

## Phytotoxic Response and Yield of Soybean (*Glycine max*) Varieties Treated with Sulfentrazone or Flumioxazin<sup>1</sup>

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**Abstract:** Flumioxazin and sulfentrazone were compared for phytotoxicity on 15 soybean varieties in a greenhouse study and four varieties in the field. In the greenhouse, injury from sulfentrazone was greater overall than with flumioxazin, 10% compared with 1%, respectively, when averaged across varieties at the labeled rates. The varieties P9552, P91B01, P9362, and P9305 were more sensitive to sulfentrazone than the 11 other varieties on the basis of visible injury and plant height reductions. Sulfentrazone at 224 g ai/ha (1× rate) reduced plant height 23 to 53% and caused 18 to 38% visible injury on the four sensitive varieties. Visible injury symptoms consisted of stunting, crinkling of leaves, and chlorotic spots. Varieties P9305, P9306, P9352, and P9362 were compared in a field study with flumioxazin at 105, 210, and 420 g ai/ha or sulfentrazone at 224, 448, and 896 g ai/ha, corresponding to 1, 2, and 4× labeled rates. An untreated control of each variety was included for comparison. Contrary to the results of the greenhouse studies, injury from flumioxazin was similar to that from sulfentrazone in the field experiments. In 1998, emergence counts were reduced 19 to 52% with flumioxazin and 27 to 73% with sulfentrazone at the 1× rate. Visible injury and stand count reductions resulting from both herbicides were also apparent in that year. Emergence count reductions, stand count reductions, and visible injury resulting from the herbicides were less severe in 1999. At the 1× rate of each herbicide, yields were not affected in either year, except P9305 treated with sulfentrazone in 1999. At the 4× rate, P9305 was most sensitive to sulfentrazone, as indicated by a 53 and 23% reduction yield in 1998 and 1999, respectively. Avoidance of sensitive varieties will reduce the potential for injury and yield reduction with sulfentrazone, and maybe flumioxazin.

**Nomenclature:** Flumioxazin, 2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2H-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-indole-1,3(2H)-dione; sulfentrazone, N-[2,4-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]phenyl]methanesulfonamide; soybean, *Glycine max* (L.).

**Additional index words:** Protoporphyrinogen oxidase inhibitors, differential herbicide tolerance.

**Abbreviations:** DAE, days after emergence; DAP, days after planting; DAT, days after treatment; PPO, protoporphyrinogen oxidase; PRE, preemergence.

### INTRODUCTION

Flumioxazin is a preemergence (PRE)-applied herbicide in development for weed control in soybean and peanut (*Arachis hypogaea* L.) and has the potential for use in corn when used with safening agents (Devlin and Zbiec 1993). The herbicide controls important broadleaf weeds such as common ragweed (*Ambrosia artemisiifolia* L.), common lambsquarters (*Chenopodium album* L.), *Amaranthus* species, eastern black nightshade (*Solanum*

*ptycanthum* Dun.), and prickly sida (*Sida spinosa* L.). Suppression of other weeds such as giant ragweed (*Ambrosia trifida* L.), Pennsylvania smartweed (*Polygonum pennsylvanicum* L.), velvetleaf (*Abutilon theophrasti* Medik.), and some grass species has also been observed (Talbert et al. 1990; Valent 1998; Yoshida et al. 1991). As a PRE herbicide, flumioxazin offers residual activity that is absent with many foliar-applied herbicides (Valent 1998).

The mode of action of flumioxazin is inhibition of protoporphyrinogen oxidase (PPO), an enzyme in the chlorophyll biosynthesis pathway (Yoshida et al. 1991). Inhibition leads to an accumulation of the pathway intermediate protoporphyrinogen IX (Protogen), which is subsequently converted to protoporphyrin IX (Proto IX). The Proto IX generates oxygen radicals that destroy the

<sup>1</sup> Received for publication January 31, 2000, and in revised form October 17, 2000.

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plasma membrane in the presence of light, causing death in susceptible plants (Dayan and Duke 1996). The herbicide has several environmental benefits including low use rate, rapid soil dissipation, and effectiveness on acetolactate synthase- and triazine-resistant weed biotypes. A concern with the use of flumioxazin is the potential for soybean injury under certain environmental conditions. The potential for phytotoxicity increases with high soil moisture (Sakaki et al. 1991).

Problems with soybean injury have occurred with a similar herbicide, sulfentrazone. Sulfentrazone is also a PRE-applied PPO inhibitor and has been shown to cause symptoms such as chlorosis, discoloration of veins, and reduced internode length in some soybean varieties. Oliver et al. (1997) demonstrated that cultivars varied in sensitivity to sulfentrazone, with susceptibility in 34% of 248 cultivars tested. In a comparison of 40 soybean cultivars, which represent 95% of the parentage of modern soybean varieties, Hulting et al. (1997) found notable differences in tolerance to sulfentrazone. In that study, soybean height was found to be a good indicator of susceptibility. Reductions in hypocotyl and root elongation have been demonstrated in soybean plants treated with sulfentrazone, and may be used to classify soybean variety response (Li et al. 1999). Cultivar variation is likely due to differential tolerance to the peroxidative stress from the herbicide; no differences in either uptake or translocation have been demonstrated (Dayan et al. 1997). Tolerance in several varieties was shown to be dominant over susceptibility with single-gene control (Swantek et al. 1998). Although the sensitivity of some cultivars increases the likelihood of injury following application, environmental conditions also play a critical role. Sulfentrazone injury is more likely in soil low in organic matter content and under conditions of high moisture (Wehtje et al. 1997). The availability of the herbicide increases with higher pH and coarser soil texture, resulting in increased crop injury potential (Grey et al. 1997).

Little research has been conducted to determine the potential for soybean injury and differential cultivar tolerance with flumioxazin, or to compare results with those of sulfentrazone. By developing a better understanding of the potential for soybean injury with flumioxazin, problems could be minimized upon registration of the herbicide. Recommendations of tolerant cultivars could be made where a flumioxazin application was anticipated. If flumioxazin exhibited the same cultivar sensitivity patterns as sulfentrazone, previous research with sulfentrazone may apply to flumioxazin. The objectives of the

study were to determine the potential for soybean injury with flumioxazin compared with sulfentrazone, establish the conditions in which injury could occur, and evaluate the effect of soybean injury on yield.

Greenhouse studies were conducted to compare the response of 15 soybean varieties to flumioxazin or sulfentrazone, and determine the effect of herbicide rate on soybean injury. In a 2-yr field study, four soybean varieties were evaluated for sensitivity to flumioxazin or sulfentrazone to determine if injury resulting from the herbicide applications would reduce crop yield.

## MATERIALS AND METHODS

**Soybean Seeds.** Seeds for the varieties used in the field study and the majority of those in the greenhouse study were donated by Mark Vogt, Pioneer Hi-Bred International, Inc. Fifteen varieties were included in the greenhouse study to cover a wide range of maturity and suspected tolerance levels to sulfentrazone: Elgin, P91B01, P9151, P9282, P9294, P9305, P9306, P9311, P9322, P9333, P9352, P9362, P9552, P9584, and P9671. For the field study, two varieties considered susceptible, P9305 and P9362, and two tolerant varieties, P9306 and P9352, were selected on the basis of the classifications in the Pioneer Soybean Herbicide Variety Management Guide (Pioneer 1998). The varieties were also chosen to represent similar maturity groups typically used in east central Illinois, where the study was conducted. The varieties included in the studies were Pioneer<sup>3</sup> varieties because their tolerance to sulfentrazone had been well-established. However, Pioneer varieties are not known to be more or less tolerant than other brands.

**Greenhouse Study.** Five seeds of five soybean varieties were planted 2 cm deep in 25 × 12 cm pots and covered with soil. A total of three pots per replication of each treatment was required to hold the 15 varieties. Rows were perpendicular to the length of the pot. The soil used in the study was a Drummer silty clay loam (fine-silty, mixed, mesic Typic Endoqualls) with 5% organic matter and a pH of 6.5 and was collected between May and August 1998 in Urbana, IL.

Herbicide treatments were applied immediately after planting with a laboratory sprayer equipped with a Tee-jet<sup>4</sup> 8002E flat fan nozzle tip calibrated to deliver 187 L/ha at 207 kPa. Treatments included 53, 105, and 210 g

<sup>3</sup> Mention of a trademark, vendor, or proprietary product throughout this paper does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or the University of Illinois and does not imply its approval to the exclusion of other products that may also be suitable.

<sup>4</sup> Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189-7900.

ai/ha flumioxazin or 112, 224, and 448 g ai/ha sulfentrazone, corresponding to 0.5, 1.0 and 2.0 $\times$  labeled rates. After application, pots were subirrigated until moisture began to appear at the soil surface. Following subirrigation, 1 cm of irrigation was provided with a misting nozzle to ensure activation of the herbicides. Plants were grown in a glasshouse with natural sunlight supplemented by metal halide lamps, the combination providing approximately 1,000  $\mu\text{E}/\text{m}^2/\text{s}$  photosynthetically active radiation on a 16-h photoperiod. Plants were watered daily and fertilized<sup>5</sup> 7 days after treatment (DAT) to promote active soybean growth. Visible injury ratings including the combined effect of stunting, malformation, and chlorosis were determined at 12 DAT and plant heights were measured at 14 DAT.

A randomized complete block design with four replications was used and the experiment was repeated. Interactions of herbicide treatments with repeated experiments were not significant, so runs one and two were pooled. Data for variety (height) or treatment (visible injury) were compared and subjected to analysis of variance using the SAS<sup>6</sup> system. Means were separated using Fisher's protected LSD at the 5% level.

**Field Study.** Soybean yield studies were conducted in 1998 and 1999 at Urbana, IL in fields that had not been treated with either sulfentrazone or flumioxazin for the previous 3 yr. The majority of the field consisted of an Elburn silt loam (fine-silty, mixed, mesic Aquic Argiudolls) with approximately 3.5% organic matter and a pH of 6.0. Field plots were chisel-plowed each fall and field-cultivated in the spring before planting. The plots were planted on May 19, 1998 and May 26, 1999 at a seeding rate of 363,000 seeds/ha. Plots were four rows wide by 3.5 m long, with 75 cm between rows. Plots contained one of the four soybean varieties: P9305, P9306, P9352, or P9362. The treatment/variety combinations were arranged randomly within a block. The herbicide treatments consisted of 1, 2, and 4 $\times$  labeled used rates (either 105, 210, and 420 g/ha flumioxazin or 224, 448, and 896 g/ha sulfentrazone). A weed-free untreated check of each variety was included for comparison. Applications were made PRE with a CO<sub>2</sub> backpack sprayer equipped with Teejet 8003 flat fan nozzles at a volume of 234 L/ha and pressure 205 kPa. All treatments including the untreated check were maintained weed free to demonstrate only the injurious effects of the herbicides on yield, without

weed competition. Sethoxydim at 210 g ai/ha was applied with 1% crop oil concentration and ammonium sulfate at 2.8 kg/ha to control grasses throughout the entire area. One application of sethoxydim was made when weeds were 20 cm. All plots were also cultivated and hand weeded as necessary to eliminate remaining weeds.

Soybean plants were counted in the center two rows for the entire length of the plot to give emergence and stand counts. Emergence counts were taken approximately 10 d after planting (DAP) when 90% of the plants in untreated plots had emerged. Stand counts were taken 21 days after emergence (DAE). At the same time, visible injury was evaluated on a scale of 0 (no injury) to 100 (complete plant death) on the basis of combined symptomology including chlorosis, necrosis, bronzing, and stunting in comparison with the untreated control for a particular variety. At maturity, the two center rows of each plot were end-trimmed to 3.0 m and harvested with a plot combine to determine yield. Grain yield was adjusted to 13% moisture. Weekly environmental conditions starting 2 wk before planting until the time of harvest are given in Table 1. In 1999, additional 2.5 cm of irrigation was applied 3 DAP with a sprinkler system to ensure adequate herbicide activation.

A randomized complete block design with four replications was used. Each herbicide/rate/soybean variety combination was considered a separate treatment for randomization. Yield values were converted to percentage of control of dividing the average yield for a treatment by that of the untreated control for the appropriate variety and multiplying by 100. Treatment-by-year interactions were significant with all variables; thus the data for each year are presented separately. Data were subjected to analysis of variance using SAS, and treatment or variety means were separated using Fisher's protected LSD at the 5% significance level.

## RESULTS AND DISCUSSION

**Greenhouse Study.** With all varieties averaged, flumioxazin injury was less than 2%, even at the highest rate. Visible injury with sulfentrazone was much higher, with greater than 10% injury with the 1 $\times$  rate (224 g ai/ha) averaged across the 15 varieties. Soybean injury increased with the herbicide rate. In Table 2, visual injury ratings were reported for each variety/treatment combination. At the highest rate, most varieties were injured by sulfentrazone compared with the untreated check. Four varieties, P9552, P91B01, P9362, and P9305, were the most sensitive to sulfentrazone, each exhibiting greater than 40% injury at the 2 $\times$  rate. In

<sup>5</sup> RAPID GRO soluble plant food (23-19-17). Chevron Chemical Company, P.O. Box 5047, San Ramon, CA 94583-0947.

<sup>6</sup> SAS Proprietary Software Release 6.12, SAS Institute Inc., Cary, NC. Copyright 1989-1996.

Table 1. Environmental conditions at Urbana, IL during the soybean growing seasons in 1998 and 1999.

Weeks from planting <sup>a</sup>	Precipitation Total		Mean air temperature						
	1998	1999	1998			1999			
			Low	High	Mean	Low	High	Mean	
cm		°F							
-2	2.3	4.3	54	72	63	56	75	66	
-1	2.2	3.2	58	84	71	51	74	63	
1	9.5	6.7 <sup>b</sup>	58	75	67	56	80	68	
2	0.3	2.1	62	83	73	64	85	75	
3	2.8	7.3	50	67	59	65	83	74	
4	11.6	0.1	61	80	71	56	76	66	
5	6.5	2.9	64	83	74	66	83	75	
6	1.3	0.7	71	91	81	69	86	78	
7	3.9	0	65	84	75	61	83	72	
8	1.9	3.6	66	83	75	66	89	78	
9	0	3.5	68	86	77	72	92	82	
10	3.7	2.0	63	85	74	69	88	79	
11	1.7	2.0	63	81	72	59	82	71	
12	3.9	9.9	69	83	76	61	82	72	
13	0.1	1.7	64	84	74	58	80	69	
14	0.2	0	66	88	77	58	82	70	
15	0.2	0	65	86	76	60	89	75	
16	0.1	0.3	60	88	74	50	79	65	
17	0	0	55	84	69	47	74	61	
18	3.4	3.9	65	85	75	49	82	66	
19	0.8	2.4	57	81	69	40	62	51	
Total	56.4	54.1	Ave	62	83	72	59	81	70

<sup>a</sup> Negative numbers are weeks before planting, positive numbers are weeks after planting.

<sup>b</sup> The 6.7 cm includes supplemental 2.5 cm via sprinkler irrigation.

general, injury was much lower for all varieties treated with flumioxazin; however, P9352 and Elgin were injured slightly with 1 or 2× rate.

Because the height of the untreated varieties differed, analysis of height among treatments was done within varieties (Table 3). The same four varieties that demonstrated the greatest sensitivity to sulfentrazone on the

basis of visible injury (P9552, P91B01, P9362, and P9305) also had the greatest height reduction. With sulfentrazone at 448 g/h, plant height of the four sensitive varieties was reduced 45 to 70%. Heights of soybean varieties P9552, P91B01, and P9305 were reduced compared with the untreated control with all herbicide rates. In general, height reduction and visible injury were less

Table 2. Visible injury<sup>a</sup> ratings taken 12 d after treatment of 15 soybean varieties with several rates of two herbicides, sulfentrazone and flumioxazin. Resulting means are the averages for the two experiments, each with four replications, and data were pooled.

Variety	Herbicides (g ai/ha)					
	Sulfentrazone			Flumioxazin		
	112	224	448	53	105	210
% Injury						
P9552	18	38	61	1	2	4
P91B01	11	29	58	0	0	1
P9362	3	17	43	0	0	1
P9305	7	18	41	0	0	0
P9352	11	16	21	0	5	8
P9282	0	8	19	0	0	1
Elgin	6	9	18	0	4	8
P9306	2	4	15	0	0	0
P9322	4	8	10	0	1	3
P9311	1	7	9	0	0	2
P9294	1	2	9	0	0	1
P9151	0	4	8	0	0	0
P9333	1	1	8	0	0	0
P9584	1	3	5	0	0	0
P9671	0	1	5	0	0	0
LSD (.05)	5	6	8	1	2	4

<sup>a</sup> Visible injury ratings included stunting, chlorosis, and bronzing symptomology (0 = no injury; 100 = complete plant death).

Table 3. Average height (cm) at 14 d after treatment of 15 soybean varieties with several rates of two herbicides, sulfentrazone and flumioxazin. Resulting means are the averages for the two experiments, each with four replications, and data were pooled.

Variety	Herbicides (g ai/ha)							LSD
	Untreated	Sulfentrazone			Flumioxazin			
	0	112	224	448	53	105	210	
	Height, cm							
P9552	23	17	11	7	23	23	23	2
P91B01	23	17	14	8	24	24	23	2
P9362	22	20	17	12	23	23	22	2
P9305	24	19	16	12	23	23	24	3
P9352	21	18	19	17	22	21	21	3
P9282	22	22	21	18	24	25	24	3
Elgin	21	20	19	17	22	21	20	2
P9306	23	21	20	19	23	22	23	2
P9322	20	20	20	19	21	22	21	2
P9311	22	22	21	21	22	24	22	2
P9294	23	22	23	21	23	23	23	3
P9151	23	24	23	22	24	25	25	2
P9333	22	20	22	20	23	22	22	3
P9584	25	23	22	22	25	26	25	3
P9671	25	24	25	22	26	25	25	3

with varieties P9322, P9311, P9294, P9151, P9333, P9584, and P9671 at the 1× rates of sulfentrazone compared with the most sensitive varieties. Flumioxazin did not reduce soybean height of any of the varieties at the rates tested.

Sulfentrazone was much more injurious than flumioxazin in the greenhouse study. As previous studies have shown, soybean varieties differed in sensitivity to sulfentrazone (Oliver et al. 1997) and to a much lower degree, flumioxazin. The varieties most sensitive to flumioxazin were different from those that were sensitive to sulfentrazone, indicating that the soybean tolerance mechanisms may be different for the two herbicides, even though they exhibit the same mode of action.

**Field Study.** Stand count reductions and visible plant injury were generally greater in 1998 than in 1999. An activating rainfall of approximately 3 cm occurred the same day as application in 1998 to ensure optimal activity. Slightly lower temperature during soybean emergence may have also contributed to the increased injury by reducing metabolism in the soybean plants (Table 1).

Crop density decreased with increasing rates of either flumioxazin and sulfentrazone for all varieties (Table 4). In 1998, all herbicide treatments reduced emergence of all varieties, even at the 1× rate. Emergence of all varieties was reduced by sulfentrazone at 896 g/ha in 1999. In the year, 420 g/ha flumioxazin reduced emergence of all varieties except P9352. Emergence reductions from flumioxazin or sulfentrazone on the basis of the percentage of the untreated control for each variety were generally greater for variety P9305 than for the other varieties.

Stand reductions were noted in stand counts taken 21 DAE for most varieties with all herbicide rates in 1998. Stands were reduced 20 to 60% with sulfentrazone at 224 g/ha and 20 to 50% with flumioxazin at 105 g/ha (Table 5). With all treatments, the reductions in stand counts were greater with P9305 than with the other varieties. The 4× rates of flumioxazin and sulfentrazone reduced stands of all varieties 59 to 90% in 1998 and 15 to 50% in 1999. Although stands were still reduced with some treatments at 21 DAE, most counts had increased compared with the emergence counts, indicating that herbicidal injury included delayed emergence as well as reduced stand count.

Visible injury evaluations with each herbicide for all varieties are shown in Figure 1. Variety differences were greatest with sulfentrazone in 1998, where P9305 was

Table 4. Mean emergence counts (plants/m<sup>2</sup>)<sup>a</sup> of four soybean varieties approximately 10 d after treatment with flumioxazin or sulfentrazone. Field experiments were conducted in Urbana, IL.

Herbicide	Rate	P9305		P9306		P9352		P9362	
		1998 <sup>b</sup>	1999 <sup>c</sup>	1998	1999	1998	1999	1998	1999
	g ai/ha	Plants/m <sup>2</sup>							
None	0	23	25	28	17	26	26	22	26
Flumioxazin	105	11	20	16	18	21	26	14	23
Flumioxazin	210	3	20	9	18	7	23	11	23
Flumioxazin	420	2	19	3	12	4	21	5	19
Sulfentrazone	224	5	19	14	17	19	21	6	23
Sulfentrazone	448	3	22	11	16	8	21	2	19
Sulfentrazone	896	0	12	4	12	3	17	1	20
LSD (.05)		5	5	5	5	5	6	5	5

<sup>a</sup> The number of plants in center two rows by 3 m long were counted and expressed in the table as counts/m<sup>2</sup>.

<sup>b</sup> In 1998, soybean was planted on May 19 and emergence counts taken on May 28.

<sup>c</sup> In 1999, soybean was planted on May 26 and emergence counts taken on June 6.

Table 5. Stand counts (plants/m<sup>2</sup>)<sup>a</sup> at approximately 21 d after emergence of four soybean varieties treated with flumioxazin or sulfentrazone. Field experiments were conducted in Urbana, IL.

Herbicide	Rate	P9305		P9306		P9352		P9362	
		1998 <sup>b</sup>	1999 <sup>c</sup>	1998	1999	1998	1999	1998	1999
	g ai/ha	Plants/m <sup>2</sup>							
None	0	29	25	34	19	33	26	30	26
Flumioxazin	105	15	23	25	21	26	26	24	25
Flumioxazin	210	8	23	17	20	13	23	20	24
Flumioxazin	420	5	21	12	13	10	20	13	22
Sulfentrazone	224	11	20	28	19	27	23	19	24
Sulfentrazone	448	8	24	19	17	16	23	13	21
Sulfentrazone	896	3	12	14	13	9	18	9	21
LSD (.05)		5	5	6	5	5	6	6	5

<sup>a</sup> The number of plants in center two rows by 3 m long were counted and expressed in the table as counts/m<sup>2</sup>.

<sup>b</sup> In 1998, soybean was planted on May 19 and stand counts taken on June 17.

<sup>c</sup> In 1999, soybean was planted on May 26 and stand counts taken on June 25.

injured more than the other three varieties at all sulfentrazone rates. The variety P9362 was also sensitive to sulfentrazone in that year, with visible injury greater than P9352 and P9306. The varieties P9305 and P9362 were also more sensitive on the basis of the greenhouse experiment and the Pioneer Soybean Herbicide Management Guide (Pioneer 1998). In 1999, variety differences were not as great as the previous year, but followed a similar trend. Differences between varieties were more apparent with sulfentrazone than with flumioxazin. However, in 1998, flumioxazin injured P9305 more than other varieties at the higher rates (approximately 10% greater visible injury). The variety P9306 was most sensitive to

flumioxazin in 1999, demonstrating again that the variety differences with flumioxazin may be unrelated to those with sulfentrazone.

Differential tolerance to herbicide injury has been demonstrated with other herbicides such as metribuzin and propanil in soybean (Wax et al. 1976; Karazawa and Caviness 1977). With metribuzin, differences among several varieties were shown to be the result of more rapid metabolism in the tolerant variety (Mangeot et al. 1979). As with sulfentrazone and flumioxazin, the injury from metribuzin appeared to increase when an adequate rainfall event moved the herbicide into the root zone soon after planting (Moshier and Russ, 1981).

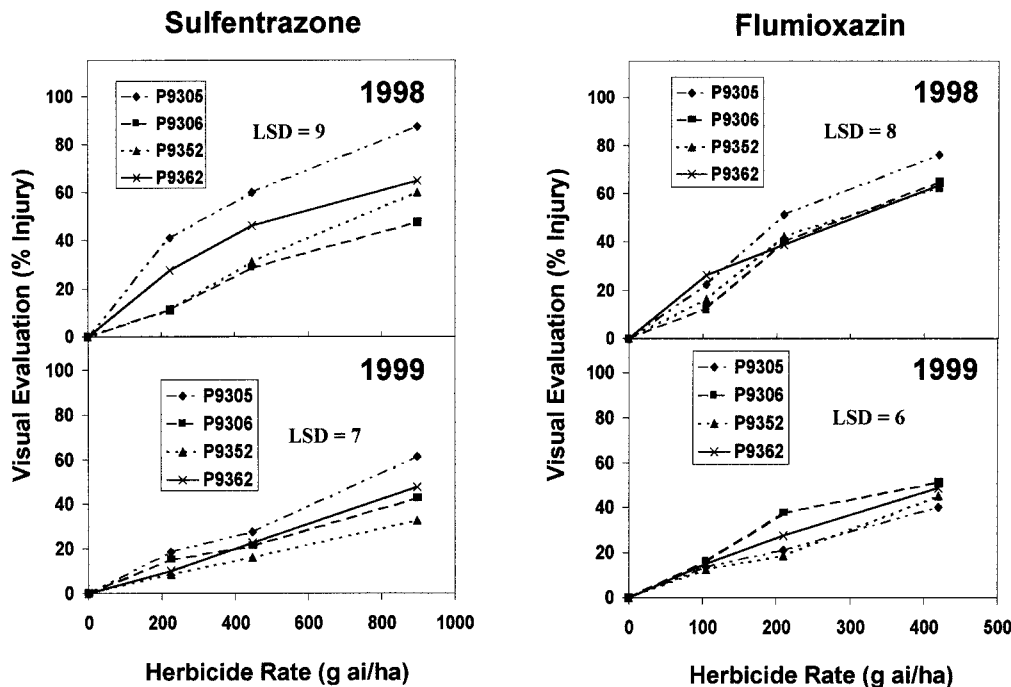


Figure 1. Visible injury ratings at 21 d after emergence with four soybean varieties treated with three rates of sulfentrazone or flumioxazin. Field experiments were conducted in Urbana, IL. Numbers for LSD indicate Fisher's protected LSD at  $\alpha = 0.05$ .

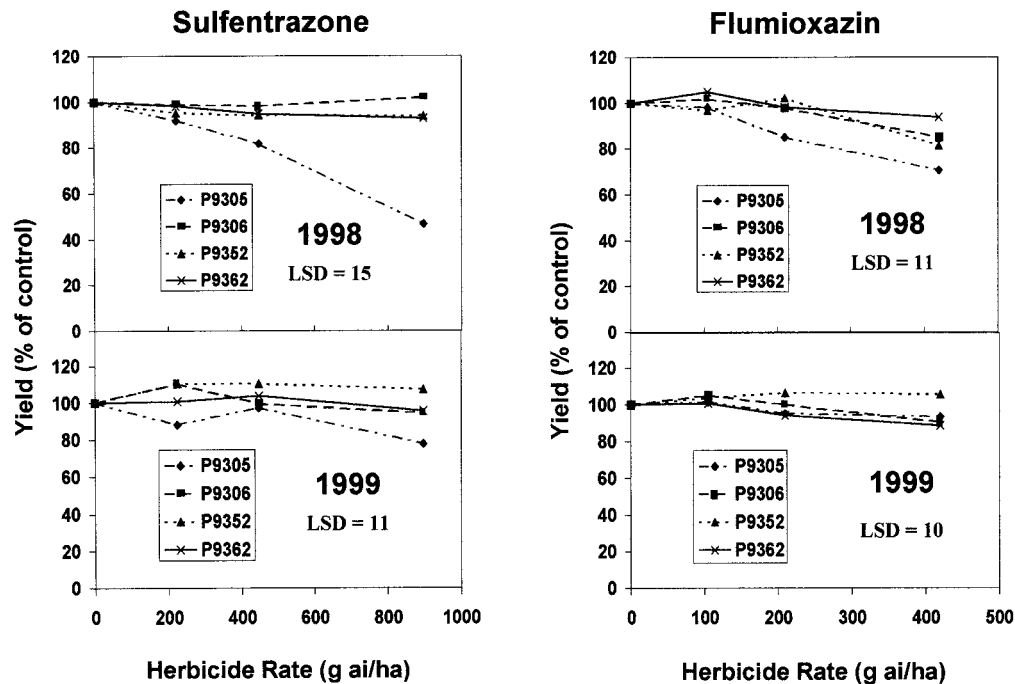


Figure 2. Grain yield as a percentage of the untreated control for each of four soybean varieties treated with three rates of sulfentrazone or flumioxazin. The grain yields (kg/ha) of the untreated controls for each variety were as follows: 4010, 4020, 3730, and 3630 in 1998; and 2840, 3030, 2850, and 2570 in 1999 for P9305, P9306, P9352, and P9362, respectively. Field experiments were conducted in Urbana, IL. Numbers for LSD indicate Fisher's protected LSD at  $\alpha = 0.05$ .

The yields as a percentage of control for the particular variety are shown in Figure 2. At 1 $\times$  use rates of each herbicide, yields were not reduced, except with P9305 treated with sulfentrazone in 1999. The yields of P9305 were lower than other varieties after treatment with sulfentrazone at 2 and 4 $\times$  rates in 1998 and 1 and 4 $\times$  rates in 1999. The yields for P9305 were also lower with the 2 and 4 $\times$  rates of flumioxazin in 1998. In the same year, the yields for P9306 and P9352 were reduced with the 4 $\times$  rates of flumioxazin, whereas the yields of those varieties were not reduced with sulfentrazone.

Yield reduction appeared to be related to, but not as severe as, visible injury and stand count reductions. The variety P9305 was most sensitive by all parameters. However, there were many cases in which reductions in stand count did not affect yield, indicating the ability of soybean plants to grow aggressively to compensate for a certain degree of thinning. Where yield reductions did occur, the percentage reduction in yield was much less than the reduction in stand count; for example, with P9305, a 75% stand count reduction caused only 15 to 20% reduction in yield.

Previous studies on the relation between herbicide injury and a subsequent reduction in yield have given mixed results. In a study with a number of different herbicides, Hagood et al. (1980) concluded that yield re-

ductions could not particularly be predicted by visible injury symptoms. Reductions in stand count appeared to be more closely related to yield effects than other parameters. The herbicides oryzalin, dinitramine, vernolate, and metribuzin caused a reduction in soybean yield only at rates higher than the labeled rate. With linuron, chlorbromuron, chloramben, and alachlor, no reduction in yield was observed at any rate (Hagood et al. 1980). As with flumioxazin and sulfentrazone, yield reductions were less likely with reduced herbicide rates. Although the yields were affected little at the 1 $\times$  rate, the use of sensitive varieties on soils with low organic matter may increase the likelihood of yield reductions due to herbicide injury resulting from sulfentrazone or flumioxazin applications.

In general, emergence, stand count, and yields resulting from flumioxazin applications were similar to sulfentrazone in the field study. However, in the greenhouse study, sulfentrazone was much more injurious. This contradiction may be related to the difference in the degradation of the two herbicides. The half-life for flumioxazin is only 11.9 to 17.5 d (Valent 1998), whereas the half-life of sulfentrazone is 100 to 280 d (Gey et al. 1979). In the greenhouse, where conditions are warm and moist, herbicide degradation is likely to be enhanced. Because flumioxazin degrades much more rap-

idly, less of the herbicide will be available for plant uptake at the time of soybean emergence. In the field, the conditions were cooler and dry for some periods before and during soybean emergence. The degradation of flumioxazin was likely to be slower in the field, so more was available. Because sulfentrazone has a much longer half-life, the majority of the material was probably still present at the time of emergence to cause injury in both the greenhouse and field. Both herbicides appear to have the potential to cause severe soybean injury under certain environmental conditions. However, recommendations of tolerant soybean varieties will reduce the potential for injury from sulfentrazone, and maybe flumioxazin. More research is needed to confirm whether or not variety differences from flumioxazin applications can be predicted by sensitivity to sulfentrazone.

### ACKNOWLEDGMENTS

We thank Ronnie Jones at Valent USA Corp. for assistance in the design of the greenhouse experiment, Mark Vogt at Pioneer Hi-Bred International, Inc. for soybean seeds, German Bollero for statistical insight, and Doug Maxwell for technical field assistance.

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