Safening of Native Grass to Herbicides by Using Carbon Bands

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Abstract

Greenhouse and field experiments were conducted to evaluate the use of a **carbon band** to provide a "safe zone" for seedling emergence and growth of three native grass species. 'KIKA677' streambed bristlegrass germplasm, 'Alamo' switchgrass, and 'Waelder' shortspike windmillgrass germplasm were used in combination with several PRE- and POST-applied herbicides including cloransulam, flumioxazin, imazapic, imazethapyr, and 2,4-D. In a greenhouse experiment, switchgrass emergence was improved when a **carbon band** was used with imazapic or imazethapyr at 0.04 and 0.07 kg ai ha^{-1} or 2,4-D at 2.12 kg ae ha^{-1}. Windmillgrass emergence was improved when **carbon** was used in combination with flumioxazin at 0.05 and 0.1 kg ai ha^{-1}, imazapic at 0.04 and 0.07 kg ha^{-1}, imazethapyr at 0.07 kg ha^{-1}, and 2,4-D at 1.06 kg ha^{-1}, whereas bristlegrass emergence was improved when **carbon** was used in combination with flumioxazin at 0.1 kg ai ha^{-1}, imazapic at both rates, and imazethapyr at 0.04 kg ha^{-1}. Field studies indicated that flumioxazin at 0.05 and 0.1 kg ha^{-1}, imazapic at 0.04 kg ha^{-1}, and imazethapyr at 0.04 and 0.07 kg ha^{-1}, were safened for bristlegrass and switchgrass emergence when used with **carbon**. Windmillgrass emergence and growth were improved when **carbon** was used in combination with flumioxazin at 0.1 kg ha^{-1}.

Nomenclature: Cloransulam; 2,4-D; flumioxazin; imazapic; imazethapyr; switchgrass,*Panicum virgatum* L. 'Alamo'; streambed bristlegrass, *Setaria leucopila* (Scribn. & Merr.) K. Schum. 'KIKA677'; shortspike windmillgrass, *Chloris subdolichostachya*Nash 'Waelder'.

Resumen

Se realizaron experimentos de invernadero y de campo para evaluar el uso de una banda de carbón activado para propiciar una 'zona segura' para la emergencia de plántulas y el crecimiento de tres especies de zacate nativas. El germoplasma 'KIKA677' de *Setaria leucopila*, 'Alamo' de *Panicum virgatum*, y 'Waelder' de *Chloris subdolichostachya*fueron usados en combinación con varios herbicidas aplicados PRE y POST incluyendo cloransulam, flumioxazin, imazapic, imazethapyr y 2,4-D. En un experimento de invernadero, la emergencia de *P. virgatum* mejoró cuando se usó una banda de carbón con imazapic o imazethapyr a 0.04 y 0.07 kg ha^{-1} o 2,4-D a 2.12 kg ha^{-1}. La

emergencia de *C. subdolichostachya* fue mejorada cuando se usó carbón en combinación con flumioxazin a 0.05 y 0.1 kg ha^{-1}, imazapic a 0.04 y 0.07 kg ha^{-1}, imazethapyr a 0.07 kg ha^{-1} y 2,4-D a 1.06 kg ha^{-1}; mientras la emergencia de *S. leucopila* mejoró cuando se usó carbón en combinación con flumioxazin a 0.1 kg ha^{-1}, imazapic a ambas dosis e imazethapyr a 0.04 kg ha^{-1}. Estudios de campo indicaron que flumioxazin a 0.05 y 0.1 kg ha^{-1}, imazapic a 0.04 kg ha^{-1} e imazethapyr a 0.04 y 0.07 kg ha^{-1} fueron seguros para la emergencia de *S. leucopila* y *P. virgatum* cuando se usaron con carbón. La emergencia y crecimiento de *C. subdolichostachya* mejoraron cuando el carbón fue usado en combinación con flumioxazin a 0.1 kg ha^{-1}.

The grasslands of North America, at one time among the most diverse and floristically rich communities in the world, are now among the most reduced (Jordan et al. 1988; Masters et al. 1996). Reasons for the reduction of these grasslands include conversion to cropland and overstocking of domestic livestock (Masters et al. 1996). More than 11.6 million ha of tallgrass prairie in Iowa were converted to cropland between 1825 and 1920 (Smith 1992) and in Nebraska about 40%, or 7.7 million ha, of mixed-grass and tallgrass prairies has been converted to cropland (Masters et al. 1996).

Grassland ecosystems have the potential to provide high-quality forage for livestock as well as habitat for wildlife, water, and recreation, and to serve as a repository for diverse native plant germplasm (Masters et al. 1996). To realize this potential, strategies are needed to reestablish native grasses over large areas of degraded grasslands and marginal cropland. Current guidelines for grassland revegetation are usually anecdotal, based on experiences of practitioners (Betz 1986; Mlot 1990; Schramm 1992; Shirley 1994). These practitioners consistently indicate that weed interference is the primary obstacle to efficient and effective grassland restoration (Masters et al. 1996). Because native grasses are slow growing, weeds compete with these plants during establishment.

One approach to reducing weed pressure during establishment is the use of activated **carbon** slurry sprayed in approximately a 3-cm **band** to provide a “safe zone” for the perennial grasses when PRE-applied herbicides are used. Activated **carbon** readily absorbs many organic compounds (Fishel 1996;Hassler 1963; Smisek and Cerny 1970) and a wide range of uses of activated **carbon** in conjunction with herbicides have been reported (Burr et al. 1972; Lee 1973; Linscott and Hagin 1967; Rolston et al. 1979a,b). When activated **carbon** was sprayed in a slurry as a narrow **band** above the seed row, it protected perennial grasses (Burr et al. 1972; Lee 1973), subterranean clover (*Trifolium subterraneum*L.) (Kay 1972), and rose clover (*Trifolium hirtum* All.) (Kay 1972) from PRE-applied nonselective herbicides. Alfalfa (*Medicago sativa* L.) has previously been successfully established by use of the**carbon band** technique with methylthio-*s*-triazine herbicide (Linscott and Hagin 1967). However, atrazine was injurious when used with activated **carbon** at the rate of 100 kg ha^{-1} in the **band** (Linscott and Hagin 1967). In 1977, an estimated 6,300 ha of perennial grass seed were established with activated **carbon** and diuron in Oregon (Rolston et al. 1979a,b). In addition, **carbon banding** in combination with labeled herbicides has been used in the Northwest for establishment of blue wildrye (*Elymus glaucus* Buckley), which is a rapidly developing, short-lived perennial bunchgrass native to the central and western United States (Darris et al. 1996).

Cloransulam applied PRE and POST controls broadleaf weeds such as common cocklebur (*Xanthium strumarium* L.), morningglories (*Ipomoea* spp.), ragweeds (*Ambrosia* spp.), and velvetleaf (*Abutilon theophrasti* Medicus) (Askew et al. 1999; Franey and Hart 1999; Oliver et al. 1997). Flumioxazin applied PRE was shown to control morningglory, prickly sida (*Sida spinosa* L.), and Florida beggarweed [*Desmodium tortuosum* (Sw) DC.] (Scott et al. 2001), whereas in Texas, control of pitted morningglory [*Ipomoea lacunosa* L.] was greater than 75% with PRE applications of flumioxazin (Grichar and Colburn 1996).

Several studies have shown that certain imidazolinone herbicides, such as imazapic and imazethapyr, can reduce weed interference and facilitate rapid establishment of some native legumes and warm-season grasses (Beran et al. 1999, 2000; Masters et al. 1996). The imidazolinone herbicides have been used to reduce competition of weeds in the establishment of the native legume, Illinois bundleflower [*Desmanthus illinoensis* (Michx.) MacMill.] throughout the Great Plains (Beran et al. 2000; Masters et al. 1996).Masters et al. (1996) reported that the emergence of Illinois bundleflower seedlings was greater in imazapic- and imazethapyr-treated plots than in plots not treated with herbicide. They also reported that imazapic reduced Illinois bundleflower emergence compared to imazethapyr, but the adverse impact on emergence became less apparent as the growing season progressed. Beran et al. (2000) reported similar results when Illinois bundleflower was planted in mixtures with big bluestem (*Andropogon gerardii*Vitman var. gerardii). In these studies, imazapic only caused stunting of bundleflower and did not cause any death. They concluded that imazapic could effectively be used in bundleflower establishment.

The plant growth regulator herbicide 2,4-D is widely used for broadleaf weed control in corn (*Zea mays*L.), sorghum [*Sorghum bicolor* (L.) Moench], small grains, and pasture (Anderson et al. 2004). Other herbicides are often added to 2,4-D to improve the spectrum of weed control (Culpepper et al. 2001;Hutto et al. 2000). Hutto et al. (2000) reported that the addition of 2,4-D amine to imazapic increased the control of Carolina geranium (*Geranium carolinianum* L.) compared with imazapic alone. The above mentioned herbicides provide excellent control of many broadleaf weeds that can be found in a pasture situation where native grasses are trying to be established (W. J. Grichar, J. Lloyd-Reilley, J. Rahmes, W. R. Ocumpaugh, and J. L. Foster, unpublished data).

Three native grasses have shown promise for establishment and use in the restoration of native grasses in the south Texas area. These grasses will add some important tools to the arsenal in trying to diversify invasive grass monocultures and greatly improve seed mixes for producers desiring both wildlife and livestock benefit. Switchgrass (*Panicum virgatum* L.) is a tall perennial bunchgrass with culms to 2 m in height found in moist lowlands in all regions of the United States except the Pacific Coast (Gould 1975). It provides good livestock forage as well as providing ground nesting cover and seed for birds and is adapted in Texas where rainfall is 635 mm or more per year. Switchgrass performs well on all kinds of soils, from clays to fine sands, and is easy to establish except where severe weed competition exists (Gould 1975). Streambed bristlegrass [*Setaria leucopila* (Scribn. & Merr.) K. Schum.] is a stout perennial bunchgrass with culms up to 1 m in height and is abundant in prairie associations on clay and clay loam soils. Its large, hard seed provides good seed for birds, and its forage is good for livestock and wildlife. Streambed bristlegrass is adapted to south Texas where rainfall is 450 mm or greater (Gould 1975). Shortspike windmillgrass (*Chloris subdolichostachya* Nash) is a warm-season native perennial grass that is found in Texas, New Mexico, and northern Mexico (Gould 1975). It is a strongly stoloniferous perennial grass with culms to 70 cm in height and plants of hooded windmillgrass will produce seed monthly from May to November under favorable conditions (Correl and Johnson 1996). It is found primarily on sandy and sandy loam sites across Texas, provides forage for livestock, and is particularly useful for erosion control on Texas roadsides (Correl and Johnson 1996).

Little or no research could be found on the use of **carbon bands** on the establishment of the native grasses (switchgrass, streambed bristlegrass, and shortspike windmillgrass). Therefore, the objectives of this research were to determine the tolerance of the native grasses to selected PRE-applied herbicides in combination with or without activated **carbon bands**.

Materials and Methods

Greenhouse Experiments

Two greenhouse experiments were conducted in 2007 at the Kika de la Garza Plant Materials Center near Kingsville, TX. Victoria clay soil (fine, montmorillonitic, thermic Udic Pellusterts) with 1% organic matter and pH of 6.8 to 7.0 was collected from a field located on the Plant Materials Center, sifted of rocks, etc., and then sterilized in an oven for 30 min at 200 C. Soils were then placed in bleach-sterilized metal trays with a layer of newspaper covering the bottom of the trays to prevent any loss of soil.

Seeds of the native grasses—switchgrass, shortspike windmillgrass, and streambed bristlegrass—were seeded in 60-cm-long rows (4.5 cm apart) in flats (56 cm wide by 64 cm long by 9 cm deep) without any water. Two days later, rows in the flats designated as activated **carbon** were sprayed and flats were then bottom-watered and drained. The following day herbicides were applied.

The experimental design was a randomized complete block with four replications and a factorial arrangement of herbicide treatment (five), herbicide rate (two), and **carbon** treatment (two). Herbicide treatments consisted of 0.5X and 1X the labeled rate. See Table 1 for rates and other information. A nontreated check was included for comparison. Activated **carbon** treatments included **carbon** or no**carbon**. Activated **carbon** (activated charcoal **carbon**, AAA Aircare Systems, 7422 N.E. 120th Place, Kirkland, WA 98034) was mixed with water and sprayed in a slurry at 190 L ha^{-1} in a 3-cm-wide **band**over the seed row at the rate of 114 kg ha^{-1} (Fishel 1996). Herbicide treatments were applied with a CO_2-pressurized backpack sprayer with Teejet 11002 DG flat fan spray tips (Spraying Systems Company, P.O. Box 7900, North Avenue, Wheaton, IL 60188) calibrated to deliver 190 L ha^{-1} at 180 kPa.

Table 1. Herbicides included in carbon study

Common name	Trade name	Formulation*	Rate	Manufacturer	Location
Cloransulam	First Rate	84 WDG	0.03, 0.06 kg ai ha-1	Dow AgroSciences	Indianapolis, IN
Flumioxazin	Valor	51 WDG	0.05, 0.10 kg ai ha -1	Valent U.S.A. Corp.	Walnut Creek, CA
Imazapic	Cadre	2 AS	0.04, 0.07 kg ai ha -1	BASF Corp.	Research Triangle Park, NC
Imazethapyr	Pursuit	2 AS	0.04, 0.07 kg ai ha -1	BASF Corp.	Research Triangle Park, NC
2,4-D	Weedar	3.8	1.06, 2.12 kg ae ha -1	Nufarm, Inc.	St. Joseph, MO

* Abbreviations: WDG, wettable dispersible granules; AS, aqueous solution.

Greenhouse day/night temperatures were set for approximately 33/30 C and natural light was not supplemented. Blocks were rotated weekly and rerandomized to minimize local greenhouse light variation. Trays were watered daily to field capacity.

Native grass seedling stand counts (45 cm of row) and plant heights were obtained 5 wk after treatment from flats that contained rows of planted grasses. Plant heights were measured from ground line in trays to the tip of the growing point of five individual plants within each row and then averaged.

Field Experiments

Field experiments were conducted in 2008 and 2009 at the Texas AgriLife Research Station near Beeville, TX. The soil for the 2008 experiment was a Clareville sandy clay loam (fine, montmorillonitic, hyperthermic Pachic Argiustolls) with pH 7.4 and 1.2% organic matter; for the 2009 experiment, the soil was a Weesatche sandy clay loam (fine-loamy, mixed, hyperthermic Typic Argiustolls) with pH 7.0 and 1.2% organic matter. Native grasses were sown in a prepared seedbed with an eight-row plot drill (Tye Pasture Pleaser, AGCO, 1500 North Raddant Rd., Batavia, IL 60510) with 18-cm spacing between rows using an attachment that sprayed activated **carbon** over designated rows. Activated **carbon** was sprayed with a Teejet 4004E drop nozzle mounted immediately behind the press wheels of each planter. Plot size was 1.9 m wide by 3.2 m long.

The experimental design, herbicide treatments, and procedures were those used in the greenhouse studies. Herbicides were applied 1 d following the application of activated **carbon** on September 30, 2008, and May 6, 2009.

Seedling stand counts and plant heights were obtained 8 wk after treatment in 2008 and 12 wk after treatment in 2009. Plant height was measured from the ground line to the top of the growing point of three randomly selected plants per plot.

All field plots were naturally infested with Palmer amaranth (*Amaranthus palmerii* S. Wats) (8 to 10 plants m^{-2}), annual grasses consisting of a mixed stand of 60% fall panicum (*Panicum dichotomiflorum*Michx.) and 40% southern crabgrass [*Digitaria ciliaris* (Retz.) Koel.] (6 to 8 plants m^{-2}), and pitted morningglory (4 to 6 plants m^{-2}). No weeds had emerged at the time of native grass planting. Visual estimates of weed control were recorded 5 to 6 wk after herbicide application. Weed control ratings were based on a scale of 0 (no weed control) to 100 (complete control), relative to the nontreated check. For weed control ratings, significant differences among treatments were determined using ANOVA and means were separated by Fisher's Protected LSD at $P \leq 0.05$. Arcsine square-root transformation of treatment means for all weeds control ratings did not change the statistical analysis from nontransformed data; therefore, nontransformed data are presented.

Native grass plant stand numbers and plant height were subjected to ANOVA with appropriate partitioning for herbicide and **carbon**. Because native grasses grew differently in each year, no attempt was made to combine data over years. Means for significant main effects and interaction were separated with the appropriate Fisher's Protected LSD test at the 0.05 level of significance.

Results and Discussion

Because the ANOVA of the greenhouse experiment indicated no significant experimental time by treatment interaction, treatment means were averaged over the two experiments. However, there was a herbicide rate by **carbon band** interaction for number of plants and plant heights when evaluated 5 wk after herbicide application.

Table 2. Native grass response to herbicides (5 wk after application) with and without activated carbon in greenhouse study.

		No. of plants per 45- cm row						Plant height					
		Switchgrass		Windmillgrass		Bristlegrass		Switchgrass		Windmillgrass		Bristlegrass	
Treatment	Rate	Carbon	No carbon	Carbon	No carbon	Carbon	No carbon	Carbon	No carbon	Carbon	No carbon	Carbon	No carbon
	kg ha^{-1}	no.						cm					
Cloransulam	0.03	29.8	22.5	18.5	17.8	23.3	27.0	9.7	7.9	12.9	14.3	9.5	8.4
	0.06	27.0	23.0	21.8	20.3	52.0	42.5	11.7	7.5	19.1	12.3	8.8	6.9
Flumioxazin	0.05	29.3	24.5	19.8	4.5	29.0	16.0	9.0	8.2	14.8	6.8	10.5	5.3
	0.10	25.3	18.0	22.0	3.3	37.5	3.0	10.6	7.1	18.3	14.5	10.0	1.9
Imazapic	0.04	30.8	12.5	18.8	12.8	64.0	30.8	8.9	3.1	17.7	4.1	10.7	5.2
	0.07	31.0	14.8	22.8	14.0	55.3	9.8	6.0	1.7	16.6	2.6	7.8	0.6
Imazethapyr	0.04	32.3	23.8	20.8	21.0	35.8	14.3	8.8	6.1	16.1	4.1	9.0	3.1
	0.07	30.8	17.3	24.3	13.8	23.0	15.0	8.6	4.0	14.3	1.7	6.7	2.7
2,4-D	1.06	29.8	23.8	23.8	13.8	48.8	42.0	9.6	8.6	19.1	13.9	10.6	7.8
	2.12	31.8	23.0	19.3	17.0	37.5	33.0	12.1	6.3	16.6	15.3	10.5	9.2
Nontreated	-	27.3	24.5	24.0	22.5	54.8	40.3	7.2	9.8	9.8	12.8	7.0	7.7
LSD (0.05)[a]		7.8		2.5		15.5		3.2		6.5		3.7	

[a] LSD values are for differences within native grasses.

Greenhouse Experiments

Switchgrass plant stand numbers were influenced by the **carbon band** when imazapic, imazethapyr, or the high rate of 2,4-D were applied (Table 2). The use of a **carbon band** did not improve emergence of switchgrass when cloransulam, flumioxazin, or the low rate of 2,4-D were applied. With the exception of both rates of cloransulam, imazethapyr at 0.04 kg ha^{-1}, and 2,4-D at 2.12 kg ha^{-1}, the use of a **carbonband** resulted in greater windmillgrass plant stand numbers than those herbicide treatments that did not include **carbon** (Table 2). The use of **carbon** with flumioxazin resulted in the greatest increase in windmillgrass plant stand numbers. With bristlegrass, only flumioxazin at 0.1 kg ha^{-1}, imazapic at both rates, and imazethapyr at 0.04 kg ha^{-1} resulted in greater plant stand numbers when **carbon** was used with the respective herbicide compared with treatments that did not include **carbon**.

Switchgrass growth did not show an increase in plant height with the low rates of cloransulam, flumioxazin, and 2,4-D when **carbon** was used compared to treatments without any **carbon** (Table 2). Windmillgrass height was not influenced when **carbon** was used with cloransulam at 0.03 kg ha^{-1}, flumioxazin at 0.1 kg ha^{-1}, or both rates of 2,4-D. Bristlegrass heights were increased with the use of**carbon** with all herbicides with the exception of cloransulam or 2,4-D.

Field Experiments

Weed control

Weed control ratings were taken 5 to 6 wk after herbicide application. No attempt was made to try to rate weed control within the **carbon band** due to the difficulty of visual estimates with the narrowness of**band** and the weed population. Since there was not a herbicide rate by year interaction for weed control, weed efficacy data were combined over years.

Table 3. Weed control 5 to 6 wk after herbicide application.[a]

Treatment	Rate	Palmer amaranth	Pitted morningglory	Annual grasses[b]
	kg ha^{-1}	%		
Cloransulam	0.03	96	80	87
	0.06	92	75	80
Flumioxazin	0.05	93	68	79
	0.10	98	93	90
Imazapic	0.04	98	84	87
	0.07	100	85	92
Imazethapyr	0.04	99	68	73
	0.07	99	97	93
2,4-D	1.06	14	22	38
	2.12	30	56	39
Nontreated	-	0	0	0
LSD (0.05)		18	28	29

[a] Data combined over years.

[b] Mixed stand of fall panicum and southern crabgrass.

Palmer amaranth control was greater than 90% with all herbicides with the exception of 2,4-D, which failed to provide acceptable control (Table 3). Poor control with 2,4-D can be attributed to the lack of PRE activity (Senseman 2007). Pitted morningglory control was at least 93% with flumioxazin and imazethapyr at the high rates whereas cloransulam and imazapic provided 75 to 85% control. The low rates of flumioxazin and imazethapyr and 2,4-D failed to adequately control pitted morningglory (≤68%).

The high rates of flumioxazin, imazapic, and imazethapyr controlled the mixed stand of fall panicum and southern crabgrass at least 90%, whereas the low rates of these herbicides controlled the annual grasses 73 to 87%. Cloransulam at both rates provided 80 to 87% control of fall panicum and southern crabgrass, whereas 2,4-D failed to control the annual grasses (Table 3). Cloransulam applied PRE has a broader weed control spectrum than when applied POST (Barnes and Oliver 2004). Pigweed species and some grass species are either controlled or suppressed by soil applications of cloransulam but are not affected by POST applications (Krausz et al. 1998; Reddy 2000; Vidrine et al. 2000).

Imazethapyr and imazapic are imidazolinone herbicides registered for use in several crops, including peanut (*Arachis hypogaea* L.), and pastures. Imazethapyr may be applied preplant incorporated (PPI), PRE, ground-cracking, or POST for effective weed control in peanut (Wilcut et al. 1995). Imazethapyr applied PPI or PRE controls many troublesome weeds such as coffee senna (*Cassia occidentalis* L.), common lambsquarters (*Chenopodium album* L.), morningglory species, pigweed species including Palmer amaranth, prickly sida (*Sida spinosa* L.), purple and yellow nutsedge (*Cyperus rotundus* L. and*Cyperus esculentus* L., respectively), spurred anoda [*Anoda cristata* (L.) Schlecht.], and wild poinsettia (*Euphorbia heterophylla* L.) (Cole et al. 1989; Grichar et al. 1992; Wilcut et al. 1991).

Imazapic is similar to imazethapyr and controls all the weeds controlled by imazethapyr (Grichar 1997;Grichar and Nester 1997; Wilcut et al. 1994, 1995). In addition, imazapic provides control and suppression of Florida beggarweed [*Desmodium tortuosum* (S.W.) D.C.] and sicklepod [*Senna obtusifolia* (L.) Irwin & Barneby), which are not adequately controlled by imazethapyr (Grey et al. 2003). Imazethapyr provides consistent control of many broadleaf and sedge species if applied within 10 d after emergence, but imazapic has a longer effectiveness period when applied POST (Richburg et al. 1993, 1996; Wilcut et al. 1995). Imazapic also is effective for control of rhizome and seedling johnsongrass [*Sorghum halepense* (L.) Pers.], Texas millet [*Urochloa texana* (Buckl.) R. Webster], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], southern crabgrass [*Digitaria ciliaris* (Retz.) Koel.], and broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash] (Wilcut et al. 1995).

Native Grass Response

In 2008, there was a herbicide rate by **carbon** treatment interaction for switchgrass and bristlegrass stand counts (Table 4); however, windmillgrass stand counts were significant for herbicide only (Table 5). There was also a herbicide rate by **carbon** interaction for plant height for all three grasses (Table 4). In 2009, bristlegrass germination was poor and therefore, no attempt was made to evaluate this grass. Windmillgrass showed a **carbon** by herbicide interaction for stand counts and plant heights (Table 6), whereas switchgrass showed a **carbon** by herbicide interaction for plant height (Table 6) but only a herbicide response for stand counts (Table 7).

Table 4. Native grass response to herbicides with and without activated carbon in field study, 2008.

		Plant numbers				Plant height					
		Switchgrass		Bristlegrass		Switchgrass		Windmillgrass		Bristlegrass	
Treatment	Rate	Carbon	No carbon	Carbon	No carbon	Carbon	No carbon	Carbon	No carbon	Carbon	No carbon
	kg ha^{-1}	No. per 3 m				cm					
Cloransulam	0.03	8.3	7.3	7.0	6.5	12.8	11.5	4.5	6.5	5.3	3.3
	0.05	7.5	8.5	5.8	5.8	11.3	9.0	6.8	3.3	5.3	4.0
Flumioxazin	0.05	10.5	4.3	8.3	2.3	17.3	15.3	7.5	2.0	4.8	3.0
	0.10	6.5	0.5	10.3	0	13.0	4.8	7.5	0	5.0	0
Imazapic	0.04	6.8	0.8	7.0	1.8	8.0	1.3	4.3	1.5	4.0	1.0
	0.07	1.8	0	1.5	1.0	2.3	0	0.8	0	1.5	0.8
Imazethapyr	0.04	17.3	9.3	11.5	3.3	16.5	7.8	6.8	7.0	4.8	2.3
	0.07	12.0	2.0	12.8	1.8	10.3	2.5	6.0	4.8	4.0	1.0
2,4-D	1.06	6.5	11.3	6.8	6.5	8.8	18.3	9.5	4.8	5.3	4.8
	2.12	4.3	2.5	10.5	8.5	15.0	7.5	4.8	7.5	3.8	4.5
Nontreated	-	4.3	3.0	6.0	4.5	11.3	14.5	3.6	7.0	5.3	5.3
LSD (0.05)		3.3		4.4		6.5		3.7		1.5	

Table 5. Windmillgrass response to herbicides, 2008.

	Rate	Plant numbers
Treatment	kg ha^{-1}	No. per 3 m
Cloransulam	0.03	2.8
	0.05	1.9
Flumioxazin	0.05	2.9
	1.10	1.9
Imazapic	0.04	2.1
	0.07	0.1
Imazethapyr	0.04	3.4
	0.07	2.8
2,4-D	1.06	2.3
	2.12	1.4
Nontreated	-	1.4
LSD (0.05)		1.6

Table 6. Native grass response to herbicides with and without activated carbon in a field study, 2009.

		Plant numbers		Plant height			
		Windmillgrass		Switchgrass		Windmillgrass	
	Rate	Carbon	No carbon				
Treatment	kg ha^{-1}	No. per 3 m	cm	Carbon	No carbon	Carbon	No carbon
Cloransulam	0.03	4.0	4.8	20.8	10.5	13.3	13.3
	0.05	4.3	2.8	28.8	7.5	16.0	8.8
Flumioxazin	0.05	4.8	5.0	38.0	28.3	15.0	18.0
	0.10	5.3	1.0	26.8	22.5	18.3	8.0
Imazapic	0.04	1.5	0.5	65.0	10.3	12.5	4.8
	0.07	0.3	0	0	0	5.0	0
Imazethapyr	0.04	3.5	4.3	11.5	0	15.3	13.0
	0.07	5.0	3.5	0	8.5	19.0	15.8
2,4-D	1.06	4.5	4.8	27.0	18.8	18.3	12.0
	2.12	2.5	4.5	25.5	20.8	5.5	17.8
Nontreated	-	5.3	5.3	21.5	24.3	17.3	13.0
LSD (0.05)		1.7		13.4		5.3	

Table 7. Switchgrass response to herbicides, 2009.

	Rate	Plant numbers
Treatment	kg ha^{-1}	No. per 3 m
Cloransulam	0.03	2.5
	0.05	3.4
Flumioxazin	0.05	4.8
	0.10	4.9
Imazapic	0.04	1.9
	0.07	0.0
Imazethapyr	0.04	0.8
	0.07	0.3
2,4-D	1.06	5.4
	2.12	5.8
Nontreated	-	4.0
LSD (0.05)		2.7

In 2008, switchgrass and bristlegrass stand counts were higher when **carbon** was used with both rates of flumioxazin or imazethapyr and the low rate of imazapic compared with these herbicides without the**carbon band** (Table 4). Windmillgrass stand counts did not show a response to **carbon** (data not shown) and stand counts were higher with imazethapyr at 0.04 kg ha^{-1} than the nontreated check; however, no other response to herbicides were noted (Table 5). Imazapic at 0.07 kg ha^{-1} resulted in the lowest plant stand counts.

Switchgrass plant heights were higher when **carbon** was used with the high rate of flumioxazin, the low rate of imazapic, both rates of imazethapyr, and the high rate of 2,4-D than when these herbicides were used without **carbon** (Table 4). Windmillgrass heights were greater when **carbon** was used with both rates of flumioxazin and the low rate of 2,4-D compared with no **carbon**. Bristlegrass heights were greater when **carbon** was used with cloransulam at 0.03 kg ha^{-1}, both rates of flumioxazin and imazethapyr, and imazapic at 0.04 kg ha^{-1}.

In 2009, windmillgrass stand counts were improved when **carbon** was applied with flumioxazin at 0.1 kg ha^{-1}; however, the use of **carbon** with 2,4-D at 2.12 kg ha^{-1} resulted in lower stand counts than 2,4-D at 2.12 kg ha^{-1} without **carbon** (Table 6). Switchgrass plant heights were improved when **carbon**was used with cloransulam at 0.05 kg ha^{-1} and imazapic at 0.04 kg ha^{-1}. No switchgrass plants were produced with the high rate of imazapic, the low rate of imazethapyr without **carbon**, or the high rate of imazethapyr with **carbon** (Table 6). The switchgrass height in all of these plots was less than all other herbicide treatments with the exception of cloransulam at 0.05 kg ha^{-1}. Windmillgrass heights were greater when **carbon** was used with the high rate of cloranuslam or flumioxazin or the low rate of imazapic and 2,4-D (Table 6). Switchgrass plant numbers were reduced with the high rate of imazapic and both rates of imazethapyr when compared with the nontreated check (Table 7).

Based on the greenhouse and field studies, switchgrass plant stands were improved when **carbonbanding** was used with imazethapyr at 0.04 and 0.07 kg ha^{-1}. Windmillgrass and bristlegrass had improved stand establishment from **carbon banding** with the application of flumioxazin at the 0.05 kg ha^{-1} rate. Furthermore, switchgrass appeared to be tolerant of flumioxazin at the 0.05 kg ha^{-1}rate and windmillgrass appeared to be tolerant of imazethapyr at the 0.04 kg ha^{-1} rate, whether with or without the protective **carbon band**. Beran et al. (2000) stated that imazapic and imazethapyr could be used to improve the establishment of big bluestem (*Andropogon gerardii* Vitman var. *gerardii*) planted with Illinois bundleflower. Further research into these tolerance characteristics should be investigated.

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