Influence of Certain Postemergence Broadleaf Herbicides on Soybean Stressed from Iron Deficiency Chlorosis

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ABSTRACT

Postemergence herbicides are widely used in soybean [*Glycine max* (L.) Merr.]. Although yield is seldom reduced following herbicide applications to soybean under normal growing conditions, little is known regarding their application when the crop is under stress. Iron deficiency chlorosis (IDC) is a common problem in the Red River Valley of North Dakota and Minnesota. Postemergence herbicide applications are usually made early in the season when IDC is most expressed. The objective of this experiment was to compare the effects of selected postemergence soybean herbicides applied to soybean under stress from IDC. Treatments were applied at 12 locations during a 3-yr study. Stunting and necrosis were evaluated at 14 and 28 d after treatment (DAT), and plots were harvested to determine grain yield. There were treatment differences in stunting at 11 locations 14 DAT and at nine locations 28 DAT. Differences in leaf necrosis were found among treatments at 11 locations 14 DAT and at four locations 28 DAT. Lactofen significantly lowered yield at six locations, and imazamox and imazethapyr lowered yield at three locations. These results suggest that herbicides with harsh contact activity (lactofen) and some acetolactate synthase (ALS) inhibitors (e.g., imazamox, thifensulfuron, and imazethapyr) may have potential for greater injury under these soil and environmental conditions. It may be important to consider herbicide injury effects, in addition to weed spectrum, when selecting herbicides for use on IDC-stressed soybean.

Iron deficiency chlorosis (IDC) in soybean is common in many areas where soybean is grown in the North-Central United States and is especially common and severe in the calcareous soils of the Red River Valley of eastern North Dakota and northwestern Minnesota. Calcareous soils interfere with iron uptake by soybean (Inskeep and Bloom, 1987; Uvalle-Bueno and Romero, 1988; Goos and Johnson, 2000). Iron is essential for chlorophyll production, and IDC is characterized by stunted plants with interveinal pale green or yellow to nearly white leaves with green veins (Anderson, 1982; Clark, 1982).

Iron deficiency chlorosis is not usually observed until the first trifoliolate emerges since before this stage, iron from the seed is translocated to new growth (Clark, 1982). After the first trifoliolate emerges, iron becomes immobile, and the soybean plant must rely on soil availability to supply iron (Vose, 1982). Due to a combination of soil factors, including pH, temperature, $CaCO_3$ content, water content, and the concentration of HCO_3^- in the soil solution (Inskeep and Bloom, 1984, 1986; Goos and Johnson, 2000), iron uptake may be reduced (Inskeep and Bloom, 1987; Chaney et al., 1992). Chlorosis develops when insufficient iron is supplied to leaves (Lin et al., 1998). Iron deficiency chlorosis may be so severe that necrosis and death of the leaf or entire plant may occur. Cool, wet soil conditions or poorly drained soils intensify IDC in calcareous regions where iron deficiencies are common (Moraghan and Mascagni, 1991).

Several studies have been conducted to ascertain why soybean becomes iron deficient under calcareous soil conditions. Soil pH in the Red River Valley typically ranges between 7.5 and 8.5 (Franzen, 1999). High soil pH, calcium carbonates, organic matter, and soluble salts (Dahiya and Singh, 1979) in combination with high moisture contribute to IDC in this region (Bloom and Inskeep, 1986; Inskeep and Bloom, 1987; Springer et al., 1999; Franzen and Richardson, 2000).

Postemergence herbicides are used by nearly all soybean growers in North Dakota (Zollinger et al., 1998) and are an important component of an integrated weed control strategy. Following herbicide label directions and using proper application techniques may not prevent crop burning, stunting, and chlorosis (Wichert and Talbert, 1993). Though postemergence herbicides are effective at controlling weeds (Kapusta et al., 1986), crop injury and reduced yield have been observed. Soybean can be stressed by iron deficiency and soluble salts but may also be stressed from postemergence herbicides. Common foliar effects of postemergence herbicides may include stunting, chlorosis (not associated with iron deficiency), bronzing, and crinkling or burning of the leaves. Although soybean may express symptoms from herbicide activity, soybean growth and yield usually are unaffected if all other stresses are minimized (Browde et al., 1994). Kapusta et al. (1986) observed that bentazon [3-(1-methylethyl)-1*H*-2,1,3-benzothiadiazin-4(3*H*)-one-2,2-dioxide] and acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid} caused early crop injury. However, the soybean recovered by 21 d after application without any significant effect on yield.

Some herbicide labels caution users that temporary injury may result from use, without affecting yield under some conditions. Current research suggests that under certain stress, some yield loss is possible. Harvey and Ateh (1996) conducted an experiment in Wisconsin to measure the effects of postemergence herbicides on soybean yield. Labeled rates of 12 common postemergence herbicides were applied to soybean. Compared with the nonsprayed soybean, the herbicide treatments averaged an 11, 1, and 4% reduction in yield in 1993, 1994, and

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Abbreviations: DAT, days after treatment; EC, electrical conductivity; IDC, iron deficiency chlorosis.

Table 1. Locations, varieties, planting dates, and treatment dates for field experiments, 1998 to 2000.

Location/year	Variety	Planting date	Treatment date
Fairmount, ND, 1998	Cenex LOL† 946	12 May 1998	16 June 1998
Arthur, ND, 1998	Pioneer 90B71	27 May 1998	1 July 1998
Horace, ND, 1998	Pioneer 9071	30 May 1998	1 July 1998
Colfax, ND, 1998	Interstate 110	17 May 1998	30 June 1998
Rothsay, MN, 1998	Pioneer 9091	9 May 1998	18 June 1998
Moorhead, MN, 1998	Stine 0846	19 May 1998	1 July 1998
Walcott, ND, 1999	Interstate 111	26 May 1999	2 July 1999
Rothsay, MN, 1999	Pioneer RR‡ 90B72	14 May 1999	30 June 1999
Moorhead, MN, 1999	Mycogen 013	29 May 1999	2 July 1999
Walcott, ND, 2000	Pioneer RR 91B72	19 May 2000	27 June 2000
Arthur, ND, 2000	Pioneer 90B43	16 May 2000	28 June 2000
Rothsay, MN, 2000	Pioneer RR 90B70	3 May 2000	27 June 2000

† LOL, Land O' Lakes.
‡ RR, Roundup Ready (glyphosate tolerant).

1995, respectively. These researchers concluded that the use of postemergence herbicides resulted in only a slight soybean yield loss compared with a hand-weeded check. It was noted that environmental conditions after herbicide application could influence soybean recovery.

Since there was evidence of soybean stress due to herbicides under normal growing conditions, research was needed to determine the extent of yield loss from soybean plants exhibiting IDC at the time of herbicide application. It is hypothesized that combining these two stresses will result in severe visible injury as well as a significant yield loss. It is also hypothesized that each herbicide will affect the yield differently. Currently, there is no published research regarding herbicide treatment and IDC on soybean yield.

A 3-yr (1998–2000) field study was conducted in the Red River Valley of North Dakota and Minnesota to quantify the effects of POST herbicides applied to soybean exhibiting IDC symptoms. The objectives of this research were to determine whether certain soybean postemergence broadleaf herbicides reduced soybean yield when soybean was stressed from IDC and whether some herbicides reduced yield more consistently and at greater magnitude than others.

MATERIALS AND METHODS

Field Experiments

Ideally, fertility experiments are conducted on uniform sites with similar cultivars seeded on each site. However, IDC is an ephemeral quality that varies in area of appearance and severity due to a number of uncontrollable soil and environmental factors, such as soluble salt level, soil moisture, and temperature. It would be impractical to set up a number of field studies related to IDC without first finding locations that actually exhibit chlorosis in a given year. Therefore, it was important to establish the studies in farmer fields with soybean already exhibiting IDC although by doing so, the ability to combine all sites statistically was lost since most fields were seeded to different soybean cultivars. However, the frequency of treatment differences across a number of sites would support the study objectives and were similar to methods used by Haq and Mallarino (2000).

From 1998 to 2000, 12 sites were established on production fields exhibiting IDC (Table 1). Sites were also selected with a history of low weed pressure. Soils from each location and selected chemical properties are listed in Table 2. Since soybean plants do not exhibit IDC until the first trifoliate leaves have emerged, field locations were selected when the soybean was in the one to two trifoliate stage. Uniformly chlorotic areas within each field were selected to reduce variability within each experiment. Chlorosis was evaluated as follows: 0% = no chlorosis; 20% = slight general chlorosis of the upper leaves; 40% = moderate interveinal chlorosis of upper leaves; 60% = chlorosis of the entire plant with necrosis and stunting observed; 80% = severe chlorosis, stunting, and necrosis with dead growing point; and 100% = entire plant dead.

Plots were 3 m wide by 6 m long with a 1.5-m border strip between blocks and a 1.5-m border around the entire experiment. Buffer strips were used as a precaution to minimize cooperator-applied herbicide, from adjacent acres, from drifting into the experimental areas. The experimental design was a randomized complete block experiment with 10 to 11 herbicide treatments depending on the location and year. Plant populations were recorded for each plot immediately before

Table 2. Soil series and chemical characteristics of experimental sites.

Site	Soil series†	pH	Mean EC‡	EC range	Mean CCE§	CCE range
			dS m^{-1}		g kg^{-1}	
Fairmount, 1998	Colvin, sicl	8.0	1.4	0.6–2.5	78	50–100
Arthur, 1998	Arveson, sl	8.1	0.4	0.3–0.6	24	5–40
Horace, 1998	Bearden, sicl	8.0	0.5	0.5–0.7	28	5–100
Colfax, 1998	Arveson, sl	8.0	0.5	0.2–1.0	10	2–40
Rothsay, 1998	Arveson, sl	8.1	0.7	0.3–1.0	32	20–100
Moorhead, 1998	Colvin, sicl	8.2	0.6	0.5–2.5	263	190–320
Walcott, 1999	Bearden, sicl	8.1	1.8	1.0–3.0	110	90–140
Rothsay,1999	Arveson, sl	8.1	1.0	0.3–1.7	70	30–100
Moorhead, 1999	Colvin, sicl	8.1	0.7	0.5–1.1	164	100–210
Walcott, 2000	Hegne, sicl	8.0	0.3	0.3–0.4	34	27–60
Arthur, 2000	Arveson, sl	8.1	0.25	0.2–0.4	51	27–89
Rothsay, 2000	Arveson, sl	8.1	0.7	0.4–1.2	21	9–35

† sicl, silty clay loam; sl, sandy loam.
‡ EC, electrical conductivity.
§ CCE, calcium carbonate equivalent.

Table 3. Spray date, time, temperature, humidity, wind speed and direction, percentage clouds, and percentage initial soybean chlorosis by location.

Site	Date	Time	Temperature Air	Temperature Soil	Humidity	Wind	Clouds	Chlorosis
		h	°C	°C	%	km/h	%	%
Fairmount, 1998	16 June	0800–0900	23.3	22.2	68	0	40	18
Arthur, 1998	1 July	1600–1700	25.6	28.3	65	0–7 NW	5	15
Horace, 1998	1 July	0900–1000	22.2	26.1	55	0–4 S	0	15
Colfax, 1998	30 June	1800–1900	24.4	27.8	76	0–5 NW	25	20
Rothsay, 1998	18 June	0900–1000	17.2	18.6	80	3–5 S	100	16
Moorhead, 1998	1 July	1700–1800	27.2	32.8	56	0–5 NW	25	20
Walcott, 1999	2 July	1300–1400	26.7	39.4	75	5–8 SE	40	40
Rothsay, 1999	30 June	1400–1500	25.6	30.0	55	5–8 W	60	45
Moorhead, 1999	2 July	1500–1600	27.2	41.0	70	5–10 SE	20	65
Walcott, 2000	27 June	1000–1100	18.9	21.7	60	0–8 SW	0	15
Arthur, 2000	28 June	1000–1200	20.0	17.8	53	8–12 N	10	18
Rothsay, 2000	27 June	1100–1300	21.1	27.8	74	8–14 S	30	25

herbicide application and before harvest. Two rows, approximately 6 m long, were measured from each plot. Soybean plants were counted, and mean stand count for the plot was recorded. Following herbicide application, plots were hand-weeded weekly to ensure that yield differences between treatments were the result of the herbicides and not uncontrolled weeds. Weeds present before herbicide application likely had little or no effect on soybean grain yield since they were small and present at low populations.

Soil samples were taken from all plots before herbicide treatments and consisted of four to five random cores (2.5-cm diam.) taken from the 0- to 15-cm depth to form the composite sample from each plot. Soil pH and soluble salts [electrical conductivity (EC)] were measured in 1:1 soil/water (Watson and Brown, 1998). Calcium carbonate equivalent (CCE) was determined by adding 2 *M* hydrochloric acid (HCl) and measuring pressure resulting from the reaction (Nelson, 1982) (Table 2).

Herbicide treatments were applied to the entire area within each plot using a bicycle-wheeled-type plot sprayer equipped with drift cones (devices designed to minimize drift to neighboring plots) delivering 80 L ha^{-1} at 280 kPa (delivered by CO_2) through 8001 flat fan nozzles. Weeds at the time of spraying were small, ranging from one to two leaves in size and were at the proper stage for treatment according to herbicide labels. At the time of application, the date, time, air and soil temperature, relative humidity, wind speed and direction, percentage cloud cover, and crop chlorosis ratings were recorded (Table 3). Herbicide treatments used are listed in Table 4. Visual evaluations for stunting and necrosis, on a scale of 0 (no effect) to 100% compared with an untreated area, were collected 14 and 28 d after herbicide application.

Table 4. Herbicide treatments, adjuvants, and rates, 1998–2000.

Herbicide treatment	Rates	Adjuvants†
	g ha^{-1}	
Bentazon	1120	PO‡
Acifluorfen	420	NIS§
Bentazon and acifluorfen (2:1) + PO	560 + 280	PO
Bentazon and acifluorfen (4:1) + PO	840 + 190	PO
Lactofen	175	PO
Fomesafen and adjuvant	200	PO
Thifensulfuron	4	NIS
Cloransulam	18	NIS + UAN¶
Imazethapyr	53	PO + UAN
Imazamox	35	PO + UAN
Glyphosate	840	AMS#

† Adjuvant selection and rates from label directions.
‡ PO, petroleum oil.
§ NIS, nonionic surfactant.
¶ UAN, urea ammonium nitrate.
# AMS, ammonium sulfate.

At maturity, a 1.4-m-wide strip 6 m long was harvested from the center of each plot using a plot combine. Soybean from each plot was dried to uniform moisture, cleaned, and weighed for yield determination.

Since the locations were not seeded to the same variety, location effects with respect to soil properties could not be statistically evaluated between locations. Due to considerable variability in soluble salts, as measured by EC between plots in some experiments, EC was used as a covariate in analysis of covariance within each location, reducing any possible interference of EC differences on treatment effects. A correlation analysis was also conducted for each treatment between soil EC and yield to determine whether some herbicide–soybean interactions were more sensitive to EC than others.

RESULTS AND DISCUSSION

Generally, chlorosis due to IDC was more severe in 1999 than in 1998 or 2000 (Table 3).

There were statistical differences between treatments in stunting 14 DAT (Tables 5, 6, and 7) among treatments at 11 locations. Soybean stunting was most commonly observed with the lactofen {2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate} treatment (seven locations). Acifluorfen, bentazon/acifluorfen 2:1, imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid}, imazamox {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid}, and fomesafen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-*N*-(methylsulfonyl)-2-nitrobenzamide} also resulted in significant stunting in at least one location. Stunting was still evident at 9 of the 12 locations at the 28 DAT evaluation. At this rating, stunting due to lactofen was evident at nine locations. Other treatments with stunting injury were imazethapyr (three locations), bentazon/acifluorfen 2:1 and imazamox (two locations), and bentazon/acifluorfen 4:1, acifluorfen, fomesafen, thifensulfuron {3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino] sulfonyl]-2-thiophenecarboxylic acid}, and cloransulam {3-chloro-2-[[(5-ethoxy-7-fluoro[1,2,4]triazolo[1,5-*c*]pyrimidin-2-yl)sulfonyl]amino]benzoic acid} (one location).

There were significant differences in necrosis 14 DAT at 11 of 12 locations (Tables 8, 9, and 10). Necrosis was most often observed with lactofen (11 locations). Fomesafen and bentazon/acifluorfen 2:1 resulted in higher ne-

Table 5. Treatment and stunting, 1998 locations.

Treatment	Fairmount		Arthur		Horace		Colfax		Rothsay		Moorhead	
	14 DAT†	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT
	stunting, %											
Bentazon	28ab‡	13ab	28b	12	23ab	18ab	19	21	8a	11a	10ab	0a
Acifluorfen	36b	16ab	34b	10	22ab	13a	27	27	19ab	8a	3ab	0a
Bentazon/acifluorfen 4:1	28ab	17b	28b	12	25ab	16ab	17	22	15ab	12a	7ab	0a
Bentazon/acifluorfen 2:1	25ab	24b	15ab	15	28ab	22ab	24	29	23b	8a	18b	0a
Lactofen	45b	36c	14ab	14	33b	27b	28	26	43c	26b	16ab	13b
Fomesafen	28ab	19b	8a	8	21ab	13a	23	18	23b	9a	12ab	3a
Thifensulfuron	18a	2a	11a	11	20a	11a	19	19	8a	12a	0a	0a
Cloransulam	17a	13ab	14ab	14	19a	18ab	20	19	8a	11a	0a	0a
Imazethapyr	28ab	11ab	10a	10	21a	13a	21	18	18ab	6a	5ab	0a
Imazamox	23ab	13ab	11a	11	22ab	13a	28	28	19ab	7a	6ab	0a
LSD (0.05)	13	14	14	NS	12	12	NS	NS	11	10	17	4

† DAT, days after treatment.
‡ Means within a column followed by the same letter are not significantly different at the 0.05 level according to Fisher's protected least significant difference.

Table 6. Treatments and stunting, 1999 locations.

Treatment	Walcott		Rothsay		Moorhead	
	14 DAT†	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT
	stunting, %					
Bentazon	13a‡	13ab	10ab	7a	32ab	25a
Acifluorfen	13a	11a	13ab	8ab	28a	25a
Bentazon/acifluorfen 4:1	18ab	15ab	14ab	12ab	37ab	30a
Bentazon/acifluorfen 2:1	19ab	20b	15ab	10ab	38b	31a
Lactofen	23b	25b	33d	23c	50c	46b
Fomesafen	23b	22b	13ab	23c	37ab	28a
Thifensulfuron	17ab	21b	9a	8a	35ab	28a
Cloransulam	18ab	22b	15ab	13b	38b	28a
Imazethapyr	23b	24b	15ab	17b	37ab	32a
Imazamox	21b	25b	23c	23	38b	31a
Glyphosate	–	–	16b	10ab	–	–
LSD (0.05)	6	7	6	5	9	10

† DAT, days after treatment.
‡ Means within a column followed by the same letter are not significantly different at the 0.05 level according to Fisher's protected least significant difference.

Table 7. Treatments and stunting, 2000 locations.

Treatment	Walcott		Arthur		Rothsay	
	14 DAT†	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT
	stunting, %					
Bentazon	0a‡	0	10ab	10b	0a	0a
Acifluorfen	15b	0	9a	12bc	21bc	18b
Bentazon/acifluorfen 4:1	10b	5	6a	5ab	20bc	15ab
Bentazon/acifluorfen 2:1	8a	5	22c	18c	25c	20b
Lactofen	15b	0	15b	15bc	33c	37c
Fomesafen	5a	5	5a	5ab	14b	9ab
Thifensulfuron	5a	0	0a	0a	12b	13ab
Cloransulam	0a	0	0a	1ab	7ab	5ab
Imazethapyr	5a	0	15b	13bc	5ab	0a
Imazamox	10b	5	10ab	8b	16bc	11ab
Glyphosate	5a	5	–	–	5ab	10ab
LSD (0.05)	9	NS	10	7	10	16

† DAT, days after treatment.
‡ Means within a column followed by the same letter are not significantly different at the 0.05 level according to Fisher's protected least significant difference.

crosis at three sites. Other treatments with necrosis injury were bentazon, acifluorfen, imazethapyr, and imazamox (one site). Necrosis was observed at 4 of 12 locations by 28 DAT (Tables 5, 6, and 7). At this rating, necrosis due to lactofen was evident at three locations. Other treatments with necrosis were imazethapyr and imazamox (two locations) and bentazon/acifluorfen 2:1, fomesafen, thifensulfuron, and cloransulam (one location).

In 1998, significant yield differences among herbicide treatments were observed at three of six locations (Table 11). At Fairmount, acifluorfen, thifensulfuron, imazethapyr, and imazamox treatments were lower in yield than the bentazon/acifluorfen (4:1), fomesafen, and cloransulam treatments. At Arthur, soybean treated with lactofen produced the lowest yields. At Rothsay, bentazon/acifluorfen 2:1 and thifensulfuron were the lowest-yielding treatments. The magnitude of differences among treatments is particularly remarkable. At Fairmount, for example, the highest-yielding treatments were nearly double the yield of the lowest-yielding treatments.

In 1999, there were yield differences at two of three locations (Table 12). Chlorosis was much more intense in 1999 (Table 3) than in 1998 or 2000. At Walcott, the bentazon, acifluorfen, bentazon/acifluorfen (4:1), and

Table 8. Treatment and percentage necrosis, 1998 locations.

Treatment	Fairmount		Arthur		Horace		Colfax		Rothsay		Moorhead	
	14 DAT†	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT
	necrosis, %											
Bentazon	12ab‡	4a	15ab	0	15a	0	17ab	0	2a	0	14ab	0
Acifluorfen	28b	2a	18ab	0	22a	0	27b	0	17b	0	16ab	0
Bentazon/acifluorfen 4:1	20b	7a	17ab	0	23a	0	15ab	0	11ab	0	14ab	0
Bentazon/acifluorfen 2:1	25b	24b	18ab	0	21a	0	23ab	0	18b	0	27b	0
Lactofen	38c	20b	23b	0	32b	0	26b	0	45c	2	23b	0
Fomesafen	14ab	7a	20ab	0	22a	0	22a	0	21b	0	22b	0
Thifensulfuron	7a	2a	13a	0	18a	0	17ab	0	3a	0	4a	0
Cloransulam	11ab	2a	15ab	0	13a	0	15ab	0	2a	0	9ab	0
Imazethapyr	15ab	3a	12a	0	14a	0	12a	0	11ab	0	8ab	0
Imazamox	15ab	0a	18ab	0	18a	0	18ab	0	5a	0	8ab	0
LSD (0.05)	10	11	8	NS	9	NS	13	NS	9	NS	17	NS

† DAT, days after treatment.
‡ Means within a column followed by the same letter are not significantly different at the 0.05 level according to Fisher's protected least significant difference.

Table 9. Treatments and necrosis, 1999 locations.

Treatment	Walcott		Rothsay		Moorhead	
	14 DAT†	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT
	necrosis, %					
Bentazon	9a‡	13ab	7a	5a	19ab	22a
Acifluorfen	11ab	10a	6a	5a	15a	26ab
Bentazon/acifluorfen 4:1	9a	14ab	6a	5a	26b	28ab
Bentazon/acifluorfen 2:1	13ab	19ab	9ab	6a	27b	33b
Lactofen	23b	18ab	27c	7a	42c	45c
Fomesafen	17b	27b	8ab	6a	21ab	28ab
Thifensulfuron	15ab	25b	7a	5a	17ab	23a
Cloransulam	11ab	22b	10ab	6a	26b	23a
Imazethapyr	15ab	27b	9ab	9a	26b	29ab
Imazamox	17b	30b	13b	13b	27b	29ab
Glyphosate	–	–	8ab	7a	–	–
LSD (0.05)	6	9	5	4	10	8

† DAT, days after treatment.
‡ Means within a column followed by the same letter are not significantly different at the 0.05 level according to Fisher's protected least significant difference.

Table 10. Treatments and necrosis, 2000 locations.

Treatment	Walcott		Arthur		Rothsay	
	14 DAT†	28 DAT	14 DAT	28 DAT	14 DAT	28 DAT
	necrosis, %					
Bentazon	0	0	5ab‡	0	0a	0
Acifluorfen	5	0	10b	5	11ab	10
Bentazon/acifluorfen 4:1	3	0	5ab	7	15b	10
Bentazon/acifluorfen 2:1	8	0	10b	5	16b	15
Lactofen	15	2	5ab	6	25b	20
Fomesafen	5	0	9b	0	15b	8
Thifensulfuron	5	0	0a	1	6ab	5
Cloransulam	0	0	2a	0	5ab	0
Imazethapyr	0	0	5ab	5	0a	0
Imazamox	5	0	5ab	5	6ab	0
Glyphosate	0	0	–	–	0a	0
LSD (0.05)	NS	NS	6	NS	14	NS

† DAT, days after treatment.
‡ Means within a column followed by the same letter are not significantly different at the 0.05 level according to Fisher's protected least significant difference.

bentazon/acifluorfen (2:1) treatments were higher in yield than other treatments. This site was particularly high in EC compared with other sites. This may have contributed to the lower yields within the experiment and the high level of stunting and necrosis symptoms evident at 14 and 28 DAT (Table 6) compared with Moorhead 99. Yields of the highest-yielding treatments were more than three times the yield of the lowest-yielding treatment. At Rothsay, the lactofen and imazamox treatments were lower in yield than other treatments. The Rothsay site included glyphosate [*N*-(phosphonomethyl)glycine]. It is notable that the glyphosate treatment was not higher in yield than most treatments. The variety used at Moorhead was so unadapted to the soil conditions that the soybean plants in the plots never greened up all season. The cooperator tilled under several areas of soybean surrounding these plots before harvest. There were no significant yield differences due to treatment at this location.

In 2000, there were yield differences due to herbicide treatments at all three locations (Table 13). Two of the locations, Walcott and Rothsay, were glyphosate-tolerant soybean varieties, and the treatments included glyphosate. At Walcott, soybean treated with lactofen

Table 11. Treatment and yield, 1998 locations.

Treatment	Fairmount†	Arthur	Horace	Colfax	Rothsay	Moorhead
	yield, kg ha^{-1}					
Bentazon	1523ab‡	2199a	1606	1934	2371a	3064
Acifluorfen	1358b	1966ab	1512	1961	1672b	3153
Bentazon/acifluorfen 4:1	2090ab	2258a	1653	2149	2240a	2979
Bentazon/acifluorfen (2:1) + PO§	2124a	2037a	1566	1611	1809b	2865
Lactofen + PO	1976ab	1404b	1518	1860	2349a	2821
Fomesafen + adjuvant + PO	2318a	2084a	1693	1989	2488a	2977
Thifensulfuron + NIS¶	1263b	2345a	1713	1694	1706b	3013
Cloransulam + NIS + UAN#	2312a	1953ab	1814	2276	2557a	3105
Imazethapyr + PO+ UAN	1216b	2254a	1700	1453	2683a	3016
Imazamox + PO + UAN	1404b	2393a	1754	1470	2105a	3120
LSD (0.05)	887	618	NS	NS	660	NS

† Yields in this column are adjusted yields from a significant analysis of covariance with electrical conductivity as covariate.
‡ Means within a column followed by the same letter are not significantly different at the 0.05 level according to Fisher's protected least significant difference.
§ PO, petroleum oil.
¶ NIS, nonionic surfactant.
# UAN, urea ammonium nitrate.

was lower in yield than all other treatments. All other treatments were similar in yield. At Arthur, soybean treated with cloransulam, imazamox, thifensulfuron, acifluorfen, bentazon/acifluorfen 4:1, and fomesafen was higher in yield than other treatments. Soybean treated with bentazon/acifluorfen (2:1), imazethapyr, and lactofen had the lowest yield. At Rothsay, bentazon/acifluorfen 2:1 and lactofen were lower yielding than other treatments. Significant differences in yield were observed. Imazethapyr had the highest yield. Although some treatments tended to be consistently high or low yielding, some treatments, such as acifluorfen, were both higher or lower yielding depending on the site and year.

One of the factors that might have influenced activity of the herbicide was environmental conditions at the time of spraying. There were wide ranges of temperature, clouds, humidity, and application time of day between sites. Several herbicides, including acifluorfen, are known to be sensitive to these conditions (Zollinger, 2001).

Yield and EC were significantly correlated at 4 of 12 sites within the imazethapyr treatment; 3 of 12 sites within the cloransulam, acifluorfen, and bentazon/acifluorfen 2:1 treatments; and 2 of 12 sites within the fomesafen and thifensulfuron treatments (Table 14). In each correlation, yield was negatively correlated with soil EC. Analysis of covariance was conducted at each site; however, in only one site, Colfax 1998, was the level of significant yield differences improved. However, the results shown in Table 14 are an indication that EC may have more influence on the effect of some herbicides than others. Within the bentazon treatments, no sites exhibited significant correlation between yield and EC. This suggests that soybean treated with bentazon may be less affected by variation in soil EC than those herbicide treatments with a higher frequency of correlation among sites, such as imazethapyr.

SUMMARY

Soybean treated with lactofen had significantly less yield than other treatments at six of eight locations where significant treatment differences were observed. Soybean treated with imazamox and imazethapyr yielded significantly less than most other treatments at three of eight locations. Soybean with glyphosate and the bentazon/aciflourfen 4:1 treatments were not lowest yielding at any location. These results suggest that herbicides with harsh contact activity (lactofen) and some herbicides in the general class of acetolactate synthase (ALS) inhibitors, e.g., imazamox, thifensulfuron, and imazethapyr, may have potential for greater injury than other types of postemergence herbicides.

There were significant differences in soybean yields stressed from IDC between treatments at 8 of 12 locations. Stunting and necrosis 14 DAT were observed at 11 locations. Visual symptoms of stunting and necrosis

Table 12. Treatments and yield, 1999 locations.

Treatment	Walcott	Rothsay	Moorhead
	yield, kg ha^{-1}		
Bentazon	1657a†	2022a	515
Acifluorfen	1673a	2097a	923
Bentazon/acifluorfen 4:1	1165a	1844a	500
Bentazon/acifluorfen 2:1	1114a	1821a	659
Lactofen	963b	1220b	237
Fomesafen	570b	1959a	462
Thifensulfuron	911b	1940a	985
Cloransulam	934b	1770a	581
Imazethapyr	671b	1959a	383
Imazamox	499b	1430b	261
Glyphosate	–	1757a	–
LSD (0.05)	578	481	NS

† Means within a column followed by the same letter are not significantly different at the 0.05 level according to Fisher's protected least significant difference.

Table 13. Treatments and yield, 2000 locations.

Treatment	Walcott	Arthur	Rothsay
	yield, kg ha^{-1}		
Bentazon	2695a†	2119b	1809b
Acifluorfen	2589a	2255a	1804b
Bentazon/acifluorfen 4:1	2666a	2217ab	1820b
Bentazon/acifluorfen 2:1	2575a	2004b	1572c
Lactofen	1945b	1868b	1371c
Fomesafen	2558a	2216ab	1896b
Thifensulfuron	2742a	2329a	1991ab
Cloransulam	2649a	2548a	2030ab
Imazethapyr	2614a	1876b	2163a
Imazamox	2722a	2394a	1961ab
Glyphosate	2678a	–	2057ab
LSD (0.05)	212	363	264

† Means within a column followed by the same letter are not significantly different at the 0.05 level according to Fisher's protected least significant difference.

Table 14. Correlation values (r) within herbicide treatments of yield and electrical conductivity measurements.

Site	Bentazon	Acifluorfen	Bentazon/ aciflourfen 4:1	Bentazon/ aciflourfen 2:1	Lactofen	Fomesafen	Thifensulfuron	Cloransulam	Imazethapyr	Imazamox	Glyphosate
Fairmount 98	NS†	NS	NS	NS	NS	NS	NS	NS	−0.78‡	NS	NI§
Arthur 98	NS	NS	−0.84	NS	NS	NS	NS	NS	NS	NS	NI
Horace 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NI
Colfax 98	NS	NS	NS	−0.82	NS	−0.90	NS	NS	NS	−0.91	NI
Rothsay 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NI
Moorhead 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NI
Walcott 99	NS	−0.82	NS	−0.93	NS	NS	−0.75	−0.74	NS	NS	NI
Rothsay 99	NS	−0.85	NS	NS	NS	−0.73	NS	−0.77	−0.95	NS	NS
Moorhead 99	NS	NS	NS	−0.93	−0.74	NS	−0.77	NS	NS	NS	NI
Walcott 00	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Arthur 00	NS	NS	NS	NS	NS	NS	NS	NS	−0.88	NS	NI
Rothsay 00	NS	−0.75	NS	NS	NS	NS	NS	−0.76	−0.81	NS	NS

† NS = nonsignificant at the 0.1 probability level.
‡ Significant correlation at the 0.1 level within treatment between soil electrical conductivity and soybean yield.
§ NI = not included in that site treatment plan.

were observed at nine and four locations, respectively, 28 DAT. Use of EC as a covariate was useful at one location in removing variable soil EC effects from treatment effects.

It may be important to evaluate soybean stress before herbicide selection or to factor in possible injury into the economic analysis of the use of a certain postemergence broadleaf herbicide before application. Some of the labels of the herbicides tested in this experiment currently have warnings against use while soybean is under stress. Those that do not may consider reevaluating their products so that they contain such wording.

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