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Carfentrazone Improves Broadleaf Weed Control in Proso and Foxtail Millets

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Proso and foxtail millets are regionally important dryland crops for the semiarid portions of the Central Great Plains. However, few herbicides are registered for use in either crop. The efficacy of carfentrazone was studied in proso millet from 2003 through 2005 at the University of Nebraska High Plains Agricultural Laboratory located near Sidney, NE, and in foxtail millet in 2004 and 2005 at the University of Wyoming Sustainable Agriculture Research and Extension Center near Lingle, WY. Carfentrazone was applied POST at 9.0, 13.5, and 18.0 g ai/ha with combinations of 2,4-D amine, prosulfuron, and dicamba. Although leaves of treated plants exhibited localized necrosis, leaves emerging after treatment were healthy. Grain and forage yields were not affected by the application of carfentrazone. Dicamba and 2,4-D amine provided visual control of 30% or less for buffalobur. Adding carfentrazone to one or both of these herbicides improved buffalobur control to 85% or greater. Carfentrazone applied at 18.0 g/ha improved Russian thistle, kochia, and volunteer sunflower control in 2003, when plants were drought-stressed, but did not help with these and other weeds during wetter years. Carfentrazone provides proso millet producers with a way to selectively control buffalobur, a noxious weed in several western states. In foxtail millet, carfentrazone provides POST broadleaf weed control with little risk for serious crop injury. Crop injury has been a concern with 2,4-D, which is currently the only other herbicide registered for use in foxtail millet.
Nomenclature: Carfentrazone; 2,4-D; dicamba; prosulfuron; buffalobur, *Solanum rostratum* Dun. SOLCU; kochia, *Kochia scoparia* (L.) Schrad. KCHSC; Russian thistle, *Salsola iberica* Sennen & Pau SASKR; foxtail millet, *Setaria italica* (L.) P. Beauv.; proso millet, *Panicum miliaceum* L.; sunflower, *Helianthus annuus* L.
Key words: Herbicides.

Proso and foxtail millets are short-season (45 to 90 d) summer cereals with low water requirements and high water-use efficiencies for both grain and dry matter (Hanna et al. 2004). Both crops are well adapted for the crop production systems of the semiarid Great Plains. In the United States, proso millet is primarily grown for grain, whereas foxtail millet is primarily grown for fodder (Hanna et al. 2004).

Proso and foxtail millets grow slowly at first and are relatively poor competitors with weeds during the first few weeks of growth (Hanna et al. 2004). Weeds can be a major obstacle to proso millet production (Grabouski 1971). Atrazine and propazine have been shown to provide effective residual weed control in proso millet (Anderson 1990; Anderson and Greb 1987; Robinson 1973). However, no triazine herbicide is currently registered for use in proso or foxtail millet in the United States.

Grabouski (1971) reported excellent control of redroot pigweed (*Amaranthus retroflexus* L.) in proso millet with POST applications of 2,4-D ester, 2,4-D amine, bromoxynil, and dicamba. Crop injury was observed with all treatments except 2,4-D amine applied at 0.28 kg ai/ha, but yields were not greatly affected. Despite some early season injury, Lyon and Baltensperger (1993) observed no effect of POST applications of bromoxynil, clopyralid, dicamba, or metsulfuron tank-mixed with 2,4-D amine on proso millet grain yield, test weight, seed weight, moisture content, or plant height. No research involving POST herbicide treatments in foxtail millet were found in the literature.

Carfentrazone is a relatively new herbicide that controls broadleaf weeds primarily through the inhibition of the protoporphyrinogen oxidase enzyme (Dayan et al. 1997). Grain and forage millets were recently added to carfentrazone product registrations (Anonymous 2005). The objective of this study was to evaluate the efficacy of carfentrazone applied POST with tank-mix partners for weed control in proso and foxtail millet. Carfentrazone was not applied alone because at the labeled use rates for millets, it provides only suppression of kochia and Russian thistle, which are common problematic weeds in the region.

Materials and Methods

Field studies were conducted from 2003 through 2005 at the University of Nebraska High Plains Agricultural Laboratory (41°12′N, 103°0′W at 1,320 m elevation) located near Sidney, NE, and from 2004 through 2005 at the University of Wyoming Sustainable Agriculture Research and Extension Center (42°05′N, 104°23′W at 1,390 m elevation) near Lingle, WY. Studies were conducted on an Alliance silt loam soil (Aridic Argiustolls) at Sidney, NE, and on a Mitchell silt loam soil (Ustic Torriorthents) at Lingle, WY.

The experimental design at both locations was a randomized complete block with three replications of each treatment. At Sidney, NE, proso millet was no-till seeded into either sunflower or winter wheat (*Triticum aestivum* L.) residues in late May to early June at 17 kg seed/ha (Table 1). The entire plot area was treated with glyphosate at 0.96 kg ai/ha within 10 d before planting each year. Rows were spaced 25 cm apart. Herbicide treatments were applied with an all-terrain vehicle–mounted sprayer set to deliver 187 L/ha at 138 kPa when proso plants were in the two- to five-leaf stage of development. Plots were 3 m wide by 12.2 m long.

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Table 1. Crop cultivars, seeding dates, herbicide application dates, and harvest dates for field studies conducted at Sidney, NE, and Lingle, WY.

Location	Year	Crop	Cultivar	Seeding date	Treatment date	Harvest date
Sidney, NE	2003	Proso	Earlybird	May 30	June 27	September 12
	2004	Proso	Earlybird	June 4	July 6	None
	2005	Proso	Sunrise	May 27	June 24	August 29
Lingle, WY	2004	Foxtail	White Wonder	June 2	June 29	August 24
	2005	Foxtail	White Wonder	June 7	June 30	September 22

At Lingle, WY, foxtail millet was no-till seeded into winter wheat or sunflower residues in early June at 24 and 17 kg seed/ha in 2004 and 2005, respectively. Rows were spaced 19 cm apart. Herbicide treatments were applied with a knapsack sprayer delivering 187 L/ha at 275 kPa when foxtail plants were in the two- to four-leaf stage of development. Plots were 2.7 m wide by 9.1 m long.

Treatments were evaluated for visual crop injury on a scale from 0 to 100, with 0 being no injury and 100 being plant death, at approximately 1, 2 and 4 wk after treatment (WAT). At 4 WAT, proso plant height and tiller density were measured. Visual weed control was evaluated by species at 4 WAT on a scale of 0 to 100, with 0 being no control and 100 being complete control. Weed density by species was also measured in the nontreated checks at that time (data not shown).

Grain yield of proso and foxtail millets were obtained by machine harvest, without swathing. Grain weights were adjusted to a 12% moisture basis. Foxtail millet forage yields were obtained by hand-clipping samples at ground level from a 0.5-m^2 area from each plot. Samples were dried at 60 C for 48 h and dry weights recorded.

The general linear-models procedure was used to obtain the ANOVA (SAS 1999). Data for each location were pooled across years if no significant year-by-treatment interactions occurred. If these interactions were significant, then data were analyzed separately by year. Mean separations were performed using Fisher's Protected LSD at an alpha level of 0.05.

Results and Discussion

At Sidney, NE, precipitation totals for the principal growing season months of June through August were 113, 195, and 312 mm in 2003, 2004, and 2005, respectively. Average precipitation for these months at Sidney is 176 mm. At Lingle, WY, precipitation totals for 2004 and 2005 were 153 and 297 mm, respectively. Average precipitation for these months at Lingle is 129 mm. With the exception of June, average air temperatures were well above normal in 2003 at Sidney. In 2004 and 2005, average air temperatures during the growing season were near normal at both locations. A severe hail storm at Sidney in late July 2004 destroyed the crop and prevented seed harvest.

Proso Millet. All herbicide treatments containing carfentrazone caused localized leaf necrosis. Visual injury ratings taken 1 WAT generally ranged between 10 and 20% (data not shown). Leaves emerging after treatment were not affected and injury symptoms became progressively less visible with time.

In 2003, the crop and weeds experienced significant drought stress. Kochia was the predominant weed with an average density of 117 plants/m^2 in the weedy check. Russian thistle and volunteer sunflower densities in the weedy check averaged 7 and 4 plants/m^2, respectively. Kochia was particularly difficult to control, with 2,4-D amine applied alone providing less than 30% visual control (Table 2). Adding 18 g/ha of carfentrazone to 2,4-D increased kochia control to $>$ 70% and Russian thistle control to $>$ 90%, but lesser rates of carfentrazone tank-mixed with 2,4-D were ineffective. Three of the four herbicide treatments that provided significantly greater kochia control than 2,4-D amine alone contained carfentrazone. Likewise, four of five treatments providing greater Russian thistle control than 2,4-D amine alone contained carfentrazone.

Volunteer sunflower can be troublesome if proso millet is planted the year after sunflower. Herbicide treatments that provided greater control of sunflower than 2,4-D amine alone contained carfentrazone (Table 2). Under drought conditions in 2003, carfentrazone improved weed control as a tank-mix partner to 2,4-D amine, dicamba, or prosulfuron.

In 2004, precipitation and air temperatures were near normal, and drought stress was not severe. All herbicide treatments provided good weed control (Table 2). Carfentrazone did not provide the additional weed control benefit it did in 2003. Weed density counts were not taken in 2004, but lanceleaf sage (*Salvia reflexa* Hornem. SALRE) densities were moderate to heavy whereas volunteer sunflower densities were light to moderate. Lanceleaf sage control was 87 and 90% with 2,4-D amine and 2,4-D amine + dicamba, respectively. Volunteer sunflower was controlled 100% with 2,4-D amine + prosulfuron. The addition of carfentrazone to these treatments did not significantly increase control.

Buffalobur was the primary weed in the 2005 study. The average buffalobur density in the weedy check was 24 plants/m^2. Buffalobur is considered a noxious weed in several western states including Washington, Idaho, and Utah. Because of this designation, the importation of any product containing buffalobur seed into these states is prohibited. Local bird-seed packaging plants will not purchase proso millet seed containing buffalobur seeds. Buffalobur control was $<$ 30% with 2,4-D amine alone or tank-mixed with dicamba (Table 2). Prosulfuron + 2,4-D provided 80% control. Treatments containing carfentrazone provided at least 85% control of buffalobur.

There were no significant year-by-treatment interactions for plant height ($P = 0.344$), reproductive tiller density ($P = 0.085$), or grain yield ($P = 0.489$), so data were averaged across years. Proso millet plant height was reduced compared with the hand-weeded check by herbicide treatments contain-

Table 2. Visual weed control in proso millet at Sidney, NE in 2003, 2004, and 2005.[a]

Treatment[b]	Rate	2003 KCHSC	2003 SASKR	2003 Sunflower	2004 SALRE	2004 Sunflower	2005 SOLCU
	g ai/ha	%					
Carfentrazone + 2,4-D amine	9 + 280	27	72	52	92	93	90
Carfentrazone + 2,4-D amine	13.5 + 280	33	77	43	88	100	87
Carfentrazone + 2,4-D amine	18 + 280	72	92	87	88	98	93
Carfentrazone + 2,4-D amine	9 + 561	40	90	62	92	100	85
Carfentrazone + 2,4-D amine + dicamba	9 + 280 + 140	70	92	93	95	95	85
Prosulfuron + 2,4-D amine	10.1 + 280	23	90	85	82	100	80
Carfentrazone + prosulfuron	9 + 10.1	53	47	93	87	98	92
Carfentrazone + prosulfuron + 2,4-D amine	9 + 10.1 + 280	70	90	97	90	98	93
2,4-D amine	561	27	63	53	87	93	20
2,4-D amine + dicamba	280 + 140	57	67	70	90	95	30
Weedy check		0	0	0	0	0	0
Hand-weeded check		100	100	100	100	100	100
LSD (5%)		27	22	37	8	6	11

[a] Abbreviations: KCHSC, kochia; SASKR, Russian thistle; SALRE, lanceleaf sage; SOLCU, buffalobur.

[b] A nonionic surfactant was added to all treatments containing carfentrazone or prosulfuron at 0.25% v/v.

ing the high rate of 2,4-D amine and by the 2,4-D amine + dicamba treatment (Table 3). Plant height and tiller density were also reduced by weed growth in the weedy check.

Mean grain yield was 1,800 kg/ha, but yield levels were significantly different between the 2 yr ($P < 0.001$). In 2003, under drought conditions, mean grain yield was just 377 kg/ha, whereas in 2005, with rainfall well above average, yield was 3,220 kg/ha. Four treatments had yields significantly lower than the hand-weeded check ($P = 0.082$). These included the two treatments containing the high rate of 2,4-D amine, the 2,4-D + dicamba treatment, and the weedy check. Much of this reduction is probably explained by weed competition as a result of poor weed control (Table 2); however, some crop injury cannot be excluded. The high rate of 2,4-D amine did reduce plant height in this study, and both 2,4-D amine and dicamba have been reported to cause crop injury in proso millet (Grabouski 1971).

Carfentrazone appears to provide much better control of buffalobur than 2,4-D or 2,4-D + dicamba. This is a welcome tool for control of this noxious and troublesome weed. Carfentrazone also provided improved weed control under drought conditions, which is a common occurrence in the Central Great Plains. Despite some leaf damage, carfentrazone did not negatively affect plant height, tiller density, or grain yield of proso millet.

Foxtail Millet. Visual crop injury was evaluated approximately 4 and 2 WAT in 2004 and 2005, respectively. Weed densities in both years were light. Average Russian thistle densities were 0.5 and 0.7 plants/m^2 in 2004 and 2005, respectively. In 2005, prickly lettuce (*Lactuca serriola* L. LACSE) and sunflower were each present at an average density of 1.4 plants/m^2.

In 2004, herbicide treatments containing carfentrazone at 18 g/ha or dicamba caused visual crop injury of less than 10% (data not shown). Injury symptoms with carfentrazone were localized spotting of treated leaves. The injury symptoms from dicamba were stunting and prostrate growth. No crop injury was observed in 2005.

In 2004, all herbicide treatments provided excellent control of Russian thistle (Table 4). Similar results were observed with Russian thistle in 2005. All herbicide treatments

Table 3. Proso millet plant height, reproductive tiller density, and grain yield averaged across 2003 through 2005 at Sidney, NE.

Treatment[a]	Rate	Plant height	Tiller density	Grain yield
	g ai/ha	cm	tillers/m^2	kg/ha
Carfentrazone + 2,4-D amine	9 + 280	55	103	2,010
Carfentrazone + 2,4-D amine	13.5 + 280	53	103	1,780
Carfentrazone + 2,4-D amine	18 + 280	54	108	1,970
Carfentrazone + 2,4-D amine	9 + 561	49	101	1,550
Carfentrazone + 2,4-D amine + dicamba	9 + 280 + 140	52	98	2,020
Prosulfuron + 2,4-D amine	10.1 + 280	52	100	1,930
Carfentrazone + prosulfuron	9 + 10.1	59	110	1,940
Carfentrazone + prosulfuron + 2,4-D amine	9 + 10.1 + 280	52	109	1,930
2,4-D amine	561	47	101	1,580
2,4-D amine + dicamba	280 + 140	50	102	1,540
Weedy check		43	76	1,200
Hand-weeded check		57	105	2,120
LSD (5%)		6	13	NS[b]

[a] A nonionic surfactant was added to all treatments containing carfentrazone or prosulfuron at 0.25% v/v.

[b] No significant differences at an alpha level of 0.05, but differences are significant at an alpha level of 0.1 with an LSD = 480 kg/ha.

Table 4. Visual weed control in foxtail millet at Lingle, WY in 2004 and 2005.[a]

Treatment[b]	Rate	2004 SASKR	2005 LACSE	2005 SASKR	2005 Sunflower
	g ai/ha	%			
Carfentrazone + 2,4-D amine	9 + 280	100	96	94	99
Carfentrazone + 2,4-D amine	13.5 + 280	100	92	94	99
Carfentrazone + 2,4-D amine	18 + 280	100	99	96	93
Carfentrazone + 2,4-D amine	9 + 561	100	91	95	91
Carfentrazone + 2,4-D amine + dicamba	9 + 280 + 140	100	89	98	99
Prosulfuron + 2,4-D amine	10.1 + 280	99	91	91	99
Carfentrazone + prosulfuron	9 + 10.1	98	90	88	93
Carfentrazone + prosulfuron + 2,4-D amine	9 + 10.1 + 280	100	91	94	99
2,4-D amine	561	91	86	89	98
2,4-D amine + dicamba	280 + 140	95	67	99	66
Weedy check		0	0	0	0
LSD (5%)		2	20	7	30

[a] Abbreviations: SASKR, Russian thistle; LACSE, prickly lettuce.

[b] A nonionic surfactant was added to all treatments containing carfentrazone or prosulfuron at 0.25% v/v.

provided excellent control of prickly lettuce and volunteer sunflower in 2005, with the exception of 2,4-D and 2,4-D + dicamba.

The year-by-treatment interaction was not significant for grain ($P = 0.917$) or forage yield ($P = 0.853$), so yield data were averaged across years. There were no significant treatment differences for grain ($P = 0.813$) or forage ($P = 0.824$) yields. Grain yields did not differ significantly between years ($P = 0.242$) and the mean yield was 1,500 kg/ha. Forage yields did differ between years ($P < 0.001$). Mean forage yield was 4,020 and 8,970 kg/ha for 2004 and 2005, respectively.

Before carfentrazone was registered in forage millets, only a few 2,4-D products were registered for use. Severe crop injury occurred occasionally with 2,4-D. The risk for severe crop injury may be reduced, and efficacy maintained, by using a lower rate of 2,4-D and tank-mixing with carfentrazone. Although not screened in foxtail millet in 2003, carfentrazone is likely to provide superior control of broadleaf weeds experiencing drought stress.

Herbicide options in proso and foxtail millets are limited. Although growers are encouraged to use various cultural practices, such as increased seeding rates, banding of N fertilizer with the seed, and growing taller cultivars to minimize the need for chemical weed control (Anderson 2000), there are times when herbicides are required. For example, buffalobur seeds are not permitted in bird seed to be shipped to several western states and adding carfentrazone to 2,4-D amine, dicamba, or prosulfuron greatly improves buffalobur control. Carfentrazone also improves weed control when weeds are under drought stress. Carfentrazone is a welcome addition to the limited arsenal of herbicides registered for use in proso and foxtail millet.

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