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Profitable, Effective Herbicides for Planting-Time Weed Control in No-till Spring Wheat (*Triticum aestivum*)[1,2]

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Abstract. **High herbicide costs and uncertainty about annual weed control at planting have limited adoption of no-till spring wheat production systems in the northern Great Plains. Chlorsulfuron, metsulfuron, and CGA-131036 at 10 to 20 g ai ha^{-1} plus nonionic surfactant generally controlled both emerged kochia and wild mustard equally well (>80%) whether or not combined with glyphosate at 250 g ha^{-1} plus nonionic surfactant. In two of three trials persistent phytotoxic residues of these sulfonylurea herbicides in soil controlled both weeds better in midseason and early summer 1 yr after treatment than did glyphosate, which has only foliar activity. While the absolute net returns of different treatments varied among herbicides, relative net returns were insensitive to changes in either herbicide or wheat price. Herbicide use tended to boost net returns for no-till spring wheat in years with good weather but depressed net returns in a drought year. Chlorsulfuron at 10 and 20 g ha^{-1} increased net returns in all three trials. Metsulfuron and combinations of either metsulfuron or chlorsulfuron with glyphosate had variable effects on net returns. Nomenclature: Chlorsulfuron, 2-chloro-*N*-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide; CGA-131036, 3-(6-methoxy-4-methyl-1,3,5-triazin-2-yl)-1-[2-(2-chloroethoxy)phenylsulfonyl]urea; glyphosate, *N*-(phosphonomethyl)glycine; metsulfuron, 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid; kochia, *Kochia scoparia* (L.) Schrad. # KCHSC[4]; wild mustard, *Sinapis arvensis* L. # SINAR; spring wheat, *Triticum aestivum* L. 'Wheaton'.**
Additional index words. **Chlorsulfuron, CGA-131036, glyphosate, metsulfuron, sulfonylurea, *Kochia scoparia*, *Sinapis arvensis*, KCHSC, SINAR.**

INTRODUCTION

Annual broadleaf and grass weed control in no-till spring wheat in the northern Great Plains has been reviewed (5). Weeds that emerge before no-till planting must be controlled prior to spring wheat emergence because these weeds will have a growth advantage over the emerging crop and will be highly competitive. The early weeds also may be too large for effective control by the time selective postemergence herbicides can be applied in wheat. Shortly before or at planting in late April or early May, a nonselective herbicide, usually paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) or glyphosate, is applied to control early emerging annual broadleaf weeds, notably kochia, wild mustard, and wild buckwheat (*Polygonum convolvulus* L.). Glyphosate at 0.25 to 0.35 kg ha^{-1} also controls fall-germinating winter annual weeds, such as field pennycress (*Thlaspi arvense* L.), shepherdspurse [*Capsella bursa-pastoris* (L.) Medik.], and flixweed [*Descurainia sophia* (L.) Webb. ex Prantl.], which otherwise would be large and competitive when wheat emerges later. Summer annual grasses, such as green foxtail [*Setaria viridis* (L.) Beauv. # SETVI], emerge after most spring wheat is planted. However, wild oats (*Avena fatua* L. # AVEFA) is the only widespread summer annual grass weed that emerges appreciably before planting in the region. Wild oats is more of a concern when wheat planting is delayed beyond normal seeding dates. Glyphosate at 0.5 to 2.24 kg ha^{-1} will suppress or kill perennial grass and broadleaf weeds present at planting, although lower rates, usually 0.25 to 0.35 kg ha^{-1}, are applied to control small annual weeds. Application of selective postemergence herbicides may be needed in wheat for acceptable weed control (5). Weed species and control measures in no-till spring wheat in the northern Great Plains differ from those for no-till winter wheat in the central and southern Great Plains (12).

If annual broadleaf weeds or wild oats are present on conventionally tilled spring wheat farms in the northern Great Plains, they pose the greatest weed problems at planting for several years after no-till production practices are adopted. After several years of no-till cropping, new winter annual or perennial weeds, such as foxtail barley (*Hordeum jubatum* L.), that are adapted to no-till production systems may encroach on farmland in the northern Great Plains (2, 3).

High herbicide costs and uncertainty about weed control have limited adoption of no-till cereal production systems in the northern Great Plains, although no-till acreage has increased during the last decade (5). Less costly herbicides are needed for nonselective weed control at spring wheat planting, especially in situations where annual grasses are absent. Metsulfuron and chlorsulfuron are sulfonylurea herbicides registered for postemergence broadleaf weed control in spring wheat, whereas CGA-131036, a sulfonylurea

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[2]Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U. S. Dep. Agric. and does not imply its approval to the exclusion of other products that also may be suitable.

[3]Res. Agron., USDA, Agric. Res. Serv., formerly of USDA-ARS Biosciences Res. Lab. and Dep. Crop and Weed Sci., North Dakota State Univ., Fargo, ND 58105; and Prof., Dep. Agric. Econ., Univ. Missouri, Columbia, MO 65211, respectively. First author's current address: Cropping Systems and Water Quality Res. Unit, 244 Agric. Eng., Univ. Missouri, Columbia, MO 65211.

[4]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

Table 1. Dates field operations were performed.

	Trial 1	Trial 2	Trial 3
	Date		
Wheat residue determined	. . .	4/22/87	4/26/88
Preplant herbicides applied	5/21/86	4/24/87	5/16/88
Wheat planted	5/23/86	4/28/87	5/13/88
Wheat fertilized	5/23/86	4/28/87	5/13/88
Diclofop applied to all plots	6/17/86	6/12/87	6/10/88
Weed-shoot density determined:			
Early	6/12/87	6/15/87	6/20/88
Midseason	. . .	7/31/87	8/1/88
1 yr later	. . .	6/16/88	6/13/89
Weed control visually evaluated:			
Early	6/17/86	6/15/87	6/16/88
Midseason	7/18/86	7/6/87	7/13/88
1 yr later	6/15/87	6/16/88	6/14/89
Wheat harvested	8/28/86	8/5/87	8/3/88

Table 2. Sprayer parameters and environmental conditions at the time of herbicide application.

	Planting-time herbicides		
	Trial 1	Trial 2	Trial 3
Date applied	5/21/86	4/24/87	5/16/88
Carrier volume (L ha^{-1})	78	100	97
Pressure (kPa)	138	207	207
Nozzle size	8001	8001	8001
Nozzle spacing (cm)	50	50	50
Ground speed (km h^{-1})	4.8	4.0	4.8
Relative humidity (%)	44	46	. . .
Temperature (C)	30	21	. . .
Time before first precipitation (days)	2	7	3
First precipitation (cm)	0.6	0.3	0.5

analogue, was still under development when this research was completed. The objective of this research was to determine whether these three sulfonylurea herbicides could be profitably substituted for glyphosate to control annual broadleaf weeds present at planting of no-till spring wheat when annual and perennial grasses were absent.

MATERIALS AND METHODS

Field research was established in 1986 (trial 1) using a randomized complete block design with four blocks and was repeated in 1987 and 1988 on adjacent no-till sites (trials 2 and 3). All plots measured 3.3 by 7 m in trials 1 and 2 and 3.3 m by 8.5 m in trial 3. Trials 1, 2, and 3 were conducted in 1986 and from the spring of 1987 to 1988, and 1988 to 1989, respectively. The trials were conducted on sites that had been no-till planted to spring wheat for the previous 2, 3, and 4 yr, respectively. Dates of significant field events are presented in Table 1.

The trials were conducted on the North Dakota State University experimental farm, near Fargo, on a Fargo silty clay soil (fine, montmorillonitic, frigid Vertic Haplaquolls) with 2.5% sand, 51.7% silt, 45.8% clay, 4.5% organic matter, and a pH of 7.9. At the start of the experiment, chlorsulfuron and metsulfuron were registered for use on such high pH soils, although subsequent label changes have restricted use on high pH soils.

Planting-time herbicide treatments were applied with a bicycle wheel sprayer equipped with flat-fan nozzles[5] (Table 2). Herbicides were applied either shortly before or shortly after spring wheat planting (Table 1), but before wheat emergence. Dense stands of kochia and wild mustard had emerged by spraying and were the major annual broadleaf weeds present in all three trials. Winter annual weeds were sparse and summer annual grass weeds had not yet emerged at planting. Application parameters and environmental conditions at the time of herbicide application are presented in Table 2. All glyphosate and sulfonylurea herbicide treatments received nonionic surfactant[6] at 0.25% by vol.

Wheaton hard red spring wheat, a semidwarf variety, was planted at 84 to 90 kg ha^{-1} 2 to 3 cm deep in rows spaced 17.5 cm apart with a no-till grain drill[7] (Table 1). Wheat seed was treated with carboxin (5,6-dihydro-2-methyl-*N*-phenyl-1,4-oxathiin-3-carboxamine) fungicide at 75 to 100 g per 100 kg seed. Each year at planting, urea was band applied at approximately 123 kg nitrogen ha^{-1} 6 cm deep banded in 17.5 cm rows halfway between wheat rows. Nitrogen applications were made based on North Dakota State University soil test recommendations for a wheat yield goal of 3360 kg ha^{-1}. No other mineral nutrients were recommended or added. Soil samples for fertility analysis were collected in late fall.

Diclofop {(±)-2-[4-(2,4-dichlorophenoxy)phenoxy]propanoic acid} was applied postemergence at 1.1 kg ae ha^{-1} to all plots each spring in tillered spring wheat to control sparse stands of wild oats, green foxtail, and yellow foxtail (*Setaria glauca* L. # SETLU).

Densities of kochia and wild mustard, the major annual broadleaf weeds, were determined in three randomly placed 0.25- or 0.5-m^2 quadrats per plot approximately 1 and 2 months after spraying and in early summer of the following year in trials 2 and 3 (Table 1). All weed density data were expressed "per m^2" for comparisons. Weed control was estimated visually on a scale of 0 (no control) to 100 (complete control). Wheat was machine harvested[8] and cleaned. Grain moisture content was determined and net yield was adjusted to a moisture content of 10%. Analyses of variance were conducted and means were separated with Fisher's Protected Least Significant Difference Test (P =

[5]TeeJet flat-fan 8001 spray nozzles. Spraying Systems Co., Wheaton, IL 60188.

[6]Surfactant was Ortho X-77 spreader (Principal agent: alkylaryl polyoxyethylene glycols, free fatty acids, and isopropanil, 90%), now available as Valent X-77 from Valent U.S.A. Corp., 1333 N. California Blvd., Walnut Creek, CA 94596-8025.

[7]Haybuster 107 double-disc no-till grain drill with deep banding fertilizer attachment. Haybuster Manufacturing, Box 1950, Jamestown, ND 58401.

[8]Hege small-plot combine. Hege Equipment, Inc., Colwich, KS 67030.

Table 3. The effect of planting-time herbicide treatment on kochia control in mid-June (early) and in mid-July (midseason)[a].

		Early kochia control			Midseason kochia control		
Herbicide[b]	Rate	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
	g ha^{-1}	%					
Glyphosate	250	93	86	99	53 abc	40 a	92
CGA-131036	10	88	98	99	85 cd	99 c	97
	20	94	94	99	80 cd	92 bc	99
Chlorsulfuron	10	84	74	99	35 a	97 bc	97
	20	88	99	99	60 a-d	97 bc	99
Metsulfuron	10	94	97	99	70 a-d	99 c	99
	20	. . .	99	99	. . .	99 c	99
Glyphosate + CGA-131036	250 + 10	94	99	99	74 bcd	97 bc	80
	250 + 20	90	99	99	79 cd	99 c	94
Glyphosate + chlorsulfuron	250 + 10	81	89	99	38 ab	91 bc	99
	250 + 20	95	99	99	95 d	99 c	99
Glyphosate + metsulfuron	250 + 10	95	72	99	86 cd	70 b	98
	250 + 20	. . .	98	99	. . .	99 c	99
P > F		NS	NS	NS	0.0426	0.0037	NS

[a]Means in a column followed by the same letter were not different at P = 0.05 by the LSD test.

[b]Ortho X-77 spreader (Principal agent: alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol: 90%) was added at 0.25% by vol to all treatments.

0.05). The results were not combined across years because they differed between years, likely due to differences in yearly rainfall (Figure 1). Standard errors are presented for certain tables, as recommended by statisticians (1, 6, 7, 9), providing the reader with different statistical information than in tables containing only multiple comparison mean separation tests.

The economic feasibility of several herbicide treatments was determined by comparing changes in net returns per hectare between the untreated control and each treatment for 1986, 1987, and 1988 in a partial budget analysis. Differences in net returns were calculated using the formula: gross returns (measured wheat yield × average wheat price) for treated plots minus gross returns for untreated check minus the herbicide cost (herbicide plus surfactant costs, where appropriate, plus a custom application cost of \$4.94 ha^{-1}). A positive or negative difference in net returns indicates that the herbicide treatment was either more profitable or less profitable than the untreated control, respectively, for selected base years.

RESULTS AND DISCUSSION

Weed control. Three to 4 weeks after treatment, early kochia control was good (>80%) following glyphosate application at planting in all three trials (Table 3). Kochia seedlings had emerged at planting and there was limited subsequent emergence after glyphosate application. In contrast, wild mustard control was unsatisfactory (≤75%) with glyphosate alone, presumably because new seedlings continued to emerge following planting (Table 4). Because glyphosate lacks soil residual phytotoxicity (11), weeds emerging after application were not controlled.

With some exceptions, early kochia and wild mustard control generally was good (≥80%) to excellent (≥90%) after applying chlorsulfuron, metsulfuron, or CGA-131036 either alone or with glyphosate at 250 g ha^{-1} at planting (Tables 3 and 4). In two of three trials, early wild mustard control was generally superior with sulfonylurea herbicides alone or combined with glyphosate than with glyphosate alone. In the third trial, wild mustard control was excellent (≥95%) with all sulfonylurea treatments.

Two months following treatment, midseason kochia and wild mustard control generally was fair (>70%) to excellent (>90%) for most sulfonylurea herbicide treatments although

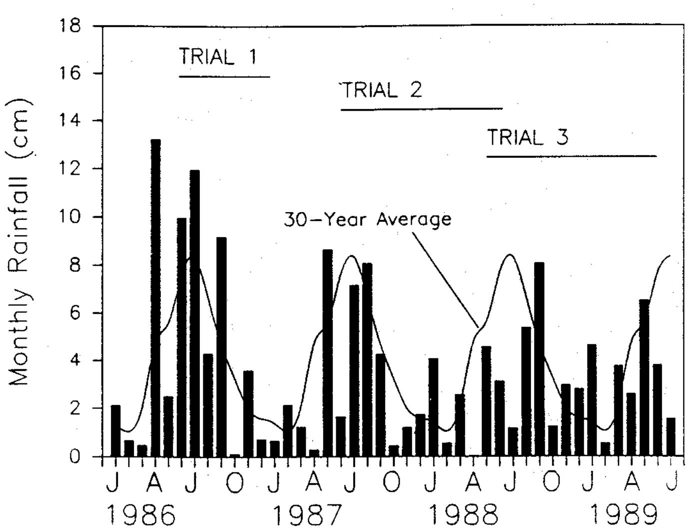

Figure 1. Monthly precipitation (bars) and the 30-yr average precipitation (splined lines) over the course of trials 1 to 3. Weather data were gathered at Hector International Airport, approximately 7 km southeast of the experimental site.

Table 4. The effect of planting-time herbicide treatment on wild mustard control in mid-June (early) and in mid-July (midseason)[a].

Herbicide[b]	Rate	Early wild mustard control			Midseason wild mustard control		
		Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
	g ha^{-1}	%					
Glyphosate	250	55 a	40 a	72	5 a	28 a	74
CGA-131036	10	94 b	89 b	93	90 b	94 cd	74
	20	95 b	97 b	99	91 b	90 bcd	74
Chlorsulfuron	10	86 b	70 ab	98	66 b	92 bcd	74
	20	84 b	98 b	95	70 b	95 cd	74
Metsulfuron	10	88 b	87 b	97	80 b	70 bcd	74
	20	. . .	91 b	97	. . .	71 bcd	74
Glyphosate + CGA-131036	250 + 10	93 b	99 b	96	95 b	97 d	74
	250 + 20	95 b	99 b	99	94 b	99 d	74
Glyphosate + chlorsulfuron	250 + 10	83 b	92 b	94	70 b	60 ab	74
	250 + 20	91 b	95 b	97	90 b	98 d	99
Glyphosate + metsulfuron	250 + 10	93 b	69 ab	97	91 b	63 bc	74
	250 + 20	. . .	98 b	97	. . .	96 d	74
P > F		0.0139	0.0497	NS	0.0001	0.0011	NS

[a]Means in a column followed by the same letter were not different at P = 0.05 by the LSD test.

[b]Ortho X-77 spreader (Principal agent: alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol: 90%) was added at 0.25% by vol to all treatments.

control had decreased somewhat from earlier visual evaluations (Tables 3 and 4). Presumably, phytotoxic sulfonylurea herbicide residues persisted long enough to kill weeds emerging after application, as previously reported (4, 13, 14). Chlorsulfuron, metsulfuron, or CGA-131036 applied alone at 10 g ha^{-1} controlled kochia and wild mustard at midseason as well as when applied at 20 g ha^{-1}. It was not advantageous to add glyphosate to sulfonylurea herbicides as planting-time treatments for either early or late in-crop weed control. By midseason, about 2 months after application, glyphosate alone had not maintained control of kochia and wild mustard adequately in two of three trials.

Wheat yield. Wheat yields following all three sulfonylurea herbicide treatments were either equal to or better than glyphosate alone in all trials (Table 5). Drought during the third trial (Figure 1) probably prevented wheat from achieving the potential yield for which it was fertilized[9]. Annual precipitation during trial 3 (1988) was 74% of the 30-yr average (48.8 cm). Only one treatment in trial 2 achieved the yield goal expected for the fertilizer program used. Tank mixtures of glyphosate and sulfonylurea herbicides did not provide a consistent yield or weed control advantage over sulfonylurea herbicides alone. In terms of either visually evaluated weed control (Tables 3 and 4) or yield (Table 5), sulfonylurea herbicides alone could substitute for glyphosate treatment for planting-time control of certain annual broadleaf weeds.

Partial budget analysis. Wheat yields were highest in 1987. Net returns were increased by six treatments in 1987; namely, \$61.68 ha^{-1} for glyphosate at 250 g ha^{-1} plus metsulfuron at 20 g ha^{-1}, \$32.75 $ha^{-1}$for metsulfuron at 10 g ha^{-1}, \$16.39 ha^{-1} for chlorsulfuron at 20 g ha^{-1}, \$15.78 ha^{-1} for glyphosate at 250 g ha^{-1} plus metsulfuron at 20 g ha^{-1}, \$15.42 ha^{-1} for chlorsulfuron at 10 g ha^{-1}, and \$3.47 ha^{-1} for glyphosate at 250 g ha^{-1} plus chlorsulfuron at 10 g ha^{-1} (Table 6). Four of the six treatments that increased net returns in 1987, including the two treatments that showed the largest increase in net returns, reduced net returns in 1988, a drought year. Only three of the nine treatments examined increased net returns relative to the control in 1988 due to drought and low wheat yields. The increases were: \$12.64 ha^{-1} for chlorsulfuron at 20 g ha^{-1}, \$2.18 ha^{-1} for metsulfuron at 20 g ha^{-1}, and \$1.84 ha^{-1} for chlorsulfuron at 10 g ha^{-1}. The added expense of treating weeds with herbicides combined with lower wheat yields during a drought year caused net returns of these cases to be lower compared to the untreated control. Herbicide use tended to boost net returns for no-till spring wheat in years (1986 and 1987) of normal rainfall but depress net returns in a drought year (1988).

The sensitivity of the ranking of differences in net returns for herbicide treatments relative to the untreated controls to variation in herbicide and wheat prices was tested for 12 cases (Table 7). Sensitivity analysis consisted of three price scenarios: a 10 or 20% decrease in glyphosate price, a constant or 10% increase in chlorsulfuron and metsulfuron price, and a constant 15% increase or 15% decrease in wheat price. Percentage changes in herbicide prices are based on projected market conditions, and percentage changes in wheat prices are arbitrary. In particular, percentage changes in Table 7 were applied to herbicide costs and gross returns for 1987 and 1988 (Table 8). Due to the substantial differences in wheat yields between 1987 and 1988, a separate sensitivity analysis was done for 1987 and 1988 which represents years of average rainfall and drought, respectively.

[9]The spring wheat yield goal was 3360 kg ha^{-1} whereas the average yields for North Dakota were 2080, 2080, and 1010 kg ha^{-1} in 1986, 1987, and 1988, respectively, according to U. S. Dep. Agric. Agricultural Statistics, 1989. U. S. Gov. Printing Off., Washington, DC.

Table 5. The effect of planting time herbicide treatment on spring wheat yield[a].

Herbicide[b]	Rate	Net yield		
		Trial 1	Trial 2	Trial 3
	g ha^{-1}	kg ha^{-1}		
Untreated control	0	240 ± 140 a	2340 ± 290 ab	350 ± 30
Glyphosate	250	2140 ± 150 b	2140 ± 220 a	460 ± 120
CGA-131036	10	2310 ± 130 bc	3020 ± 280 de	420 ± 20
	20	2360 ± 240 bc	2700 ± 170 bcd	470 ± 30
Chlorsulfuron	10	1960 ± 200 b	2630 ± 40 a-d	470 ± 70
	20	1950 ± 290 b	2710 ± 180 bcd	600 ± 170
Metsulfuron	10	2070 ± 170 b	2850 ± 110 b-e	410 ± 60
	20	. . .	2500 ± 60 abc	630 ± 210
Glyphosate + CGA-131036	250 + 10	2420 ± 130 bc	2750 ± 110 b-e	450 ± 50
	250 + 20	2340 ± 240 bc	2740 ± 240 bcd	440 ± 100
Glyphosate + chlorsulfuron	250 + 10	2200 ± 330 bc	2630 ± 190 a-d	440 + 30
	250 + 20	2430 ± 230 bc	3250 ± 160 e	500 ± 70
Glyphosate + metsulfuron	250 + 10	2720 ± 88 c	2610 ± 70 a-d	340 ± 70
	250 + 20	. . .	2930 ± 140 cde	420 ± 60
MSE		151 013	126 804	36 365
P > F		0.0001	0.0172	NS
F ratio		10.35	2.38	0.74

[a]Means in a column followed by the same letter were not different at P = 0.05 by the LSD test. Means ± standard errors are presented.

[b]Ortho X-77 spreader (Principal agent: alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol: 90%) was added at 0.25% by vol to all treatments. Diclofop at 1.1 kg ha^{-1} was applied in-crop to all plots.

Table 8 summarizes treatment rankings in net returns using 1987 and 1988 as base years. While absolute net returns of different treatments varied somewhat from case to case (data not shown), the ranking of net returns for the 12 cases tested was generally insensitive to changes in either herbicide or wheat price within a base year and can be considered to be economically "robust." The ranking of net returns for herbicide treatments differed for 1987 and 1988, presumably because of the impact of differences in seasonal rainfall on wheat yield and weed density, growth, and competitiveness with spring wheat, as well as differences in year-to-year herbicide costs and wheat price. In 1987, a year

Table 6. Effect of herbicide treatment on gross and net returns in spring wheat.

Herbicide[a]	Rate	Herbicide cost[b]			Gross returns[c]			Difference in net returns[d]		
		1986	1987	1988	1986	1987	1988	1986	1987	1988
	g ha^{-1}	\$ ha^{1}								
Untreated control	0	0	0	0	23.40	248.00	50.40	. . .	. . .	. . .
Glyphosate	250	14.70	11.95	11.95	206.33	223.93	63.26	163.29	−40.96	−4.03
Chlorsulfuron	10	7.51	7.51	7.72	188.78	275.87	64.90	152.93	15.42	1.84
	20	15.02	15.02	15.44	187.80	284.35	83.42	144.44	16.39	12.64
Metsulfuron	10	NA	13.50	15.10	199.49	299.19	56.06	NA	32.75	−14.38
	20	NA	27.00	30.20	NA	262.09	87.72	NA	−17.85	2.18
Glyphosate + chlorsulfuron	250 + 10	22.21	19.46	19.67	212.18	275.87	60.38	161.63	3.47	−14.63
Glyphosate + chlorsulfuron	250 + 20	29.72	26.97	27.39	234.60	341.59	69.02	176.54	61.68	−13.71
Glyphosate + metsulfuron	250 + 10	NA	25.45	27.05	262.88	273.75	45.98	NA	−4.64	−36.41
Glyphosate + metsulfuron	250 + 20	NA	38.95	42.1	NA	307.67	57.5	NA	15.78	−39.94

[a]Diclofop was applied at 1.1 kg ha^{-1} in-crop to all plots.

[b]Glyphosate cost 0.0588, 0.0478, and 0.0478 \$ g^{-1} in 1986, 1987, and 1988, respectively, according to Ostlund Chemical Co., Fargo, ND. Chlorsulfuron cost 0.751, 0.751, and 0.772 \$ g^{-1} in 1986, 1987, and 1988, respectively, according to Ostlund Chemical Co., Fargo, ND. Metsulfuron cost 1.35 and 1.51 \$ g in 1987 and 1988, respectively, according to Ostlund Chemical Co., Fargo, ND. Metsulfuron was not marketed in 1986.

[c]Gross returns are net of diclofop plus application costs. Diclofop cost 0.033, 0.032, and 0.034 \$ g^{-1} in 1986, 1987, and 1988, respectively, according to Ostlund Chemical Co., Fargo, ND. Wheat sold for 0.0975, 0.106, and 0.144 \$ kg^{-1} in 1986, 1987, and 1988, respectively, according to N. A. Dorow, Agric. Econ. Dep. and Ext. Serv., N. D. State Univ., Fargo, ND.

[d]Difference in net returns = gross returns (treated) − gross returns (untreated) − herbicide cost − herbicide application cost (\$4.94 ha^{-1}).

Table 7. Percentage changes in herbicide and wheat prices for sensitivity analysis[a].

Parameter	Case 1	2	3	4	5	6	7	8	9	10	11	12
	% price change											
Glyphosate	−10	−10	−20	−20	−10	−10	−20	−20	−10	−10	−20	−20
Chlorsulfuron + metsulfuron	0	+10	0	+10	0	+10	0	+10	0	+10	0	+10
Wheat	0	0	0	0	+15	+15	+15	+15	−15	−15	−15	−15

[a]Percentage changes relative to actual market prices.

of normal rainfall, glyphosate plus chlorsulfuron at 20 g ha^{-1} ranked first in providing the greatest increase in net returns relative to the untreated control, whereas metsulfuron at 10 g ha^{-1} and glyphosate plus metsulfuron at 20 g ha^{-1} ranked second and third, respectively. In 1988, a drought year, chlorsulfuron at 20 g ha^{-1} ranked first in relative net returns but exceeded the untreated control only for cases 1 to 8. Metsulfuron at 20 g ha^{-1} and chlorsulfuron at 10 g ha^{-1} ranked second or third in net returns in 1988.

Except for the combination of glyphosate at 250 g ha^{-1} plus chlorsulfuron at 20 g ha^{-1} with 1987 as the base year, herbicide use reduced net returns relative to the untreated control when wheat prices were 15% lower (cases 9 to 12). All treatments except glyphosate at 250 g ha^{-1} were relatively more profitable than the untreated control when wheat prices were 15% higher with 1987 as the base year (cases 5 to 8). However, with 1988 as the base year, only four treatments were more profitable even though wheat prices were 15% higher (cases 5 to 8). Allowing glyphosate prices to decrease 10 or 20% while letting chlorsulfuron and metsulfuron price remain constant or increase 10% (cases 2 and 4) had no effect on the relative net returns of treatments or which treatments increased or decreased net returns with 1988 as the base year.

Residual weed control 1 yr after application. Residual weed control reportedly lasted for part of the growing season 1 yr after chlorsulfuron treatment elsewhere in the U. S. (10, 13, 14). For example, fall-applied chlorsulfuron at 18 to 26 g ha^{-1} controlled Russian thistle (*Salsola iberica* Sennen and Pau) in spring wheat until July (13, 14). The 1989 label for chlorsulfuron and metsulfuron and a recent review (4) indicate that these sulfonylurea herbicides have both preemergence and postemergence activity. Soil residues of chlorsulfuron can be activated by rainfall or shallow incorporation to control certain weeds (8).

Table 8. Ranking of net returns following herbicide treatments to spring wheat for 12 sensitivity cases (described in Table 7) with either 1987 as a base year (normal rainfall conditions) or with 1988 as a base year (drought stress conditions).

Herbicide	Rate	Ranking of net returns by case: 1	2	3	4	5	6	7	8	9	10	11	12
		1987 as base year											
	g ha^{-1}												
Untreated control	0	7	7	7	7	9	9	9	9	2	2	2	2
Glyphosate	250	10	10	10	10	10	10	10	10	10	10	10	10
Chlorsulfuron	10	5	5	5	5	5	5	5	5	6	5	5	5
	20	4	4	4	4	4	4	4	4	7	6	6	6
Metsulfuron	10	2	2	2	2	2	2	2	2	3	3	3	3
	20	9	9	9	9	8	8	8	7	9	9	9	9
Glyphosate + chlorsulfuron	250 + 10	6	6	6	6	6	6	6	6	4	7	7	7
	250 + 20	1	1	1	1	1	1	1	1	1	1	1	1
Glyphosate + metsulfuron	250 + 10	8	8	8	8	7	7	7	8	8	8	8	8
	250 + 20	3	3	3	3	3	3	3	3	5	4	4	4
		1988 as base year											
Untreated control	0	4	4	4	4	5	5	5	5	1	1	1	1
Glyphosate	250	5	5	5	5	4	4	4	4	5	5	5	5
Chlorsulfuron	10	3	3	3	3	2	3	2	3	4	4	4	4
	20	1	1	1	1	1	1	1	1	2	2	2	2
Metsulfuron	10	8	8	8	8	8	8	8	8	6	6	6	6
	20	2	2	2	2	3	2	3	2	3	3	3	3
Glyphosate + chlorsulfuron	250 + 10	7	7	7	7	7	7	7	7	7	7	7	7
	250 + 20	6	6	6	6	6	6	6	6	8	8	8	8
Glyphosate + metsulfuron	250 + 10	9	9	9	9	9	9	9	9	9	9	9	9
	250 + 20	10	10	10	10	10	10	10	10	10	10	10	10

Table 9. Effect of planting time herbicide treatments to spring wheat on kochia density[a].

Herbicide[b]	Rate	Kochia shoot density					
		Early		Midseason		1 yr later	
		Trial 2	Trial 3	Trial 2	Trial 3	Trial 2	Trial 3
	g ha^{-1}	no. m^{-2}					
Untreated control	0	33 ± 8 c	8 ± 2 b	40 ± 10 b	9 ± 2.3 c	14 ± 7 c	266 ± 25 g
Glyphosate	250	17 ± 6 c	6 ± 4 b	33 ± 10 b	3 ± 1.4 b	10 ± 4 bc	162 ± 28 f
CGA-131036	10	10 ± 6 bc	0.2 ± 0.2 a	6 ± 4 a	0.2 ± 0.2 a	2 ± 1 a	127 ± 25 ef
	20	0 a	0 a	0.3 ± 0.3 a	0.2 ± 0.2 a	0.3 ± 0.3 a	33 ± 13 abc
Chlorsulfuron	10	1 ± 1 ab	0 a	2 ± 1 a	0.3 ± 0.2 a	0.6 ± 0.3 a	65 ± 35 a-d
	20	0 a	0 a	1 ± 1 a	0 a	0 a	28 ± 6 ab
Metsulfuron	10	6 ± 4 ab	0 a	8 ± 7 a	0 a	4 ± 3 ab	80 ± 14 cde
	20	2 ± 1 ab	0 a	2 ± 1 a	0 a	1 ± 1 a	58 ± 12 a-d
Glyphosate + CGA-131036	250 + 10	1 ± 0.4 ab	0 a	2 ± 2 a	0.5 ± 0.2 a	0.3 ± 0.3 a	106 ± 19 de
	250 + 20	2 ± 2 ab	0 a	0 a	0.2 ± 0.2 a	1 ± 1 a	33 ± 7 abc
Glyphosate + chlorsulfuron	250 + 10	3 ± 2 ab	0.2 ± 0.2 a	2 ± 2 a	0 a	2 ± 1 a	39 ± 4 abc
	250 + 20	0.3 ± .3 ab	0.2 ± 0.2 a	0.3 ± 0.3 a	0 a	0 a	15 ± 5 a
Glyphosate + metsulfuron	250 + 10	8 ± 5 ab	0.2 ± 2 a	1 ± 1 a	0 a	3 ± 3 ab	74 ± 7 bcd
	250 + 20	2 ± 1 ab	0.2 ± 0.2 a	1 ± 0.4 a	0.2 ± 0.2 a	1 ± 1 a	35 ± 8 abc
P > F		0.0001	0.0001	0.0001	0.0001	0.0069	0.0001
MSE		49.0	6.0	75	2.19	25	1233
F-ratio		6.64	4.36	8.58	9.58	2.73	15.10

[a]Means in a column followed by the same letter were not different at P = 0.05 by the LSD test. Means ± standard errors are presented.

[b]Ortho X-77 spreader (Principal agent: alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol: 90%) was added at 0.25% by vol to all treatments.

Table 10. Effect of planting time herbicide treatment to spring wheat on wild mustard density[a].

Herbicide[b]	Rate	Wild mustard shoot density					
		Early		Midseason		1 yr later	
		Trial 2	Trial 3	Trial 2	Trial 3	Trial 2	Trial 3
	g ha^{-1}	no. m^{-2}					
Untreated control	0	35 ± 12 a	5 ± 3	0	2.8 ± 1.0 a	62 ± 16 cd	3 ± 1.2
Glyphosate	250	48 ± 4 a	14 ± 11	3 ± 7	1.0 ± 0.6 b	73 ± 20 d	3 ± 1.1
CGA-131036	10	10 ± 6 bc	0.5 ± 0.3	0	0.5 ± 0.3 b	6 ± 6 a	1 ± 0.3
	20	8 ± 4 bc	0	0	0 b	12 ± 11 ab	3 ± 1
Chlorsulfuron	10	10 ± 4 bc	0.2 ± 0.2	0	0.2 b	11 ± 8 ab	2 ± 0.4
	20	6 ± 4 bc	0.3 ± 0.2	0	0.2 ± 0.2 b	2 ± 0.6 a	4 ± 1
Metsulfuron	10	26 ± 10 b	0	4 ± 7	0 b	44 ± 22 bcd	3 ± 0.4
	20	15 ± 9 bc	0.2 ± 0.2	0	0 b	34 ± 28 abc	2 ± 0.6
Glyphosate + CGA-131036	250 + 10	5 ± 1 c	0.2 ± 0.2	0	0.2 ± 0.2 b	4 ± 2 a	1 ± 1.0
	250 + 20	4 ± 3 c	0	0	0 b	4 ± 2 a	1 ± 0.5
Glyphosate + chlorsulfuron	250 + 10	15 ± 7 bc	0.5 ± 0.3	0	0.8 ± 0.8 b	7 ± 3 a	3 ± 0.8
	250 + 20	14 ± 11 bc	0.2 ± 0.2	0	0.2 ± 0.2 b	0.3 ± 0.3 a	4 ± 1.2
Glyphosate + metsulfuron	250 + 10	8 ± 2 bc	0.8 ± 0.6	0	0 b	18 ± 9 ab	2 ± 0.7
	250 + 20	7 ± 4 bc	0.2 ± 0.2	0	0.2 ± 0.2 b	1 ± 0.6 a	1 ± 0.4
P > F		0.0016	NS	NS	0.0006	0.0008	NS
MSE		160	38	6	0.62	647	2.81
F-ratio		3.5	1.43	1.14	3.71	3.57	0.23

[a]Means in a column followed by the same letter were not different at P = 0.05 by the LSD test. Means ± standard errors are presented.

[b]Ortho X-77 spreader (Principal agent: alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol: 90%) was added at 0.25% by vol to all treatments.

This research verified that sulfonylurea herbicides applied in one growing season could control certain annual broadleaf weeds the following summer in the northern Great Plains (Tables 9 and 10). Kochia densities in sulfonylurea-treated plots were less than in the untreated control 1 yr following most planting-time treatments. Presumably, reduced seed production due to sulfonylurea treatment and carryover of phytotoxic herbicide residues contributed to lower weed emergence 1 yr after treatment. Reduced seed production likely contributed to part of the observed decreases in weed emergence because glyphosate applied alone at 250 g ha^{-1} also reduced kochia densities 1 yr after treatment relative to the untreated control even though glyphosate has no soil residual activity (11).

Substitution of either chlorsulfuron, metsulfuron, or CGA-131036 for glyphosate has several potential advantages for planting-time weed control in no-till spring wheat. These sulfonylurea herbicides provide postemergence and season-long preemergence control of certain annual broadleaf weeds, reducing the need for in-crop herbicide treatment. In contrast, in-crop herbicide treatments may be needed to control later emerging weeds following planting-time glyphosate application. Weed control 1 yr following application of these sulfonylurea herbicides also may be advantageous in subsequent no-till or reduced-till cereal crops. Fewer tillage operations or herbicide applications may be required to control weeds during mechanical or chemical fallow, respectively.

Substituting sulfonylurea herbicides for glyphosate at planting may have several disadvantages. Glyphosate may be required when annual grasses are present because these sulfonylurea herbicides do not provide adequate annual grasses control (4). Because persistent phytotoxic residues may damage rotational crops, chlorsulfuron and metsulfuron use is limited to certain geographic regions (4). Residual weed control 1 yr after application of chlorsulfuron, metsulfuron, and CGA-131036 also was unpredictable and highly dependent on weather.

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