Native warm-season GRASS

and forb establishment using imazapic and 2,4-D

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Above: A red admiral (*Vanessa atalanta* L. [Lepidoptera: Nymphalidae]) on a purple coneflower (*Echinacea purpurea* (L.) Moench [Asteraceae])

Abstract

Of 7 herbicide mixtures applied pre- and post-emergence, a pre-emergence application of 0.07 kg active ingredient (ai) per ha (1 oz ai/ac) imazapic (Plateau) yielded the best establishment of 3 native warm-season grasses and 3 native forbs seeded on conventionally-tilled sites in Kentucky. Following this application, weed cover was reduced to < 5% during the first growing season, compared to > 95% in the control. After 2 growing seasons, plant density and percentage cover of little bluestem, big bluestem, and indiangrass both averaged 4.5X more than in the control. Illinois bundleflower, purple prairieclover, and lance-leaf coreposis were unaffected by the treatment, but purple coneflower density was reduced.

KEYWORDS: imazapic, little bluestem, big bluestem, indiangrass, Illinois bundleflower, purple prairieclover, lance-leaved coreopsis, purple coneflower

NOMENCLATURE: ITIS (1998)

Native warm-season grasses provide habitat for wildlife, quality summer hay and forage for livestock, and are components of important ecosystems like tallgrass prairie. Hectares of tallgrass prairie in the US have been reduced by 97%, mostly altered for row crops or converted to introduced cool-season pasture (Sampson and Knopf 1996). Interest in prairie restoration is rapidly growing (Lutz 1989). Planting native warm-season grasses and forbs is an integral component of prairie restoration (Packard and Mutel 1997).

Slow to establish, native warm-season grasses are extremely susceptible to weed competition during the initial growing season (McKenna and others 1991; Martin and others 1982). Pre-emergence and early post-emergence herbicide applications may improve establishment of native warm-season grasses from seeds by reducing weed interference. Pre-emergence applications of atrazine provided weed control and improved the establishment of big bluestem (*Andropogon gerardii* Vitman [Poaceae]) and switchgrass (*Panicum virgatum* L. [Poaceae]) (Martin and others 1982; Hintz and others 1988). Metolachlor, alone and in combination with atrazine, has been shown to increase big bluestem and sand bluestem (*Andropogon hallii* Hack. [Poaceae]) establishment during the initial growing season (Masters 1995).

Recently, imidazolinone herbicides have shown promise in enhancing native warm-season grass establishment. Several native warm-season perennial grass species are tolerant to this family of herbicides. Imazethapyr applied at the time of planting increased establishment of little bluestem (*Schizachryrium scoparium* (Michx.) Nash [Poaceae]) and big bluestem (Masters and others 1996). Imazapic, another imidazolinone herbicide, may be particularly useful in native warm-season grass establishment because several native warm-season grasses and native forbs are tolerant to this herbicide (Vollmer forthcoming). Masters and others (1996) found imazapic increased establishment of several native forbs in Nebraska.

Combinations of imazapic and other herbicides, applied pre-emergence or early during the post-emergence seedling stage, may increase establishment of native warm-season grasses and forbs from seeds. The combination of imazapic and a broad-leaf selective herbicide, such as 2,4-D, may control a wider variety of "weedy" grasses and forbs and therefore increase native-warm season grass establishment during the initial growing season if the grasses and/or forbs being established are tolerant to the herbicides. Our study objective was to determine the necessary rates of imazapic and imazapic plus 2,4-D applied at the time of seeding (pre-emergence) or after seedling emergence (post-emergence) to establish 3 native grasses and 4 native forbs following conventional tillage.

TABLE 1

Herbicide mixtures and rates

Imazapic [a] ***+ 2,4-D amine***
(kg active ingredient (ai) per ha [b])
0 + 0 (untreated check)
0.07 + 0
0.14 + 0
0.21 + 0
0.07 + 0.07
0.14 + 0.14
0.21 + 0.21
0.14 [c] + 0

[a] Plateau herbicide (imazapic) in liquid formulation.
[b] Convert kg ai / ha to ounces of product per acre by multiplying the value by 57.
[c] Plateau 70DG (dry formulation).

Materials and Methods

Experiments were conducted at 3 study sites on the Bluegrass Sportsman's League property, located in the Inner Bluegrass physiographic region in Jessamine County, Kentucky. The soil at site #1 was a McAfee silt loam (fine, mixed, mesic, Mollic Hapludalfs), the site #2 soil was a Faywood silt loam (fine, mixed, active, mesic, Typic Hapludalfs), and soil at site #3 was a Fairmount flaggy silty clay (clayey, mixed, mesic, Lithic Hapludolls). The sites were hayfields dominated by tall fescue (*Festuca arundinacea* Shreb. [Poaceae]) before treatment applications. Conventional tillage methods were used to prepare a firm seedbed in spring 1998: each site was deep moldboard plowed on 5 May, disked to prepare a seedbed on 4 June, and cultipacked on 5 June.

The experiment was designed as a randomized complete block design with 3 replicates at each site. Little bluestem, big bluestem, and indiangrass (*Sorghastrum nutans* (L.) Nash [Poaceae]) were hand-planted at 61, 39, and 41 pure live seeds (PLS) per m^2 (5.6, 3.6, and 3.8 PLS/ft^2) respectively, into 3.1- by 1.5-m (10- by 5-ft) plots on 10 June 1998 (Capel 1995). Illinois bundleflower (*Desmanthus illinoensis* (Michx.) MacMill. [Fabaceae]), purple prairieclover (*Dalea purpurea* Vent. [Fabaceae]), lance-leaved coreopsis (*Coreopsis lanceolata* L. [Asteraceae]), and purple coneflower (*Echinacea purpurea* (L.) Moench [Asteraceae]) at 14, 69, 50, and 27 PLS/m^2 (1.3, 6.4, 4.6, and 2.5 PLS/ft^2) respectively were hand-planted into 1.5- by 0.8-m (5- by 2.5-ft) plots on 10 June 1998.

Seven herbicide mixtures and an untreated check (Table 1) were implemented as a pre-emergence and a post-emergence treatment in the grass and forb plots. Herbicides were mixed with water and methylated soybean oil (a surfactant) at 2.34 l/ha (1 qt/ac) and broadcast sprayed with a Solo 435 backpack sprayer delivering a spray volume of 187 l/ha (20 gal/ac) at 414 kPa (60 psi) through a TeeJet 8003 flat fan nozzle. Pre-emergence herbicide mixtures were applied to the appropriate grass and forb plots on 12 June 1998 under environmental conditions consisting of 27 °C (81 °F) air temperature, 5 to 8 km/h (3 to 5 mph) winds, and 87% relative humidity. Post-emergence herbicides were applied to the appropriate grass and forb plots on 22 August 1998 under environmental conditions consisting of 28 °C (82 °F) air temperature, 2 to 3 km/h (1 to 2 mph) winds, and 56% relative humidity. Most planted native warm-season grass and forb seedlings were in the 4- to 6-leaf stage and approximately 10 to 15 cm (4 to 6 in) tall at post-emergence application time. Weed cover (consisting of several grasses and forbs) was considerable (90% to 100%) and weeds were 40 to 120 cm (16 to 47 in) tall.

Grass and forb plots with a pre-emergence herbicide application were described 2, 4, and 11 mo after herbicide treatment (MAT; Table 2). Grass and forb plots with a post-emergence herbicide application were described before herbicide application and 2 and 9 MAT (Table 2). Grass and forb density (plants per m^2) and

TABLE 2

Treatment evaluation dates

	Year 1		***Year 2***
Treatment timing	***12 Aug 1998***	***19 Oct 1998***	***20 May 1999***
Pre-emergence	2 MAT [a]	4 MAT	11 MAT
Post-emergence	—	2 MAT	9 MAT

[a] MAT = months after herbicide treatment.

TABLE 3

Mean densities (plants per m²) of native grasses after 7 herbicide treatments

Herbicide mixtures and rates (kg ai/ha)	Little bluestem Year 1 2 MAT[a]	Little bluestem Year 1 4 MAT	Little bluestem Year 2 11 MAT	Big bluestem Year 1 2 MAT	Big bluestem Year 1 4 MAT	Big bluestem Year 2 11 MAT	Indiangrass Year 1 2 MAT	Indiangrass Year 1 4 MAT	Indiangrass Year 2 11 MAT
0 + 0 (untreated check)	4[b] a[c]	2 a	1 a	7 a	2 a	3 a	7 a	1 a	2 a
0.07 imazapic[d,e]	17 b	12 b	8 b	20 c	12 b	10 b	19 cd	9 b	8 c
0.14 imazapic	14 b	11 b	7 b	15 b	11 b	8 b	21 d	12 b	7 bc
0.21 imazapic	18 b	12 b	8 b	16 bc	12 b	9 b	14 bc	9 b	6 b
0.07 imazapic + 0.07 2,4-D[f]	16 b	12 b	8 b	13 b	12 b	9 b	16 bcd	10 b	6 bc
0.14 imazapic + 0.14 2,4-D	17 b	10 b	8 b	13 b	11 b	8 b	15 bc	9 b	6 b
0.21 imazapic + 0.21 2,4-D	19 b	13 b	9 b	12 ab	11 b	8 b	12 b	8 b	7 bc
0.14 imazapic[g]	17 b	14 b	8 b	11 ab	9 b	8 b	14 bc	10 b	6 b

[a] MAT=months after herbicide treatment.
[b] Convert plants per m² to plants per ft² by dividing the value by 10.8.
[c] Means within the same column with the same letter are not different ($P > 0.05$) according to Fisher's protected LSD.
[d] Plateau herbicide (imazapic) in liquid formulation.
[e] Convert kg ai/ha to ounces of product per acre by multiplying the value by 57.
[f] Amine formulation.
[g] Plateau 70DG (dry formulation).

grass percent coverage were determined in one 1-m² herbaceous sampling plot centered in each plot (Bonham 1989). The presence of multi-tillered plants may have slightly increased the density values during later evaluations. Percent coverage was measured during the second growing season on 20 May 1999 (Bonham 1989).

Each species of grass and forb was analyzed separately using ANOVA procedures to test for differences in seedling density due to site effects, herbicide effects, and site by herbicide interactions (Neter and others 1990). Fisher's protected LSD methods were used for multiple comparisons when overall treatment effects were significant at the $\alpha = 0.05$ level (SAS Institute Inc 1985).

Results and Discussion

In most comparisons, significant site by treatment interactions were absent. Therefore, data across sites were pooled for treatment analyses and data across treatments were pooled for site analyses. In situations with significant site by treatment interactions, data were analyzed separately for each site.

Native Grasses

Pre-emergence Treatments

Pre-emergence herbicide mixtures applied at planting increased density and coverage of native warm-season grasses compared to the untreated check (Tables 3 and 4). Imazapic at 0.07, 0.14, and 0.21 kg active ingredient (ai) per ha (1, 2, and 3 oz ai/ac) alone or combined with an equal rate of 2,4-D resulted in mean seedling densities of little bluestem, big bluestem, and indiangrass that exceeded 5 plants per m² (0.5/ft²) at 2, 4, and 11 MAT (Table 3). Mean percent cover of the 3 grasses in

TABLE 4

Mean coverage (%) of native grasses 11 mo after pre-emergence herbicide applications

Herbicide mixtures and rates (kg ai/ha)	Little bluestem[a] Site #1	Little bluestem Site #2	Little bluestem Site #3	Big bluestem	Indiangrass
0 + 0 (untreated check)	5 a[b]	3 a	3 a	13 a	10 a
0.07 imazapic[c,d]	37 bc	38 b	67 b	57 c	43 c
0.14 imazapic	30 b	38 b	52 bc	46 bc	38 bc
0.21 imazapic	45 cd	32 b	42 b	49 bc	31 c
0.07 imazapic + 0.07 2,4-D[e]	55 cd	33 b	48 bc	51 bc	34 bc
0.14 imazapic + 0.14 2,4-D	48 cd	35 b	37 b	43 bc	30 b
0.21 imazapic + 0.21 2,4-D	63 d	42 b	38 b	44 bc	31 b
0.14 imazapic[f]	60 d	28 b	52 bc	41 b	28 b

[a] The data for little bluestem are presented separately for each site because the site by treatment interaction was significant.
[b] Means within the same column with the same letter are not different ($P > 0.05$) according to Fisher's protected LSD.
[c] Plateau herbicide (imazapic) in liquid formulation.
[d] Convert kg ai/ha to ounces of product per acre by multiplying the value by 57.
[e] Amine formulation.
[f] Plateau 70DG (dry formulation).

all 7 pre-emergence plots ranged from 30% to 67% at 11 MAT (Table 4). Grass plants in this study were approximately 5 to 15 cm (2 to 6 in) tall at 2 MAT and 15 to 90 cm (6 to 35 in) tall at 4 and 11 MAT. In addition, > 80% of the grass plants produced seeds by 4 MAT. Launchbaugh and Owensby (1970) reported that native grass seedling densities > 10 plants per m^2 (0.9/ft^2) during the initial year of establishment resulted in grazable stands the following year in Kansas. The first winter season after planting native warm-season grasses can be a critical time in determining establishment success. The high density and coverage levels of all 3 native grasses during 1999 (the second year of our study) suggests "overwinter" mortality was low. Therefore, little bluestem, big bluestem, and indiangrass were successfully established by the second growing season in plots treated with a pre-emergence herbicide.

Little bluestem, big bluestem, and indiangrass were tolerant to imazapic and 2,4-D applied at the time of planting. Mean plant densities of these 3 grasses at 2, 4, and 11 MAT were similar ($P > 0.05$) among the 7 pre-

TABLE 5

Mean densities (plants per m^2) of native grasses averaged across the 7 pre-emergence herbicide treatments 4 mo after pre-emergence treatments

Site	Little bluestem	Big bluestem	Indiangrass
1	15.3 a [a,b]	14.1 a	7.0 a
2	5.3 b	5.3 b	0.4 b
3	11.3 c	10.5 c	11.3 a

[a] Convert plants per m^2 to plants per ft^2 by dividing the value by 10.8.
[b] Means within the same column with the same letter are not different ($P > 0.05$) according to Fisher's protected LSD.

emergence herbicide mixtures, with 2 exceptions (Table 3). Pre-emergence applications of imazapic alone or in combination with 2,4-D did not affect seed germination, seedling mortality, or growth of native warm-season grass seedlings in this study.

Plots treated with pre-emergence herbicides were essentially free of weeds (< 5% cover) throughout the initial growing season (Figure 1). In contrast, untreated plots were dominated by large amounts (95% to 100% cover) of "weedy" annual grasses and forbs. Severe weed interference apparently reduced the number of native grass seedlings in untreated plots.

Plant community composition of "weedy" species varied among the 3 study sites. Hairy crabgrass (*Digitaria sanguinalis* (L.) Scop. [Poaceae]),

Figure 1 • Top: Native warm-season grasses, like this big bluestem, dominated plots that received a pre-emergence herbicide application (0.14 kg ai/ha (8 oz/ac) imazapic). Bottom: Control (untreated) plots were dominated by weeds, like yellow-brown nut sedge, and few native warm season grasses survived.

meadow foxtail (*Alopecurus pratensis* L. [Poaceae]), yellow-brown nut sedge (*Cyperus esculentus* L. [Cyperaceae]), and three-seeded mercury (*Acalypha virginia* var. *rhomboidea* (Raf.) Copperrider [Euphorbiaceae]) dominated site #1. Johnsongrass (*Sorghum halepense* (L.) Pers. [Poaceae]) and giant foxtail (*Setaria faberi* Herrm. [Poaceae]) dominated site #2, whereas giant foxtail, hairy crabgrass, horsenettle (*Solanum carolinense* L. [Solanaceae]), and common ragweed (*Ambrosia artemisiifolia* L. [Asteraceae]) dominated site #3.

TABLE 6

Mean densities and standard errors ($s_{\bar{x}}$) of indiangrass 9 mo after pre-emergence herbicide treatments

Treatments	Plants per m^2 [a]
Untreated check	1.9, $s_{\bar{x}}$ = 0.3 a [b]
0.21 kg ai/ha imazapic	3.2, $s_{\bar{x}}$ = 0.8 b
0.14 kg ai/ha imazapic + 0.14 kg ai/ha 2,4-D	3.3, $s_{\bar{x}}$ = 0.8 b
0.21 kg ai/ha imazapic + 0.21 kg ai/ha 2,4-D	4.3, $s_{\bar{x}}$ = 1.0 b

[a] Convert plants per m^2 to plants per ft^2 by dividing the value by 10.8.
[b] Means within the same column with the same letter are not different ($P > 0.05$) according to Fisher's protected LSD.

TABLE 7

Average mean densities (plants per m^2) of native grasses by site 2 mo after post-emergence herbicide treatments

Site	Little bluestem	Big bluestem	Indiangrass
1	6.9 a [a,b]	11.1 a	7.0 a
2	0.4 b	0.5 b	0.4 b
3	5.3 b	4.4 c	4.1 c

[a] Convert plants per m^2 to plants per ft^2 by dividing the value by 10.8.
[b] Means within the same column with the same letter are not different ($P > 0.05$) according to Fisher's protected LSD.

Mean seedling densities for the 3 planted native grasses varied considerably among the sites during the initial growing season (Table 5). The variation in seedling density among sites may have resulted from differences in plant community composition (that is, different "weedy" species), inherent site productivity (that is, nutrient levels), or other unknown factors.

Using conventional tillage and a pre-emergence application of imazapic at 0.07 kg ai/ha (1 oz ai/ac), native warm-season grasses were successfully established during the initial growing season in our study. However, other studies suggest a higher rate (0.21 kg ai/ha [3 oz ai/ac]) of imazapic is necessary for native warm-season grass establishment when no-till seeding methods are used (Washburn and others 1999). No-till situations require more imazapic to kill existing vegetation (that is, tall fescue) and provide post-emergence weed control. In contrast, plowing and disking for seedbed preparation removes existing vegetation and the herbicide is needed only for post-emergence weed control in conventional tillage situations.

Post-emergence Treatments

Post-emergence herbicide mixture applications did not increase density or coverage of native warm-season grass seedlings compared to plots receiving no herbicide. Mean seedling densities of little bluestem, big bluestem, and indiangrass were similar ($P > 0.05$) among the 7 post-emergence herbicide mixtures ($\bar{x} = 2.3$ to 7.1 plants per m^2 [0.2 to 0.7/ft^2]) and the untreated check ($\bar{x} = 1.2$ to 3.0 plants per m^2 [0.1 to 0.3/ft^2]) at 2 and 9 MAT, with 1 exception. Three herbicide treatments increased density of indiangrass over the untreated check (Table 6). Percent cover of the 3 native grasses in the untreated check (6.7% to 14.1%) was similar ($P > 0.05$) to the 7 post-emergence plots (11.3% to 36.1%) at 9 MAT. Although not statistically different, all plots receiving a post-emergence herbicide application did have mean seedling densities somewhat higher than the untreated check at 2 and 9 MAT and higher cover at 9 MAT, suggesting the possibility of some benefit from a reduction in weed interference. Native grass plants in our study were approximately 15 to 60 cm tall at 2 and 9 MAT. In addition, many native warm-season grass plants produced seeds by 2 MAT. Imazapic at 0.07, 0.14, and 0.21 kg ai/ha (1, 2, and 3 oz ai/ac) alone or combined with an equal rate of 2,4-D resulted in mean seedling densities of little bluestem, big bluestem, and indiangrass ranging from 2 to 5 seedlings per m^2 (0.2 to 0.5/ft^2) at 9 MAT. Compared to plots receiving a pre-emergence application, the post-emergence herbicide applications were less successful in establishing native grasses by the second growing season.

Little bluestem, big bluestem, and indiangrass appear to be tolerant to imazapic and 2,4-D applied post-emergence during the initial growing season. Post-emergence applications of imazapic alone or in combination with 2,4-D apparently did not result in seedling mortality of native warm-season grasses. Also, no indications of injury (for example, browning) to native warm-season grass plants by herbicide applications was evident during this study.

Mean seedling densities for the 3 planted grass species varied considerably among the 3 sites during the first 2 growing seasons (Table 7). Overall densities of little bluestem, big bluestem, and indiangrass at site #1 were higher ($P < 0.05$) than at sites #2 and #3 when evaluated at 9 MAT. Such variation existed in the pre-treatment period prior to application of post-emergence herbicide mixtures, suggesting differences in seedling density are not due to variation in post-emergence herbicide activity among the 3 sites. Variation in seedling density among

TABLE 8

Mean densities (plants per m^2) and standard errors ($s_{\bar{x}}$) of Illinois bundleflower and purple prairieclover after post-emergence herbicide applications

	4 MAT [a]		11 MAT	
Treatment	Illinois bundleflower	Purple prairieclover	Illinois bundleflower	Purple prairieclover
Untreated Check	1.8 [a,b], $s_{\bar{x}} = 1.0$ a [c]	1.9, $s_{\bar{x}} = 1.0$ a	5.2, $s_{\bar{x}} = 0.7$ a	2.7, $s_{\bar{x}} = 1.4$ a
Herbicides	1.7 to 3.4 a	1.9 to 5.2 a	3.8 to 5.8 a	2.2 to 3.4 a

[a] MAT = months after herbicide treatment.
[b] Convert plants per m^2 to plants per ft^2 by dividing the value by 10.8.
[c] Means within the same column with the same letter are not different ($P > 0.05$) according to Fisher's protected LSD.

TABLE 9

Mean densities (plants per m²) of lance-leaved coreopsis after herbicide treatments

Herbicide mixtures and rates (kg ai/ha)	Pre-emergence applications Year 1 2 MAT [a]	Pre-emergence applications Year 1 4 MAT	Pre-emergence applications Year 2 11 MAT	Post-emergence applications Year 1 2 MAT	Post-emergence applications Year 2 9 MAT
0 + 0 (untreated check)	5.5 [b] a [c]	8.0 a	16.4 a	7.5 a	16.0 a
0.07 imazapic [d,e]	4.2 ab	6.6 ab	12.4 abc	5.9 ab	13.9 ab
0.14 imazapic	3.3 abc	4.7 bcd	14.2 ab	4.3 abc	13.0 abc
0.21 imazapic	2.4 bc	6.2 abc	12.2 abc	4.7 ab	11.3 abc
0.07 imazapic + 0.07 2,4-D [f]	2.7 bc	4.8 bcd	9.3 bc	3.2 bc	8.3 cd
0.14 imazapic + 0.14 2,4-D	1.9 bc	3.4 cd	10.7 bc	3.4 bc	10.2 bcd
0.21 imazapic + 0.21 2,4-D	1.1 c	2.2 d	8.4 c	1.3 c	6.6 d
0.14 imazapic [g]	2.7 bc	4.4 bcd	9.9 bc	4.0 bc	10.4 bcd

[a] MAT = months after herbicide treatment.
[b] Plants per m² can be converted to plants per ft² by multiplying the value by 10.8.
[c] Means within the same column with the same letter are not different ($P > 0.05$) according to Fisher's protected LSD.
[d] Plateau herbicide (imazapic) in liquid formulation.
[e] Convert kg ai/ha to ounces of product per acre by multiplying the value by 57.
[f] Amine formulation.
[g] Plateau 70DG (dry formulation).

sites may have resulted from differences in plant community composition (for example, different "weedy" species), inherent soil productivity (for example, nutrient levels), soil texture, the amount of surface erosion, or other unknown factors.

Native Forbs

Native forb tolerance to imazapic and 2,4-D applied at the time of planting (pre-emergence) or early in the seedling establishment period (post-emergence) varied by species. The application of pre-emergence herbicides did not change the number of Illinois bundleflower and purple prairieclover plants compared to plots receiving no herbicide.

Post-emergence herbicide applications did not change the density of Illinois bundleflower and purple prairieclover compared to plots without herbicides (Table 8). Mean seedling densities (plants per m²) and standard error ($s_{\bar{x}}$) of Illinois bundleflower ($\bar{x} = 5.6$, $s_{\bar{x}} = 1.0$; [0.5/ft²]) and purpleprairie clover ($\bar{x} = 3.3$, $s_{\bar{x}} = 1.5$; [0.3/ft²]) were not different ($P > 0.05$) than the 7 post-emergence herbicide mixtures ($\bar{x} = 2.2$ to 6.1 plants per m² [0.2 to 0.6/ft²]) during the second growing season (9 MAT). Pre- or post-emergence applications of imazapic alone or in combination with 2,4-D apparently did not hamper seed germination, result in seedling mortality, or reduce establishment of these 2 legumes. This result is consistent with the findings of Masters and others (1996) who found that imazapic at 0.07 kg ai/ha enhanced establishment of Illinois bundleflower and purple prairieclover in Nebraska. Forb plots treated with pre-emergence herbicides were essentially free of weeds (< 5% cover) throughout the initial growing season. Similar to the grass plots, untreated forb plots were dominated by large amounts (95% to 100% cover) of "weedy" annual grasses and forbs. However, unlike native grasses, these 2 forbs appear to be more tolerant of the severe weed interference and established equally well in untreated plots.

Lance-leaved coreopsis appears to be tolerant only to imazapic. Mean densities of lance-leaved coreopsis seedlings were reduced ($P < 0.05$) by pre- and post-emergence applications of imazapic plus 2,4-D at all levels (Table 9). Pre- or post-emergence applications of imazapic in combination with 2,4-D apparently resulted in seedling mortality, an expected result given the selectivity of 2,4-D for broadleaf forbs.

Purple coneflower appears to be less tolerant to pre- and post-emergence applications of imazapic and imazapic plus 2,4-D mixtures than the other forb species. Density of purple coneflower in untreated check plots was higher ($P < 0.05$) than the density of purple coneflower in 6 of 7 pre-emergence plots at 11 MAT (Table 10). Similarly, application of 6 of 7 post-emergence herbicide mixtures resulted in purple coneflower densities less than ($P < 0.05$) the density of purple coneflower in the plots that received no herbicide at 9 MAT (Table 10). Although the herbicide applications did not completely remove the purple coneflower plants during the study, using imazapic and imazapic plus 2,4-D mixtures applied pre- and post-emergence did reduce establishment success.

Practical Applications

Native warm-season grasses (little bluestem, big bluestem, and indiangrass) and native forbs (Illinois bundleflower, purple prairieclover, and lance-leaved coreopsis) can be successfully established in 2 growing

TABLE 10

Mean densities (plants per m²) of purple coneflower

Herbicide mixtures and rates (kg ai/ha)	Pre-emergence applications							Post-emergence applications			
	Year 1						Year 2	Year 1			Year 2
	2 MAT [a]			4 MAT			11 MAT	2 MAT			9 MAT
	Site #1 [b]	Site #2	Site #3	Site #1	Site #2	Site #3		Site #1	Site #2	Site #3	
0 + 0 (untreated check)	3.7 [c] a [d]	3.1 a	0.6 a	2.0 a	3.7 a	2.0 ab	4.2 a	1.7 a	4.0 a	2.0 a	4.2 a
0.07 imazapic [e]	3.2 a	0.6 b	0.0 a	4.6 a	0.6 b	0.3 c	2.4 bc	4.3 a	0.6 bc	0.0 c	2.1 b
0.14 imazapic	2.6 a	0.3 b	0.0 a	3.1 a	1.7 b	0.0 c	2.2 c	2.6 a	2.0 bc	0.0 c	2.5 b
0.21 imazapic	1.1 a	0.6 b	0.0 a	1.7 a	0.6 b	0.6 c	2.5 bc	2.6 a	0.3 c	0.9 bc	2.2 b
0.07 imazapic + 0.07 2,4-D [f]	0.9 a	0.9 b	0.3 a	2.0 a	1.7 b	2.3 a	2.8 bc	0.9 a	2.9 ab	2.3 a	3.3 ab
0.14 imazapic + 0.14 2,4-D	4.3 a	0.0 b	0.0 a	2.8 a	0.6 b	0.9 bc	3.4 ab	3.5 a	0.9 bc	1.4 ab	2.4 b
0.21 imazapic + 0.21 2,4-D	2.9 a	0.9 b	0.0 a	2.6 a	0.3 b	0.0 c	2.1 c	1.2 a	0.3 c	0.6 bc	1.9 b
0.14 imazapic [g]	0.3 a	1.1 b	0.0 a	0.6 a	1.7 b	0.0 c	2.0 c	0.9 a	2.6 abc	0.0 c	2.1 b

[a] MAT = months after herbicide treatment.
[b] The data are presented separately for each site when the site by treatment interaction was significant.
[c] Convert plants/m² to plants/ft² by multiplying the value by 10.8.
[d] Means within the same column with the same letter are not different ($P > 0.05$) according to Fisher's protected LSD.
[e] Convert kg ai/ha to ounces of product per acre by multiplying the value by 57.
[f] Amine formulation.
[g] Plateau 70DG (dry formulation).

seasons following conventional tillage and a pre-emergence application of imazapic at 0.07 kg ai/ha (4 oz of Plateau per ac). Post-emergence applications of imazapic and imazapic plus 2,4-D during the first growing season did not enhance establishment of native warm-season grasses, did not effect Illinois bundleflower and purple prairieclover, but decreased the density of lance-leaved coreopsis and purple coneflower. Consequently, Illinois bundleflower, purple prairieclover, and lance-leaved coreopsis may be appropriate choices to include in native warm-season grass and forb seed mixtures planted in conjunction with a pre-emergence imazapic application.

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