleaf weeds. Glyphosate was applied at 1 kg ha^{-1} in late March 2003 and early April 2004 (when switchgrass was dormant) to control cool-season weeds. Pastures were clipped once with a rotary mower after the first grazing in 2002, 2003, and 2004.

Three 1 m by 6.3 m strips were cut from each 0.4-ha pasture before each grazing to estimate dry matter yield. Strips were cut to a stubble height of 15 cm and the fresh weight of herbage measured. A 400-g subsample of herbage was dried at 55°C for 48 hours to determine dry matter yield.

In both studies, the morphological developmental stage (Sanderson 1992) at each harvest was determined on a sample of 50 switchgrass tillers from each plot or pasture. Tillers from individual stage categories from each plot at each harvest were composited to provide one sample per plot. Composite samples were ground to pass a 1-mm screen in a shear mill for nutritive value analysis. Only samples from the years 2001, 2002, and 2003 were analyzed for nutritive value in the grazing experiment.

The dried and ground samples were analyzed for crude protein (CP), neutral detergent fiber (NDF), and digestible neutral detergent fiber (dNDF) by a commercial laboratory (DairyOne, Ithaca, NY). Detergent fiber and IVTD (48 h fermentation period) procedures were according to Van Soest and Robertson (1980). Digestible NDF was calculated from NDF and IVTD values. Nitrogen was determined by the Dumas combustion method (AOAC, 1990) and CP calculated as N x 6.25. In both experiments, a weighted seasonal average was calculated for NDF, CP, and dNDF using individual harvest yields as the weighting factor.

The clipping experiment was analyzed as a randomized complete block with a split-plot arrangement of treatments. Cultivars were the whole plots, and cutting frequency was the subplot. Blocks were considered random, and treatments were fixed effects. The grazing experiment was analyzed as a randomized complete block. Blocks were considered random, and cultivars were fixed effects. PROC MIXED in SAS (1996) was used to conduct the analyses. The REML option was used to estimate the covariance structure, and the Satterthwaite option was used to estimate denominator degrees of freedom.

Results and Discussion

Clipping Experiment

There were no differences in dry matter yield ($P < 0.35$) among switchgrass varieties under clipping at Rock Springs (Table 3). There were differences in dry matter yield ($P < 0.01$) among years, cutting treatments, and a year-by-cutting-treatment interaction. Averaged for cultivars, the three-cut treatment yielded 24% more forage than the two-cut treatment in 2000 and 11% more forage in 2001.

There was a year-by-cultivar and year-by-cutting treatment interaction ($P < 0.05$) for nutritive value of switchgrass at Rock Springs. Crude protein was similar among cultivars in 2000, whereas Trailblazer had slightly lower CP than Shawnee or Cave-in-Rock in 2001 (Table 4). Trailblazer had slightly higher NDF than the other cultivars in both years. In 2000, Trailblazer had somewhat greater NDF digestibility than the other cultivars, whereas in 2001 it was lower. The year-by-cutting treatment interaction was caused by changes in magnitude of the means and not by changes in the direction of response in each year. Concentrations of CP, NDF, and dNDF were higher in the two-cut system compared to the three-cut system except for dNDF in 2001.

Grazing Experiment

There was a year-by-cultivar interaction ($P < 0.01$) for dry matter yield caused by differences among cultivars in 2003 (Table 5). Cultivars did not differ in dry matter yield in any other year. Trailblazer yielded 44% less than Cave-in-Rock or Shawnee in 2003. Lodging and leaf disease were noted in the Trailblazer pastures in 2003 and 2004 but were not quantified. We also noted significant leaf disease and lodging in Trailblazer in plots at Rock Springs compared with Cave-in-Rock and Shawnee in 2003 and 2004. We did not notice leaf disease problems on the other cultivars.

Yields were highly variable among years due to differences in grazing schedule and weather (Tables 2 and 6). Variation among years was much greater than variation among cultivars. Grazing started and ended later in 2002 and 2003, which may have allowed for greater dry matter accumulation compared with other years. Weed competition became a problem during summer 2004, and visual estimations of weeds indicated 25 to 40% weeds in the dry matter.

Cultivars did not differ ($P > 0.08$) in CP or dNDF ($P > 0.35$) averaged for three years (Table 7). Trailblazer had a greater ($P < 0.03$) NDF concentration than the other cultivars, similar to the results for the clipping experiment. There were differences ($P < 0.05$) among years in CP and dNDF concentrations averaged across the cultivars. Crude protein was lower in 2002 than the other years and dNDF decreased in each year. Morphological developmental stage was similar among the cultivars in each year (data not shown). Reid et al. (1992) also reported no differences in nutritive value among four switchgrass varieties (including Trailblazer).

Conclusions

In this study, annual variation and harvest management had larger effects on yield and nutritive value of switchgrass than did genetics of the switchgrass cultivars. The Trailblazer cultivar suffered from leaf diseases and lodging during very wet years (2003 and 2004). Cave-in-Rock and Shawnee are equally suited for Pennsylvania and similar areas in the Northeast.

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Table 1. Harvest dates for Rock Springs clipping experiment.

Two Cut		Three Cut	
2000	**2001**	**2000**	**2001**
21 June	19 June	8 June	19 June
9 August	7 August	12 July	23 July
		6 September	2 October

Table 2. Grazing dates of three switchgrass cultivars in southeastern Pennsylvania.

2000	2001	2002	2003	2004
25 May	30 May	3 June	11 June	27 May
20 June	25 June	23 July	28 July	1 July
13 July	16 August	1 October	5 September	12 August
17 August				

Table 3. Yields of three switchgrass cultivars under clipping at Rock Springs, Pennsylvania.

Cultivar	Two Cut	Three Cut
	-------- kg DM ha^{-1} ---------	
Cave-in-Rock	6200	7100
Shawnee	6000	7200
Trailblazer	5900	6900
Mean	6000[a]	7100[b]
SE†	110**	
Year		
2000	6100[a]	7600[b]
2001	5900[a]	6500[b]
SE‡	156*	

* and ** = significant at P < 0.05 and 0.01, respectively.
† Standard error for comparing cutting treatment means.
‡ Standard error for comparing cutting treatment means within years.

Table 4. Nutritive value of three switchgrass cultivars under clipping at Rock Springs, Pennsylvania.

	Crude Protein		Neutral Detergent Fiber		Digestible NDF	
Cultivar	**2000**	**2001**	**2000**	**2001**	**2000**	**2001**
	----------	----------	---------- g kg^{-1} DM	----------	----------	----------
Cave-in-Rock	129	112[a]	598[a]	664[a]	654[ab]	597[a]
Shawnee	131	114[a]	594[a]	657[a]	649[a]	606[a]
Trailblazer	126	98[b]	615[b]	687[b]	662[b]	564[b]
SE[†]	1.7**		4.9ns		8.6**	
Cutting Treatment						
3-cut	117[a]	103[a]	592[a]	651[a]	644[a]	593[a]
2-cut	140[b]	113[b]	613[b]	688[b]	665[b]	584[a]
SE[‡]	1.4**		4.2*		7.0**	

* and ** = significant at P < 0.05 and 0.01, respectively.

[†] Standard error for comparing cultivar means within years. Cultivar means within years with different superscripts differ at P < 0.05.

[‡] Standard error for comparing cutting treatment means within years. Cutting treatment means within years with different superscripts differ at P < 0.05.

Table 5. Yields of three switchgrass cultivars under grazing in southeastern Pennsylvania.

Cultivar	**2000**	**2001**	**2002**	**2003**	**2004**
			kg DM ha^{-1}		
Cave-in-Rock	5400	3500	7800	9400[a]	3600
Shawnee	4600	3400	7700	9300[a]	3300
Trailblazer	6400	4000	8300	5900[b]	2800
	5468[b]	3630[c]	7951[a]	8199[a]	3248[c]
SE[†]			367		

* and ** = significant at P < 0.05 and 0.01, respectively.

[†] Standard error for comparing cultivars within years. Cultivar means (2003 only) with different superscripts differ at P < 0.05). Yearly means with different superscripts differ at P < 0.05).

Table 6. Monthly total rainfall at Rock Springs and the farm site in southeast Pennsylvania.

	Rock Springs			Southeast Pennsylvania Farm					
Month	**2000**	**2001**	**30-yr. avg.**	**2000**	**2001**	**2002**	**2003**	**2004**	**30-yr. avg,**
			----------	---------- mm	----------				
March	---	107	79	---	124	101	102	64	88
April	74	62	74	94	46	75	60	122	101
May	62	35	92	108	111	113	102	104	109
June	97	138	102	143	69	83	268	93	107
July	53	59	92	62	20	10	70	243	119
Aug	74	91	81	121	142	66	126	188	98
Sept	48	80	82	142	89	97	318	---	107
Oct	---	---	---	28	18	204	160	---	81

Table 7. Nutritive value of three switchgrass cultivars during three years at a farm in southeast Pennsylvania.

	Crude Protein	NDF	dNDF
Year			
2001	135[a]	683	622[a]
2002	104[b]	689	529[b]
2003	126[a]	694	457[c]
SE†	3.1**	4.1NS	10.4**
Cultivar			
Cave-in-Rock	121	682[a]	542
Shawnee	128	683[a]	543
Trailblazer	116	701[b]	523
SE‡	3.1NS	4.1*	10.4NS

* and ** = significant at P < 0.05 and 0.01, respectively.
† Standard error for comparing years.
‡ Standard error for comparing cultivars.

The Big Bluestem Story

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Big bluestem (*Andropogon gerardii)* is an important warm-season grass native to most of the United States. It is an important grass for livestock grazing, wildlife habitat, restoration projects, and conservation programs. The story of release (cultivar) development, seed production procedures, planting methods, and uses of the species will be explained through the experience and eyes of the Bismarck Plant Materials Program.

The Status of Native Grass Material Held in the USDA Warm-Season Germplasm Collection

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The USDA National Plant Germplasm System warm-season grass collection, which is maintained in Griffin, Georgia, currently has more than 6,000 accessions of which less than 10% of the collection can be classified as native grass material. This native material has been

collected from different areas of the United States by various cooperators dating back to the 1950s. The species maintained include *Andropogon gerardii*, *A. hallii*, *Bouteloua gracilis*, *B. eriopoda*, *B. curtipendula*, *Schizachyrium scoparium*, *Panicum virgatum*, and *Sorghastrum nutans*. The collection of sideoats grama, *Bouteloua curtipendula*, is the largest with 77 accessions followed by little bluestem, *Schizachyrium scoparium*, with 30 accessions. The remaining species are represented by only 20 or fewer accessions each. Accessions of little bluestem include Aldous, Pastura, Blaze, Cimarron, and a Badlands ecotype. The material maintained for little bluestem has been exclusively collected from the United States from states including Kansas, New Mexico, Nebraska, Rhode Island, Texas, and Wyoming. Accessions of sideoats grama include El Reno, Trailway, Butte, Vaughn, Coronado, Tucson, Haskell, Killdeer, Pierre, Uvalde, and Niner. The majority of the sideoats grama accessions were collected from the United States from numerous states including Arizona, Kansas, Nebraska, New Mexico, North and South Dakota, Oklahoma, Texas, and Wyoming but also include material collected in Mexico and two accessions from Argentina. Limited descriptor data are available on the Germplasm Resources Information Network Web site (www.usda-grin.gov) including plant height and width, foliage amount, height and distribution, leaf length and width, stem size, tiller production, maturity, seed production, and winter survival.

As interest in native grass research increases, the need to acquire additional accessions to add to the collection becomes more important as well as to increase the amount and quality of descriptor data available for the material. Future regeneration efforts at our site will focus on increasing the quality of seed harvested and the collection of more detailed and useful descriptor data. Future plant explorations for native grasses, whether done by state, federal, or private entities that result in donations to the system would help to further enhance the value of the collection and assure the preservation of material collected.

Traditional Establishment Recommendations for Native Warm-Season Grasses Seed

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Abstract

Over the past 60 years, the USDA, Natural Resources Conservation Service, USDA, Agricultural Research Service, and State Agricultural Experiment Stations have developed establishment technology to restore ecosystems and produce forage and wildlife habitat. In the eastern United States, poor technology transfer, low levels of utilization of the technology by producers and agency and university employees, and employee turnover have resulted in a low level of awareness of traditional establishment technology. The simplest of establishment principles such as seed stratification, seeding dates to overcome stratification, seeding dates, the importance of firm seedbeds, the necessity of drilling, PLS calculation, drill calibration, seedbed preparation, and weed control have been developed and must be reinforced. The poster will present these principles.

Summary of Recommendations

Site Preparation

Into stands of introduced species: Kill the stand with herbicide while the introduced grass is actively growing (previous summer for warm-season grasses, previous fall for cool-season grasses). Sow seed no-till to avoid exposing dormant weed seeds to optimum germination conditions.

Into row crops: Practice good weed control the previous growing season to control annual weeds. Sow seed with or without tillage.

Seeding Method

Drill into firm seedbed preferred. Pack after the drilling. Broadcast seedings should be packed after sowing. Broadcast seedings are susceptible to drought stress as the slow-germinating seedlings are not in the soil where soil moisture can sustain them through drought.

Seeding Depth

• Small seeds (switchgrass)—¼ inch.
• Medium seeds (bluestems, indiangrass, sideoats grama, deertongue, coastal panicgrass)—½ inch.
• Large seeds (eastern gamagrass)—1 inch.

Seeding Rate

• Sow seed at the standard rates specified in Table 1, or adjust to desired seed densities specified in Table 2.
• Check spacing with data in Table 3. Most rates are set to yield 50 seeds per square feet when drilled.

Pure Live Seed (PLS)

Native seed does not have dependable germination and often cannot be cleaned to pure seed easily. Therefore, native grass and forb seed are specified and sold by the pounds of pure live seed to account for low germination and chaffy seed. Drills must be calibrated so they are sowing enough bulk seed to deliver the specified amount of pure live seed (PLS).

$$\text{Pounds of Bulk Seed} = \frac{\text{Pounds of Pure Live Seed}}{\text{Purity (decimal) x Germination (decimal)}}$$

For example, to sow 10 pounds of pure live seed with 50% purity and 50% germination, you must sow 10/0.5 x 0.5 = 40 pounds of bulk seed.

Seeding Dates

Sow unstratified seed before the date of last frost in the spring with most species (Table 4). Sow unstratified seed of eastern gamagrass before December 1 and stratified seed of eastern gamagrass at normal corn planting time. Sow coastal panicgrass before June 1.
Late seedings: Seed sown after the date of last frost will not germinate at optimum rates the first year and may be susceptible to summer heat and drought. The seed will germinate in the second year after natural stratification during the winter after being seeded.

Weed Control
Perennial introduced grass species: Glyphosate or paraquat before seeding or during the winter. Plateau any time recommended on the label.
Annual species: Mow tops after flowering and before seed production; apply 2,4-D and/or dicamba to kill all broadleaf plants; apply Plateau to kill grass and broadleaf weeds and allow native forbs to survive.

Fertilization
Establishment year: Apply phosphorus and potassium to soil test to produce 100 bushels of corn per acre. Apply nitrogen when a stand is established at 40 to 50 pounds per acre (mid-year).
Maintenance: Apply phosphorus and potassium to soil test to produce 100 bushels of corn per acre. For forage or biofuel, apply nitrogen at 40 to 50 pounds per acre (70 to 80 for eastern gamagrass) as growth begins and 40 to 50 pounds per acre (70 to 80 for eastern gamagrass) in the middle of the growing season. For wildlife or erosion control, apply nitrogen at 20 to 25 pounds per acre as growth begins and 20 to 25 pounds per acre in the middle of the growing season.

Harvesting
Grazing: Remove half the height growth when the grass is 8 to 12 inches tall (leave 4 to 6 inches of stubble).
Hay: Mow when the grass is 24 inches tall and leave a stubble height of 6 inches.

Wildlife Stand Management
Burn every three years. It is best to burn one-third of the area every year on a three-year rotation so there are two other areas with different levels of residue in the stand.

Table 1. Seeding rate (pounds of pure live seed per acre).

Species	Erosion Control/ Forage Production		Wildlife Habitat Development (Calibrate to Rate for 8-Inch Rows)			Example 3-Species Mixture
	Drilled in 8-in. rows	Broadcast	Drilled in 16-in. rows	Drilled in 24-in. rows	Drilled in 32-in. rows	Drilled in 8-in. rows
Eastern gamagrass	8-16 (30" rows)	N/A	N/A	N/A	N/A	
Big bluestem	8-12	12-18	4-6	3-4	2-3	3-4
Indiangrass	8-12	12-18	4-6	3-4	2-3	3-4
Sideoats grama	8-12	12-18	4-6	3-4	2-3	
Deertongue	12-16	18-24	6-8	4-5	3-4	
Little bluestem	8-12	12-18	6-8	4-5	3-4	
Coastal panicgrass	10-15	15-20	5-8	3-5	2-4	
Switchgrass	6-8	10-12	3-4	2-3	1-2	2-3

Table 2. Pounds of seed per acre.

Species	Seeds per Pound	Seeds per Square Foot										
		1	5	10	20	30	40	50	60	70	80	90
Eastern gamagrass	6,000	7	14	73								
Big bluestem	165,000			3	5	8	11	13	16	18	21	24
Indiangrass	175,000			2	5	7	10	12	15	17	20	22
Sideoats grama	191,000			2	5	7	9	11	14	16	18	21
Deertongue	225,000			2	4	6	8	10	12	14	15	17
Little bluestem	260,000			2	3	5	7	8	10	12	13	15
Coastal panicgrass	300,000			1	3	4	6	7	9	10	12	13
Switchgrass	390,000			1	2	3	4	6	7	8	9	10

Table 3. Seeds per square foot.

Row Spacing		Seed Spacing in Inches (Seed per Foot)					
Inches	Feet	0.25(48)	0.50(24)	0.75(16)	1.00(12)	2.00(6)	4.00(3)
8	0.67	71	35	24	17	9	5
16	1.33	36	18	12	9	5	3
24	2.00	24	12	8	6	3	1.5
30	2.50	19	10	7	5	3	1.5
32	2.67	18	9	6	5	3	1.5
36	3.00	16	8	5	4	2	1
40	3.33	14	7	5	4	2	1
48	4.00	12	6	4	3	1.5	0.75

Table 4. Dates of last frost of selected locations (10% of frost after dates).

Date	City	Date	City	Date	City
February 1	Ft Lauderdale, FL	April 15	New York, NY	May 15	Bar Harbor, ME
February 15	Fort Pierce, FL		Philadelphia, PA		Hartford, CT
March 1	Orlando, FL		Virginia Beach, VA		Syracuse, NY
March 15	Brunswick, GA		Beaufort, NC		Williamsport, PA
	Jacksonville, FL		Columbia, SC		Lexington, VA
	Mobile, AL		Augusta, GA		Middlesboro, KY
	Biloxi, MS		Birmingham, AL		Cleveland, OH
April 1	Manteo, NC		Tupelo, MS		Fort Wayne, IN
	Beaufort, SC		Nashville, TN		Rockford, IL
	Savannah, GA		Evansville, IN		Detroit, MI
	Gainesville, FL	May 1	Boston, MA		Madison, WI
	Montgomery, AL		Harrisburg, PA	June 1	Portland, ME
	Jackson, MS		Williamsburg, VA		Hyannis, MA
	Memphis, TN		Raleigh, NC		Nashua, NH
	Cairo, IL		Greenville, SC		Montpelier, VT
			Kingsport, TN		Elmira, NY
			Wheeling, WV		Erie, PA
			Lexington, KY		Buckhannon, WV
			Columbus, OH		Athens, OH
			Indianapolis, IN		Lansing, MI
			East St. Louis, IL		Green Bay, WI

Seed Selection

Cultivars

Cultivars (cultivated varieties) have been developed by federal and state agencies, universities, and nongovernment organizations and tested to provide certain benefits (forage and seed production, pest resistance, persistence under grazing, wildlife habitat) over a proven range of adaptation (usually multi-state or regional). Their range of adaptation is proven by research. They are usually less expensive and more readily available than local ecotypes since growers have a more dependable market.

Local Ecotypes (Source-Identified Material)

Local ecotypes are desirable in restoration seedings on which genetic integrity is important. They usually are not tested beyond their historic range and not tested for any specific characteristics. They are usually more expensive and less readily available than cultivars since growers cannot depend on the market for th

Wednesday, October 6, 2004
PLENARY SESSION

Cajun Prairies and Calcareous Prairies

Charles Allen

Retired Professor of Botany, University of Louisiana at Monroe, and co-founder of the Cajun Prairie Habitat Preservation Society.

Wednesday, October 6, 2004
SESSION IV, SECTION A

Gulf Coast Prairie Restoration in Louisiana

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Coastal prairie once covered 1.1 million ha in southwest Louisiana and 2.8 million ha in Texas. Today, less than 0.1% remains due to intensive agricultural practices and loss to urban sprawl. In Louisiana, less than 100 ha remain primarily as narrow fragmented strips between highways and railroad rights-of-way. In an attempt to restore prairie and document the practical aspects of prairie restoration, 98 ha near Gueydan, Louisiana, have been enrolled in the USDA NRCS Wetlands Reserve Program. In 2002, 45 ha were restored to pre-cultivation hydrology by removing levees, and pimple mounds were constructed to mimic historic topographic features. The restoration plan includes large-scale demonstrations comparing spring and fall planting (April and October 2003) at 3.4, 6.7, and 11.2 pls kg ha^{-1} using a prairie seed mixture consisting primarily of little bluestem [*Schizachyrium scoparium* (Michx.) Nash]. The following species were interseeded into the spring and fall planted areas: switchgrass (*Panicum virgatum*), Florida paspalum (*Paspalum floridanum*), Kansas gay feather (*Liatris pycnostachya*), yellow wild indigo (*Baptisia bracteata*), black-eyed susan (*Rudbeckia hirta*), bur marigold (*Bidens aristosa*), plains coreopsis (*Coreopsis tinctoria*), partridge pea (*Chamaecrista fasciculate*), and wooly rose mallow (*Hibiscus moscheutos*). To increase diversity, 1,500 pieces of prairie sod from a remnant area scheduled for destruction were transplanted on the restoration site by a volunteer group of 275 people on 01 Feb. 2003. This project is a multiple partner and agency effort that will evaluate success, assist in future restoration attempts, and foster the importance of this endangered ecosystem. Demonstration results are pending.

Assessment of Native Warm-Season Grass Establishment in Louisiana

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Native warm-season grasses historically made up a large component of the vegetation across Louisiana. Urban development, overgrazing, and planting of introduced pastures have reduced the distribution of these species to protected areas. However, there is a renewed interest in using native grasses for forage and hay production, critical area plantings, wildlife habitat, and conservation buffers. Additionally, there are some new uses for these species, such as carbon sequestration, prairie restoration, and biofuels.

From 1996 through 2002, the Natural Resources Conservation Service (NRCS) Grazing Land Conservation Initiative (GLCI) has planted 10 sites to native warm-season grasses, using existing cultivars, to demonstrate their use for grazing and hay production. The success of these plantings has been inconsistent. Seedling emergence and establishment were considered successful during the first growing season for five sites; however, on three of these sites, plant density and cover have decreased under grazing or haying pressure. Two sites (planted to switchgrass [*Panicum virgatum*]), under heavy competition from johnsongrass (*Sorghum halepense*), took three years to establish. Seedling emergence and establishment were not successful at two sites, and a success determination at the final site is still pending after seeding during the spring of last year.

Observations on these sites have shown that establishing and maintaining stands of eastern gamagrass (*Tripsacum dactyloides*), switchgrass, and indiangrass (*Sorghastrum nutans*) is difficult. Additionally, there has been no seedling emergence observed from plantings of little bluestem (*Schizachyrium scoparium*) and big bluestem (*Andropogon gerardii*). Probable causes for these results include poor seedbed preparation, lack of proper weed control following planting, and adaptability of cultivars to existing environmental conditions. As a result, it was determined that more information on the suitability of available cultivars of native warm-season grasses was needed for Louisiana. In addition, these assessments needed to be conducted under similar conditions to minimize the variability associated with cultural practices affecting seedling emergence and establishment.

To address these concerns, GLCI and the Golden Meadows Plant Material Center are partnering to develop a statewide assessment of the adaptability of existing, commercially available cultivars for eastern gamagrass, indiangrass, switchgrass, little bluestem, and big bluestem. These assessments will identify existing cultivars that can be used within Louisiana for grazing and other applications.

In 2003, three plantings were initiated to look at the adaptability of available and potentially adapted cultivars of big bluestem (‘Kaw’ and ‘Earl’), little bluestem (‘Aldous’, ‘Cimarron’, and ‘O.K. Select’), indiangrass (‘Lometa’ and ‘Cheyenne’), switchgrass (‘Alamo’, ‘Blackwell’, and ‘Pangburn’), and eastern gamagrass (Pete, IUKA, and Highlander) across the state. In 2004, seven plantings were also placed on larger acreages across the state.

These plantings will be monitored for production and long-term survival under different management scenarios. The resulting information will be used to da1 wil797m ne the adapustability ofnt erenofnt state of Louisiana is the largest contributing factor to stand failures. Cultivars that are not adapted to the state exhibit signs of summer stress and are less vigorous with lower biomass yields than local ecotypes of the same species. Performance may also be affected by changes in flowering date, seed set, dormancy initiation, and precipitation. Commercially available sources of locally adapted plant materials have the potential to provide substantial ecological and economic benefits for Louisiana. A Memorandum of Understanding (MOU) was signed April 22, 2004, between McNeese State University, U.S. Geological Survey National Wetlands Research Center, Coastal Plain Conservancy, and Natural Resources Conservation Service. This MOU will formalize a partnership to develop a comprehensive plant materials program to collect, increase, and release locally adapted ecotypes of native grasses, forbs, and legumes. The Louisiana Native Plant Initiative will utilize the NRCS Plant Materials Program model for all releases. Native plants currently in production include little bluestem (*Schyzachrium scoparium*), big bluestem (*Andropogon geradii*), indiangrass (*Sorghastrum nutans*), rattlesnake master (*Eryngium yuccifolium*), cluster bushmint (*Hyptis alata*), Texas coneflower (*Rudbeckia texana*), black wand root (*Pterocaulon virgatum*), and wooly rose mallow (*Hibiscus lasiocarpos*).

Development of a Native Plant Program to Restore and Preserve the Cultural Landscape of Stones River National Battlefield

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Stones River National Battlefield has been using native plants in its rehabilitation and preservation efforts since 1994. We first used natives while restoring two Civil War-era earthwork sites. At the beginning of this process, we planted warm-season native grass seed and plant plugs from commercially available sources that were rarely local. Since our first use of natives on the earthworks of Fortress Rosecrans, we have expanded our restoration efforts. We have extended native plantings to other areas across the park, increased species diversity in our planting mixes, established a geographic range from which we will accept plant material, experimented with a variety of establishment and collection techniques, and established monitoring plots to determine the effectiveness of our planting efforts. We also continue to fine-tune our plant establishment techniques at the earthwork sites. We are now using natives to revegetate former house sites, old agricultural fields, and sites where exotic invasive plants have been treated. Our new native mixes include forbs and cool-season native grasses in addition to the warm-season native grasses we began with in 1994. We are trying to restrict our planting to “local” genotype plant material. Fortunately, we are now able to purchase seed and plants from commercial sources in Kentucky and middle Tennessee. We are also becoming increasingly reliant on plant material from noncommercial sources in Rutherford County including Stones River National Battlefield itself. We have collected seed from a state natural area within eight miles of the park and hope to expand our collection activities to other comparable sites within Rutherford County. We make extensive use of hay, collected locally and on-site, that has been cut in late October or early November when native warm-season grasses and many native forbs bear viable seed. Through a contract with the USDA Natural Resource Conservation Service

(NRCS), grass and forb plugs are being grown from propagules collected from a high-quality xeric limestone prairie within the park. This spring we planted the first plugs produced through this contract in increase fields on the park. Data collected through monitoring aid us in fine-tuning our techniques and determining the effectiveness of our eradication and planting efforts. We monitor the earthworks using a protocol and permanent plots established in collaboration with The Nature Conservancy and a private contractor. We also monitor sites where we have treated exotics and planted natives. We have experimented with plant establishment methods to deal with the unique and challenging conditions presented by the earthworks. With steep slopes and highly compacted nutrient-poor soil, establishment of almost any kind of desirable vegetation can be very problematic. To increase the probability of successful plant establishment, we built a low-tech seeder that can be used on the steep slopes of the earthworks, and we are also experimenting with turf composed of native warm- and cool-season grasses. Through these concerted efforts, we have greatly increased our ability to manage park land in a sustainable manner. We have learned much since 1994 and have had a good deal of help along the way. We have relied on the knowledge and assistance of local, state, and national organizations and agencies; nonprofit groups; Middle Tennessee State University; local businesses; and hundreds of volunteers. Through these partnerships and the contributions of an inventive and energetic resources staff, Stones River National Battlefield has made great progress in its efforts to rehabilitate, restore, and preserve one of this country's significant cultural resources.

Wednesday, October 6, 2004
SESSION IV, SECTION B

Management and Composition of Conservation Lands in the Northeastern United States

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Abstract

Conservation grasslands reduce soil loss, improve water quality, are important wildlife habitat, and have the potential to be a source of biomass for biofuel production. Most currently established conservation grasslands in the northeastern United States are on land with marginal crop production potential. Little is known about the plant composition or amount of biomass produced on these grasslands. To assemble a database for the resource assessment of warm-season grasslands in the northeastern United States, we determined plant species composition at multiple scales using the modified Whittaker plot technique, measured various soil properties, and quantified biomass yield on CRP, WHIP, mine reclamation, and other grasslands. A total of 34 sites were sampled in New York, Pennsylvania, New Jersey, Maryland, and Virginia during late August through mid-October in 2002 and 2003. We identified more than 280 different plant species across the study region. Total plant species richness ranged from 12 to 60 species with an average of about 34 per 0.1ha. Perennial forbs were the most diverse functional group, but perennial grasses had about five times more cover than perennial forbs. The top five native plant species accounted for more than 65% of the cover, whereas the top five nonnative species

accounted for only about 12%. Nonnative species richness and cover decreased with native cover. However, as native species richness increased, so did nonnative species richness. Aboveground biomass decreased with species richness but increased with the percentage cover of switchgrass, big bluestem, and indiangrass. Aboveground biomass averaged 6.6 Mg per ha across sites and years. To predict potential biomass yield on conservation grasslands, corn yield based on site soil series in the NRCS soil survey may be able to be used.

Introduction

Conservation grasslands reduce soil loss, improve water quality, are important wildlife habitat, and have the potential to be a source of biomass for biofuel production. Most currently established grasslands in the northeastern United States are on land with marginal crop production potential. Land in the Conservation Reserve Program (CRP) has been suggested as a potential readily available resource for biomass feedstock production in the United States (National Research Council 2000; De La Torre Ugarte et al. 2003). The goal of the CRP is to remove land from crop production and plant long-term resource-conserving vegetation cover to prevent soil erosion, improve water quality, and enhance wildlife habitat. Assessing the quality of the feedstock and developing management systems consistent with maintaining the environmental benefits of the CRP are key considerations in its potential use for bioenergy.

De La Torre Ugarte et al. (2003) identified 6.8 million of the 12.1 million ha of CRP land (1998 data) as potentially available for biomass feedstock production. In 2003, there were 14 million ha of CRP land concentrated mainly in the central plains and midwestern United States (USDA-Farm Service Agency 2004). Of the total CRP area, 1.4 million ha were planted to CP-1 mixtures (introduced grasses), 2.6 million ha were planted to CP-2 mixtures (native grasses), and 6.2 million ha were classified as CP-10 (established grass). The remaining 3.8 million ha were in trees, wildlife habitat, or other conservation practices.

Maintaining the environmental benefits of the CRP is a concern when considering its potential for bioenergy production. This would include maintaining a perennial vegetative cover to prevent soil erosion and judiciously using fertilizers to obtain economic yields and not compromise water quality. Other management considerations for the use of CRP lands for biofuels in the future would include harvest management consistent with maintaining wildlife habitat. In 2003, a new interim rule was adopted that allowed managed haying or grazing on CRP land one out of every three years after the cover is fully established. Managed haying or grazing is not allowed during the primary bird nesting or brood rearing season. In addition, a payment reduction of 25% is assessed for the acreage harvested (Federal Register 2003).

Little is known about the plant composition or amount of biomass produced on CRP grasslands. The objective of this study was to assemble a database for the resource assessment of warm-season conservation grasslands in the northeastern United States, describing the plant composition and quantity of aboveground biomass.

Materials and Methods

This resource assessment included CRP (Conservation Reserve Program), CREP (Conservation Reserve Enhancement Program), WHIP (Wildlife Habitat Incentives Program), Partners for Wildlife, National Wildlife Refuges, State Parks, Wildlife Management Areas, Pennsylvania State Game Lands, mine land reclamation sites, and other grasslands in the northeast region of the United States. At each location, plant species cover, richness, and pattern diversity were quantified over a range of spatial scales (1, 10, 100, and 1000 m^2) using the modified Whittaker plot technique (Stohlgren et al. 1995) as described by Stohlgren et al. (1998). Aboveground biomass and soil samples, management history, initial species seeded, and landscape details were obtained from each location along with weather data. Ten 1 m^2 areas, at the four corners and adjacent to the 6-1 m^2 plots, surrounding the outside of each Whittaker plot were harvested to determine the amount of standing biomass. Thirty-four sites were sampled in New York, Pennsylvania, New Jersey, Maryland, and Virginia during late August through mid-October in 2002 and 2003 when plants are fully mature at late seed set and beyond, but before a frost. For soil analysis, 10 soil cores were taken near the 10-1 m^2 plots and the four corners of the 1000 m^2 plot, composited, and then analyzed for C, N, P, K, cation exchange capacity, organic matter, and texture using standard methods by the Agricultural Analytical Services Laboratory, Pennsylvania State University. Locations for Whittaker plots were chosen to represent the major physiographic regions where conservation lands with warm-season grasses were located in each state. Plant species scientific name, functional group, and U.S. nativity were as defined on the National PLANTS Database (USDA-NRCS 2004). Pearson correlation coefficients (r) were calculated between native and nonnative cover and richness and aboveground biomass using the PROC CORR procedure in SAS (SAS Institute 1999).

Results and Discussion

Plant Species Composition

Plant species richness varied over a range of spatial scales (Figure 1). Native plant species richness averaged 18.4, and nonnative plant species richness averaged 13.2 in 1000 m^2 plots. The total number of plant species in 1000 m^2 plots ranged from 12 to 60 species with an average of 34.4 ± 1.6 and a total of more than 280 species at the 34 sites sampled. These values of species richness were similar to those found in the central U.S. grasslands (Stohlgren et al. 1998) and pastures in the northeastern U.S. (Tracy and Sanderson 2000). Perennial forbs were the most diverse functional group (Figure 2a), whereas perennial grasses were the most dominant functional group (Figure 2b) with about five times more cover than perennial forbs. As determined by the percent mean importance value (the product of the mean relative frequency and the mean percent cover), the top five native plant species were *Panicum virgatum* L., *Andropogon gerardii* Vitman, *Sorghastrum nutans* (L.) Nash, *Schizachyrium scoparium* (Michx.) Nash, and *Solidago canadensis* L. (accounting for more than 65%), and nonnative species were *Lespedeza cuneata* (Dum.-Cours.) G. Don, *Poa pratensis* L., *Poa trivialis* L., *Pennisetum glaucum* (L.) R. Br., and *Lotus corniculatus* L. (accounting for about 12%) (Figure 3). These results show that native plants dominated these sites. A survey of CRP lands in Minnesota established according to the NRCS CP-2 recommendations (use of native grasses and no herbicides) revealed that switchgrass was planted in 100% of the CP-2 fields (Jewett et al. 1996). Switchgrass persisted on 94% of the fields planted and generally exceeded 50% ground cover on all sites after six to eight years.

There has been interest in describing the relationship between native and nonnative plants species across a range of ecosystems to assess the current state of invasion by nonnative plants and describe potential mechanisms to prevent further invasion. In this study, as native plant species cover increased, nonnative species richness (Figure 4a) and cover (Figure 4b) decreased. This observation is consistent with the finding that native plant biodiversity can act as a barrier to invasion by nonnative plants (Kennedy et al. 2002). However, as native plant species richness increased, so did nonnative plant species richness (Figure 4c). This has been observed in other natural landscapes (Stohlgren et al. 1998; Levine 2000) and has been suggested as evidence against the ability of native plants to act as a barrier to nonnative plant invasion and that native and nonnative plant species respond similarly to environmental conditions (Stohlgren et al. 2003; Huston 2004). The stochastic niche theory (Tilman 2004), proposes that as spatial scale increases, species pools are large enough to fully exploit areas with low spatial heterogeneity but not areas with the greatest spatial heterogeneity. These areas of high spatial heterogeneity, which are least fully exploited, are most susceptible to invasion.

Aboveground Biomass

Aboveground biomass has been shown to increase with plant biodiversity in grassland ecosystems (Tilman et al. 2001). In this study, aboveground biomass was significantly negatively correlated with species richness (r = -0.51, P < 0.001; Figure 5), decreasing as plant species richness increased. Aboveground biomass seemed to be more related to specific species present than to the species richness. When plant species were divided into nonnative and native, aboveground biomass did not increase with the percent cover of nonnative species (r = -0.07, P < 0.657), although it did increase with native species cover (r = 0.33, P < 0.037). To determine which plant species accounted for the increase in aboveground biomass with cover, the three most dominant plant species across the 34 sites were selected from the mean importance values (*Panicum virgatum*, *Andropogon gerardii*, *Sorghastrum nutans*). When the percent cover of these three tall warm-season grasses were summed and then graphed with site biomass, aboveground biomass increased with cover (r = 0.61, P < 0.0001), indicating that the increase in presence of these grasses lead to the increase in site biomass (Figure 6) rather than species biodiversity in general. Dominant plant species in other grasslands have been important to maintaining high productivity. Ecosystem stability of Inner Mongolia grasslands resulted from compensatory interactions among dominant species with high relative biomass (Tilman 1999; Bai et al. 2004). This study also found that dominant species were important in maintaining high site productivity rather than the large number of transient species.

To determine what other factors contributed to site variability of aboveground biomass, in addition to plant species, soil properties and climate variables were determined for each site. There was not a clear relationship between aboveground biomass and either soil fertility or climate (data not shown). Geographic yield estimates from Walsh et al. (2003) were compared with specific site data from this grassland survey and were also found not to correlate well with the observed data, ranging from under- to over-predictions (data not shown). The best relationship between site aboveground biomass was found with predicted corn yields (r = 0.47, P < 0.004; Figure 7), based on soil series data in the NRCS state soil survey’s with county-level resolution. Predicted corn yields were probably the best correlated with specific site yields because they were the best integrator of several factors contributing to productivity. Corn yield based on site soil series in the NRCS soil survey could be used to estimate the potential biomass yield on conservation grasslands.

Management History

Both establishment and management practices affect the success of warm-season grass (WSG) establishment. Management history was collected from all 34 sites in the survey. Only preliminary results are presented below. The general consensus is that due to herbicide options for weed control, it is easier to establish WSGs into fields with a row crop history, such as corn and soybean, than pasture or CRP land converted from cool-season grasses. In our survey, the mean cover of WSGs was similar between sites planted in row crops and cool-season grasses

(Figure 8a); however, there was more variability in cover on row crop sites, and these were the best sites. Herbicides are a critical tool for establishing WSGs. Plateau is an effective herbicide for control of cool-season grasses but also inhibits switchgrass growth. There was less variability in sites that used Plateau in establishment, but the sites with the greatest cover were those that did not use Plateau during establishment (Figure 8b). These sites may have had more switchgrass.

Grassland management can affect productivity, species diversity, cover and richness, and wildlife habitat value. Litter accumulation was not measured directly, but management practice is expected to affect litter accumulation and was used as a surrogate for litter accumulation. Haying and burning remove litter, whereas areas left unmanaged or mowed will result in litter accumulation. The mean WSG cover was similar between mowed and burned sites, but there was more variability in the burned sites, which also had the highest percentage cover (Figure 8c). Litter production increases with productivity. A dense litter layer mulches the soil surface and intercepts light, thus inhibiting plant growth (Facelli and Pickett 1991). Some plant species are more inhibited by litter than others. The accumulation of litter can lead to oscillations in aboveground biomass productivity (Tilman and Wedin 1991), and these oscillations increase with increased soil N (Bascompte and Rodriguez 2000). High productivity sites on our survey would be expected to have greater oscillations in biomass and species diversity than low productivity sites.

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Figure 1. Species richness over a range of spatial scales from Whittaker plots averaged across all 34 different sites from 2002 and 2003.

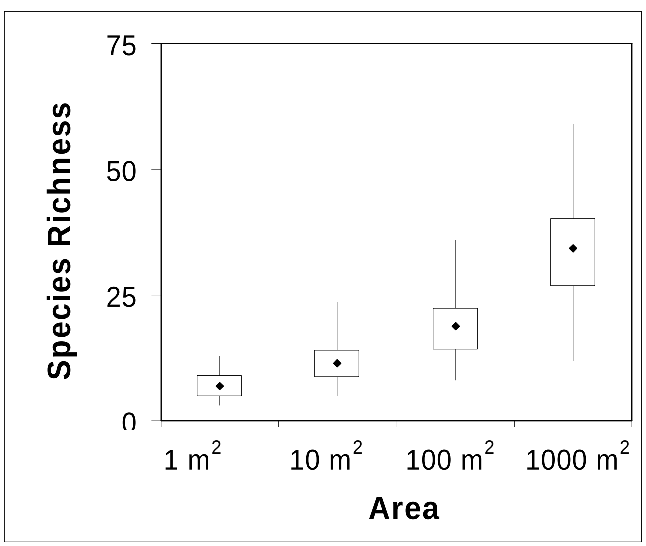


Figure 2. Mean species richness and percent cover of plant functional groups averaged across all 34 different sites in New York, Pennsylvania, New Jersey, Maryland, and Virginia from 2002 and 2003.

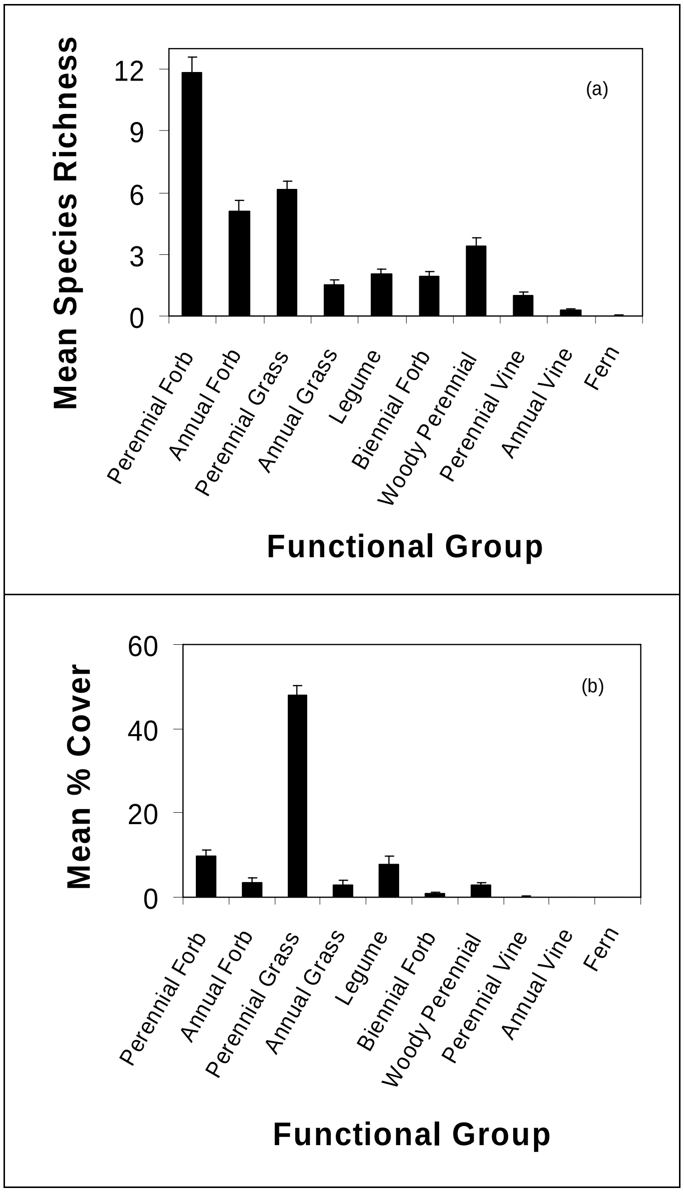


Figure 3. Mean importance value; the product of the mean relative frequency and the mean percent cover. As determined by the % mean importance value, the top five native plant species were *Panicum virgatum, Andropogon gerardii, Sorghastrum nutans, Schizachyrium scoparium*, and *Solidago canadensis* (accounting for more than 65%), and nonnative species were *Lespedeza cuneata, Poa pratensis, Poa trivialis, Pennisetum glaucum*, and *Lotus corniculatus* (accounting for about 12%).

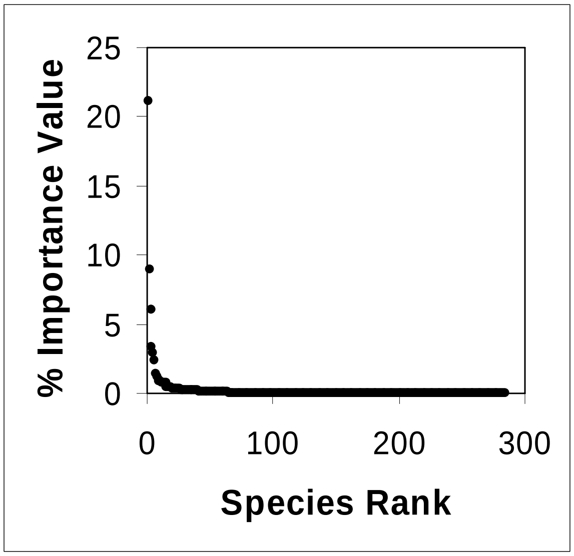
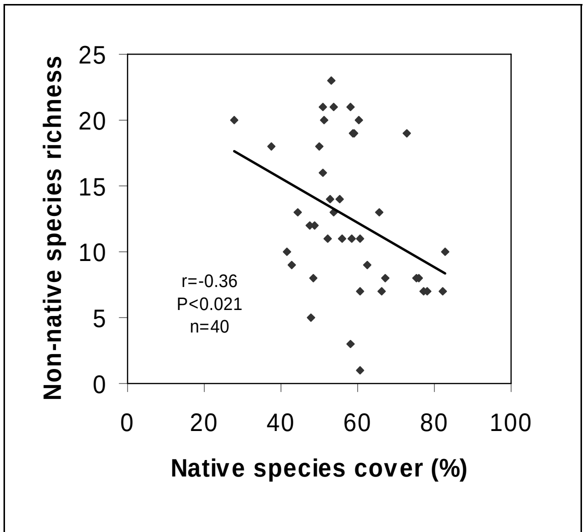
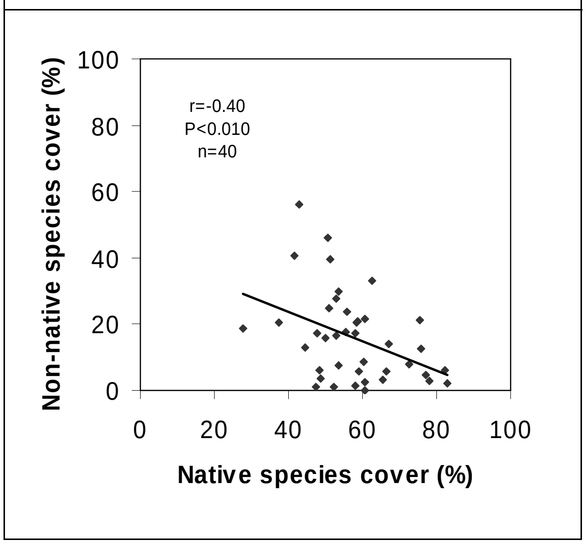


Figure 4. Relationship of richness and cover between native and nonnative plant species in conservation lands from the northeastern United States.





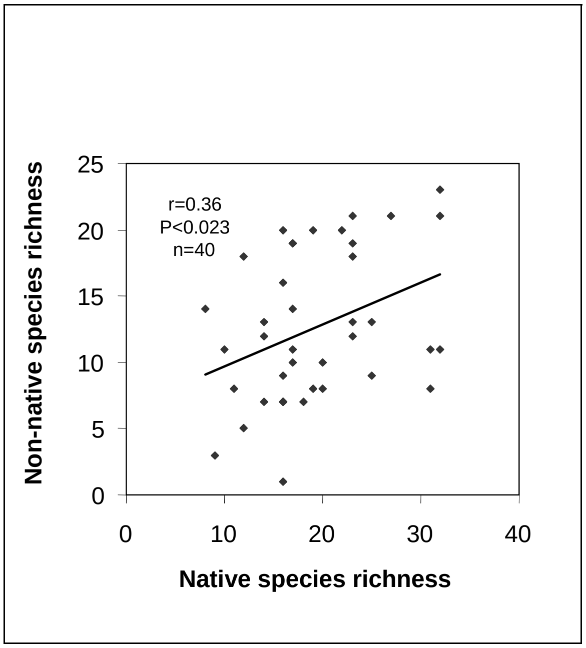

r=0.36
P<0.023
n=40
Non-native species richness
Native species richness
0
5
10
15
20
25
0
10
20
30
40

Figure 5. Relationship of plant species richness and aboveground biomass production in conservation lands from the northeastern United States.

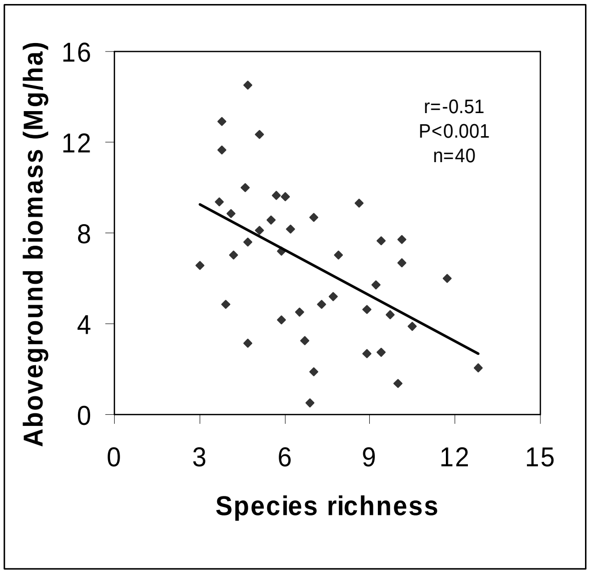


Figure 6. Influence of the percent cover of the three tall warm-season grass species (*Panicum virgatum*, *Andropogon gerardii*, and *Sorghastrum nutans*) on aboveground biomass.

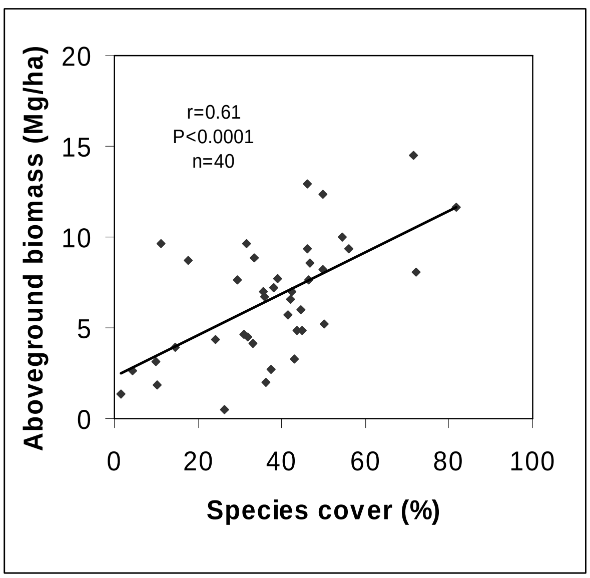


Figure 7. Correlation of site aboveground biomass with predicted corn yield based on NRCS soil survey.

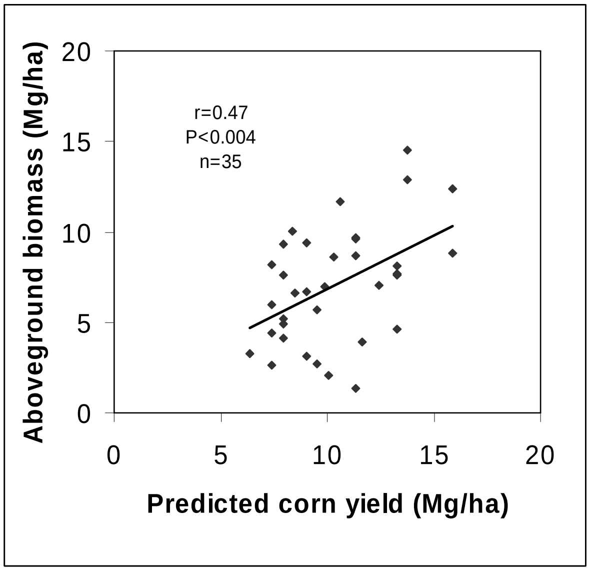
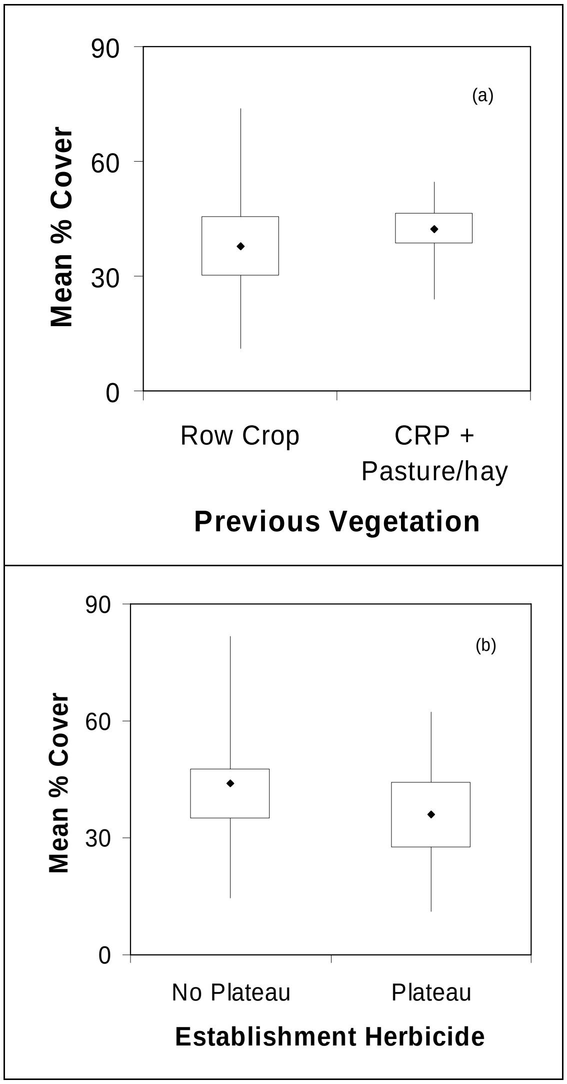
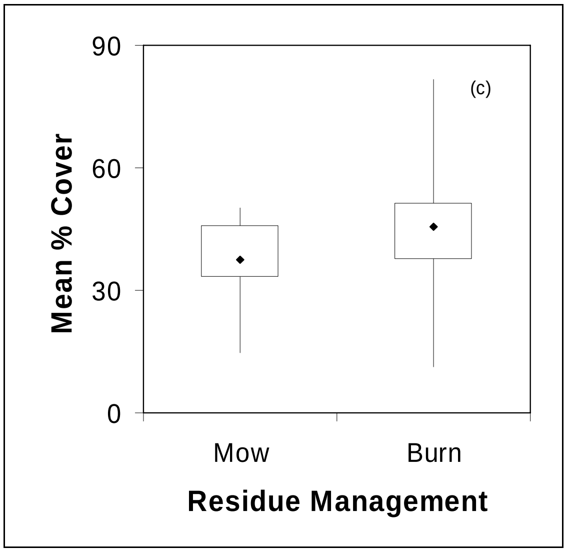


Figure 8. Influence of management practices on percent cover of *Panicum virgatum*, *Andropogon gerardii*, and *Sorghastrum nutans*. Specific management practices were: a) previous vegetation, b) use of Plateau herbicide during establishment, and c) litter management (haying and burning or mowing and unmanaged sites).





Considering Grass-Based Covers for the Winnipeg Floodway Project

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Abstract

The Red River Floodway Expansion Project will enhance the carrying capacity of the channel that protects the City of Winnipeg. Approximately 32 million square meters of freshly exposed subsoils must be vegetated during the five-year reconstruction project. Concerns about flood tolerance and meeting secondary criteria for floodway uses were addressed in a vegetation concept report prepared for KGS Group, the primary engineering consultant for the initial project phase. Grass-based vegetation options were considered for tractive stress tolerance, inundation tolerance, adaptation to expected soil conditions, local climate, management implications, forage production, and potential recreational and aesthetic uses of the floodway. The original floodway was planted to a smooth brome, alfalfa, and red fescue mix that has degraded to red fescue and Kentucky bluegrass over broad areas, while a volunteer mix of herbaceous and woody species now dominates the floodway floor. Native grass species are adapted to the site conditions and offer a long-term cover option with associated benefits to the site. Seed of Manitoba selections is available in the marketplace in sufficient quantities to meet the planting goals of the project.

Introduction

The Manitoba Floodway Expansion Authority will enlarge the channel that carries floodwaters of the Red River of the north around the east side of the Winnipeg metropolitan area. The drainage area of the river basin above Winnipeg lies south and west of the city, extending into Minnesota, North and South Dakota, and Saskatchewan. The Red River flows to Lake

Winnipeg, north of the city. The existing floodway was constructed in the late 1960s. Experience since then has created concern that the floodwater capacity is insufficient.

The floodway is earthen, with surface protection and stability provided by vegetation. The floodway can be expected to carry spring floodwater during two of three years and summer floodwater one year in two (although recent records seem to show an increasing frequency of summer flooding).

The existing 46-km-long floodway was built to carry spring floodwaters. In recent years, summer floods have become common, and the floodway use has been extended to handle that water. Summer flooding adds very significant stress on the floodway vegetation. The tolerance of upland vegetation to inundation is markedly lower during the growing season than it is during the dormant season. Most of the time, however, the floodway is dry. Due to the dry and sometimes droughty conditions that prevail on the channel side slopes and spoil piles of the floodway, upland grass cover is the vegetation of choice to protect the structure. Wet meadow vegetation is prevalent on the channel floor, and this will be enhanced by adding suitable species.

Floodway reconstruction will enlarge the channel width to improve the capacity of the system. The construction task is currently projected to take five years to complete, and excavation work will be done in four annual increments beginning in 2005. Earth moving activities will commence after spring runoff has occurred and will likely continue into December of each year. The current estimate of the exposed soil surface area is 32,476,000 sq m for the entire project.

Challenges to Vegetation Success

Planning vegetative treatment for the floodway poses challenges with an interesting dichotomy. With the exception of the floodway floor, the vegetation will be exposed to periodic drought. During most growing seasons, there will be a deficit between the available soil moisture and evapo-transpiration. To be effective, vegetation has to not only survive the dry periods but also must prosper and produce sufficient ground cover to provide soil protection for the flood events that are likely to follow. Then the vegetation needs to survive the flood event and inundation in sufficient condition to self repair as necessary.

There are a host of challenges to establishing and maintaining effective vegetation on the reconstructed floodway. A few key challenges are discussed here: soil (natural and created limitations), climate, and hydrology.

Soil Limitations

The soil resource along the excavated floodway consists of two primary textural types. Both are subsoil dominated but markedly different in texture. A transition zone integrates them. Most of the floodway length is dominated by heavy blue clay (montmorillonite). The blue clay is very cohesive, with high bulk density. Near Birds Hill the soil condition becomes gravelly/sandy with poor soil moisture retention and much lower soil cohesiveness. However, the gravel derives from a dense glacial till that will be freshly exposed. North of Birds Hill the subsoil transitions to brown clay, then to some rock outcropping near the outflow structure. Subsoil bulk density will be a problem along the newly exposed floodway floor and sides. Natural density will be increased by heavy equipment operation.

None of the newly exposed subsoils will have the naturally occurring surface layer organisms that enhance plant growth. Arbuscular mycorrhizal fungi associate with plant roots and greatly aid the plants in absorbing water and nutrients from the soil. These fungi are associated with the roots of grasses and most of the rest of the world's flora. Mycorrhizae produce a substance called glomalin which is now known to be the primary "glue" used to form soil aggregates. Soil aggregation is important to turning exposed subsoils into a medium that will support a healthy, effective plant cover. Thus, the presence of mycorrhizal associations on plant roots has implications for water quality, plant biomass production, species diversity, carbon sequestration, maintenance costs, and the development of soil surface aggregation and quality (Wright et al. and Wright and Anderson, both 1999). Mycorrhizal fungi must either be imported with topsoil, be added artificially, or arrive by fungal spores over extended time (Habte and Osorio 2001).

Climate and Precipitation

The Winnipeg area of southern Manitoba has a growing season that lasts about 110 days. The frost-free season mostly consists of June, July, and August, although frost can occur in June and August. About 380 mm (15 in.) of precipitation is expected during the growing season, mostly in thundershower events.

Hydrology

Velocities at the soil-plant-water interface on straight sections are anticipated to be in the range of 3.5 to 4.0 fps (KGS 2004). This equates to a tractive shear of about 0.25 lb/sq ft. This stress will exceed the tolerance (about 0.20 lb/sq ft) of newly planted herbaceous vegetation and will likely cause some damage where that condition exists as floods occur during construction. Established grass cover can have a tolerance range of 0.35 to over 2.0 depending on species makeup, quality of the stand, and soil factors (Chen and Cotton 1988). Established native grasses have high tolerance to shear stress (Temple et al. 1987).

Flood depth and flood duration are the greatest threats to plant survival. When upland plants are completely submerged, they are no longer able to move oxygen into the root zone, and anaerobic conditions develop. Anaerobic conditions become toxic as ethylene and other substances build up in the saturated soil. While plants vary in their ability to deal with these stresses, none except aquatic species can tolerate total inundation for extended periods. This is particularly true while plants are actively growing; thus, flood timing is critical. Dormant plants typically have greater flood tolerance than do growing plants. The age of the plant stand affects inundation tolerance; older plants are usually more tolerant than newly planted material.

The literature concerning flood tolerance of upland and lowland grass species expresses that tolerance in the relative terms of poor, fair, good, and excellent or very tolerant, tolerant, and slightly tolerant (Whitlow and Harris 1979). A few bold authors have stated limit ranges in number of days, but these are best used in a general sense rather than as gospel. The interactions of biology, soils, and weather with flood timing, depth, and duration in natural systems are simply too complex and generally unreproducible so as to preclude the generation of reliable data sets for any given location. Summarizing the reports from various locations and situations reveals that general break points in grass flood tolerance may exist around 14, 21, 35, 48, and 60 days. Floodway use history for spring runoff since 1970 contains 22 events with the shortest event lasting five days and the longest lasting 53 days (Table 1).

Table 1. Spring flood events, Red River at Winnipeg.

	No. Of Events	Ave. Duration
2 wks+	13	33 days
3 wks+	11	37 days
4 wks+	9	40 days

These data appear to demonstrate that if the spring floodway use lasts longer than a week or two, it is likely to last about five weeks or longer. That scenario fits 13 of the 22 events, or about 60% of the usages. The overall average start date for the 22 spring events was April 12, with the earliest starting March 22 and the latest starting May 6. The frost-free season at Winnipeg is expected to begin around May 26. So, using the average flood start date of April 12, and the likelihood of a 37-day event, most floods will have passed through the floodway before the average "start" of the growing season. However, cool-season grasses will initiate growth in late April-early May in southern Manitoba so they may be doing so while covered in floodwater just about every third year, on average. That is assuming the last 30 years of record is a reasonable predictor of the future, of course. Warm-season grasses do not initiate growth until late May and should "miss" most of the spring floods. Based on this analysis, it is likely that the 13 spring events that lasted more than two weeks caused significant damage to the bromegrass originally seeded on the floodway. Unfortunately, we have found no vegetation surveys that relate flooding events to stand damage on the floodway.

Summer flood data shows that of the 15 events since floodway construction, seven lasted two weeks or less, one lasted two to three weeks, and the rest were three to seven weeks. By definition, all summer floods occur during the active growing season of all potentially useful perennial upland grass species. The longer summer floods are likely to kill or severely hurt growing grass stands composed of upland species. Wet meadow species are generally more tolerant.

Comparison of Two Vegetative Approaches

In this discussion, we will compare the original species mixture to the native grass option.

Existing Floodway-Brome and Alfalfa

The existing floodway was planted to an introduced forage species mixture of smooth bromegrass (*Bromus inermis* Leyss.) and alfalfa (*Medicago sativa* L.). Minor species included in the mix were Russian wild rye (*Psathyrostachys juncea* (Fisch.)Nevski), creeping red fescue (*Festuca rubra* L.), sweet clover (*Melilotus officinalis* L.), and red clover (*Trifolium pretense* L.) These are all introduced forage species common to the Winnipeg area. This mixture provided farmers with a hay crop, and the rhizomatous growth of smooth bromegrass would have been attractive from an engineering and hydraulic perspective.

The management of the brome-alfalfa mix varied with the leaseholders and over time. By 2003, at least one farmer was irrigating hay nearby, possibly including on the floodway right-of way (ROW). Several farmers have been interviewed regarding current management practices. To maintain productivity, they have periodically plowed and reseeded with alfalfa, smooth bromegrass, and timothy (*Phleum pretense* L.) except for a dairy farmer who seeds solid stands of alfalfa. This is because the smooth bromegrass "peters out." Fertility practices differ, but each farmer interviewed applies some nitrogen, phosphorus, and potassium. Some apply a small amount of sulphur as well. Hay yields are reported in the 1.5 to 2.5 tons per acre range.

SMOOTH BROMEGRASS TRAITS

Smooth bromegrass is a perennial, rhizomatous, introduced grass from Eurasia. It has a relatively deep (for cool-season grass) root system that is aggressive and extensive in the soil surface layer, although this does vary with soil quality factors. Smooth brome is best adapted on deep, fertile, well-drained silt loams and clay loams. It is not very well adapted to persistent flooding (Table 2), wet soil conditions, or droughty sites. This grass requires annual fertility inputs to remain economically productive on agricultural soils. Common recommendations for brome-alfalfa mixtures call for 50 to 60 lb/ac each of P_2O_5 and K_2O. Nitrogen recommendations vary depending on the relative presence of alfalfa in the stand. Where alfalfa has declined, the nitrogen recommendation is commonly in the 50 to 100 lb/ac range. On degraded soils such as the floodway, even higher applications are likely necessary to maintain bromegrass on the site in sufficient plant density.

Once established on productive soils with suitable management, smooth brome spreads aggressively with rhizomes to dominate grass stands and minimize species diversity. Thus, in the case of smooth brome, stand diversity is an indicator of poor adaptation of brome to the site.

Utilizing the C3 photosynthetic pathway, smooth brome produces most of its annual biomass in the spring growth period, with a secondary growth period in late summer/early fall when moisture may be available and temperatures decline. Stand productivity and persistence of smooth brome on marginal soils is highly dependent on recurring and significant fertilizer inputs and supplemental moisture during drought.

Smooth brome tends to hold forage value longer into maturity than other introduced species such as reed canarygrass (*Phalaris arundinacea* L.), which is better adapted to flooding, or sheep fescue (*Festuca ovina* L.), which has deeper roots but lower forage value. Timely cuttings of smooth brome are high in protein and digestible dry matter.

ALFALFA TRAITS

Alfalfa is often referred to as the queen of forages due to its very high quality and yields when grown on class one and two soils. However, this species is short-lived, has many pests, and tends to decline over four to six years even under quality management for hay crops. Therefore, it is a poor choice for permanent cover on highly disturbed soils. Alfalfa is a legume with deep taproots (where soil conditions allow) capable of growing 5 to 10 ft deep to give the plants good drought tolerance. The taproots are thick but relatively few in number, adding little to soil stability. Alfalfa prefers well-drained soil and is poorly adapted to wet soils or soils with poor internal drainage. Alfalfa only tolerates brief flooding (Table 2) and can even be killed by extended periods of ice cover in the winter and spring while it is still dormant.

BROME-ALFALFA MIXTURES

Brome-alfalfa mixtures tend to become essentially solid bromegrass stands within four to six years after planting on agricultural soils. The alfalfa declines to scattered plants, and the bromegrass rhizomes generate new grass where the alfalfa had been. On sites with low natural fertility and poor moisture-holding capacity and on sites that do not receive regular and significant fertilizer inputs, the bromegrass cannot maintain quality stands and thins over time. Weeds and other grasses invade the stand.

Smooth bromegrass and alfalfa are not rated highly by the authors as choices for the reconstructed floodway. The current assessment of the existing floodway reveals that the alfalfa is essentially reduced to remnant stands except where it has been replanted and that bromegrass has become a minor species over large sections of the structure.

The Native Species Alternative

The climax vegetation in the Winnipeg area is tallgrass prairie. Through drought and other weather vagaries, the prairie has endured while supporting a rich and extremely prolific wildlife component. There is increasing evidence that the prairie was and is a very efficient storage sink for carbon.

Tallgrass prairie as found in southern Manitoba is a mixture of native cool- and warm-season grasses with associated broadleaved forbs. The warm-season species evolved with sporadically intensive grazing and fire and have genetic strategies that give them a competitive edge as long-term cover in a region where drought is expected and can be prolonged. Prairie species tend to be deeper rooted than their European counterparts that evolved under cooler, moist summer conditions. The warm-season grasses regrow much faster after summer harvest than do the cool-season grasses. The resulting structure supports a diverse wildlife.

Native grasses inhabit all the moisture regimes found in the prairie from lowland wetlands to dry uplands (Table 2). Species can be selected to fit these regimes when prairie vegetation is to be reestablished. Wet sites commonly contain other plant groups such as sedges and rushes in combination with the grasses and forbs. Several performance parameters are positively met by native grasses.

Carbon Sequestration

Global interest in warming trends and greenhouse gasses has spurred research in the relative impacts that vegetation types have on carbon sequestration. The estimates of carbon storage vary from report to report, but general trends are emerging. An example is a recent Iowa study that investigated the role of upland cover types comparing agricultural practices and crops with successional communities established if cropping ceased (Robertson, Paul, and Harwood 2000). The comparisons were made in CO_2 equivalents (g/sq.m/yr). In this study, early successional vegetation (herbaceous, grasses, and weeds) had the best net global warming mitigation potential with 211 g/sq.m/yr of CO_2 equivalents moved to storage. Next best were hybrid poplar plantations at 105 g/sq.m/yr. Alfalfa was rated at 20 g/sq.m/yr, or less than 10% of the value of successional vegetation. Annual cropping systems ranged from a loss of 14 for no-till systems to 114 g/sq.m/yr for conventional tillage.

A conference at Oak Hammock Conservation Center in Manitoba (Wylynko 1999) considered the ability of wetlands to store carbon. The proceedings referred to an earlier meeting in Downsview, Ontario (January 1999), at which carbon flux experts confirmed that wetlands are the largest terrestrial carbon reservoir in Canada. While Canadian wetlands cover only 14% of the land area, they are estimated as containing 60% of the carbon stock. The floor of the floodway is currently dominated by wet meadow vegetation, and this should be retained and enhanced.

Roots

The native warm-season prairie grasses have, as a group, very deep and extensive fibrous roots. Weaver studied root growth patterns of prairie plants in Nebraska and documented their ability to grow to extraordinary depths on loess soils. Recent work by Collison and Simon in Mississippi has added to our appreciation of the root strength of prairie grasses and their impressive capability in soil stabilization and reinforcement. The USDA-Natural Resources Conservation Service Plant Materials Program has cooperated with the Agricultural Research Service (Skinner et al. 2001) to document the ability of native grass species to generate aerenchyma root tissue. Aerenchyma tissue allows roots to grow into soils with poor oxygen status such as exists in saturated and compacted or heavy (high clay content) soils. Thus, there is reason to expect root penetration over time into dense subsoil material.

Biomass Productivity and Stress

Warm-season grasses are also known as C4 grasses, a designation of their method of photosynthesis. The C4 photosynthetic pathway and the physiology that supports it produces impressive aboveground biomass in a very efficient fashion. Repeated biomass measurements at Natural Resources Conservation Service Plant Materials Centers to the east of the Rocky Mountains have established the superior productivity of the native prairie grasses, especially when environmental stresses occur. The C4 photosynthesis is roughly 35% more efficient in turning nutrients and water (Reinsch 1975) into plant biomass than is the system employed by cool-season (C3) grasses. C4 grasses have become the herbaceous vegetation of choice for stabilizing many critical sites in the eastern states and the prairie-plains region of the continent from Mexico to Manitoba (Miller and Dickerson 1999).

The efficiency of forage production has a second positive aspect. The lower nutrient requirement of native grasses means that less fertilizer is required to maintain the stand; thus, there will be less risk of nutrient loss to Lake Winnipeg.

Forage Production and Quality

The forage produced by native prairie plants is available for harvest in July and August in the Winnipeg area. The warm-season grasses produce their biomass while soil and air temperatures are too warm for efficient production by the C3 cool-season grasses. This presents scheduling opportunities to hay harvesters who can rotate from cutting cool-season grass hay to cutting warm-season grass hay while capturing quality and yield from both types. The native warm-season grasses are harvested at a higher height than are cool-season grasses. The higher harvesting height leaves more residue and vertical structure on the floodway for spring protection yet does not reduce hay yields for the farmer because the plants are more productive when managed in that way.

The forage quality of warm-season grasses has been a subject of debate among researchers for decades. Reid, Jung (1998), and others have investigated the quality of native grasses and concluded that they provide a valuable forage resource. While not the first choice for lactating dairy cows, native grass prairie hay has successfully fed millions of beef breed animals and can be used for feeding nonlactating dairy animals.

Benefits to the Floodway and the Birds

The cell wall structure of native grasses can be appreciated in the spring. The standing dead material from the previous summer has greater strength than that of introduced cool-season grasses. This has three implications for use on the floodway: 1) more snow is trapped so better moisture will be available, and there is less risk of winter injury, 2) there is superior winter cover and spring habitat for ground nesting birds, and 3) the stronger (and taller) stem and leaf structure will resist loss in flood events while providing superior ground surface protection.

Native grasses and associated forbs provide critical habitat for ground nesting birds and many species of mammals, reptiles, amphibians, etc. Since the inception of the USDA Conservation Reserve Program (CRP) in the United States, millions of acres of marginal farmland have been converted to native grasslands with this objective in mind.

Prairie Landscape Aesthetics

The floodway is a highly purposeful but unnatural feature on the landscape. Native prairie grasses are compatible with the prairie wildflowers and legumes that add genetic diversity, wildlife benefits, and sensual interest for human appreciation. Native legumes fix nitrogen that the grasses utilize to maintain vigor and productivity. Most wildflowers and native legumes are eaten by livestock, so they do not present an anti-quality factor in prairie hay.

Table 2. Selected environmental tolerances of representative plant species.

Species	Flood Tolerance/ Drought Tolerance		Preferred Drainage; Water Table (W.t.)	Soil Texture Optimum	Fertility Requirements
Native Grasses					
WESTERN WHEATGRASS Pascopyrum smithii (Rydb.)A.Love	Flood: Drought:	good (50-60d) good	Poorly drained W.T. 0-40 cm	mod. coarse to v. fine	low
AWNED WHEATGRASS (Agropyron subsecundum)	Flood: Drought:	moderate moderate	well drained, W.T. >90 cm	mod. coarse to medium	moderate
SLENDER WHEATGRASS Elymus trachycaulus (Link) Gould ex Shinners	Flood: Drought:	good (50-60d) moderate	deep and well drained, W.T. 15-90 cm	mod. coarse to v. fine	low
THICKSPIKE (NORTHERN) WHEATGRASS Elymus lanceolatus (Scribn.&J.G.Sm.) Gould ssp. lanc.	Flood: Drought:	good excellent	moderately; W.T. >90 cm	mod. coarse to v. fine	low
STREAMBANK WHEATGRASS Elymus lanceolatus (Scribn,&J.G.Sm.) Gould ssp. Lanceolatus	Flood: Drought:	good good	well to poorly drained W.T. 15-90 cm	mod. coarse to mod. fine	moderate
BLUEBUCH WHEATGRASS Pseudoroegneria spicata (Pursh)A.Love ssp. spicata	Flood: Drought:	poor excellent	medium; W.T. >90 cm	mod. coarse to mod. fine	low
NEEDLE AND THREAD (Nassella comata)	Flood: Drought:	poor excellent	moderate to poor; W.T. >90 cm	mod. coarse to mod. fine	low
SANDBERG BLUEGRASS Poa secunda J. Presl	Flood: Drought:	poor fair	well drained; W.T. >90 cm	coarse sands to fine cáliz	low

Table 2. Selected environmental tolerances of representative plant species.

Species	Flood Tolerance/ Drought Tolerance		Preferred Drainage; Water Table (W.t.)	Soil Texture Optimum	Fertility Requirements
JUNEGRASS (Koeleria gracilis)	Flood: Drought:	fair good	well to poorly drained; W.T. 15>90 cm	coarse to mod. Fine	low
GREEN NEEDLEGRASS Nassella viridula (Trin.) Barkworth	Flood: Drought:	fair medium	poorly drained; W.T. >90 cm	medium to mod. fine	moderate
BASIN WILD RYE Leymus cinereus (Scribn. & Merr.) A. Love	Flood: Drought:	poor moderate	well to poor; W.T. 15-90 cm	mod. coarse to mod. fine	low
CANADA WILD RYE Elymus canadensis L.	Flood: Drought:	good good	moist (medium to well drained) to moderately dry areas	coarse to mod. fine	low
BEARDGRASS WILD RYE Lrymus triticoides (Buckl.) Pilger	Flood: Drought:	good moderate	poorly drained; W.T. 0-15 cm	coarse to mod. fine	low
PRAIRIE SANDREED Calamovilfa longifolia (Hook.) Scribn.	Flood: Drought:	poor excellent	well drained; W.T. >90 cm	coarse to medium	low to moderate
SWITCHGRASS Panicum virgatum L.	Flood: Drought:	good fair	well drained to poorly drained; W.T.15 - 90 cm	medium to fine	moderate to high
TICKLEGRASS (Agrostis scabra)	Flood: Drought:	good (60 d) good	well to poorly drained;	medium to mod. fine	low
REED CANARYGRASS Phalaris arundinacea L.	Flood: Drought:	good (60 d) good only on fertile soils	poorly drained; W.T. 0-15 cm	medium to mod. fine	high
SIDEOATS GRAMA Bouteloua curtipendula (Michx.)Torr.	Flood: Drought:	poor good	well to poorly drained. WT > 90 cm	moderately coarse to moderately fine	moderate to low
BLUE GRAMA Bouteloua gracilis (Willd. Ex Kunth) Lag. Ex Griffiths	Flood: Drought:	poor excellent	well to poorly drained. WT > 90 cm	moderately coarse to fine	low
LITTLE BLUESTEM Schizachyrium scoparium (Michx.) Nash	Flood: Drought:	fair to poor good	well drained; W.T. >90 cm	moderately coarse to moderately fine	moderate
BIG BLUESTEM Andropogon gerardii Vitman	Flood: Drought:	moderate moderate to fair	well drained; W.T. >90 cm	moderately coarse to moderately fine	high

Table 2. Selected environmental tolerances of representative plant species.

Species	Flood Tolerance/ Drought Tolerance		Preferred Drainage; Water Table (W.t.)	Soil Texture Optimum	Fertility Requirements
SLOUGHGRASS (Beckmannia syzigachne)	Flood: Drought:	excellent (60 d) requires some spring flooding	poorly drained; W.T. 0-15 cm	medium coarse to mod. fine	non-specific
WHITETOP (Scolochloa festucacea)	Flood: Drought:	good (60 d) requires some spring flooding	poorly drained; W.T. 0-15 cm	medium to mod. fine	non-specific
PRAIRIE CORDGRASS Spartina pectinata Bosc ex Link	Flood: Drought:	excellent (60 d)	well to poorly drained; W.T. 15 - 90 cm	moderately coarse to fine	moderate
INDIAN RICEGRASS Oryzopsis hymenoides (Roemer & J.A. Schultes) Ricker ex Piper	Flood: Drought:	poor excellent	well drained; W.T. >90 cm	coarse to mod. coarse	low
SAND DROPSEED Sporobolus cryptandrus (Torr.) Gray	Flood: Drought:	poor excellent	well drained; W.T. >90 cm	coarse to mod. coarse	low
INDIANGRASS Sorghastrum nutans (L.) Nash	Flood: Drought:	good moderate	medium to well drained; W.T. 15-90 cm	moderately coarse to mod. fine.	moderate
BLUEJOINT REEDGRASS Calamagrostis Canadensis (Michx.) Beauv.	Flood: Drought:	excellent poor	well to poorly drained; W.T. 15-90 cm	moderately coarse to fine	low
NORTHERN REEDGRASS (Calamagrostis inexpansa)	Flood: Drought:	excellent poor	well to poorly drained; W.T. 15-90 cm	moderately coarse to fine	low
Introduced Grasses					
PUBESCENT WHEATGRASS Thinopyrum intermedium (Host) Barkworth & D.R. Dewey	Flood: Drought:	good moderate	well drained; W.T. >90 cm	moderately coarse to mod. fine	medium
INTERMEDIATE WHEATGRASS Thinopyrum intermedium (Host) Barkworth & D.R. Dewey	Flood: Drought:	moderate (21-35 d) poor to mod.	moderate to well W.T. >90 cm	med. to mod. fine	medium to high
TALL WHEATGRASS Thinopyrum ponticum (Podp.) Z.-W.Liu & R.-C. Wang	Flood: Drought:	good (35-50 d) fair	prefers well drained but will grow on poorly drained, W.T. 15-90 cm	med. to mod. fine	low

Table 2. Selected environmental tolerances of representative plant species.

Species	Flood Tolerance/ Drought Tolerance		Preferred Drainage; Water Table (W.t.)	Soil Texture Optimum	Fertility Requirements
CRESTED WHEATGRASS Agropyron cristatum (L.) A. desertorum (Fisch. Ex Link) J.A. Schultes	Flood: Drought:	poor excellent	medium to well W.T. >90 cm	med. to mod. fine	moderate
HARD FESCUE Festuca trachyphylla (Hack.) Trajina	Flood: Drought:	poor moderate	well drained; W.T. > 90 cm	mod. coarse to mod. fine	low to mod.
RUSSIAN WILD RYE Psathrostachys juncea (Fisch.) Nevski)	Flood: Drought:	good (21-35d) excellent	medium to poorly; W.T. 15-90 cm	mod. coarse to mod. fine	moderate
MEADOW FOXTAIL Alopecurus pratensis L.	Flood: Drought:	good (50-63d) poor	poorly drained, W.T. --15 cm	mod. coarse to mod. fine	high
TIMOTHY Phleum pratense L.	Flood: Drought:	good (50-63d) poor	mod. well to poorly drained; W.T. 15-90 cm	mod. coarse to mod. fine	high
ORCHARDGRASS Dactylis glomerata L.	Flood: Drought:	good (20d) moderate	well drained; W.T. 15-90 cm	mod. coarse to mod. fine	high
SMOOTH BROMEGRASS Bromas inermis Leyss.	Flood: Drought:	moderate (24-28d) moderate	moderate-poorly drained; W.T. 15-90 cm	mod. coarse to mod. fine	moderate to high
TALL FESCUE Festuca arundinacea L.	Flood: Drought:	good good	moderate	coarse to fine	moderate
CREEPING RED FESCUE Festuca rubra L.	Flood: Drought:	excellent poor		mod. coarse to fine	moderate
CREEPING FOXTAIL Alopecurus arundinaceus Poir.	Flood: Drought:	excellent fair, poor		mod. coarse to fine	moderate
Legumes					
SWEET CLOVER Melilotus sp.	Flood: Drought:	poor fair	well to poorly drained; W.T. >90 cm	mod. coarse to mod. fine	low
WHITE CLOVER Trifolium repens L.	Flood: Drought:	poor poor	mod. well to poorly; W.T. 15-90 cm	mod. coarse to medium	high
ALSIKE CLOVER Trifolium hydridum L.	Flood: Drought:	good (21d) poor	well to poorly drained; W.T. >90 cm	mod.coarse to mod. fine	high
RED CLOVER Trifolium pretense L.	Flood: Drought:	poor poor	well drained soild, W.T. 15-90 cm	mod. coarse to mod. fine	high
ALFALFA Medicago sativa L.	Flood: Drought:	fair (21d) fair	Deep well drained, W.T. >90 cm	mod. coarse to mod. fine	high

Table 2. Selected environmental tolerances of representative plant species.

Species	Flood Tolerance/ Drought Tolerance		Preferred Drainage; Water Table (W.t.)	Soil Texture Optimum	Fertility Requirements
BIRD'S-FOOT TREFOIL Lotus corniculatus L.	Flood: Drought:	fair	deep well drained, W.T. >90 cm	mod. coarse to mod. fine	high
CICER MILKVETCH Astragalus cicer L.	Flood: Drought:	good fair	well drained W.T. 0-15 cm	coarse to medium	low
PURPLE PRAIRIE CLOVER Dalea purpurea Vent.	Flood: Drought:	fair good	well to poorly drained, W.T. 15 - 90 cm	mod. coarse to mod. fine	low
WHITE PRAIRIE CLOVER Dalea candida Michx. Ex Willd.	Flood: Drought:	fair very good	well to poorly drained, W.T. 15 - 90 cm	mod. coarse to mod. fine	low
CANADA MILKVETCH Astragalus canadensis L.	Flood: Drought:	good fair	well drained, W.T. > 90 cm	mod. coarse to mod. fine	low

Conclusions

The environmental concerns in play as the floodway is rebuilt will be more inclusive than were those during the 1960s. Also expanded are the number of tested native grass species and selections available in the marketplace for use in southern Manitoba. The additional stresses imposed upon the grass cover by the new floodway very notably include increased usage for passing summer floodwaters. Forage production and expanded recreational uses of the floodway must be supported and enhanced by the vegetative cover.

The benefits provided by native grass cover, if utilized, will include improved flood tolerance, better root and aboveground biomass, stand longevity, strong drought tolerance, enhanced carbon sequestration, stand diversity to include native forbs, support for native pollinator activity, reduced fertilizer use, improved wildlife cover, and a shift to a native landscape approach.

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Establishing Native Warm-Season Grasses in Pennsylvania Through the USDA Conservation Reserve Enhancement Program

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Background

The Pennsylvania Conservation Reserve Enhancement Program (PA CREP) began with a meeting between United States Department of Agriculture (USDA)-Farm Service Agency (FSA) representatives from Washington, D.C., state agencies, and nongovernmental organizations (NGOs) in March 1998. The Pennsylvania proposal was approved in April 2000. The original PA CREP covered 20 south-central counties of the Lower Susquehanna River and Potomac River watersheds, major tributaries to the Chesapeake Bay, with an authorization to enroll 100,000 acres.

The two primary objectives of the PA CREP are to improve water quality and wildlife habitat. Due to the steep topography throughout much of the original 20 counties, the state water quality agency (Department of Environmental Protection—DEP) recommended that Highly Erodible cropland (HEL) be eligible for enrollment in addition to buffer areas. Pennsylvania was the twelfth state to have a CREP approved, and the first to include HEL cropland as a basic eligibility component.

Pennsylvania state agencies and NGOs recognized that in addition to buffer practices, large acreages of HEL cropland would have to be put into permanent vegetative cover in order to significantly improve water quality and also wildlife habitat for some species, particularly ground nesting, grassland-dependent wildlife. The Pennsylvania Game Commission (PGC) recommended that one-fourth to one-third of the HEL cropland enrolled and seeded to permanent vegetative cover be established in native warm-season grasses to increase the diversity of grassland habitat. The DEP also recognized that native warm-season grasses would require less application of nutrients both for establishment and maintenance. Less nutrients applied meant less chance for excess nutrients to wind up in surface and ground water.

The original 20-county PA CREP has been so successful that in September 2003 the FSA approved a proposal from Pennsylvania to expand PA CREP to the remainder of the Susquehanna River Watershed counties. With approval for these additional 23 counties came an authorization to enroll another 100,000 acres. Shortly after this expansion proposal was initiated, another proposal was begun to address the Ohio River Watershed in the remaining 16 western

Pennsylvania counties. This separate CREP was approved in April 2004 with an authorization to enroll 65,000 acres. With a combined authorization of 265,000 acres, Pennsylvania now has the largest approved CREP in the country. Although Pennsylvania was the twelfth state approved, the PA CREP is now second largest in acres enrolled (more than 102,000 acres).

The Challenge

Getting proposals approved can be a daunting task, especially proposals that involve a large partnership. But once the proposal is approved or authorized comes the real challenge of making good on the promise!

The CREP program requires a minimum 20% contribution by the state, including NGOs. The USDA's 80% contribution provides 50% cost sharing for establishing conservation practices and annual land rental payments for the 10 to 15 years' contracts required. The two key components of the state contribution are additional cost sharing for establishing conservation practices provided by the DEP and technical assistance provided by the PGC. The PGC has also provided 28 native warm-season grass drills to date.

The CREP program allows for incentives (increases) on the annual land rental payments. In Pennsylvania these incentives range from 75 to 225%. With adequate land rental payments plus essentially 100% cost sharing for establishing conservation practices, the financial obstacles for farmers participating appear to have been addressed. The design for the PA CREP has been so successful that the major obstacle has been providing enough technical assistance for farmers to complete the enrollment process.

Solutions

Technical Assistance

The PGC anticipated that technical assistance may become a limiting factor to enrollment. Also, with a large demand for technical assistance, there would likely be little native warm-season grasses recommended and established. The PGC entered into an agreement with the USDA-Natural Resources Conservation Service (NRCS) to fund nine biologists to assist farmers enrolling in the original 20-county PA CREP. With the expansion of the PA CREP to 59 counties, new NRCS/PGC agreements are currently providing a total of 21 biologists. Adequate technical assistance is the first of the two key resources needed to successfully establish mixtures of native warm-season grasses in a rapidly expanding program that covers a large geographic area.

During the 1980s and 1990s, the PGC established native warm-season grasses primarily on state lands, and the NRCS in Pennsylvania attempted to establish native warm-season grasses with dairy and beef farmers. While the PCG successfully established several thousand acres of native warm-season grasses during these two decades, Pennsylvania livestock farmers following NRCS recommendations resulted in what were perceived as partial to complete failures at establishment. The major difference was that the PGC could afford to wait approximately three to five years for establishment, while livestock farmers could barely afford to wait even two years.

When the PA CREP was approved in 2000, native warm-season grasses were unknown to the majority of Pennsylvania farmers. And most of those who were aware of native warm-season grasses had the impression that their value for forage was questionable and that they were virtually impossible to establish. With severely limited technical assistance, there would be little time to devote to either promoting native warm-season grasses or helping farmers successfully seed them.

The PGC recognized the need to influence technical assistance provided for the PA CREP in order to encourage the establishment of native warm-season grasses. Placing additional planners in NRCS field offices who have a specific interest in improving wildlife habitat, including increasing grassland acreage and diversity, assures that NRCS conservation plans developed for PA CREP contracts include native warm-season grasses. This increased technical assistance is also available for establishing native warm-season grasses through PA CREP, including monitoring and recommending follow-up weed control.

Equipment

The second key resource is the specialized equipment needed to establish mixtures of native warm-season grasses. By the time the PA CREP started in 2000, it was recognized that no-till seeding methods were the most successful way to establish native warm-season grasses. This is primarily due to the ability of these machines to accurately control seed placement, particularly depth and soil contact. Prior to the PA CREP, statewide the PGC, U.S. Fish and Wildlife Service, and NGOs such as Pheasants Forever and Ducks Unlimited had acquired approximately a dozen narrow (5- to 6-foot planting width) fluffy seed, no-till drills. These drills had been used on the majority of the several thousand acres of native warm-season grasses successfully established during the 1980s and 1990s.

Sign-up by farmers began in June 2000. In the spring of 2001, the PGC bought 10 new no-till, native warm-season grass drills. For 2002 the PGC bought another eight drills, and in 2004, 10 more drills were purchased. By the spring of 2004, there were 28 of these drills available across 43 counties, plus some older drills. Although two different brands were purchased, all new drills were of approximate 8-foot planting width and end wheel construction. Frequent transportation from farm to farm by various methods dictated the maximum planting width and end wheel construction. Pheasants Forever also purchased a few 10-foot and 12-foot planting width drills and leased them to farmers for seeding native warm-season grasses.

Monoculture seedings of switchgrass (*Panicum virgatum*) are permitted in the PA CREP, particularly where fluffy seed drills are not available. However, native warm-season grass mixtures are preferred. In order to seed mixtures such as a combination of big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), and indiangrass (*Sorghastrum nutans*), either fluffy seed drills or de-bearded seed must be available. Since it was unlikely that enough de-bearded seed could be acquired to seed several thousand acres per year, the PGC realized the only way to prevent the majority of the acreage from being seeded to monoculture switchgrass would be to provide fluffy seed drills.

Accomplishments

More than 22,600 acres of native warm-season grass seedings are under contract with USDA in the PA CREP as of August 31, 2004. Approximately 80% of this has already been seeded, primarily in the original 20 counties of the Lower Susquehanna River and Potomac River watersheds (only 10% of the native warm-season grass acreage under contract thus far is in the 23 Upper Susquehanna River Watershed counties).

In order to seed more than 15,000 acres on small fields across hundreds of farms in up to 43 counties in just three years, technical assistance and equipment have been combined in a variety of methods. One or two regional one-day technical workshops for NRCS and PGC personnel are held every year. These technical workshops combine formal presentations by NRCS Plant Materials Specialists, interagency coordination on drill distribution and transportation between farms, and equipment demonstrations. Many local NRCS, PGC, and Pheasants Forever teams then hold one-day meetings for farmers who will be seeding native warm-season grasses.

When planting season arrives, there are a variety of ways the drills are managed. Methods range from farmers transporting drills from farm to farm as it becomes their turn to use the drill, to the PGC or Pheasants Forever transporting drre m mrcasse o(pearting theea)4.6equipem.e sparrow (*A. henslowii*), Vesper sparrow (*Pooecetes gramineus*), upland sandpiper *(Bartramia longicauda*), and sedge wren (*Cistothorus platensis*). Projects are distributed throughout New Jersey but are typically within the Delaware River drainage.

Site preparation depends on the requirements or conditions of the cooperating landowner. Planting after corn or other crop fields provides the best opportunity for establishment since little to no site preparation is required, there usually is a history of weed control, and previous crops have absorbed many of the soil nutrients giving a competitive advantage to native warm-season grasses that thrive in low nutrient soils. In sites where landowners resist the use of herbicides, require mechanical site preparation (e.g., mowing, tilling, discing), results are mixed with mechanical-only site preparation, and success appears to depend on frequency of mowing to reduce cool-season grass competition during seedling growth of warm-season grasses. Often these sites need to be mowed three to four times during the establishment year for adequate weed control. Annual weeds and cool-season grasses usually come in very thick in the tilled fields and can outcompete the new warm-season seeding without multiple mowings. Establishment of warm-season grasses at sites with pasture or heavy turf are successful, provided turf grass is initially treated with herbicide (i.e., glyphosate-based product), lightly disced prior to planting, and followed by application of a pre-emergent herbicide (e.g., Plateau). Other factors that affect site preparation include competition with invasive warm-season grasses (e.g., lovegrass [*Eragrostis* spp.]), which respond poorly to traditional site preparation. Adjacent areas also may affect site preparation including proximity to salt marsh areas (introducing saline materials to the soils). Soil viability is also a concern. Despite the ability of warm-season grasses to thrive in nutrient-poor soils, establishment within coastal barrier plain sands is still difficult.

Planting methods include no-till drill seeding and hand-seeding (for smaller sites). Competition with cool-season grasses before, during, and after planting is a primary concern. The weather is also a concern, and implementation success has been impacted as a result of drought conditions, especially on droughty sites with coarse, sandy soils. Seed viability, in particular the germination rate, is also a significant factor affecting not only implementation success, but the distribution rate during planting. Seed storage prior to planting will also affect project success, and a dry, cold storage unit is a preferable storage site. Predation may also affect project success, in particular predation by Canada geese (*Branta canadensis*) (both adults and particularly goslings), which can dramatically affect the success of growing seedlings. Establishment will take time, and most sites are not fully established for at least two to three years. After that time, if positive results have not been achieved, rediscing and replanting a site are an option, and this has produced positive results in at least two projects.

Prescribed fire and mowing are the two primary methods of achieving maintenance of grasslands. Prescribed fire is preferable, and warm-season grasses appear to respond positively to this management method. However, in many parts of New Jersey, prescribed fire is an infrequent option due to proximity to residential and commercial development, air quality concerns, and state regulations. Mowing is the more frequently practiced maintenance method to control cool-season competition and manage colonizing woody vegetation. Large fields can be split to provide rotating mowing regimes and increased vertical diversity to wildlife. In addition, vegetative diversity within established grasslands should be encouraged. A variety of forbs and wildflowers throughout a grassland establishment project support a higher diversity of wildlife including insect pollinators and nontarget wildlife species. However, invasive plants that can affect long-term success should continue to be monitored (e.g., foxtail [*Alopecurus* spp.]).

Native Grass Development Efforts for Coastal Shoreline Stabilization in the Northeast/Mid-Atlantic

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The USDA-NRCS Plant Materials Program in the Northeast is working to develop a number of native grass releases for shoreline stabilization. The two broad ecosystems of interest include coastal shorelines (dunes) and tidal brackish/fresh shorelines.

A major promotional effort is under way to broaden plant diversity associated with dune stabilization efforts. This is especially important since many Army Corps of Engineers-Beach Nourishment Projects are occurring in the mid-Atlantic states. One problem associated with these projects is the dieout of American beachgrass (*Ammophila breveligulata*). American beachgrass is best adapted to the frontal sand dunes where sands are constantly shifting. Once the sand is stabilized, the beachgrass loses vigor and yields to other species, if present. Unfortunately, in our highly developed coastlines, little if any natural succession is taking place. The need exists to develop additional plants and planting technology for dune stabilization. Native grass species that may be planted with American beachgrass on the foredunes include bitter panicgrass (*Panicum amarum*), seaoats (*Uniola paniculata*; New Jersey and south), and American dunegrass (*Leymus mollis*; Massachusetts and north). Some grass species that have application for backdune stabilization include saltmeadow cordgrass (*Spartina patens*) and seacoast bluestem (*Schizachyrium scoparium* var. *littoralis*).

Another ecosystem of concern are tidal shorelines. For instance, in the upper reaches of the Chesapeake Bay, stabilizing eroding shorelines with saltmeadow cordgrass and smooth cordgrass (*Spartina alternifolia*) has been unsuccessful in tidal freshwater areas. These species are best adapted to tidal brackish environments. A need exists to develop grass species adapted to the intertidal zone in freshwater areas. Species being developed include high-tide switchgrass (*Panicum virgatum*), giant cordgrass (*Spartina cynosuroides*), prairie cordgrass (*Spartina pectinata*), and giant cane (*Arundinaria gigantean/tecta*). In addition, a native beachgrass (*Ammophila breveligulata* subspecies *champlain*) identified growing along Lake Champlain in New York/Vermont is being propagated/tested for freshwater dune ecosystems.

The author will present the status of these grass development efforts and the expected outcome and plant products.

Blue Grama for Low Maintenance Roadside Use

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Blue grama is a short-statured, warm-season native grass. It is the dominant species over much of the short grass prairie region of North America from Canada to Mexico and tolerates a range of soil types and environmental conditions. Recent research in Canada and Virginia showed that it has potential as a low-maintenance grass for turf and roadside use (Smith et al. 2002). The objective of this research was to evaluate six blue grama seed sources for roadside use across a range of locations in North America. Locations included Blacksburg, Culpeper, Roanoke, and Petersburg, Virginia; Fort Collins, Colorado; Urbana, Illinois; and Rapid City, Manitoba, Canada. The experiments were established on native, unfertilized soils in a RCBD design at 20 lb PLS/acre in 6 x 10 ft plots. The original source of the following entries spanned over 1,000 miles south to north: Hachita, New Mexico; Alamo, Texas; Kansas Common, Kansas; Birdseye, Wyoming; Bad River, South Dakota; and DUC Ecovar, Manitoba, Canada. Plots were clipped once a year in late winter/early spring to stimulate the initiation of new growth. Measurements included germination, percent ground cover, winter survival, spring green-up, and point-quadrat cover. Percent ground cover provided a good measure of survival, stand vigor, and general adaptation under low-maintenance roadside conditions.

All entries showed rapid germination across locations and good seedling vigor in comparison to other native grass species. Although there was environmental variation, Hachita and Alamo showed a consistent positive establishment response across locations. These two entries ranged from 20 to 30 inches in height at the seedhead stage, approximately twice the height of the other entries. In Illinois and Manitoba, all entries showed good establishment, likely reflecting the rich soils and adequate rainfall at these locations. Hachita and Alamo were the most consistent in maintaining percent cover across locations, with the exception of severe winterkill in Manitoba. Interestingly, even though these two entries were from the arid Southwest, they were well adapted to the harsh soil conditions (low pH, low fertility) and high humidity of Virginia. The northern origin seed sources generally performed well in Manitoba, Colorado, and Illinois but not in Virginia with several exceptions. Bad River showed the best performance of the northern short-statured entries across locations. Kansas Common was the weakest entry across all locations.

In conclusion, blue grama should be considered when a low-maintenance native grass is desired for roadside use. Ideally, the seed source should be obtained from the region in which you are planting unless test results show a wider adaptation. Hachita had the most consistent response and appears to show good adaptation, but winterkill is likely under extreme winter temperatures.

References

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