RESEARCH ARTICLE

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Using Imazapic and Prescribed Fire to Enhance Native Warm-Season Grasslands in Kentucky, USA

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ABSTRACT: Tall fescue (*Festuca arudinacea* Shreb.) is an exotic cool-season grass that aggressively invades native grassland communities in the eastern and central United States, reducing native plant cover and botanical diversity. We conducted two studies in Kentucky to determine the usefulness of post-emergence herbicide applications for eradicating tall fescue and increasing native warm-season grasses. In one study, we applied imazapic (0.21 kg active ingredient ha^{-1}) to three previously planted native warm-season grass stands in April 1998 and evaluated tall fescue and seeded native grass cover in fall 1998. Tall fescue cover was reduced to less than 10% in most treatment plots. Mean native warm-season grass cover increased from 30% to 100% following herbicide application. In a second study, we evaluated prescribed burning and post-emergence imazapic applications (0.07–0.18 kg active ingredient ha^{-1}, with and without non-ionic surfactant) for tall fescue control and increasing native warm-season grasses and native forbs in remnant native barrens plant communities. Prescribed burning in spring followed by a post-emergence application of imazapic at 0.14 or 0.18 kg active ingredient ha^{-1} with or without non-ionic surfactant reduced tall fescue cover to less than 25% and increased native grass cover by 18% to 50% in all treatment plots. Imazapic at 0.18 kg active ingredient ha^{-1} and non-ionic surfactant (without prescribed burning) was also effective. Cover of Indiangrass (*Sorghastrum nutans* [L.] Nash), big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachryrium scoparium* [Michx.] Nash), broomsedge bluestem (*Andropogon virginicus* L.), and tall dropseed (*Sporobolus asper* [Michx.] Kunth) increased in the herbicide treatments. Imazapic may be a useful tool for removing tall fescue and enhancing native warm-season grasses and native forbs in planted stands and in native barrens ecosystems.

Uso de Imazapic y Fuego Recetado para Mejorar los Pastizales Nativos de Estación Cálida en Kentucky, USA

RESUMEN: La festuca alta (Festuca arudinacea Shreb.) es una herbácea exótica de estación fría que agresivamente invade las comunidades nativas de pastizales en el este y centro de Estados Unidos reduciendo la cobertura de planta nativas y la diversidad botánica. Realizamos dos estudios en Kentucky para determinar la utilidad de aplicaciones de herbicidas después de emerger para erradicar la festuca alta y aumentar los pastos nativos de estación cálida. En un estudio aplicamos Imazapic (0,21 kg de ingrediente activo ha-1) a tres parcelas previamente plantadas con pastos nativos de estación cálida en Abril de 1998 y evaluamos la cobertura de festuca alta y pastos nativos semillados en el otoño de 1998. La festuca alta se redujo a menos del 10% en la mayoría de las parcelas tratadas. El promedio de pastizales nativos de estación calidad aumentó del 30% al 100% después de la aplicación del herbicida. En un segundo estudio, evaluamos la quema recetada y la aplicación del herbicida Imazapic (0,07 a 0,18 kg de ingrediente activo ha-1, con y sin coadyuvante des-ionizado) después de emerger para controlar la festuca alta y aumentar los pastos nativos de estación cálida y herbáceas nativas en comunidades áridas remanentes. El fuego recetado en primavera seguido de una aplicación de Imazapic a 0,14 o 0,18 kg de ingrediente activo ha-1 al rebrotar con y sin coadyuvante des-ionizado redujo la cobertura de festuca alta a menos del 25% y aumentó la cobertura de pastos nativos entre el 18% y el 50% en todas las parcelas tratadas. Imazapic a 0,18 kg de ingrediente activo ha-1 y coadyuvante des-ionizado (sin quema recetada) fue también efectivo. La cobertura de pasto de la India (Sorghastrum nutans [L.] Nash), Andropogon gerardii Vitman, Schizachryrium scoparium [Michx.] Nash, Andropogon virginicus L., Sporobolus asper [Michx.] Kunth, aumentaron con los tratamientos de herbicida. El Imazapic puede ser una herramienta útil para combatir la festuca alta y mejorar los pastos nativos de estación cálida y las herbáceas nativas en las parcelas plantadas y en ecosistemas áridos nativos.

Index terms: barrens, *Festuca arundincea*, exotic species, imazapic, tall fescue

INTRODUCTION

Tall fescue (*Festuca arundinacea* Shreb.) is an exotic, cool-season perennial grass that has been seeded on more than 14 million ha in the United States (Burns and Chamblee 1979, Ball et al. 1993). Over 90% of tall fescue fields are infected with a symbiotic fungal endophyte (*Neotyphodium coenophialum* [Morgan-Jones & Gams] Glenn, Bacon & Hanlin) that gives tall fescue a competitive advantage over native grasses by increasing its drought tolerance and enhancing its growth (Bacon and Siegel 1988). Its rapid growth combined with a cool-season phenology allow tall fescue to invade native warm-season grasslands and form monocultures

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Natural Areas Journal 22:20–27

(Barnes et al. 1995).

Savannas and barrens are native plant communities characterized by a diverse, grass-dominated herbaceous layer and scattered trees and shrubs (Chester et al. 1997, Anderson et al. 1999). In Kentucky, these unique communities support some of the state's rarest plant species; tall fescue commonly invades these native communities, threatening their structure and function.

Several management tools may be useful for removing exotic cool-season grasses and other nonindigenous plants from native grasslands (Packard and Mutel 1997). Prescribed burning (Packard and Mutel 1997, Willson and Stubbendieck 2000) and herbicide application (Dill et al. 1986, Anderson 1992, Washburn et al. 1999) have been found to be effective for removing non-native plant species from degraded grassland ecosystems. Imazapic (Plateau™, BASF-American Cyanamid, Raleigh, N.C.) is a relatively new herbicide that is very effective for killing tall fescue (Washburn et al. 1999, Washburn and Barnes 2000a). In addition, imazapic reduces weed interference during planting efforts, allowing seeded native warm-season grasses (NWSG) and some native forbs to establish in one growing season (Beran et al. 1999, Washburn et al. 1999, Beran et al. 2000, Washburn and Barnes 2000b). Because this herbicide does not kill bluestems (*Andropogon* L. spp.), Indiangrass (*Sorghastrum nutans* [L.] Nash), and other NWSG (Vollmer 1998, Washburn and Barnes 2000b), it holds promise for eradicating tall fescue and increasing native plant abundance and diversity in both seeded NWSG stands and degraded native grassland ecosystems.

We conducted two studies to evaluate the use of post-emergence imazapic applications for eradicating tall fescue and increasing NWSG cover. The objective of our first study was to determine the effectiveness of a post-emergence imazapic application for removing residual tall fescue and increasing NWSG coverage in grasslands seeded to NWSG. The objective of our second study was to determine the efficacy of prescribed burning, post-emergence imazapic applications, and combinations of prescribed burning and imazapic applications for eradicating tall fescue and increasing NWSG and native forbs in a remnant native barrens.

STUDY AREAS

Improving Seeded NWSG Stands

We conducted experiments at three sites in Kentucky selected to represent a variety of silt loam soil types (Braxton, Wellston, Zanesville, and Crider) with varying levels of soil acidity (pH: 5.3–6.3), organic matter (3.3–5.2%), and inorganic nutrients (7–94 kg ha^{-1} P, 86–105 kg ha^{-1} K, 358–767 kg ha^{-1} Ca, and 5–97 kg ha^{-1} Mg). The first study site was located in the Inner Bluegrass physiographic region at the Raven Run Wildlife Sanctuary in Fayette County. The second site was located in the Western Kentucky Coal Field physiographic region in Muhlenberg County. The third study site was located in the Western Pennyroyal physiographic region in Caldwell County. Prior to experimental manipulations, all three study areas were dominated by tall fescue (85–98% cover).

Enhancing Remnant Native Barrens

We conducted a second study at the Raymond Athey State Nature Preserve (hereafter Athey Barrens), a 63-ha preserve located in Logan County, south-central Kentucky. Athey Barrens has been managed by the Kentucky State Nature Preserves Commission since 1990. Management activities at Athey Barrens are focused on the eradication of non-native plants (e.g., tall fescue) and the restoration of native plant communities and appropriate disturbance regimes necessary to maintain those communities. The study area consisted of two abandoned pastures dominated by tall fescue, broomsedge bluestem (*Andropogon virginicus* L.), and a few other grasses and forbs commonly present in agricultural fields. Study site soils were silt loams or silty clay loams with a pH of 6.6 (Rhoades et al. 2002).

Existing plant communities at Athey Barrens were described prior to treatment applications (12 November 1998) by determining tall fescue cover, NWSG cover, and plant species richness in 80 1-m^2 herbaceous sampling plots. Although plant cover varied across the study area, tall fescue was the dominant plant species ($\bar{x}$ = 58% ± 3.2 SE). Native warm-season grasses ($\bar{x}$ cover = 26% ± 3.1 SE) were also present in most plots and consisted primarily of broomsedge bluestem and little bluestem (*Schizachryrium scoparium* [Michx.] Nash). An average of 4.7 plant species per m^2 (± 0.1 SE) were present prior to treatment applications.

METHODS

Improving Seeded NWSG Stands

The first study was conducted in two phases: the initial phase involved prescribed burning, glyphosate applications, and seeding NWSG; and the second phase involved a post-emergence imazapic application. We implemented a randomized complete block design experiment with one treatment plot within each of two replicate blocks (resulting in a total of eight 500-m^2 plots) at each of three study sites. We no-till seeded NWSG into the following treatments: (1) control (no manipulation), (2) spring pre-emergence glyphosate (Round-Up PRO™), (3) spring burn, spring pre-emergence glyphosate, and (4) fall burn, spring pre-emergence glyphosate. Prescribed burns were implemented on 15 March, 10 April, 29 August, and 16 October 1996. Strip-head fire burns were conducted between 1700 and 1900 h EST during conditions of low wind speeds (2–16 kph), rising relative humidity (25–60%), and air temperatures between 4 °C and 10°C in the spring and between 21 °C and 27°C in the fall. Glyphosate was broadcast applied at a label rate of 2.24 kg active ingredient (ai) ha^{-1} (16–19 May 1996 or 10–12 May 1997) using a Demco™ (Dethmers Manufacturing Co., Boyden, Iowa) ATV-mounted sprayer equipped with Tee-Jet 8003™ (Spraying Systems Co., Wheaton, Ill.) flat fan nozzles calibrated to deliver 112 L ha^{-1} at 380 kPa.

We seeded a NWSG mixture at 6.98 kg PLS ha^{-1} using a Truax™ (Truax Co., Minneapolis, Minn.) no-till drill during 3–10 June 1996 and 23–28 May 1997 (Capel 1995, Packard and Mutel 1997). The seed mixture consisted of 32% Indiangrass, 29% big bluestem (*Andropogon gerardii* Vitman), 24% little bluestem, 8% sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.), and 3% switchgrass (*Panicum virgatum* L.).

We visually estimated tall fescue cover (%) during spring of 1998 and seeded NWSG cover (%) in fall of 1997 in five 1-m^2 plots (Bonham 1989) randomly located in each treatment plot. We determined seeded NWSG cover in each 1-m^2 plot by summing the cover estimates for individual NWSG in each sampling plot.

During the second phase of the study, we applied imazapic at a label rate (0.21 kg ai ha^{-1}) to all treatment plots during 25–28 April 1998. The herbicide was applied with a Solo 435™ (Forestry Suppliers, Inc., Jackson, Miss.) backpack sprayer delivering a spray volume of 112 L ha^{-1} at 414 kPa through a Tee-Jet 8003™ flat fan nozzle.

We evaluated the effects of the imazapic application (post-treatment) during the fall of 1998 by determining tall fescue cover (%) and seeded NWSG cover (%) in five 1-m^2 plots (Bonham 1989) randomly located in each treatment plot. Seeded NWSG cover was determined by summing the cover estimates for all seeded NWSG in each 1-m^2 plot. Seeded NWSG cover may exceed 100% because these values are a summation of estimates for all seeded NWSG.

We tested for differences in tall fescue cover and seeded NWSG cover before and after imazapic applications within each treatment using the general linear models procedure (PROC GLM) analysis of variance (ANOVA) of SAS (SAS Institute 1985, Neter et al. 1990) for each site independently. Differences were considered significant at $P = 0.05$. Significant interactions between treatment and imazapic application effects were found for both vegetational characteristics. We used the least-squares means procedure (LSMEANS) of SAS (SAS Institute 1985) to compare means.

Enhancing Remnant Native Barrens

Imazapic and prescribed burning effects were evaluated with 16 treatments in a randomized complete block design experiment with one treatment plot in each of five replicate blocks at Athey Barrens. Study plots were 120 m^2 to 320 m^2. Specific treatments included (1) control (no manipulation), (2) water only, (3) burn only, (4) burn and water only, (5) imazapic at 0.07 kg ai ha^{-1}, (6) imazapic at 0.07 kg ai ha^{-1} and Aquagene 90™ (Southern States Cooperative, Louisville, Ky.) nonionic surfactant (NIS) at 2.34 L ha^{-1}, (7) imazapic at 0.14 kg ai ha^{-1}, (8) imazapic at 0.14 kg ai ha^{-1} and NIS at 2.34 L ha^{-1}, (9) imazapic at 0.18 kg ai ha^{-1}, (10) imazapic at 0.18 kg ai ha^{-1} and NIS at 2.34 L ha^{-1}, (11) spring burn followed by imazapic at 0.07 kg ai ha^{-1}, (12) spring burn followed by imazapic at 0.07 kg ai ha^{-1} and NIS at 2.34 L ha^{-1}, (13) spring burn followed by imazapic at 0.14 kg ai ha^{-1}, (14) spring burn followed by imazapic at 0.14 kg ai ha^{-1} and NIS at 2.34 L ha^{-1}, (15) spring burn followed by imazapic at 0.18 kg ai ha^{-1}, (16) spring burn followed by imazapic at 0.18 kg ai ha^{-1} and NIS at 2.34 L ha^{-1}. These herbicide application rates were recommended by the manufacturer in the imazapic label.

Prescribed burns were conducted on 23 March 1999 between 1300 and 1600 h EST. Winds were 8–16 kph, relative humidity was 29%, and air temperatures averaged 13°C (Rhoades et al. 2002). Herbicides were applied on 19 April 1999, as previously described.

Plant community characteristics were determined at the end of the initial growing season (fall 1999), early in the second

Table 1. Mean tall fescue cover (%) in herbicide treatment plots that were seeded to native warm-season grasses and then sampled prior to (spring 1998) and after (fall 1998) a post-emergence application of imazapic at 0.21 kg ai ha^{-1} at the Raven Run, Muhlenberg, and Caldwell sites in Kentucky.

STUDY SITE Treatment	Spring 1998 $\bar{X} \pm$ SE		Fall 1998 $\bar{X} \pm$ SE
RAVEN RUN			
Control	76 ± 4.1 a[b]	*Imazapic Application*	93 ± 0.8 c
Spring Herbicide[a]	6 ± 2.2 b		3 ± 1.7 b
Spring Burn - Spring Herbicide	6 ± 2.5 b		0 ± 0.0 b
Fall Burn - Spring Herbicide	9 ± 4.9 b		26 ± 6.1 d
MUHLENBERG			
Control	93 ± 0.8 a		93 ± 0.8 a
Spring Herbicide	2 ± 1.1 b		0 ± 0.0 b
Spring Burn - Spring Herbicide	0 ± 0.0 b		0 ± 0.0 b
Fall Burn - Spring Herbicide	11 ± 2.4 c		0 ± 0.0 b
CALDWELL			
Control	94 ± 1.1 a		94 ± 0.8 a
Spring Herbicide	33 ± 5.8 b		0 ± 0.0 c
Spring Burn - Spring Herbicide	88 ± 1.7 a		2 ± 1.3 c
Fall Burn - Spring Herbicide	90 ± 0.8 a		6 ± 3.3 c

[a] Herbicide consisted of an application of glyphosate at 2.24 kg ai ha^{-1}.

[b] Means within the same row or within the same column under each site with the same letter are not different ($P > 0.05$) according to LSMEANS comparisons.

Table 2. Mean planted native warm-season grass cover (%) in herbicide treatment plots that were seeded to native warm-season grasses and then sampled prior to (fall 1997) and after (fall 1998) a post-emergence application of imazapic at 0.21 kg ai ha^{-1} at the Raven Run, Muhlenberg, and Caldwell sites in Kentucky.

STUDY SITE Treatment	Fall 1997 $\bar{x}$ ± SE		Fall 1998 $\bar{x}$ ± SE
RAVEN RUN			
Spring Herbicide[a]	16 ± 3.4 a[b]	Imazapic Application	94 ± 4.4 c
Spring Burn - Spring Herbicide	14 ± 3.3 a		107 ± 4.0 d
Fall Burn - Spring Herbicide	0 ± 0.0 b		37 ± 4.8 e
MUHLENBERG			
Spring Herbicide	47 ± 5.2 a		85 ± 7.3 c
Spring Burn - Spring Herbicide	46 ± 3.0 a		115 ± 4.3 d
Fall Burn - Spring Herbicide	24 ± 5.2 b		82 ± 8.7 c
CALDWELL			
Spring Herbicide	45 ± 4.4 a		118 ± 5.1 b
Spring Burn - Spring Herbicide	43 ± 5.9 a		122 ± 3.0 b
Fall Burn - Spring Herbicide	0 ± 0.0 b		81 ± 6.0 c

[a] Herbicide consisted of an application of glyphosate at 2.24 kg ai ha^{-1}.

[b] Means within the same row or within the same column under each site with the same letter are not different ($P > 0.05$) according to LSMEANS comparisons.

growing season (spring 2000), and near the end of the second growing season (summer 2000) following treatment applications. Five 1-m^2 herbaceous sampling plots were randomly established and sampled in each individual treatment plot on 5 October 1999, 2 May 2000, and 4 August 2000. Tall fescue cover (%), NWSG cover (%), and plant species richness (number of plant species per m^2) were visually estimated in each herbaceous sampling plot. Native warm-season grass cover consisted of little bluestem, big bluestem, Elliott's bluestem (*Andropogon gyrans* Ashe), broomsedge bluestem, tall dropseed (*Sporobolus asper* [Michx.] Kunth), and annual dropseed (*Sporobolus vaginiflorus* [Torr. ex Gray] Wood).

We tested for differences in tall fescue cover, NWSG cover, and plant species richness using GLM ANOVA (SAS Institute 1985, Neter et al. 1990). Differences were considered significant at $P = 0.05$. We used Fisher's protected LSD tests to compare treatment means (SAS Institute 1985, Neter et al. 1990).

RESULTS

Improving Seeded NWSG Stands

The initial glyphosate applications (with and without prescribed burning) were very effective and reduced tall fescue cover to less than 12% at two of three study sites (Table 1). Although tall fescue initially was reduced by the glyphosate applications at the Caldwell site, tall fescue reinvaded or increased from plants remaining in the treatment plots in the growing seasons following the initial herbicide application (Table 1). Also, seeded NWSG were slow to establish during the initial growing seasons. Mean NWSG cover ranged from 0% to 47% during fall of 1997 (Table 2). Seeded NWSG cover consisted primarily of Indiangrass and switchgrass in relatively equal amounts.

Applying imazapic reduced or eliminated residual tall fescue remaining after the glyphosate applications in seven of nine treatments (Table 1). In the remaining two treatments, no tall fescue was present at the time of the imazapic application (Muhlenberg), or tall fescue increased significantly after the imazapic application (Raven Run; Table 1). Tall fescue cover was reduced to less than 10% in the imazapic-treated plots at all three sites, with the one exception where it increased (Table 1). Furthermore, the imazapic application completely eliminated tall fescue from the Muhlenberg site.

Applying imazapic also dramatically increased seeded NWSG cover (Table 2). Mean seeded NWSG cover increased from a range of 0–47% prior to applying imazapic to 81–122% after the imazapic application. Seeded NWSG cover following the imazapic application consisted of Indiangrass, switchgrass, little bluestem, and big bluestem.

Enhancing Remnant Native Barrens

Tall fescue cover varied among treatments for fall 1999 ($F = 27.68$, df = 15, 399, $P = 0.0001$), spring 2000 ($F = 29.33$, df = 15, 399, $P = 0.0001$), and summer 2000 ($F = 5.99$, df = 15, 239, $P = 0.0001$). In addition, tall fescue cover varied ($P = 0.001$) among blocks during all three measurement periods. All 12 herbicide treatments had less ($P < 0.05$) tall fescue cover than in the control during fall 1999 and spring 2000. However, by summer 2000 only 9 of the 12 imazapic treatments had less tall fescue ($P < 0.05$) than the control (Table 3). Mean tall fescue was reduced to less than 15% in the imazapic at 0.14 kg ai ha^{-1} with NIS, in the spring burn followed by imazapic at 0.14 kg ai ha^{-1} with NIS, and the spring burn followed by imazapic at 0.18 kg ai ha^{-1} with NIS treatment plots during summer 2000 (Table 3).

There were differences in NWSG cover among treatments during fall 1999 ($F = 8.48$, df = 15, 399, $P = 0.0001$), spring 2000 ($F = 15.57$, df = 6, 567, $P = 0.0001$), and summer 2000 ($F = 4.57$, df = 15, 239, $P = 0.0001$). In addition, NWSG cover varied ($P = 0.001$) among blocks during

Table 3. Mean tall fescue cover (%) at the end of the first (fall 1999), early in the second (spring 2000), and late in the second growing seasons (summer 2000) following burning and herbicide applications at Athey Barrens in Kentucky during 1999–2000.

Treatment	Fall 1999 $\bar{x} \pm$ SE	Spring 2000 $\bar{x} \pm$ SE	Summer 2000 $\bar{x} \pm$ SE
Control	72 ± 4.6 a[a]	88 ± 2.1 a	45 ± 6.5 a
Water Only	41 ± 4.4 b	88 ± 1.9 a	47 ± 5.7 a
Burn Only	41 ± 4.5 cd	68 ± 5.0 b	38 ± 8.0 ab
Burn, Water Only	44 ± 4.9 cd	60 ± 4.0 bc	47 ± 6.4 a
0.07 kg ai ha^{-1} Imazapic	44 ± 6.3 c	61 ± 5.5 bc	40 ± 4.8 ab
0.07 kg ai ha^{-1} Imazapic + NIS[b]	26 ± 3.9 e	37 ± 4.3 ef	40 ± 6.1 ab
0.14 kg ai ha^{-1} Imazapic	33 ± 5.2 de	46 ± 4.6 de	22 ± 5.8 cd
0.14 kg ai ha^{-1} Imazapic + NIS[b]	40 ± 5.7 cd	41 ± 4.9 def	11 ± 4.6 d
0.18 kg ai ha^{-1} Imazapic	23 ± 4.9 ef	43 ± 5.8 de	20 ± 4.2 cd
0.18 kg ai ha^{-1} Imazapic + NIS[b]	8 ± 1.8 g	22 ± 4.3 gh	22 ± 5.1 cd
Burn, 0.07 kg ai ha^{-1} Imazapic	14 ± 3.2 fg	51 ± 4.5 cd	38 ± 9.7 ab
Burn, 0.07 kg ai ha^{-1} Imazapic + NIS[b]	8 ± 2.8 g	18 ± 2.4 h	28 ± 8.2 bc
Burn, 0.14 kg ai ha^{-1} Imazapic	13 ± 3.6 fg	45 ± 4.9 de	20 ± 6.5 cd
Burn, 0.14 kg ai ha^{-1} Imazapic + NIS[b]	9 ± 2.6 g	31 ± 5.7 fg	10 ± 3.1 d
Burn, 0.18 kg ai ha^{-1} Imazapic	5 ± 1.9 g	38 ± 4.9 ef	21 ± 5.7 cd
Burn, 0.18 kg ai ha^{-1} Imazapic + NIS[b]	3 ± 1.1 g	11 ± 2.7 h	7 ± 3.2 d

[a] Means within the same column with the same letter are not different ($P > 0.05$) according to Fisher's protected LSD test.

[b] Non-ionic surfactant (Aquagene 90™) was included at a rate of 2.34 L ha^{-1}.

all three measurement periods. Mean NWSG cover exceeded 60% in four treatments (imazapic at 0.18 kg ai ha^{-1} with NIS, spring burn followed by imazapic at 0.14 kg ai ha^{-1} with NIS, spring burn followed by imazapic at 0.18 kg ai ha^{-1}, and spring burn followed by imazapic at 0.18 kg ai ha^{-1} with NIS) during summer 2000 (Table 4).

Plant species richness varied significantly among treatments in fall 1999 ($F = 2.38$, df = 15, 399, $P = 0.0001$), spring 2000 ($F = 8.27$, df = 6, 567, $P = 0.0001$), and summer 2000 ($F = 2.18$, df = 15, 239, $P = 0.0001$). During summer 2000, three treatments (imazapic at 0.07 kg ai ha^{-1}, spring burn followed by imazapic at 0.14 kg ai ha^{-1}, and spring burn followed by imazapic at 0.14 kg ai ha^{-1} with NIS) had higher ($P < 0.05$) plant species richness than the untreated control plots. Common purpletop (*Tridens flavus* [L.] A. S. Hitche), beaked panicgrass (*Panicum anceps* Michx.), sneezeweed (*Helenium amarum* [Raf.] H. Rock), green comet milkweed (*Asclepius viridiflora* Raf.), prickly pear (*Opuntia humifusa* [Raf.] Raf.), yellow flax (*Linum virginianum* L.), pencilflower (*Stylosanthes biflora* [L.] B.S.P.), prairie fleabane (*Erigeron strigosus* Muhl. ex Willd.), large senna (*Cassia marilandica* L.), Widow's cross (*Sedum pulchellum* Michx.), prairie rose (*Rosa setigera* Michx.), wild strawberry (*Fragaria virginiana* Duchesne), scaly blazingstar (*Liatrus squarrosa* L.), Adder's tongue fern (*Ophioglossum engelmanni* Prantl), white vervain (*Verbena urticifolia* L.), hyssop-leaved thoroughwart (*Eupatorium hyssopifolium* L.), late-flowering thoroughwart (*Eupatorium serotinum* Michx.), frost aster (*Aster pilosus* Willd.), and slenderstalk beeblossom (*Gaura filipies* Spach) were native grasses, forbs, wildflowers, and legumes present in the burned and unburned plots that received a post-emergence application of imazapic at 0.14 kg ai ha^{-1} with NIS or less. In addition, non-native forbs and legume species were also present in these plots, including ox-eye daisy (*Leucanthemum vulgare* Lam.), hop clover (*Trifolium campestre* Schreb.), sericea lespedeza (*Lespedeza cuneata* L.), Korean lespedeza (*Lespedeza stipulacea* Maxim.), and Deptford pink (*Dianthus armenia* L.).

DISCUSSION

Improving Seeded NWSG Stands

Our results indicate that a post-emergence imazapic (0.21 kg ai ha^{-1}) application to seeded NWSG stands two or three seasons after initial prescribed burning and glyphosate treatments is a highly effective method to achieve control of reinvading tall fescue and for enhancing seeded NWSG. Following the imazapic application, NWSG cover increased significantly from pretreatment levels. Applying imazapic apparently decreased competition from annual and perennial weeds and increased the growth of seeded NWSG. Overall, plant species sensitive to imazapic, such as tall fescue, hairy crabgrass (*Digitaria sanguinalis* [L.] Scop.), and johnsongrass (*Sorghum halepense* [L.] Pers.), were removed by the imazapic application (Washburn et al. 1999). In contrast, species tolerant to imazapic, such as the seeded NWSG, broomsedge bluestem, and Kentucky bluegrass (*Poa pratensis* L.), increased considerably due to decreased competition from the dominant weeds.

Overall, tall fescue cover prior to the imazapic applications varied considerably among the three study areas. Study plots at Caldwell were centered in a large tall fescue field, whereas the Raven Run and Muhlenberg study plots included almost all of the tall fescue present and were surrounded by woodlands. The surrounding tall fescue apparently provided a seed and tiller source and resulted in more reestablishment of tall fescue at Caldwell compared to the other two sites. We suspect a similar

Table 4. Mean native warm-season grass cover (%) at the end of the first (fall 1999), early in the second (spring 2000), and late in the second growing seasons (summer 2000) following burning and herbicide applications at Athey Barrens in Kentucky during 1999–2000.

Treatment	Fall 1999 $\bar{x} \pm$ SE	Spring 2000 $\bar{x} \pm$ SE	Summer 2000 $\bar{x} \pm$ SE
Control	14 ± 4.7 a[a]	1 ± 0.6 a	20 ± 5.9 a
Water Only	17 ± 3.7 ab	2 ± 1.6 a	33 ± 5.8 abc
Burn Only	15 ± 4.5 a	6 ± 1.2 ab	32 ± 7.9 abc
Burn, Water Only	19 ± 4.6 ab	6 ± 1.6 ab	28 ± 6.6 ab
0.07 kg ai ha^{-1} Imazapic	29 ± 6.1 bcd	3 ± 1.0 a	24 ± 7.1 a
0.07 kg ai ha^{-1} Imazapic+NIS[b]	36 ± 5.6 cde	20 ± 5.0 def	36 ± 6.8 abcd
0.14 kg ai ha^{-1} Imazapic	33 ± 6.4 cde	10 ± 2.4 abc	38 ± 10.3 abcd
0.14 kg ai ha^{-1} Imazapic+NIS[b]	23 ± 4.3 abc	13 ± 2.2 bcd	47 ± 9.2 bcde
0.18 kg ai ha^{-1} Imazapic	36 ± 6.1 cde	9 ± 2.6 abc	51 ± 10.1 cdef
0.18 kg ai ha^{-1} Imazapic+NIS[b]	52 ± 5.8 fg	37 ± 5.4 gh	62 ± 6.6 ef
Burn, 0.07 kg ai ha^{-1} Imazapic	36 ± 5.5 cde	15 ± 3.0 bcde	34 ± 10.2 abcd
Burn, 0.07 kg ai ha^{-1} Imazapic+NIS[b]	46 ± 5.1 ef	38 ± 7.2 gh	50 ± 10.0 cdef
Burn, 0.14 kg ai ha^{-1} Imazapic	50 ± 6.1 fg	28 ± 3.3 fg	54 ± 8.8 def
Burn, 0.14 kg ai ha^{-1} Imazapic+NIS[b]	42 ± 5.2 def	23 ± 5.1 ef	67 ± 6.9 ef
Burn, 0.18 kg ai ha^{-1} Imazapic	40 ± 5.4 def	18 ± 2.8 cde	68 ± 6.2 ef
Burn, 0.18 kg ai ha^{-1} Imazapic+NIS[b]	60 ± 4.4 g	46 ± 7.4 h	70 ± 6.6 f

[a] Means within the same column with the same letter are not different ($P > 0.05$) according to Fisher's protected LSD test.

[b] Non-ionic surfactant (Aquagene 90™) was included at a rate of 2.34 L ha^{-1}.

situation occurred in the treatment at Raven Run where tall fescue coverage increased following the imazapic application.

Enhancing Remnant Native Barrens

Prescribed burning and post-emergence application of imazapic appear to be very useful tools for enhancing the quality of native barrens in Kentucky. Spring burning followed by a post-emergence application of imazapic at 0.14 or 0.18 kg ai ha^{-1} with NIS at 2.34 L ha^{-1} were the most effective treatments for eradicating tall fescue and increasing native grasses and forbs. These two treatments provided the best tall fescue control and resulted in the highest NWSG cover levels, regardless of the amount of tall fescue and NWSG cover prior to treatment applications. In restoration or management efforts where prescribed burning is not an option, using a post-emergence application of imazapic at 0.18 kg ai ha^{-1} with NIS at 2.34 L ha^{-1} may also be an effective management option.

Tall fescue control and NWSG enhancement varied with herbicide application rate. Applying imazapic at a high rate (0.18 kg ai ha^{-1}) provided good tall fescue control and increased native grasses and forbs, whereas a low rate of imazapic (0.07 kg ai ha^{-1}) was typically ineffective. However, in parts of the study area characterized by less tall fescue and more native grasses prior to treatment applications (e.g., blocks #1 and #2), treatments with low amounts of imazapic (e.g., spring burning followed by 0.07 kg ai ha^{-1} with NIS) reduced tall fescue cover and increased native grasses and forbs. Consequently, lower rates of imazapic may be effective for enhancing native barrens where invasion of exotic cool-season grasses is light to moderate (e.g., <50% cover) and NWSG are present in substantial amounts (e.g., >20% cover).

Prescribed burning alone (no herbicide) did not decrease tall fescue or increase NWSG cover. Similarly, Washburn et al. (1999) found that a single prescribed burn, without a herbicide application, was ineffective for controlling tall fescue and only reduced fescue cover by less than 10% at ten study areas in Kentucky. Prescribed burning prior to applying imazapic increased tall fescue control and increased NWSG coverage in some treatments compared to unburned treatment plots during the first growing season. However, near the end of the second growing season, the influence of prescribed burning prior to herbicide application was no longer significant. A similar finding occurred for the addition of NIS to the herbicide mixtures at the time of application.

Following the initial reductions in tall fescue cover by the application of herbicides, tall fescue increased in most treatments from the end of the initial growing season to early in the second growing season. Such increases probably were due to reinvasion of tall fescue from adjacent plots or increases in residual tall fescue plants that survived the imazapic applications. As the second growing season progressed, tall fescue coverage decreased in most treatment and control plots due to the onset of summer and unfavorable growing conditions for tall fescue. Although trends in tall fescue growth varied by season, overall tall fescue coverage increased in most treatments in the two growing seasons following the imazapic applications. Consequently, reinvasion of tall fescue following initial treatment applications is an important concern for managers. Further research is needed to identify management techniques (e.g., additional burning or herbicide applications) that are effective in eradicating tall fescue and increasing native plants in the long term.

Severe drought conditions occurred throughout the study period and undoubtedly affected our results. Precipitation levels were 56% and 24% below the 20-year average for the area during the initial (1999) and second (2000) growing seasons, respectively (National Climate Data Center 2000). The lack of rainfall during the initial growing season resulted in very dry soil conditions, constrained plant growth, and reduced soil microbial activity, particularly in areas with increased bare ground due to prescribed burning (Rhoades et al. 2002). We suspect that drought conditions during the study may have lessened the native plant response to tall fescue eradication. Although the high amount of bare ground during 1999 apparently provided opportunity for increased native plant establishment, it also provided opportunity for reinvading tall fescue and increased cover of other non-native species (e.g., Kentucky bluegrass, hop clover) in some treatments.

Near the end of the second growing season following treatment application, our plant community description data showed that prescribed burning prior to applying imazapic increased NWSG cover and botanical diversity at Athey Barrens. Spring burns removed the heavy litter layer and greatly increased the amount of bare ground during the initial growing season. High amounts of bare ground apparently provided opportunity for native plant species (e.g., Adder's tongue fern, scaly blazingstar) and non-native species (e.g., Kentucky bluegrass, hop clover) to establish from the soil seed bank or increase in cover during the second growing season. Considerable bare ground also provides opportunities for active restoration management efforts, such as planting native seeds and plant plugs.

Removal of the dominant exotic plant species, in this case tall fescue, is changing the plant communities at Athey Barrens from monocultures of an invasive exotic grass to mixed-species native grasslands. Indiangrass, big bluestem, little bluestem, broomsedge bluestem, and tall dropseed are native warm-season grasses that responded well to the prescribed burning and herbicide applications. Similarly, a variety of native forb and legume species also showed a favorable response to the burning and herbicide treatments.

Prescribed burning and imazapic applications appear to be effective management practices for rapidly changing plant community composition and ecosystem structure during restoration efforts in native warm-season grass-dominated ecosystems (e.g., native barrens). However, due to the fact that the many forb species may be intolerant of imazapic, we recommend caution in using this herbicide in restoration efforts if important, rare, or endangered native forbs are present.

ACKNOWLEDGMENTS

We appreciate the financial support of American Cyanamid, Monsanto Corporation, Cooperative Extension Service and the Department of Forestry at the University of Kentucky, and the Kentucky Department of Fish and Wildlife Resources. We appreciate the generosity of the private landowners, Raven Run Nature Center, and the Kentucky State Nature Preserves Commission who graciously allowed us to conduct experiments on their land. We thank an anonymous reviewer for providing comments that improved the manuscript. This is manuscript number 01-09-05 and is approved for publication by the Director of the Agricultural Experiment Station at the University of Kentucky.

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