Restoration Ecology
THE JOURNAL OF THE SOCIETY FOR ECOLOGICAL RESTORATION INTERNATIONAL

Evaluation of Herbicides for Restoring Native Grasses in Buffelgrass-Dominated Grasslands

Aaron D. Tjelmeland,[1,3] Timothy E. Fulbright,[1] and John Lloyd-Reilley[2]

Abstract

Buffelgrass (*Pennisetum ciliare*) is an exotic grass that threatens arid and semiarid ecosystems. The objective of this study was to determine effectiveness of several herbicides at reducing competition from buffelgrass to enhance establishment of planted native grasses. In Duval County, Texas, plots were delineated in two experiments in a buffelgrass-dominated pasture and mowed on 2 September 2002. On 18 September 2002 and 7 October 2002, a 41% glyphosate (N-(phosphonomethyl) glycine) herbicide was applied to all plots. A mixture of three native grasses—green sprangletop (*Leptochloa dubia*), plains bristlegrass (*Setaria leucopila*), and four-flower trichloris (*Chloris pluriflora*)—was planted on 8 October 2002. On 9 October 2002, 1.12 and 2.24 kg/ha of a 80% tebuthiuron (*N*-[5-(1,1-dimethyethyl)-1,3,4-thiadiazol-2-yl]-*N*,*N*'-dimethylurea) herbicide was applied preemergence to the first experiment, and all other herbicides were applied postemergence on 27 July 2003 to the second experiment. Percent canopy cover of vegetation was estimated with a 20 × 50–cm sampling frame during April, June, and October 2003 and August 2004. Postemergent herbicides had no significant effect on canopy cover of buffelgrass or planted species ($p \geq 0.05$). Canopy cover of native grasses did not exceed 8% on any treatment or sampling date, and buffelgrass cover returned to pre-treatment conditions in less than 1 year; however, the 2.24 kg/ha rate of tebuthiuron suppressed ($p < 0.05$) canopy cover of buffelgrass compared with controls and increased ($p < 0.05$) native grasses almost 2 years past application. Tebuthiuron may have potential value in reducing buffelgrass canopy cover and increasing cover of native grasses, particularly *Chloris* spp.

Key words: **Buffelgrass, Chloris spp., herbicides, native grasses, *Pennisetum ciliare*, tebuthiuron.**

Introduction

A common component of non-native (hereafter "exotic") grasslands in semiarid environments is buffelgrass (*Pennisetum ciliare*), a warm-season, perennial grass native to Africa and parts of Asia. Buffelgrass was introduced as a pasture grass and has been planted in or has invaded an estimated 4 million hectares of south Texas, 6 million hectares of Mexico, 7.5 million hectares of Australia (Humphreys 1967; Cox et al. 1988), and extensive areas of Arizona. In these areas, buffelgrass threatens native ecosystems by altering fire regimes, which can further promote the spread of buffelgrass and exclude native species that are not adapted to frequent fires (D'Antonio & Vitousek 1992; Low 1997; Rutman & Dickson 2002; Butler & Fairfax 2003).

Areas dominated with buffelgrass support lower abundance and variety of grassland birds and fewer insects than native grasslands (Flanders et al. 2006). Buffelgrass decreases richness and diversity of shrub and herbaceous plant species (Clarke et al. 2005; Jackson 2005). Herbaceous plants are an important source of food and habitat for a variety of wildlife including several species of grassland birds, lagomorphs, and ungulates. In addition, buffelgrass frequently forms dense swards (Humphreys 1967; Low 1997), which may reduce the quality of habitat for bobwhite quail (*Colinus virginianus*) and other grassland birds by reducing the amount of space that these birds can access within it (Guthery 1986, 1997). Reestablishment of native plants in areas dominated by buffelgrass may improve these areas as habitat for a variety of native wildlife and increase biodiversity.

Formation of dense swards by buffelgrass makes it essential to control this grass when attempting to reestablish native plants in these areas. It is particularly important in semiarid ecosystems because of sporadic rainfall and the ability of buffelgrass to quickly draw away soil moisture from developing seedlings (Tix 2000). Several herbicides reduce competition from exotic, perennial grasses, and weeds. Imazapic ((+)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid) is effective at controlling exotic tall fescue (*Festuca arundinacea*) invasions and is used in restoration of these areas (Washburn et al. 1999, 2002; Washburn & Barnes 2000). Tebuthiuron (*N*-[5-(1,1-dimethyethyl)-1,3,4-thiadiazol-2-yl]-*N*,*N*'-dimethylurea), picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid)

[1] Caesar Kleberg Wildlife Research Institute, Department of Animal and Wildlife Sciences, MSC 218, Texas A&M University—Kingsville, Kingsville, TX 78363, U.S.A.
[2] USDA-NRCS E. "Kika" de la Garza Plant Materials Center, 3409 North FM 1355, Kingsville, TX 78363, U.S.A.
[3] Address correspondence to A.D. Tjelmeland, email ksadt05@tomuk.edu

doi: 10.1111/j.1526-100X.2007.00269.x

and dicamba (3,6-dichloro-2-methoxybenzoic acid) have detrimental effects on many grasses, including buffelgrass (Bovey et al. 1979, 1986).

The objective of this study was to determine effectiveness of dicamba, imazapic, and picloram applied following seedling emergence (hereafter "postemergent"), and tebuthiuron applied prior to seedling emergence (hereafter preemergent), at reducing competition from buffelgrass to enhance establishment of planted native grasses. We tested the hypotheses that herbicide treatments will decrease the cover of buffelgrass and increase the cover of planted native grasses compared with control treatments.

Methods

Study Site

Experiments were conducted at the Texas A&M University—Kingsville Bomer Wildlife Management Area (long 27°25′N, lat 98°24′ W) in Duval County, Texas. Duval County lies in the Tamaulipan scrub region of south Texas (Fulbright 2001). Vegetation typically consists of shrub associations of honey mesquite (*Prosopis glandulosa*) and mixed brush. Exotic grasses such as buffelgrass, Lehmann lovegrass (*Eragrostis lehmanniana*), and old world bluestems (*Bothriochloa* spp.) dominate much of the herbaceous community of rangelands in this region.

Average annual precipitation (1962–2002) in Benavidas, Texas, about 7 km north of the study area, is 604 mm with an average annual temperature of 22°C (NOAA 2006) (Fig. 1). Precipitation and temperature data reported herein were collected from the Benavides weather station. Buffelgrass growth occurs when soil moisture is available. Buffelgrass leaf growth begins at 10°C, but active growth occurs when mean minimum temperatures are between 15 and 20°C and maximum temperatures are below 40°C (Cox et al. 1988).

Soils at the study area were Randado and Brennan fine sandy loams (USDA-NRCS, Soil Survey Staff, 2006), which are classified as sandy loam ecological sites (USDA 1974). Soil chemical composition was 5–22 μg/mL nitrate (NO_3^-), 59.5–94.3 kg/ha organic matter, 311 to greater than 700 μg/mL potassium, 103–227 μg/mL magnesium, and 850–2,225 μg/mL calcium. Vegetation surrounding the study area consisted of open grasslands with a mixture of exotic grasses and mixed shrub communities. The study site was chosen based on the absence of woody plants and dominance of buffelgrass.

Experimental Design

A randomized, complete block design with four blocks and six treatments was used to compare effects of postemergent herbicides on buffelgrass and native grass percent canopy cover. A randomized, complete block design with four blocks and three treatments was used to determine the effect of two rates of the herbicide tebuthiuron, applied preemergence, on canopy cover of buffelgrass and native grasses. Experimental plots for both experiments were 10 × 10 m and were separated by 10 m buffers.

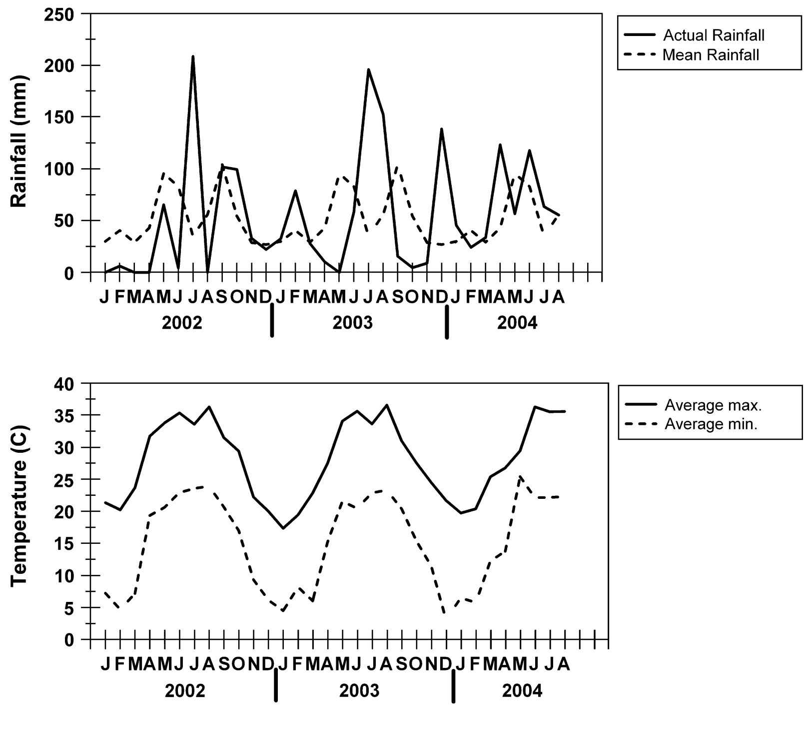

Figure 1. Monthly average rainfall and monthly average maximum and minimum temperatures recorded at National Oceanic and Atmospheric Administration weather station in Benavidas, Texas. Mean rainfall values derived from 1962 to 2002 data.

Table 1. Pre- and postemergent experiment activities conducted during study period.

Date	*Activity*
Experiment 1—postemergent herbicides	
August 2002	Pre-treatment vegetation sampling
2 September 2002	Plots mowed
11 September 2002	Plots raked
18 September 2002	First glyphosate application
7 October 2002	Second glyphosate application
8 October 2002	Planted native grasses
March 2003	First vegetation sampling
June 2003	Second vegetation sampling
July 2003	Postemergent herbicide application
October 2003	Third vegetation sampling
August 2004	Fourth vegetation sampling
Experiment 2—preemergent herbicides	
August 2002	Pre-treatment vegetation sampling
2 September 2002	Plots mowed
11 September 2002	Plots raked
18 September 2002	First glyphosate application
7 October 2002	Second glyphosate application
8 October 2002	Planted native grasses
9 October 2002	Tebuthiuron application
March 2003	First vegetation sampling
June 2003	Second vegetation sampling
October 2003	Third vegetation sampling
August 2004	Fourth vegetation sampling

Native Grass Planting

On 8 October 2002, an equal number of three native warm-season, perennial grass seeds estimated by weight were planted on all plots. The mixture consisted of green sprangletop (*Leptochloa dubia*), plains bristlegrass (*Setaria leucopila*), and four-flower trichloris (*Chloris pluriflora*). The seed mix was planted using a Tye® (Agco Corp., Duluth, GA, U.S.A.) rangeland drill at a rate of 215 pls/m^2. Seeds were planted at depths ranging from 0 to 0.5 cm. Accession 9086185 four-flower trichloris seed used for this study was obtained from the USDA-NRCS Plant Materials Center, Kingsville, Texas, United States. This accession was harvested from Jim Wells County, Texas, United States. Plains bristlegrass and green sprangletop seed used in this study were obtained commercially (Turner Seed Company, Breckenridge, TX, U.S.A).

Vegetation Sampling

Percent canopy cover of plant species and of areas not covered by living plant material, hereafter "bare ground," were visually estimated with 20, 20 × 50–cm frames in each treatment and replication combination (Daubenmire 1959). Pre-treatment sampling of both experiments began on 22 August 2002 and posttreatment sampling was conducted during March, June, and October 2003, and August 2004 (Table 1). The central 7 × 7 m of each plot was designated for sampling to avoid edge effects. Canopy cover of planted species was estimated as a group on sampling dates before October 2003 because of the difficulty in discriminating individual species of seedlings.

Sampling frames were positioned using a stratified random method. Two sampling frames were placed at 0.5-m intervals with the exception of the halfway (3.5 m) interval, whereas four frames were placed to bring the total number of frames on each plot to 20. The frames were randomly placed at one of seven possible positions spaced 1 m apart across these 0.5-m intervals.

Herbicide Application

To reduce amount of buffelgrass leaf material shielded from herbicides, plots were mowed on 2 September 2002 and hay was raked off experimental plots on 11 September 2002 (Table 1). The leaves were then allowed to grow to a height of about 15 cm to allow sufficient leaf surface area to be exposed for an effective foliar application of herbicide. On 18 September 2002, Roundup Ultra herbicide (Monsanto Co., St. Louis, MO, U.S.A) was applied at 9.3 L/ha (41% glyphosate) to all plots in preemergent and postemergent experiments. Buffelgrass was green and actively growing from rains earlier in September (Fig. 1) and conditions for spraying were good. A single application of glyphosate may not reduce competition from buffelgrass because of resprouting and dormant plant tissue. Therefore, glyphosate application was repeated at the same rate on 7 October 2002 before planting. At the time of this second glyphosate application, adequate rainfall allowed buffelgrass to begin to recover and green from the first glyphosate application, which again made for good spraying conditions.

On 9 October 2002, Spike (Dow AgroSciences LLC, Indianapolis, IN, U.S.A) was applied preemergence at 1.12 and 2.24 kg/ha rates (80% tebuthiuron). Postemergent herbicides were Weedmaster (BASF Corp., Triangle Park, NC, U.S.A) applied at 7.03 L/ha (120 g/L dicamba, 344 g/L 2,4-D), Plateau (BASF Corp.) applied at 0.29 and 0.58 L/ha (23.6% imazapic), and Grazon (Dow AgroSciences LLC) applied at 1.2 and 2.4 L/ha (65 g/L picloram, 240 g/L 2,4-D). Postemergent herbicides were applied in good conditions on 27 July 2003 following heavy rains (Fig. 1). A low volume handheld sprayer was used for all herbicide applications.

Statistical Analysis

All analyses were performed with SAS v. 9.1 software (Littell et al. 1996). For both experiments, individual species were grouped into planted grasses, buffelgrass, forb (Table 2), and bare ground for analysis. Planted species were compared among treatments using August 2002, October 2003, and August 2004 sampling dates. Data were analyzed using a repeated measures, fixed effects analysis of variance. Independent variables in analyses were sampling date, herbicide treatment, and the sampling date × herbicide treatment interaction. Dependent variables were mean percent cover of planted grasses, buffelgrass, forbs, and bare ground. The MIXED procedure using

Table 2. Relative cover of forb species found during study.

Common Name	*Scientific Name*	*Relative Cover (%)*	*Type*
Parthenium weed	*Parthenium hysterophorus*	19	Cool-season annual
Dakota verbena	*Verbena bipinnatifida*	18	Cool-season annual
Lazy daisy	*Aphanostephus spp.*	11	Warm-season annual
Silver bladderpod	*Lesquerella argyraea*	10	Warm-season biennial
Upright coneflower	*Ratibida columnifera*	7	Warm-season perennial
Common sunflower	*Helianthus annuus*	6	Warm-season annual
Sandbell	*Nama hispida*	3	Cool-season annual
Pennsylvania pellitory	*Parietaria pensylvanica*	2	Warm-season annual
Bindweed	*Convulvulus arvensis*	1	Warm-season perennial
Cowpen daisy	*Verbesina encelioides*	1	Warm-season perennial
Fanleaf vervain	*V. plicata*	1	Warm-season perennial
Tansy mustard	*Descurainia pinnata*	1	Warm-season perennial
Western ragweed	*Ambrosia artemisiifolia*	1	Warm-season annual
Broom snakeweed	*Gutierrezia sarothrae*	1	Warm-season perennial
Nightshades	*Solanum spp.*	1	Warm-season annual
Peppergrass	*Lepidium lasiocarpum*	1	Cool-season annual
Ruellia	*Ruellia matzae*	1	Warm-season perennial
Camphorweed	*Heterotheca subaxillaris*	1	Warm-season perennial
Other species		14	

a Tukey–Kramer adjustment was used to compare significantly different ($p < 0.05$) least square means.

Results

The sampling date × postemergent herbicide treatment interaction was not significant for planted grasses, buffelgrass, forbs, or bare ground ($p = 0.690$, 0.304, 0.998, and 0.153, respectively). Averaged across sampling dates, percent canopy cover of planted species, buffelgrass, forbs, and bare ground did not differ significantly ($p = 0.456$, 0.528, 0.652, and 0.643, respectively) among treatments. Cover of planted species initially increased until October 2003 and then decreased in August 2004 (Fig. 2). Cover of buffelgrass decreased following application of glyphosate, but increased to a greater percent cover than before treatment application. Buffelgrass sprayed with imazapic was discolored following the application, whereas other herbicides had almost no visible effect on buffelgrass when applied in July 2003. Cover of forbs increased during March and June 2003 compared with pre-treatment sampling and then decreased by October 2003. Bare ground cover was higher before herbicide application than on other sampling dates. Bare ground did not exceed 2 ± 0.5% because of the increase in forb cover in March and June 2003 and the increase of buffelgrass cover to pre-treatment conditions by October 2003.

Averaged across sampling dates, cover of planted species was greater on plots treated with 1.12 kg/ha tebuthiuron (6 ± 1%, $n = 5$, $p = 0.011$) than on control plots (1 ± 1%). Cover was also greater on plots treated with 2.24 kg/ha tebuthiuron (5 ± 1%, $n = 5$, $p = 0.040$) than on control plots. No significant ($p = 0.545$) difference in cover was found between the two rates. Averaged across treatments, cover of planted species initially increased during March (7 ± 1%, $n = 3$, $p = 0.002$), June (5 ± 1%, $n = 3$, $p = 0.011$), and October 2003 (4 ± 1%, $n = 3$, $p = 0.044$) compared with pre-treatment sampling cover (0 ± 1%) but then decreased by August 2004 (2 ± 1%, $n = 3$, $p = 0.524$) to conditions similar to pre-treatment sampling cover.

The sampling date × tebuthiuron treatment interaction was significant ($p < 0.001$) for buffelgrass, forb, and bare ground percent canopy cover. The 2.24 kg/ha rate of tebuthiuron resulted in less cover of buffelgrass than the control in October 2003 (Fig. 3). Control plots during March and June 2003 had greater forb cover than either rate of tebuthiuron. No significant ($p \geq 0.05$) differences in forb cover were detected between the two rates of tebuthiuron on any sampling date. On all sampling dates except pre-treatment sampling, bare ground cover was greater on plots sprayed with the 2.24 kg/ha rate of tebuthiuron than the control plots.

The sampling date × tebuthiuron treatment interaction was significant ($p = 0.012$) for four-flower trichloris percent canopy cover. During October 2003, plots treated with 1.12 kg/ha of tebuthiuron (4 ± 0.7%, $n = 5$, $p = 0.007$) and plots treated with 2.24 kg/ha of tebuthiuron (4 ± 0.7%, $n = 5$, $p = 0.015$) contained greater cover of four-flower trichloris than the control (0 ± 0.7%). During August 2004, only plots treated with the 2.24 kg/ha rate of tebuthiuron had greater cover (4 ± 0.7%, $n = 5$, $p = 0.003$). No other planted grass had significant sampling date or treatment effects ($p \geq 0.05$).

Discussion

Buffelgrass plants readily established from seed, increased, and dominated plots, whereas natives initially increased but declined in plots treated with postemergent herbicides and remained at a low cover in plots treated with tebuthiuron. Buffelgrass readily replaces native grasses, including established plants, in areas where

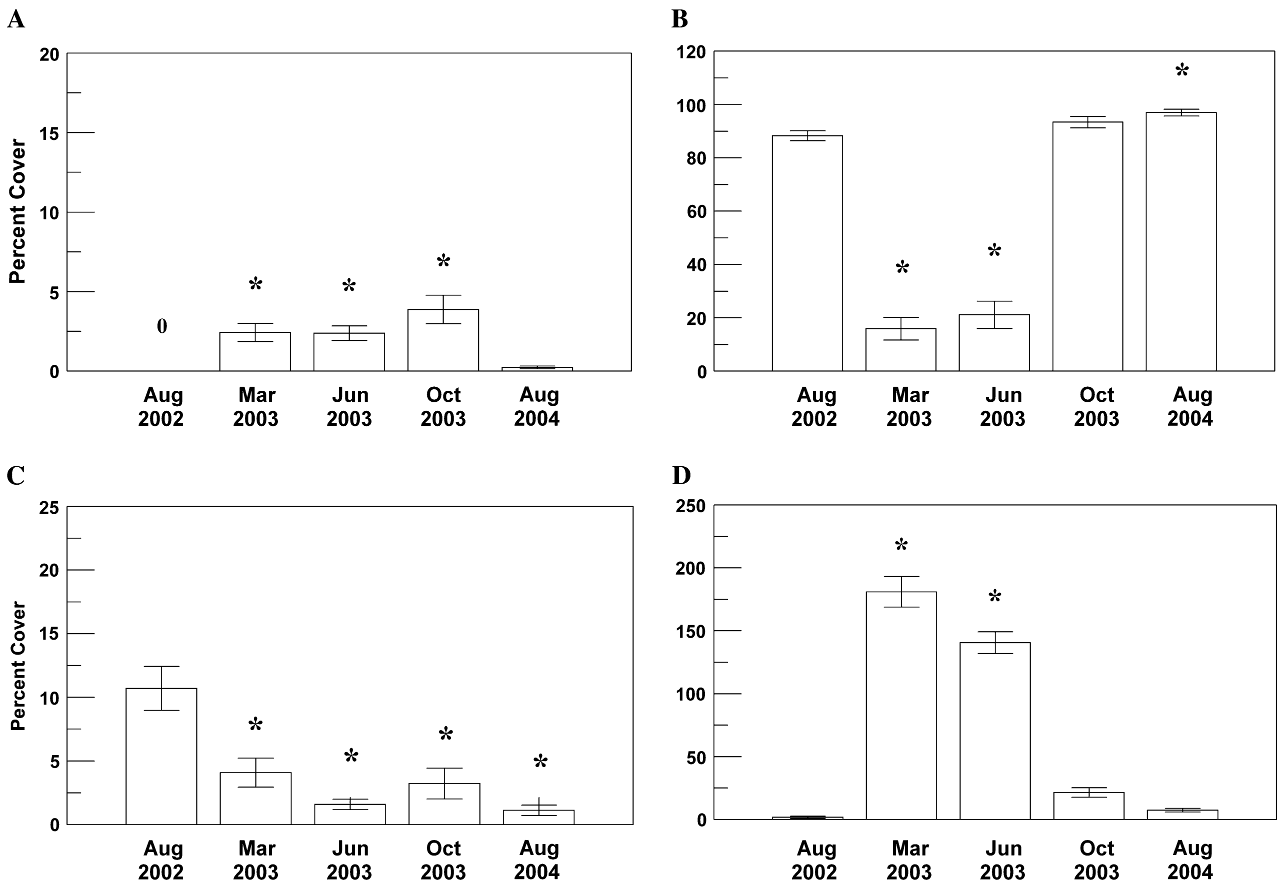

Figure 2. Percent canopy cover of (A) a mixture of planted native grasses *Leptochloa ducia*, *Setaria leucopila*, and *Chloris pluriflora*, (B) *Pennisetum ciliare*, (C) forbs, and (D) bare ground on plots in Duval County, Texas. Plots were mowed on 2 September 2002 and sprayed with glyphosate on 18 September 2002 and 7 October 2002. Native grasses were planted on 8 October 2002. Plots received application of dicamba, picloram, or imazapic herbicides on 27 July 2003. Asterisks indicate that significant ($p < 0.05$) differences between August 2002 pre-treatment sampling and posttreatment sampling dates.

buffelgrass is well adapted (Gonzales & Dodd 1979; Clarke et al. 2005). The increase in buffelgrass cover by the end of the study compared with pre-treatment sampling resulted from above-average rainfall. During 2003 and 2004, annual rainfall was 11.9 and 7.7 cm above the long-term mean, respectively. Buffelgrass responds well to rainfall in semiarid regions (Hanselka 1988), which would also account for the rapid growth of buffelgrass from seed in 2003 (Humphreys 1974).

This study demonstrates the ability of buffelgrass seedlings to quickly reestablish on areas where established plants are removed. This also indicates that the need to not only completely eliminate existing buffelgrass plants before revegetating areas where this grass is present but also to follow-up initial treatments to control growth of buffelgrass seedlings when they are vulnerable. Although buffelgrass is known to be prolific in its seed production and to have high seed longevity when stored, seeds do not fair as well in many soil conditions (Hacker 1989) and germination often drops significantly after 8–12 months in the soil (Winkworth 1963, 1971). Other studies have noted that after initially removing buffelgrass plants from invaded areas, there was a flush of seedlings that often followed (Dixon et al. 2002; Rutman & Dickson 2002). After eliminating this initial flush of seedlings, subsequent need for removal was dramatically decreased. Therefore, it may be beneficial to delay the planting of native seeds to eliminate this flush of seedlings.

Removal of grass cover in the fall of 2002 produced a flush of cool-season (C_3) and warm-season (C_4) annual and perennial forbs that germinate in late winter and early spring if fall and winter rainfall is adequate. Forbs were reduced both by treatment of tebuthiuron and by sampling date. Tebuthiuron is a broad-leaf herbicide and the residual effect suppressed forbs compared with the control treatment as late as June 2003. The decline of forbs by sampling date was likely because of the seasonality of the cool-season annual forbs and the heavy July rainfall that initiated buffelgrass growth. Buffelgrass has shown the ability to outcompete native vegetation (Gonzales & Dodd 1979; Clarke et al. 2005) and likely outcompeted warm-season forbs to some degree in this experiment.

Although plots were not sampled in spring 2004, the temporary response of forbs in 2003 has implications

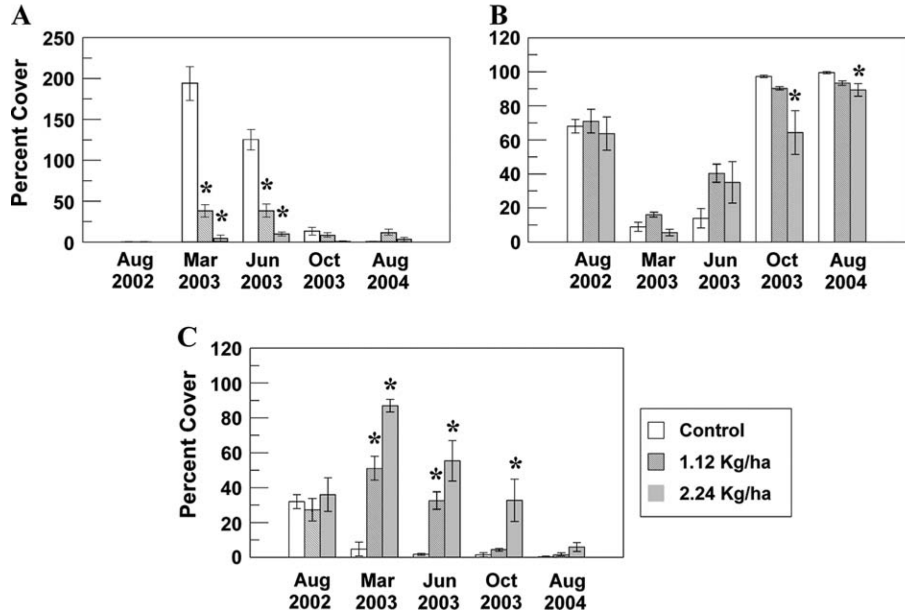

Figure 3. Percent canopy cover of (A) forbs, (B) *Pennisetum ciliare*, and (C) bare ground on plots sprayed with two rates of tebuthiuron on 9 October 2002 in Duval County, Texas. Plots were mowed on 2 September 2002 and sprayed with glyphosate on 18 September 2002 and 7 October 2002. Asterisks indicate significant ($p < 0.05$) differences between control treatment and herbicide treatment at that sampling date.

for wildlife habitat management. In south Texas, areas managed for quail are often disked to promote a temporary forb response that increases seeds upon which quail forage (Guthery 1986). Late fall or winter burns can also produce this response (Box & White 1969). The glyphosate treatment performed in October 2002 produced a similar effect through the spring of 2003. Glyphosate and similar herbicides may offer an alternative to disking, which creates heavy soil disturbance and can cause erosion (Guthery 1986), and to winter burning, which supports buffelgrass growth the following season (Hamilton & Scifres 1982).

Imazapic, picloram, and dicamba are not effective in controlling buffelgrass, at least under the environmental conditions that prevailed during our study. One reason for this failure may be that the herbicide was applied too late. Heavy July rainfall delayed the timing of the application and caused buffelgrass to quickly grow, and when herbicides were applied, the buffelgrass had grown from seed to a visually estimated height of 0.5–0.75 m. By this time, the buffelgrass may have been better able to withstand the treatments and abundant leaf material could have been shielded from the herbicides. Imazapic has been effective in other studies as a preemergent herbicide (Washburn et al. 2000) and may have been more useful in this study when applied in this manner. Other postemergent herbicides that were used for this experiment may not be effective enough at damaging buffelgrass to merit additional research on their efficacy for killing buffelgrass.

Four-flower trichloris established and persisted on a small portion of the plots treated with tebuthiuron. Presumably, this response is because of the high tolerance of the *Chloris* genus to tebuthiuron (Scifres & Mutz 1978). The same study found that plains bristlegrass also increased with tebuthiuron treatments, which was not found in this study. A mixture of native grasses composed exclusively of species from the genus *Chloris* may have a better response to tebuthiuron treatments.

Tebuthiuron may have value in restoring native plants in buffelgrass-dominated landscapes. The delayed recovery of buffelgrass and maintenance of bare ground are desirable characteristics for establishing native plants. Tebuthiuron is also effective at controlling brush species (Scifres et al. 1979), which would be an additional benefit to native grass restoration in areas where woody vegetation has steadily encroached on grassland ecosystems. Higher rates of tebuthiuron may increase its effectiveness for restoration. Scifres and Mutz (1978) noted that grass species of the genus *Chloris* were prevalent on plots where tebuthiuron rates as high as 4.48 kg/ha were applied.

Successful restoration models set forth by Dixon et al. (2002) and Daehler and Goergen (2005) in western Australia and Hawaii, United States, respectively, indicate that identifying effective herbicides and appropriate native vegetation are key elements to long-term restoration of areas dominated by buffelgrass. In this study, buffelgrass was highly resistant to herbicides that have been successfully implemented in replacement of exotics with natives. At the same time, native grasses have shown a susceptibility to an increase in buffelgrass. However, exploitation of the relationship between tebuthiuron and *Chloris* as well as the poor vigor of buffelgrass seeds may provide researchers with these essentials and increase the effectiveness of restoration in a range of areas dominated by buffelgrass.

Implications for Practice

- Following mortality of existing buffelgrass plants, eliminating at least one flush of seedlings may significantly reduce buffelgrass competition with native plants.
- Application of tebuthiuron may delay growth response of buffelgrass.
- Native grasses of the genus *Chloris* are resistant to applications of tebuthiuron and are recommended when this herbicide is applied.

Acknowledgments

The authors would like to thank the USDA-NRCS, the Jack R. and Loris J. Welhausen Experimental Station, and the San Antonio Livestock Exposition for cooperative funding. We would also like to thank K. Olenick and E. Grahmann for valuable assistance. Mention of a proprietary product does not constitute a guarantee or warranty of the product by Texas A&M University–Kingsville and does not imply its approval to the exclusion of other products that may also be suitable. This is publication number 06-133 of the Caesar Kleberg Wildlife Research Institute.

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