Established Foxtail Barley, *Hordeum jubatum*, Control with Glyphosate Plus Ammonium Sulfate[1,2]

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Abstract. The spread of perennial weeds, such as foxtail barley, is a prime deterrent to adoption of no-till cereal production in the Northern Great Plains. In a 3-yr study, the isopropylamine salt of glyphosate at 0.56 kg ai/ha plus nonionic surfactant[4] at 0.25% (v/v) did not control established perennial foxtail barley in early spring. However, adding ammonium sulfate at 2.8 kg/ha to glyphosate plus surfactant improved the effectiveness and year-to-year consistency of glyphosate for killing this weed. This spring treatment fits into no-till farm practice in the Northern Great Plains, providing no-till farmers with a defined strategy to manage this perennial bunchgrass weed. Nomenclature: Glyphosate, *N*-(phosphonomethyl)glycine; foxtail barley, *Hordeum jubatum* L. #[5] HORJU.

Additional index words: Herbicide, additives, adjuvants, perennial grass weed, HORJU.

INTRODUCTION

Foxtail barley is a perennial bunchgrass which can be a problem weed in no-till spring wheat, *Triticum aestivum* L., and other spring-sown crops in the Northern Great Plains of the United States and Canada (Figure 1). Its seed are blown easily onto farmland from field borders (1, 4, 13). The extent to which water and farm machinery, such as straw and chaff spreaders on combines, spread this weed is undetermined, although these methods of dispersal also are likely. Once established on no-till farmland, perennial foxtail barley spreads by dispersing seed and tillering (1).

This perennial bunchgrass is unique because it has only a shallow fibrous root system, and individual plants reproduce vegetatively by forming new tillers. Foxtail barley does not have rootstocks, rhizomes, or root buds that are characteristic of other perennial grasses. Foxtail barley can become a problem in alfalfa, *Medicago sativa* L., or no-till fields in as little as 3 or 4 yr[6]. This weed is usually not a concern on conventionally tilled cropland because moldboard or chisel plowing kills established perennial plants[6]. Spring seedbed preparation by discing or field cultivating and harrowing controls fall- and spring-germinating seedlings (5, 14, 23). Concern that perennial weeds, such as foxtail barley, will establish in no-till is one of the prime deterrents to adopting no-till farming in the Northern Great Plains.

Foxtail barley is well adapted to no-till spring-sown crops in the region. Perennial plants resume spring growth early, usually 3 to 5 weeks before spring wheat sowing[6]. Consequently, actively growing, established plants have a competitive advantage with the later-sown crop. Usually, spring wheat is the earliest sown crop in North Dakota and is planted between April 15 and June 10 (16). Also, established foxtail barley is not controlled by preplant or planting-time treatment with glyphosate at 0.28 kg/ha, the usual rate for control of emerged annual weeds in no-till fields in the Northern Great Plains[6]. Normally, nonselective contact or translocated herbicides must be applied at or before planting to control annual weeds. Winter and spring annual weeds that have emerged at or before planting would be too large for effective control by selective herbicides applied in the crop at the recommended cereal growth stages.

Because foxtail barley has appeared only recently in no-till cereal and row crops in the region, little information is available on its control (6, 7, 8, 9, 10, 11, 12). Several herbicides either have been tested or have been registered for foxtail barley control in alfalfa or pasture, but these herbicides have marginal selectivity in annual crops (3, 8, 9, 11, 17). Other herbicides, including trifluralin, 2,6-dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl)benzenamine, control seedling foxtail barley in conventional wheat and broad-

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[4] X-77, Ortho Chevron Chemical Co., San Francisco, CA 94110.

[5] Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

[6] Personal observation or unpublished data.

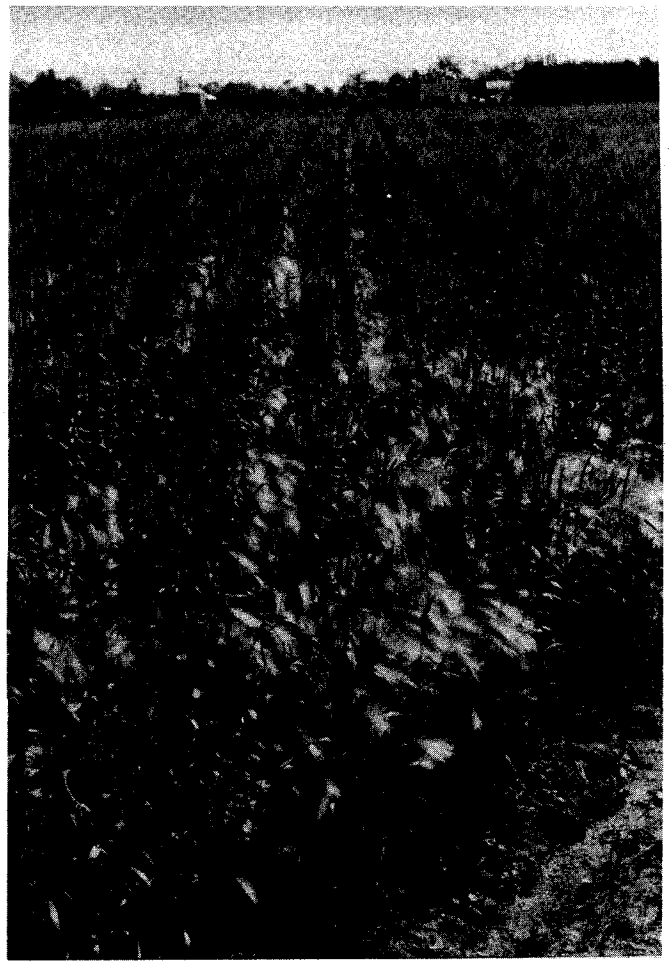

Figure 1. Infestation of foxtail barley in hard red spring wheat near Sarles, ND, in 1985.

leaf crops (12); but because these herbicides require incorporation, they have limited potential use in no-till farming. Dinitroaniline herbicides do not control established foxtail barley[6].

Adding ammonium sulfate has enhanced the herbicidal activity of several postemergence, foliage-applied herbicides (2, 15, 18, 19, 20, 21, 22, 24). Ammonium sulfate added to glyphosate also improved control of honeyvine milkweed, *Ampelamus albidus* (Nutt.)Britt. # AMPAL (15); purple nutsedge, *Cyperus rotundus* L. # CYPRO (18); and quackgrass, *Agropyron repens* (L.) Beauv. # AGRRE (2), as well as other perennial weeds (19). Ammonium sulfate at 1.5 to 10 kg/ha significantly improved the herbicidal activity of 0.2 to 0.5 kg/ha glyphosate on the shoots and rhizomes of potted greenhouse-grown quackgrass (2). Similar results were observed under field conditions (2, 19). Urea, ammonium butyl phosphate, and ammonium phosphate also enhanced glyphosate activity on purple nutsedge but had no advantage over ammonium sulfate (18).

The objective of this experiment was to determine whether ammonium sulfate, an inexpensive additive, could increase the efficacy of glyphosate, an expensive herbicide, to control foxtail barley or could maintain the level of control while reducing the rate of glyphosate. It was not the intent to establish whether or not this interaction between ammonium sulfate and glyphosate was synergistic or to determine the interaction mechanism.

MATERIALS AND METHODS

In 1985, commercially formulated glyphosate was applied to foxtail barley at 0, 0.14, 0.28, 0.39, or 0.56 kg/ha plus a nonionic surfactant[4] at 0.25% (v/v) either alone or mixed with "sprayer-grade" or "feed-grade" ammonium sulfate at 2.8, 5.6, or 11 kg/ha (Table 1). In 1986 and 1987, glyphosate was applied at 0, 0.39, or 0.56 kg/ha either alone or mixed with the 1985 rates of ammonium sulfate. A bicycle sprayer equipped with 8001 flat fan nozzles[7] was used to apply the herbicides. Water used as a carrier had a pH of 8.4, and the dissolved anions consisted of carbonate, bicarbonate, chlorine, and sulfate at 12, 598, 390, and 274 ppmw, respectively. Dissolved cations consisted of calcium, magnesium, sodium, and potassium at 10, 9, 584, and 11 ppmw, respectively.

The experiment was conducted for 3 yr on no-till cereal fields near Sarles, ND, and 1 yr on undisturbed wasteland at Langdon, ND. The soil type at Sarles was a Hammerly loam, fine-loamy, frigid Eric Calciaquolls, and the soil type at Langdon was a Svea fine loam, mixed Pachic Udic Haploboroll. The Sarles research sites used in 1985 and 1987 had been no-till cropped since 1978, whereas the 1986 site had been chisel-plowed in spring 1 yr earlier. The Langdon site had not been tilled in at least 3 yr. Neither site was cropped during the experiment.

Foxtail barley was the only perennial weed present at Sarles; but scattered, sparse stands of absinth

[7] TeeJet nozzles, Spraying Systems Co., Wheaton, IL 60188.

Table 1. Site description, sprayer specifications, and the timing of observations for three experiments at Sarles, ND, and one experiment at Langdon, ND.

Observation	Sarles			Langdon
	1985	1986	1987	1987
Blocks	4	4	3	3
Texture				
Sand (%)	31 to 32	31 to 32	28	25
Silt (%)	40 to 44	40 to 44	50	45
Clay (%)	23 to 29	23 to 29	22	30
Organic matter (%)	5.0 to 5.1	5.0 to 5.1	6	6
pH (surface)	7.8	7.8	8.0	8.0
Spraying				
Date	May 17	April 29	May 14	May 13
Carrier volume (L/ha)	100	80	100	120
Ground speed (km/h)	4.4	4.8	4.0	4.0
Pressure (kPa)	140	140	210	210
Wind speed (km/h)	21–24	8–10	4	13–14
Relative humidity (%)	45	57	85	88
Air temperature (C)	26	30	7	18
Soil temperature (C) at 2.5 cm	26	28	9	17
Weed height (cm) (mean ± SD)	...	18 ± 5	30 ± 5	16 ± 2
Ratings taken	June 14 July 8	June 27 July 23	June 17 July 14	June 17 July 14

wormwood, *Artemisia absinthium* L. # ARTAB; Canada thistle, *Cirsium arvense* (L.)Scop. # CIRAR; curly dock, *Rumex crispus* L. # RUMCR; dandelion, *Taraxacum officinale* Weber in Wiggers # TAROF; perennial sowthistle, *Sonchus arvensis* L. # SONAR; and quackgrass were present at Langdon. Annual broadleaf weeds were controlled by 2,4-D, (2,4-dichlorophenoxy)acetic acid, at 0.56 to 1.1 kg ae/ha applied in early June.

Plots were rated visually for control of established perennial plants of foxtail barley at approximately 1 and 2 months after treatment (Table 1). Seedling foxtail barley control was not rated. The first control rating was based on the proportion of plants per plot that were brown and desiccated. The 2-month control rating was based on the proportion of plants per plot that had not formed tillers; most treated foliage was dead and partially decayed. The second rating is considered a measure of the potential for later regrowth of sprayed, established plants.

A randomized complete block design was used in all trials with either 3 or 4 blocks per trial based on established foxtail barley shoot density (Table 1). All plots were 3.3 by 8.2 m. Data were subjected to analysis of variance, and means were separated by Duncan's multiple range test at $P = 0.05$.

RESULTS

Glyphosate alone at 0.39 kg/ha plus surfactant provided acceptable (≥ 80%) early and late-season control of established plants of foxtail barley in only 1 of 3 yr at Sarles (Table 2) ($P \leq 0.0001$). Glyphosate at 0.56 kg/ha provided good (≥ 80%) to excellent (≥ 90%) early season control in 2 of 3 yr at Sarles. However, good late-season control was achieved at this rate in only 1 of 3 yr. Glyphosate alone at both rates provided excellent early season control of emerged foxtail barley seedlings.

When ammonium sulfate at various rates was added to glyphosate at 0.39 kg/ha, early season control improved all 3 yr compared to the herbicide alone (Table 2). Early season control was good (≥ 80%) with this combination in 2 of 3 yr at Sarles and at Langdon. However, late-season control of established plant was acceptable (≥ 80%) with glyphosate at 0.39 kg/ha in only 1 of 3 yr at Sarles.

Glyphosate alone at 0.56 kg/ha provided good to excellent early season control in 2 of 3 yr (Table 2). When ammonium sulfate was added to glyphosate at 0.56 kg/ha, early season control was good (≥ 80%) to excellent (≥ 90%) in all 3 yr at both Sarles and Langdon. When ammonium sulfate was added, ac-

Table 2. Control of established foxtail barley at Sarles, ND, in 1985 to 1987 and at Langdon, ND, in 1987 with combinations of spring-applied glyphosate plus ammonium sulfate.

Treatment/rate		Control rating[a]							
		Sarles						Langdon	
		1985		1986		1987		1987	
Glyphosate[b]	Ammonium sulfate	June 14	July 8	June 27	June 23	June 17	July 14	June 17	July 14
(kg/ha)		(%)							
0.39	0	62 b	7 d	93 b	94 ab	27 c	43 c	43 d	14 c
0.39	2.8	92 a	57 a–c	98 a	93 ab	47 b	73 a–c	83 a–c	56 ab
0.39	5.6	93 a	56 a–c	98 a	88 b	72 a	65 a–c	83 a–c	59 ab
0.39	11	96 a	57 a–c	...	...	80 a	55 a–c	76 c	51 b
0.56	0	88 a	53 cd	100 a	87 b	22 c	53 bc	79 bc	74 ab
0.56	2.8	97 a	88 a	100 a	96 ab	88 a	88 a	93 a	78 a
0.56	5.6	100 a	84 ab	100 a	91 ab	83 a	82 ab	91 ab	63 ab
0.56	11	100 a	77 ab	...	...	87 a	87 ab	84 a–c	72 ab

[a]Means in a column followed by the same letter were not different at P = 0.05 by Duncan's multiple range test.

[b]X-77 surfactant at 0.25% (v/v) added to all herbicide treatments.

ceptable late-season control also was maintained all 3 yr at Sarles but not at Langdon. Ammonium sulfate at 5.6 and 11 kg/ha was no more beneficial than 2.8 kg/ha.

DISCUSSION

Glyphosate at 0.56 kg/ha plus nonionic surfactant at 0.25% (v/v) and ammonium sulfate at 2.8 kg/ha killed most established foxtail barley when applied in early spring (Table 2). Late-season control was good (≥ 80%) to excellent (≥ 90%) at Sarles in all 3 yr with this combination but not at Langdon. Perhaps unacceptable late-season control at Langdon was caused by incomplete spray coverage due to heavy straw residues and incomplete foliar display at the time of spraying in spring.

Ammonium sulfate apparently improved the effectiveness and year-to-year consistency of glyphosate at 0.56 kg/ha for killing established foxtail barley. Control of foxtail barley with glyphosate at 0.39 kg/ha even with ammonium sulfate and surfactant was inconsistent from year to year. Although all established plants were brown and severely desiccated when rated roughly 2 months after a late-April or mid-May treatment with glyphosate at 0.39 kg/ha, some plants had limited new tiller growth. This limited regrowth is unlikely to compete with no-till crops, although it allows later reestablishment by vegetative propagation (tillering). Those few seedheads that were present in sprayed plots had not completely emerged through the boot and were sterile 2 months after treatment. However, in 1986, glyphosate at 0.39 kg/ha plus surfactant with or without ammonium sulfate controlled 1-yr-old established plants and prevented regrowth. The influence of stand age of foxtail barley on weed susceptibility to glyphosate should be examined.

Emerged annual weeds in spring-sown no-till crops in the Northern Great Plains normally are treated with glyphosate at 0.13 to 0.28 kg/ha or with a mixture of glyphosate plus 2,4-D before or at planting[6]. Glyphosate at these rates did not control established foxtail barley[6].

Treatment of established foxtail barley with glyphosate at 0.56 kg/ha plus ammonium sulfate at 2.8 kg/ha and surfactant in early spring fits into no-till crop production practice and can be used in chemical fallow to control established and seedling foxtail barley.The herbicide application dates that were used in this research were in the middle of the normal range of dates for conventional spring wheat planting (16). No-till spring wheat is planted somewhat later than conventional spring wheat because no-till fields dry out and warm more slowly following the spring thaw. In addition, the spray application dates that were used would be appropriate for later-sown crops (16).

The combination of glyphosate and ammonium sulfate probably would be most effective when infested land is planted to competitive crops, such as barley, *Hordeum vulgare* L., or spring wheat. While glyphosate at 0.25 to 0.39 kg/ha can be used in the fall to control established plants (11), retreatment is needed to manage other weeds which may be present at spring planting. Consequently, fall application to control established foxtail barley has little economic justification. Spring treatment also effectively controls fall-germinating foxtail barley seedlings that may emerge and establish after a fall treatment.

Late-season control ratings at Sarles indicated that 4 to 12% of plants had formed some tillers 2 months after treatment with glyphosate at 0.56 kg/ha plus ammonium sulfate and surfactant (Table 2). Most other plants were standing but were dessicated and decayed at the soil surface. Since perennial foxtail barley grows slowly and takes 3 to 4 yr[6] to fully infest no-till land and to form a solid stand, glyphosate at 0.56 kg/ha plus ammonium sulfate and surfactant may need to be applied every second or third year to manage it. This possibly should be evaluated.

This research provides no-till farmers with a strategy for controlling established foxtail barley that fits into current no-till farm practice. The cost of this strategy is comparable or less than that of tillage (1) for managing this perennial weed.

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