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Effect of selected postemergence herbicides on glyphosate-resistant soybean growth, development, and yield under weed-free conditions

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EFFECT OF SELECTED POSTEMERGENCE HERBICIDES ON GLYPHOSATE-RESISTANT SOYBEAN GROWTH, DEVELOPMENT, AND YIELD UNDER WEED-FREE CONDITIONS

by

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MAJOR PROFESSOR: Dr. George Kapusta

Studies I and II. Two field studies in 1997 and 1998 were conducted at the Southern Illinois University research center at Belleville, IL to determine whether postemergence (POST) herbicides detrimentally affect glyphosate-resistant soybean yield and its yield components under weed-free conditions when planted at early and late timings. Acifluorfen caused the greatest injury followed by imazethapyr and minimal to no injury was observed with glyphosate. 'Asgrow AG3701' soybean response to acifluorfen, imazethapyr, and glyphosate were different, but despite herbicide treatment, injury was slightly greater at the V2 stage than at the V5 stage in both years at this location under weed-free conditions. Whether or not early POST applications are more prone to cause injury than late POST applications is a function of local environmental conditions. Essentially complete soybean recovery occurred within 21 days of treatment regardless of herbicide, application timing, planting date, or year.

Acifluorfen, imazethapyr, and glyphosate did not reduce soybean population in studies I and II either year. Soybean height was greater in study II than study I but was not influenced by the herbicide. Developmental stages, biomass components, leaf area index, and harvest index varied with herbicide and application timing irrespective of herbicide or stage of application, but results were not always consistent in both studies across the

two years. Higher harvest index was obtained in study II than in study I.

Overall, there was no effect of herbicide or its application timing on yield of weed-free glyphosate-resistant cultivar Asgrow AG3701 under environmental conditions found at this location when planted at early and late timings.

Studies III and IV. At the same location but with different cultivars, soybean injury apparently was more severe in 1997 than in 1998 in studies III and IV. In addition, soybean injury was slightly greater at the V2 stage than at the V5 stage in 1997 and 1998, regardless of herbicide or planting date. The rate of soybean recovery in study III was more rapid in 1998 than in 1997. Chlorosis, necrosis, and puckering disappeared by 14 days after treatment (DAT) in study III in 1998 compared to 21 DAT in 1997. Complete soybean stunting recovery in study III did not occur until approximately 28 DAT in 1997 compared to only 14 DAT in 1998. All soybean injury in study IV dissipated by 14 DAT in both years except for stunting in 1998, which took approximately 21 DAT to disappear completely. Essentially complete soybean recovery in both studies occurred by 14 to 21 days regardless of herbicide, application timing, planting date, or year.

Soybean population at the end of the season in studies III and IV in both years was not affected by the herbicides or application timings. Soybean height was similar in studies III and IV and was not influenced by the herbicide.

Data from studies III and IV indicate that early season injury from these POST herbicides had no detrimental effect on yield of glyphosate-resistant cultivars Asgrow AG3601 in 1997 and Asgrow AG4501 in 1998 under weed-free conditions when planted at early and late timings.

Dedication

This work is dedicated to my special parents, Scott and Pamela; to my Sis, Katie; and to my grandparents, Percy and Pauline; for their sincere love and support.

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INTRODUCTION

Pesticides are used in the agroenvironment to protect world soybean [*Glycine max*(L.) Merr.] production against terrestrial weeds, diseases, and insects to ensure optimum yield potential. For instance, many agronomists believe that early-season weed control in soybean is important because yield normally is not affected if fields are kept weed-free for the first three to four weeks after planting (Devlin et al. 1991; Eaton et al. 1976; Hagood et al. 1980). Weed management is a critical step in maximizing soybean yield and retaining a high quality harvest, free of weed seed. Typically, a soybean producer can control weeds by selecting a herbicide based on several factors: weed spectrum, minimal crop injury, cost, and environmental characteristics. Few herbicides available today deliver optimal performance in all of these areas. Several classes of broad-spectrum herbicides are available, but most are nonselective and kill or significantly injure crops at the application rates required for effective weed control (Padgette et al. 1995).

Glyphosate [N-(phosphonomethyl)glycine] is a highly effective herbicide in controlling many annual and perennial grass and broadleaf weeds. Recent advances in plant biotechnology have made it possible to insert a gene into soybean to provide crop tolerance specifically to glyphosate formulations and bring the benefits of its use to weed management in soybean (Barry et al. 1992; Padgette et al. 1995). The development of glyphosate-resistant soybean as an alternative agronomic practice offers soybean producers a new wide-spectrum weed control option (Mulugeta and Boerboom 1996). Soybean producers can use glyphosate as a new mode of action in their chemical rotation

to prevent weed shifts and weed resistance with minimal to no crop injury while taking advantage of planting date flexibility, which is one of the most important agronomic practices influencing soybean yield (Carter and Hartwig 1963; Egli et al. 1987). Yield in the U.S. usually is similar for mid-May to early June plantings but decreases rapidly when planting is delayed into late June and early July (Egli 1976; Egli et al. 1987; Pendleton and Hartwig 1973; Tanner and Hume 1978). The recommendation of mid to late May plantings to maximize yield is consistent across all U.S. soybean production areas, even though cultivar maturity, growth habit, and environmental conditions vary widely (Tanner and Hume 1978).

With the advent of improved cultivars, pesticides, and better cultural practices, soybean yield has increased annually. However, soybean producers have been contemplating whether soybean yield gains are less than corn (*Zea mays* L.) yield gains as a result of soybean injury by foliar herbicides. This perception has been actuated by the minimal to no soybean injury observed with foliar applications of glyphosate on glyphosate-resistant soybean to control weeds.

Several highly managed research trials have shown that soybean yield in Illinois and Iowa has exceeded 80 bushels per acre (bu/A) for some cultivars, indicating that there is the potential to exceed the state and national yield averages which are approximately 40 bu/A. The relevance of examining soybean yield potential in response to postemergence (POST) herbicide injury under diverse field conditions or agronomic practices is to better understand the multiple interactive stresses impacting soybean recovery mechanisms and yield.

MATERIALS AND METHODS

General Procedure. Four field studies were conducted in 1997 and 1998 at the Southern Illinois University research center at Belleville, IL under weed-free conditions to evaluate soybean vegetative and yield responses to several commercially available preplant incorporated (PPI) and POST herbicides when planted at early and late timings. Each study consisted of: a) POST herbicides applied at the V2 (two fully-expanded trifoliolate leaf nodes on the main stem with axillary buds; Herman 1996) and V5 (five fully-expanded trifoliolate leaf nodes with axillary buds and racemes; Herman 1996) growth stages of soybean planted at an early date (Study I); b) an immediately adjacent study consisting of the same treatments as in Study I applied to soybean planted several weeks later (Study II); c) PPI herbicides applied before soybean planting and POST herbicides applied at the V2 and V4 (four fully-expanded trifoliolate leaf nodes; Herman 1996) growth stages of soybean at an early planting date (Study III); and d) an immediately adjacent study consisting of the same treatments as in Study III applied to soybean planted several weeks later (Study IV). For all studies, the seedbed was prepared with a tandem disk, field cultivator, and cultimulcher each year.

Studies I and II. 'Asgrow AG3701' soybean was planted approximately 2.5 cm deep at 84 kg/ha on May 9 and June 11, 1997, respectively. In 1998, the soybean in studies I and II were planted on May 13 and May 31, respectively. Studies I and II were arranged in a randomized complete block design with six replications. Plots consisted of six rows, 10.7 m long with 76 cm row spacing. The POST herbicides were applied with a

CO_2-pressurized sprayer using 8003 TeeJet flat-fan nozzle tips[1] calibrated to deliver 194 L/ha water at 276 kPA. In both studies, alachlor [2-chloro-2',6'-diethyl-N-(methoxymethyl)acetanilide] at 2240 g ai/ha was applied preemergence (PRE) followed by cultivation and handwee5ding on all plots to maintain weed-free conditions. The soil type for both studies was originally mapped as an Ebbert silt loam (fine-silty, mixed, mesic Argiaquic Argialbolls) but is now reclassified as a Bethalto silt loam (fine-silty, mixed, superactive, mesic Udollic Endoaqualfs) (United States Department of Agriculture, Soil Taxonomy, 1975; United States Department of Agriculture, Soil Survey Staff, 1994) with pH 6.3 to 6.6 and 2.1% to 2.4% organic matter content. In both years, the previous crop was wheat (*Triticum aestivum* L.).

Herbicides evaluated in both studies were glyphosate at 1120 g ai /ha, imazethapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid)) at 70 g/ha, and acifluorfen {5-[2-chlor-4-(trifluoromethyl)phenoxy]-2-nitobenzoic acid}at 420 g/ha applied POST to soybean at the V2 and V5 growth stages. Study I treatments were applied at the V2 growth stage on June 16, 1997 and June 9, 1998, and at the V5 growth stage on June 24, 1997 and June 22, 1998. Study II treatments applied at the V2 growth stage were on July 7, 1997 and June 30, 1998, and at the V5 growth stage on July 14, 1997 and July 6, 1998.

Soybean population per 6 m of row was obtained approximately 14 days after emergence (DAE) and at physiological maturity in all plots. Visual estimates of soybean

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[1] Spraying Systems Co. P.O. Box 7900, North Avenue at Schmale Road, Wheaton, IL 60189-7900.

injury were based on height reduction and percent total leaf area showing chlorosis, necrosis, and puckering at intervals of 5 to 7, 21 to 24, and 35 days after treatment (DAT). Height reduction was obtained using a 0 to 100% scale (0 indicating no height reduction and 100% indicating complete death). Chlorosis, necrosis, and puckering were obtained using a 0 to 100% scale (0 indicating no discoloration, dead leaf tissue, or leaf tissue malformation to 100% indicating complete discoloration, dead leaf tissue, or leaf tissue malformation).

Soybean biomass sampling was obtained in both studies at 21 to 24 DAT to determine potential differences in soybean recovery to several POST herbicides applied at V2 and V5 growth stages at early and late planting dates. Soybean biomass sampling in both studies consisted of obtaining the following in each plot: a) vegetative and reproductive stages of three uniform soybean plants in a 1 m of one row subplot; b) the three soybean plants were separated by hand into the following components: leaves, stems and petioles, and pods for oven-dry weight analysis (63 C for 36 hr); and c) the remaining intact soybean plants in a 1 m of one row subplot were combined for separate dry weight analysis and represented as total dry matter weight minus the three uniform soybean plants.

In studies I and II, the soybean growth and reproductive stages were obtained at 21 to 24 days after the V2 and V5 growth stage treatments. In both studies, the following information also was obtained in each plot at 21 to 24 DAT: a) average soybean height of one row in each plot from the base of the plant to the top of the canopy; b) soybean population in a 1 m of one row subplot; and c) leaf area index (LAI) was obtained either

mid-morning or early afternoon using a LI-COR LAI-2000 meter[2]. This unit determines mean leaf area index which is the leaf area per unit ground area (Welles and Norman, 1991) or the area that the soybean canopy covers per unit land area. The LAI was measured once above the soybean canopy and four times below the soybean canopy between two rows at diagonal increments with the meter positioned parallel to the rows for a total of five measurements per plot.

A time line by which soybean reached full maturity or R8 stage was obtained as days after planting. A soybean at the R8 stage is when 95% of the pods having reached their mature pod color; 5 to 10 days of drying weather are required after R8 before soybean has less than 15% moisture (Herman 1996).

After 99% leaf drop, harvest index and its components were obtained in each plot. Harvest index represents the dry weight of seed per total plant dry matter weight within a 1 m row length subplot at the end of the growing season. Within each subplot, soybean plants were counted and hand-harvested; then three uniform plants were selected and divided into pod shells, seed, and stems and petioles for dry weight analysis. Dry weights were obtained following oven-drying at 63 C for 36 hr.

The second and third row of each plot were harvested for yield with a plot combine and yield adjusted to 13% moisture on September 26 (Study I) and October 7, 1997 (Study II). In 1998, the plots were harvested and yield adjusted to 13% moisture on

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[2] LI-COR, Inc. P.O. Box 4425, 4421 Superior Street, Lincoln, NE 68504

October 5 (Study I) and October 9 (Study II). For each study, treatment by year interactions were evaluated and all data were subjected to a one-way analysis of variance and treatment means separated using Fisher's Protected LSD Test at $P \leq 0.05$. Data were pooled across years when treatment by year interactions were not significant ($P > 0.05$).

Studies III and IV. 'Asgrow AG3601' and 'Asgrow AG4501' soybean were planted in 1997 and 1998, respectively. Asgrow AG4501 was used in 1998 to minimize the incidence of sudden death syndrome (*Fusarium solani*, (Mort.) Sacc. f. sp. glycines (Burk.) Snyd. and Hans.)) observed in 1997. Asgrow AG3601 was planted approximately 2.5 cm deep at 84 kg/ha on May 9 and May 29, 1997, and Asgrow AG4501 was planted at the same depth and planting rate on May 14 and June 3, 1998. These studies were arranged in a randomized complete block design with four replications. Plots consisted of four rows, 10.7 m long in 1997 and 9.1 m long in 1998 with 76 cm row spacing both years. The PPI and POST herbicides were applied with a CO_2-pressurized sprayer using 8002 TeeJet flat-fan nozzle tips calibrated to deliver 146 L/ha and 170 L/ha at 276 kPa in 1997 and 1998, respectively. These studies were maintained weed-free by cultivating and handweeding. The soil type for both studies in 1997 was originally mapped as a Rushville silt loam (fine, montmorillonitic, mesic Typic Albaqualfs). In 1998, the soil type for both studies was originally mapped as a Weir silt loam (fine, montmorillonitic, mesic Typic Ochraqualfs). Currently, the Rushville silt loam and Weir silt loam are both reclassified as a Pierron silt loam (fine, smectitic, mesic

Chromic Vertic Albaqualfs) (United States Department of Agriculture, Soil Taxonomy, 1975; United States Department of Agriculture, Soil Survey Staff, 1994). In both studies in 1997, the Pierron soil type had a pH of 6.7 with 2.2% organic matter content. In both studies in 1998, the Pierron soil type had a pH of 6.9 with 1.8% organic matter content. In 1997 and 1998, the previous crop was wheat and corn, respectively.

The treatments consisted of pendimethalin {(N-1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine} at 840 g/ha plus imazaquin (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-quinolinecarboxylic acid) at 140 g/ha, and metribuzin {4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one} at 270 g/ha plus chlorimuron (ethyl 2-[[[[(4-chloro-6-methoxypyrimidin-2-yl)amino]carbonyl]amino]sulfonyl]-benzoate) at 45 g/ha applied PPI on May 9, 1997 and May 28, 1997, and on May 14, 1998 and June 3, 1998. Glyphosate at 1120 g/ha, imazethapyr at 70g/ha, bentazon [3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide] at 1120 g/ha, acifluorfen at 420 g/ha, bentazon at 560 g/ha plus acifluorfen at 280 g/ha, and chlorimuron at 18 g/ha plus thifensulfuron (methyl 3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylate) at 6 g/ha were applied POST to soybean at the V2 and V4 growth stages in each planting date. Study III treatments were applied at the V2 growth stage on June 16, 1997 and June 9, 1998, and at the V4 growth stage on June 24, 1997 and June 22, 1998. Study IV treatments applied at the V2 growth stage were on June 24, 1997 and

June 30, 1998, and at the V4 growth stage on July 3, 1997 and July 6, 1998.

Data obtained in these studies included: a) soybean population per 6 m of row approximately 14 DAE and at physiological maturity in all plots; b) average soybean height of one row in each plot approximately 14 DAT and at physiological maturity; and c) visual estimations of soybean injury based on percent total leaf area showing chlorosis, necrosis, and puckering at intervals of 7, 14, 21, 28, and 56 DAT. Visual estimates of all plots also were obtained as described for studies I and II. In addition, the date the soybean reached the R8 stage was obtained for all plots. The center two rows of each plot were harvested for yield with a plot combine and yield was adjusted to 13% moisture on September 26 (Study III) and October 6, 1997 (Study IV). In 1998, the plots were harvested and yield adjusted to 13% moisture on October 9 (Studies III and IV).

For each study, all data were subjected to factorial analysis of variance. Factors included replication and year which were random, POST herbicide (HERB) and soybean stage at herbicide application (STAGE) which were fixed and crossed as well as three single degree of freedom regression terms. The regressors were coded to partition treatment effects associated with the check treatments from the main effects and their interaction. Data were pooled across years when year interactions with the main effects and their interaction were not significant ($P > 0.05$). Data were pooled across STAGE when the HERB by STAGE interaction was not significant ($P > 0.05$). Data were not pooled across HERB in any cases as they were distinct treatments, not a continuous scale,

nor in an "alone and in combination with each other" arrangement. Significant differences among the check treatments and significant differences between the check treatments and the crossed main effect treatments are presented along with either the HERB or HERB by STAGE effects. Therefore, the variance and degrees of freedom associated with the differences between the check treatments and the crossed main effect treatments were included in the calculation of the probability of F for either the HERB or HERB by STAGE effects. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Study I.

Environmental conditions (data not presented). Soybean growth was less vigorous from emergence to the V2 growth stage in 1997 than in 1998 despite no POST herbicide applications and similar planting dates. The growth period from emergence to V2 stage was approximately 5 weeks in 1997 and 4 weeks in 1998. Local field conditions on the day of POST herbicide application at the V2 and V5 soybean growth stages were slightly different in both years. However, visual estimation of soil moisture in all plots was greater than field capacity in both years and at both application timings. In 1997, the relative humidity was 50% at both application timings, and the average air temperatures at the V2 and V5 application timings were 26 and 31 C, respectively.

In 1998, the relative humidity was 62 and 50% at the V2 and V5 application timings, respectively. The average air temperatures at the V2 and V5 application timings were 23 and 28 C, respectively. Monthly rainfall in 1997 was 8.72, 6.67, 13.85, 8.46, and 10.77 cm in April, May, June, July, and August, respectively. The 1998 growing season had higher rainfall, with the exception of a drier August, than in 1997. Monthly rainfall in 1998 was 11.28, 10.0, 18.97, 10.77, and 7.95 cm in April, May, June, July, and August, respectively.

Soybean injury. In 1997, regardless of application timing, soybean chlorosis, necrosis, and puckering was most pronounced with acifluorfen 5 to 7 days after treatment (DAT) compared to glyphosate or imazethapyr (Table 1). Acifluorfen is known to inhibit an enzyme in chlorophyll synthesis. Acifluorfen is effective through contact action, but leaf

and stem speckling and bronzing may occur under certain conditions, particularly on younger leaves and stems that are present at the time of application. Acifluorfen resulted in 20, 33, and 20% chlorosis, necrosis, and puckering, respectively, when applied at the V2 stage. Injury from acifluorfen was manifested as 20% chlorosis, 20% necrosis, and 10% puckering when applied at the V5 stage. Imazethapyr was slightly more injurious to the soybean when applied at the V2 stage compared to the V5 stage. It is characterized as a herbicide that is translocated rapidly to younger tissue through root and foliage uptake and is known to inhibit the acetolactate synthase enzyme in plants. Occasionally, it shortens soybean internodes and causes temporary yellowing of plant tissue. Imazethapyr-treated soybean exhibited 7% chlorosis after the V2 application timing but no injury after the V5 application timing. Percent chlorosis with glyphosate applied at the V2 stage was minimal and no injury observed following the V5 application timing. Glyphosate is an amino acid inhibitor with systemic activity and known to cause some occasional yellowing of younger leaf tissue. Soybean chlorosis, necrosis, and puckering from all herbicides at both application timings dissipated by 21 to 24 DAT in 1997 (data not presented).

Soybean stunting in response to POST herbicide applications was stage and herbicide dependent (Table 1). Imazethapyr and acifluorfen applied at the V2 stage caused 21 and 17% stunting, respectively, compared to 4% with glyphosate and 0% with the nontreated at 5 to 7 DAT. Soybean stunting was substantially less when the herbicides were applied at the V5 stage compared to the V2 stage. However, similar height reduction induced by imazethapyr (5%) or acifluorfen (5%) at the V5 stage were

not relatively different to the nontreated (0%) or glyphosate (0%) at 5 to 7 DAT. At 35 DAT, minimal soybean stunting persisted following the V2 application timing with imazethapyr (2%) or acifluorfen (4%). Complete soybean recovery occurred by 35 days after the V5 application timing regardless of herbicide.

Table 1. Influence of postemergence herbicides on glyphosate-resistant soybean tolerance under weed-free conditions, 1997 (Study I).

			Soybean, days after postemergence application					
		Appli-	Chlorosis	Stunting			Necrosis	Puckering
Treatment	Rate	cation timing	5 -7	5 -7	21-24	35	5 -7	5 - 7
	kg/ha		%					
PLANTING DATE 1								
Nontreated			0	0	0	0	0	0
Glyphosate + AMS[a]	1.12	V2	3	4	1	0	0	0
Imazethapyr	0.07	V2	7	21	4	2	3	0
+ MSO[b] + 28%N[c]								
Acifluorfen + NIS[d]	0.42	V2	20	17	6	4	33	20
Glyphosate + AMS	1.12	V5	0	0	0	0	0	0
Imazethapyr	0.07	V5	0	5	3	0	0	0
+ MSO + 28%N								
Acifluorfen + NIS	0.42	V5	20	5	1	0	20	10
LSD[e]			5	9	2	1	5	1
P			0.05	0.05	0.05	0	0.05	0.05

[a]AMS = Ammonium sulfate at 2% W/W.
[b]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.
[c]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.
[d]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.
[e]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Soybean chlorosis, necrosis, and puckering in 1998 apparently was less than in 1997. Regardless of stage, acifluorfen caused greater chlorosis (10%), necrosis (20%), and puckering (10%) at 5 to 7 DAT compared to glyphosate or imazethapyr (Table 2). Imazethapyr applied at the V2 stage caused 1% chlorosis and 2% puckering, but no similar injury was observed following application at the V5 stage.

Table 2. Influence of postemergence herbicides on glyphosate-resistant soybean tolerance under weed-free conditions, 1998 (Study I).

Treatment	Rate	Application timing	Soybean, days after postemergence application				
			Chlorosis	Stunting		Necrosis	Puckering
			5 -7	5 -7	21-24	5 -7	5 - 7
	kg/ha		%				
PLANTING DATE 1							
Nontreated			0	0	0	0	0
Glyphosate + AMS[a]	1.12	V2	0	0	1	0	0
Imazethapyr + MSO[b] + 28%N[c]	0.07	V2	1	3	1	0	2
Acifluorfen + NIS[d]	0.42	V2	10	10	4	20	10
Glyphosate + AMS	1.12	V5	0	0	0	0	0
Imazethapyr + MSO + 28%N	0.07	V5	0	5	0	0	0
Acifluorfen + NIS	0.42	V5	10	1	0	20	10
LSD[e]			1	3	2	1	2
P			0.05	0.05	0.05	0.05	0.05

[a]AMS = Ammonium sulfate at 2% W/W.
[b]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.
[c]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.
[d]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.
[e]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at P≤ 0.05.

Soybean stunting apparently was less in 1998 than in 1997. Stunting at 5 to 7 DAT ranged from 0 to 10% after the herbicides were applied at the V2 stage compared to 0 to 5% after the herbicides were applied at the V5 stage (Table 2). Acifluorfen reduced soybean height (10%) following the V2 application timing compared to the V5 application timing (1%) . Imazethapyr applied at the V2 stage caused a 3% height reduction compared to a 5% height reduction when applied at the V5 stage. Irrespective of the application timing, imazethapyr stunted soybean at 5 to 7 DAT. There was no stunting observed with glyphosate at 5 to 7 DAT regardless of application timing. At 21 to 24 DAT, soybean more rapidly recovered from the stunting induced by imazethapyr or acifluorfen when applied at the V5 stage compared to the V2 stage.

Overall, soybean injury apparently was less severe in 1998 because local field conditions were more favorable for rapid recovery of soybean following initial injury from glyphosate, imazethapyr, or acifluorfen compared to 1997. Soybean exhibited more injury at the V2 stage than at the V5 stage, regardless of herbicide, but was dependent on the year characterized by its seasonal environmental conditions. It is suggested that more soil moisture was plant-available immediately prior to POST application and utilized by the soybean to either counteract or overcome herbicide injury during the 3 week soybean recovery period following both application timings in 1998. There was more rainfall during the 1998 growing season compared to 1997. The soybean plots received approximately 8.05 and 3.78 cm of rain after the V2 and V5 application timings, respectively, in 1997. In 1998, soybean plots received 10.21 and 5.84 cm after the V2 and V5 application timings, respectively.

However, relatively similar average air temperatures did occur both years during the 3 week soybean recovery period. For instance, the average air temperatures 3 weeks after the V2 and V5 application timings ranged from 26 to 27 C in both years. Whether it was the air temperature or soil moisture during the 3 week soybean recovery period that influenced soybean response to the different families of herbicides is yet to be determined at this location in a succeeding year. However, studies have shown that some acetolactate synthase herbicides such as imazethapyr reduced soybean yield in 1994 but not in 1995 (Ateh et al. 1994, 1995). These studies suggest that environmental factors play a large role in the ability of soybean to recover from herbicide injury. According to Ateh and Harvey (1996), the weather in 1994 was characterized by lower than normal temperatures

and rainfall during the early part of the season and higher than normal during the latter part of the season. These environmental conditions favored soybean growth and yield was not affected significantly by herbicide injury. Causes of soybean injury by POST herbicides are complex, and predicting yield reduction from soybean injury requires consideration of all factors influencing POST herbicide phytotoxicity (Ateh and Harvey 1995).

Soybean population (1997-1998). Soybean population per 6 m of row was obtained at 14 days after emergence (DAE) and at the end of the season (EOS). At 14 DAE, the POST herbicides had not been applied and there were no soybean population differences obtained among the plots (Table 3). At EOS, soybean population among the plots was not different regardless of herbicide or application timing. Based on many years of population counts at these timings, the decrease in population from early season to harvest is not unusual. However, the number of plants in a 1 m row subplot at 21 days after an imazethapyr treatment at the V2 stage was lower than the nontreated soybean, glyphosate-treated soybean, or acifluorfen-treated soybean subplots. At the EOS, there were no plant count differences obtained among the treatments in each subplot despite herbicide, stage, herbicide by stage, or year.

Developmental stages. In each subplot, soybean vegetative and reproductive stages were identified at 21 to 24 days after the V2 and V5 application timings. In 1997, soybean treated with glyphosate, imazethapyr, or acifluorfen at the V2 application timing developed from the V2 stage to the V10 stage by 21 DAT compared to the nontreated soybean which developed from the V2 stage to the V11 stage (Table 4), indicating the

herbicides delayed soybean vegetative development when applied at the V2 stage compared to the nontreated soybean. However, soybean vegetative development was uniform across all treatments following the V2 application timing in 1998. The vegetative development differences between years after the V2 application timing are not clearly understood because relatively similar seasonal air temperatures occurred at this location. It is hypothesized to be related to the higher manifestation of herbicide injury induced by the slightly warmer temperatures 2 weeks after the V2 POST application in 1997 than in 1998. In 1997, the average air temperature was 2.5 C higher than in 1998 during the 2 week soybean recovery period. However, by the third week of soybean recovery following the V2 application timing, the air temperature in 1998 was 3.1 C higher than in 1997.

In contrast, the soybean reproductive stage at 21 days after the V2 application was not affected by herbicide or application timing either year (Table 4). When herbicides were applied at the V5 stage, vegetative and reproductive stages were pooled across years in study I. Soybean treated with glyphosate at the V5 stage developed to the V11 stage 21 DAT compared to the V12 stage attained by the nontreated soybean, imazethapyr-treated soybean, or acifluorfen-treated soybean (Table 4). However, there were no reproductive stage differences identified among the treatments following application at the V5 growth stage.

Table 3. Influence of postemergence herbicides on glyphosate-resistant soybean population under weed-free conditions, pooled 1997 and 1998 (Study I).

Treatment	Rate	Application timing	Soybean population		Soybean subplot population		
			14 DAE[a]	EOS[a]	21 DA-V2[b]	21 DA-V5[b]	EOS[a]
	kg/ha		000/ha		No. of plants/ 1 m row		
PLANTING DATE 1							
Nontreated			293	266	25	23	21
Glyphosate + AMS[c]	1.12	V2	287	262	24		21
Imazethapyr + MSO[d] + 28%N[e]	0.07	V2	286	259	22		21
Acifluorfen + NIS[f]	0.42	V2	281	258	25		20
Glyphosate + AMS	1.12	V5	291	269		24	22
Imazethapyr + MSO + 28%N	0.07	V5	285	248		24	21
Acifluorfen + NIS	0.42	V5	276	253		21	23
LSD[g]					3		
P			NS	NS	0.05	NS	NS

[a]DAE = days after emergence; EOS = end of season.

[b]DA-V2 = days after V2 post application; DA-V5 = days after V5 post application.

[c]AMS = Ammonium sulfate at 2% W/W.

[d]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[e]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[f]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[g]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Table 4. Influence of postemergence herbicides on glyphosate-resistant soybean vegetative and reproductive stages under weed-free conditions (Study I).

Treatment	Rate	Application timing	Soybean growth stages: 21 DA-V2[a] V-stage[b]	21 DA-V2[a] V-stage[b]	21 DA-V2[a] R-stage[b]	21 DA-V5[a] V-stage[b]	21 DA-V5[a] R-stage[b]
	kg/ha		1997	1998	Pooled, 1997-1998	Pooled, 1997-1998	
PLANTING DATE 1							
Nontreated			11	8	2	12	3
Glyphosate + AMS[c]	1.12	V2	10	8	2		
Imazethapyr + MSO[d] + 28%N[e]	0.1	V2	10	8	2		
Acifluorfen + NIS[f]	0.42	V2	10	8	2		
Glyphosate + AMS	1.12	V5				11	3
Imazethapyr + MSO + 28%N	0.1	V5				12	3
Acifluorfen + NIS	0.42	V5				12	3
LSD[g]			1			1	
P			0.05	NS	NS	0.05	NS

[a]DA-V2 = days after V2 post application; DA-V5 = days after V5 post application.

[b]V-stage = vegetative stage; R-stage = reproductive stage.

[c]AMS = Ammonium sulfate at 2% W/W.

[d]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[e]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[f]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[g]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Soybean height. In each subplot, soybean height was obtained at 21 to 24 DAT. Pooled across years, the nontreated soybean and glyphosate-treated soybean at the V2 stage were both 3 and 6 cm taller than the imazethapyr or acifluorfen-treated soybean, respectively (Table 5).

Table 5. Influence of postemergence herbicides on glyphosate-resistant soybean height under weed-free conditions, pooled 1997 and 1998 (Study I).

Treatment	Rate	Application timing	Soybean subplot height[a]		Soybean height
			21 DA-V2[b]	21 DA-V5[b]	EOS[b]
	kg/ha		cm		cm
PLANTING DATE 1					
Nontreated			53	78	97
Glyphosate + AMS[c]	1.12	V2	53		96
Imazethapyr + MSO[d] + 28%N[e]	0.07	V2	50		95
Acifluorfen + NIS[f]	0.42	V2	47		96
Glyphosate + AMS	1.12	V5		74	96
Imazethapyr + MSO + 28%N	0.07	V5		72	95
Acifluorfen + NIS	0.42	V5		74	95
LSD[g]			3		
P			0.05	NS	NS

[a]Soybean subplot height = height of plants per 1 m of one row per plot.
[b]DA-V2 = days after V2 post application; DA-V5 = days after V5 post application; EOS = end of season.
[c]AMS = Ammonium sulfate at 2% W/W.
[d]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.
[e]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.
[f]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.
[g]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

The subplot soybean heights ranged from 47 to 53 cm at 21 days after V2 application. There were no soybean height differences observed in the subplots when the herbicides were applied at the V5 stage (Table 5). Regardless of herbicide, application timing, or year, soybean height was not different at the EOS with height ranging from 95 to 97 cm.

Soybean leaf area index (LAI). At 21 DAT, the LAI values in each plot of soybean were not different and ranged from 1.9 to 2.3 following V2 postemergence application (Table 6); however, the soybean may not have been intercepting 95% of the light that was infiltrating through the soybean canopy. According to Shibles and Weber (1965), a LAI value of 3.2 more nearly approximates the true value of LAI required of soybean for 95% light interception. Although the LAI values were lower in the imazethapyr (3.4) and acifluorfen (3.6) plots compared to the glyphosate (3.9) or nontreated (3.8) plots when the herbicides were applied at the V5 stage, it is assumed that in each plot, soybean was intercepting at least 95% of the light that was passing through the soybean canopy.

Soybean biomass. In each subplot, three uniform soybean plants were biomass sampled 21 to 24 DAT to determine whether glyphosate, imazethapyr, or acifluorfen influenced vegetative or reproductive growth when applied at two different soybean developmental stages and whether the herbicides detrimentally affected yield under weed-free conditions. In both years in study I, soybean leaf dry weight was reduced by acifluorfen (9.7 g) compared to the nontreated (12.5 g), glyphosate (12.8 g), or imazethapyr (11.3 g) when applied at the V2 stage (Table 6). There were no leaf dry weight differences obtained among the treatments after the V5 application timing.

Acifluorfen applied at the V2 stage resulted in a significant reduction in stem dry weight compared to the nontreated (11.6 g) or glyphosate (11.3 g) (Table 6). Imazethapyr (9.2 g) had no detrimental effect on stem dry weight. There were no stem dry weight differences among the treatments after the V5 application timing.

Whole plant dry weight was not different across years, herbicides, or application

timings and ranged from 109.6 to 130.1 g following the V2 application timing and 161.7 to 199.7 g following the V5 application timing (Table 6). Irrespective of year or herbicide, soybean pods ≥ 5 mm long were not present on soybean treated at the V2 stage in the early planting date (Table 6). However, in 1997, soybean pods ≥ 5 mm long were present on soybean treated at the V5 stage. The pod dry weight was higher in the nontreated soybean subplots (0.8 g) compared to the glyphosate (0.3 g), acifluorfen (0.3 g), or imazethapyr (0.1 g) soybean subplots suggesting the herbicides may have prematurely inhibited dry matter accumulation to the sink such as pods (Table 4).

The significant differences in pod dry weight in 1997 across all treatments are not clearly understood because pod number was not counted during the biomass sampling. If pod number had been counted, it may have determined whether glyphosate, imazethapyr, or acifluorfen prematurely abscised the axillary buds or raceme that were exposed at the time of the V5 application; initiated the axillary buds to differentiate into branches rather than develop into flower clusters and finally pods; or the axillary buds may have been dormant at the time of V5 application. It is proposed that significant differences in pod dry weight existed because dry matter accumulation was inhibited by imazethapyr or acifluorfen due to greater manifestation of injury by the two herbicides applied at the V5 stage in 1997 (Table 1) compared to 1998 (Table 2), but it does not explain why glyphosate also reduced pod dry weight despite no injury observed with glyphosate applied at the V5 stage in both years (Tables 1 and 2). There were no pod dry weight differences of soybean obtained when glyphosate, imazethapyr, or acifluorfen were applied at the V5 stage compared to the nontreated in 1998 (Table 6).

Table 6. Influence of postemergence herbicides on glyphosate-resistant soybean biomass components under weed-free conditions (Study I).

Treatment	Rate	Application timing	LAI[a] 21 DA-V2[b]	LAI[a] 21 DA-V5[b]	Leaf dry weight[a] 21 DA-V2[b]	Leaf dry weight[a] 21 DA-V5[b]	Stem dry weight[a] 21 DA-V2[b]	Stem dry weight[a] 21 DA-V5[b]	Whole plant dry weight[a] 21 DA-V2[b]	Whole plant dry weight[a] 21 DA-V5[b]	Pod dry weight[a] 21 DA-V2[b]	Pod dry weight[a] 21 DA-V5[b]	Pod dry weight[a] 21 DA-V5[b]
	kg/ha				gram								
PLANTING DATE 1			Pooled, 1997-1998									1997	1998
Nontreated			2.2	3.8	12.5	21.5	11.6	26.0	130.1	178.8	0.0	0.8	0.3
Glyphosate + AMS[c]	1.12	V2	2.3		12.8		11.3		127.7		0.0		
Imazethapyr + MSO[d] + 28%N[e]	0.07	V2	2.1		11.3		9.2		109.6		0.0		
Acifluorfen + NIS[f]	0.42	V2	1.9		9.7		8.4		110.8		0.0		
Glyphosate + AMS	1.12	V5		3.9		17.9		22.4		199.7		0.3	0.2
Imazethapyr + MSO + 28%N	0.07	V5		3.4		18.8		21.1		163.0		0.1	0.3
Acifluorfen + NIS	0.42	V5		3.6		17.7		21.1		161.7		0.3	0.2
LSD[g]				0.3	1.7		2.0					0.2	
P			NS	0.05	0.05	NS	0.05	NS	NS	NS	NS	0.05	NS

[a]LAI = leaf area index or leaf area per unit ground area (Welles and Norman, 1991); leaf dry weight = oven-dry weight of leaves from three uniform plants in one meter row per plot; stem dry weight = oven-dry weight of stems and petioles from three uniform plants in one meter row per plot; whole plant dry weight = total dry matter weight minus the three uniform soybean plants in one meter row per plot; pod dry weight = oven-dry weight of pods (≥5 mm) from three uniform plants in one meter row per plot.

[b] DA-V2 = days after V2 post application; DA-V5 = days after V5 post application.

[c]AMS = Ammonium sulfate at 2% W/W.

[d]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[e]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[f]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[g]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at P≤ 0.05.

Harvest index (HI). After 99% leaf drop in each subplot, harvest index was obtained as an expression of the available assimilates that could be translocated into the grain rather than being used to produce plant mass. Despite early season soybean injury induced by all herbicides in both years, the stem dry weight, shell dry weight, seed dry weight, or whole plant dry weight were not different between any of the treatments regardless of application timing (Table 7). However, the HI value for soybean applied with imazethapyr at the V5 stage was 55% which was lower compared to the other treatments

regardless of application timing in 1997 (Table 8). Soybean treated with imazethapyr at the V5 stage had a lower pod dry weight (0.1 g) compared to the other treatments at 21 DAT (Table 6) which suggest why the HI value in the imazethapyr-treated soybean subplot was less compared to the other treatments in 1997 (Table 8). In 1998, there were no HI value differences obtained regardless of herbicide or application timing and the HI values ranged from 50 to 54%.

Table 7. Influence of postemergence herbicides on glyphosate-resistant soybean components of harvest index[a] under weed-free conditions, pooled 1997 and 1998 (Study I).

Treatment	Rate	Application timing	Stem dry weight[a]	Shell dry weight[a]	Seed dry weight[a]	Whole plant dry weight[a]
	kg/ha		gram			
PLANTING DATE 1						
Nontreated			28.5	21.0	66.1	471.7
Glyphosate + AMS[b]	1.12	V2	26.1	19.0	61.0	470.0
Imazethapyr + MSO[c] + 28%N[d]	0.07	V2	25.9	18.5	56.4	466.5
Acifluorfen + NIS[e]	0.42	V2	21.8	16.2	50.5	444.5
Glyphosate + AMS	1.12	V5	22.7	17.1	53.1	460.8
Imazethapyr + MSO + 28%N	0.07	V5	23.8	18.2	50.8	458.5
Acifluorfen + NIS	0.42	V5	24.3	17.1	53.7	470.8
LSD[f]						
P			NS	NS	NS	NS

[a]Stem dry weight = oven-dry weight of stems and petioles from three uniform plants in one meter row per plot; shell dry weight = oven-dry weight of pods minus seeds from three uniform plants in one meter row per plot; seed dry weight = oven-dry weight of seed from three uniform plants in one meter row per plot; whole plant dry weight = total dry matter weight minus the three uniform soybean plants in one meter row per plot.

[b]AMS = Ammonium sulfate at 2% W/W.

[c]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[d]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[e]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[f]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Table 8. Influence of postemergence herbicides on glyphosate-resistant soybean harvest index[a] under weed-free conditions (Study I).

Treatment	Rate	Application timing	Harvest index[a] 1997	1998
	kg/ha			
PLANTING DATE 1				
Nontreated			60	52
Glyphosate + AMS[b]	1.12	V2	60	54
Imazethapyr + MSO[c] + 28%N[d]	0.07	V2	60	50
Acifluorfen + NIS[e]	0.42	V2	59	54
Glyphosate + AMS	1.12	V5	61	52
Imazethapyr + MSO + 28%N	0.07	V5	55	54
Acifluorfen + NIS	0.42	V5	59	51
LSD[f]			4	
P			0.05	NS

[a]Harvest index represents the dry weight of seed per total above ground plant dry matter within a one meter row length at the end of the growing season for each plot.

[b]AMS = Ammonium sulfate at 2% W/W.

[c]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[d]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[e]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[f]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Soybean maturity. In 1997, imazethapyr and acifluorfen delayed maturity by 2 days, but this delay is of minimal practical importance (Table 9). In 1998, there were no maturity differences among the treatments.

Soybean yield. Pooled across years, yield ranged from 4197 to 4382 kg/ha (Table 9). Regardless of application timing or herbicide, there were no yield differences among the treatments despite early season soybean injury both years.

Table 9. Influence of postemergence herbicides on glyphosate-resistant soybean maturity and yield under weed-free conditions (Study I).

Treatment	Rate	Application timing	Days from planting to R8 stage[a]		Soybean yield
			1997	1998	Pooled, 1997-1998
	kg/ha		days after planting		kg/ha
PLANTING DATE 1					
Nontreated			134	128	4271
Glyphosate + AMS[b]	1.12	V2	134	128	4320
Imazethapyr + MSO[c] + 28%N[d]	0.07	V2	136	128	4263
Acifluorfen + NIS[e]	0.42	V2	136	128	4323
Glyphosate + AMS	1.12	V5	134	128	4271
Imazethapyr + MSO + 28%N	0.07	V5	136	128	4197
Acifluorfen + NIS	0.42	V5	136	128	4382
LSD[f]			1		
P			0.05	NS	NS

[a]R8 stage = 95% of the pods have reached their mature pod color; data represent separate years when year interactions with the main effects and their interaction were significant at $P \leq 0.05$.

[b]AMS = Ammonium sulfate at 2% W/W.

[c]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[d]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[e]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[f]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Study II.

Environmental conditions (data not presented). Soybean growth was similar from emergence to the V2 growth stage in 1997 and 1998 despite no POST herbicide applications and an approximate 2 week difference in late planting dates. The growth period from emergence to the V2 stage was approximately 3.5 weeks in 1997 and 4 weeks in 1998. Local field conditions on the day of POST herbicide application at the V2 and V5 soybean growth stages were different both years. In 1997, soil moisture in all plots was at approximately field capacity at the V2 application timing and at slightly below field capacity at the V5 application timing. In 1998, soil moisture in all plots was greater than field capacity at both application timings. Monthly rainfall in 1997 and 1998

was the same as in study I. In 1997, the relative humidity was 42 and 60% at the V2 and V5 application timings, respectively. The average air temperatures in 1997 at the V2 and V5 application timings were 26 and 28 C, respectively. In 1998, the relative humidity was 69 and 34% at the V2 and V5 application timings, respectively. The average air temperatures in 1998 at the V2 and V5 application timings were 24 and 33 C, respectively.

Soybean injury. Similar to study I and regardless of application timing, soybean chlorosis, necrosis, and puckering was most pronounced with acifluorfen 5 to 7 DAT compared to glyphosate or imazethapyr (Table 10). Acifluorfen caused 20, 20, and 10% chlorosis, necrosis, and puckering, respectively, when applied at the V2 stage but resulted in less soybean injury when applied at the V5 stage. Imazethapyr applied at the V2 stage resulted in 3% chlorosis and 1% necrosis compared to no injury when applied at the V5 stage. Glyphosate applied at the V2 or V5 stages in 1997 resulted in no injury. Complete soybean recovery of chlorosis, necrosis, and puckering from imazethapyr and acifluorfen at both application timings occurred by 21 to 24 DAT in 1997 (data not presented).

Soybean stunting one week after application in 1997 was stage and herbicide dependent (Table 10). Imazethapyr and acifluorfen applied at the V2 stage both caused 5% stunting, respectively, compared to no injury with glyphosate or the nontreated control. Soybean stunting was less when imazethapyr and acifluorfen were applied at the V5 stage compared to the V2 stage. Imazethapyr (3%) or acifluorfen (3%) reduced soybean height compared to the nontreated (0%) or glyphosate (0%) at 5 to 7 DAT. At 21 to 24 DAT, minimal to no soybean stunting was observed among the herbicides

regardless of application timing.

Table.10. Influence of postemergence herbicides on glyphosate-resistant soybean tolerance under weed-free conditions, 1997 (Study II).

			Soybean, days after postemergence application				
		Appli-	Chlorosis	Stunting		Necrosis	Puckering
Treatment	Rate	cation timing	5 -7	5 -7	21-24	5 -7	5 - 7
	kg/ha				%		
PLANTING DATE 2							
Nontreated			0	0	0	0	0
Glyphosate + AMS[a]	1.12	V2	0	0	0	0	0
Imazethapyr + MSO[b] + 28%N[c]	0.07	V2	3	5	1	1	0
Acifluorfen + NIS[d]	0.42	V2	20	5	2	20	10
Glyphosate + AMS	1.12	V5	0	0	0	0	0
Imazethapyr + MSO + 28%N	0.07	V5	0	3	0	0	0
Acifluorfen + NIS	0.42	V5	10	3	0	10	5
LSD[e]			2	2	2	1	1
P			0.05	0.05	0.05	0.05	0.05

[a]AMS = Ammonium sulfate at 2% W/W.
[b]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.
[c]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.
[d]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.
[e]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at P≤ 0.05.

Soybean chlorosis, necrosis, and puckering in 1998 apparently were less than in 1997 in study II. Acifluorfen caused the greatest injury at the V2 and V5 stages compared to glyphosate or imazethapyr at 5 to 7 DAT (Table 11). Soybean exhibited 10% chlorosis, 10% necrosis and 10% puckering, respectively, when acifluorfen was applied at the V2 stage compared to 10% chlorosis, 20% necrosis, and 4% puckering at the V5 stage. Imazethapyr applied at the V2 stage and V5 stage caused no injury 5 to 7 DAT in 1998. Soybean chlorosis, necrosis, and puckering from all herbicides at both application timings disappeared by 21 to 24 DAT in 1997 (data not presented).

Soybean stunting apparently was less in 1998 than in 1997. Imazethapyr applied at

the V5 stage caused 10% stunting 5 to 7 DAT, but by 21 to 24 DAT almost complete recovery had occurred (Table 11). Glyphosate and acifluorfen caused minimal to no stunting at either application timing in 1998.

Table 11. Influence of postemergence herbicides on glyphosate-resistant soybean tolerance under weed-free conditions, 1998 (Study II).

			Soybean, days after postemergence application				
		Appli-	Chlorosis	Stunting		Necrosis	Puckering
Treatment	Rate	cation timing	5 -7	5 -7	21-24	5 -7	5 - 7
	kg/ha				%		
PLANTING DATE 2							
Nontreated			0	0	0	0	0
Glyphosate + AMS[a]	1.12	V2	0	1	3	0	0
Imazethapyr + MSO[b] + 28%N[c]	0.07	V2	0	3	2	0	0
Acifluorfen + NIS[d]	0.42	V2	10	3	2	10	10
Glyphosate + AMS	1.12	V5	0	0	0	0	0
Imazethapyr + MSO + 28%N	0.07	V5	0	10	3	0	0
Acifluorfen + NIS	0.42	V5	10	0	2	20	4
LSD[e]			1	2	3	1	1
P			0.05	0.05	0.05	0.05	0.05

[a]AMS = Ammonium sulfate at 2% W/W.
[b]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.
[c]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.
[d]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.
[e]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at P≤ 0.05.

Overall, soybean injury was greater when herbicides were applied at the V2 stage than at the V5 stage in Study II. Also, chlorosis, necrosis, puckering, and stunting were slightly less severe in 1998 compared to 1997 irrespective of the herbicide. There was more rainfall during the 1998 growing season compared to 1997 in study II. The soybean plots received approximately 7.49 and 2.85 cm of rain after the V2 and V5 application timings, respectively, in 1997, and 5.33 and 4.72 cm after the V2 and V5 application timings, respectively, in 1998. However, relatively similar average air temperatures

occurred in study II both years during a 3 week soybean recovery period as they did in study I. For instance, the average air temperatures 3 weeks after the V2 and V5 application timings ranged from 26 to 28 C both years.

Soybean population. At 14 DAE and at the EOS, there were no soybean population differences among the plots (Table 12).

Table 12. Influence of postemergence herbicides on glyphosate-resistant soybean population under weed-free conditions (Study II).

			Soybean population		Soybean subplot population			
Treatment	Rate	Application timing	14 DAE[a]	EOS[a]	21 DA-V2[b] 1997	21 DA-V2[b] 1998	21 DA-V5[b]	EOS[a]
			Pooled, 1997-1998				Pooled, 1997-1998	
	kg/ha		000/ha		No. of plants/1 m row			
PLANTING DATE 2								
Nontreated			395	363	28	35	30	28
Glyphosate + AMS[c]	1.12	V2	396	363	28	34		29
Imazethapyr + MSO[d] + 28%N[e]	0.07	V2	395	366	29	32		29
Acifluorfen + NIS[f]	0.42	V2	401	370	28	33		29
Glyphosate + AMS	1.12	V5	395	364			30	28
Imazethapyr + MSO + 28%N	0.07	V5	379	356			30	28
Acifluorfen + NIS	0.42	V5	394	366			31	28
LSD[g]								
P			NS	NS	NS	NS	NS	NS

[a]DAE= days after emergence; EOS = end of season.
[b]DA-V2 = days after V2 post application; DA-V5 = days after V5 post application.
[c]AMS = Ammonium sulfate at 2% W/W.
[d]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.
[e]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.
[f]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.
[g]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at P≤ 0.05.

Also, there were no plant count differences obtained in each subplot following the V2 and V5 application timings or at the EOS among herbicides.

Developmental stages. Pooled across years, there were no differences in soybean vegetative growth among herbicides applied at the V2 growth stage (Table 13).

Table 13. Influence of postemergence herbicides on glyphosate-resistant soybean vegetative and reproductive stages under weed-free conditions (Study II).

Treatment	Rate	Application timing	Soybean growth stages: 21 DA-V2[a] V-stage[b]	21 DA-V2[a] R-stage[b]	21 DA-V2[a] R-stage[b]	21 DA-V5[a] V-stage[b]	21 DA-V5[a] R-stage[b]
	kg/ha		Pooled, 1997-1998	1997	1998	Pooled, 1997-1998	
PLANTING DATE 2							
Nontreated			10	1	3	12	3
Glyphosate + AMS[c]	1.12	V2	10	1	3		
Imazethapyr + MSO[d] + 28%N[e]	0.1	V2	10	1	3		
Acifluorfen + NIS[f]	0.42	V2	10	1	3		
Glyphosate + AMS	1.12	V5				12	3
Imazethapyr + MSO + 28%N	0.1	V5				12	3
Acifluorfen + NIS	0.42	V5				12	3
LSD[g]							
P			NS	NS	NS	NS	NS

[a]DA-V2 = days after V2 post application; DA-V5 = days after V5 post application.
[b] V-stage = vegetative stage; R-stage = reproductive stage.
[c]AMS = Ammonium sulfate at 2% W/W.
[d]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.
[e]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.
[f]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.
[g]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Reproductive stage was analyzed by individual year and there were no differences among herbicides applied at the V2 growth stage. There were no differences in soybean vegetative or reproductive growth among herbicides applied at the V5 growth stage when pooled across years.

Soybean height. Regardless of year, there were no differences in height following the V2 application timing (Table 14). However, the soybean was more sensitive to imazethapyr (75 cm) or acifluorfen (78 cm) than to glyphosate (80 cm) 21 days after the V5 application timing. Regardless of herbicide, application timing, or year, there were no differences in soybean height at the EOS, ranging from 99 to 103 cm.

Table 14. Influence of postemergence herbicides on glyphosate-resistant soybean height under weed-free conditions, pooled 1997 and 1998 (Study II).

Treatment	Rate	Application timing	Soybean subplot height[a]		Soybean height
			21 DA-V2[b]	21 DA-V5[b]	EOS[b]
	kg/ha		cm		cm
PLANTING DATE 2					
Nontreated			71	80	102
Glyphosate + AMS[c]	1.12	V2	69		103
Imazethapyr + MSO[d] + 28%N[e]	0.07	V2	68		101
Acifluorfen + NIS[f]	0.42	V2	69		100
Glyphosate + AMS	1.12	V5		80	102
Imazethapyr + MSO + 28%N	0.07	V5		75	99
Acifluorfen + NIS	0.42	V5		78	100
LSD[g]				2	
P			NS	0.05	NS

[a]Soybean subplot height = height of plants per 1 m of one row per plot.
[b]DA-V2 = days after V2 post application; DA-V5 = days after V5 post application; EOS = end of season.
[c]AMS = Ammonium sulfate at 2% W/W.
[d]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.
[e]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.
[f]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.
[g]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Soybean biomass. Regardless of the year in study II, soybean leaf dry weight was not different among the herbicides when applied at the V2 or V5 stages (Table 15). There were no differences in stem dry weight among the treatments after the V2 application timing pooled across years and after the V5 application timing in 1997. In contrast, acifluorfen and imazethapyr applied at the V5 stage in 1998 caused a reduction in stem dry weight compared to the nontreated or glyphosate.

Table 15. Influence of postemergence herbicides on glyphosate-resistant soybean biomass components under weed-free conditions (Study II).

Treatment	Rate	Application timing	Leaf dry weight[a] 21 DA-V2[b]	Leaf dry weight[a] 21 DA-V5[b]	Leaf dry weight[a] 21 DA-V5[b]	Stem dry weight[a] 21 DA-V2[b]	Stem dry weight[a] 21 DA-V5[b]	Stem dry weight[a] 21 DA-V5[b]
	kg/ha		gram			gram		
PLANTING DATE 2			Pooled, 1997-1998	1997	1998	Pooled, 1997-1998	1997	1998
Nontreated			10.4	12.8	13.2	12.3	15.7	18.4
Glyphosate + AMS[c]	1.12	V2	10.8			12.4		
Imazethapyr + MSO[d] + 28%N[e]	0.07	V2	10.5			11.8		
Acifluorfen + NIS[f]	0.42	V2	9.8			11.0		
Glyphosate + AMS	1.12	V5		16.5	12.3		20.1	17.4
Imazethapyr + MSO + 28%N	0.07	V5		14.5	12.9		15.9	16.3
Acifluorfen + NIS	0.42	V5		15.1	11.2		17.5	14.8
LSD[g]								2.0
P			NS	NS	NS	NS	NS	0.05

[a]Leaf dry weight = oven-dry weight of leaves from three uniform plants in one meter row per plot; stem dry weight = oven-dry weight of stems and petioles from three uniform plants in one meter row per plot.

[b] DA-V2 = days after V2 post application; DA-V5 = days after V5 post application.

[c]AMS = Ammonium sulfate at 2% W/W.

[d]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[e]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[f]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[g]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Whole plant dry weight was not different across years, herbicides, or application timings (Table 16). The whole plant dry weight ranged from 141.9 to 172.3 g following the V2 application timing and 186.5 to 215.7 g following the V5 application timing. Pooled across years and irrespective of herbicides, soybean pods ≥ 5 mm long were present on soybean treated at the V2 stage and V5 stage in study II. However, the pod dry weight after the V5 application timing was higher in the nontreated soybean subplots (0.7 g) compared to the glyphosate (0.5 g), acifluorfen (0.4 g), or imazethapyr (0.2 g) soybean subplots.

Soybean leaf area index (LAI). Pooled across years, there were no differences in LAI

values among the herbicides applied at the V2 stage. However, LAI value was lower in plots treated with imazethapyr (3.0) and acifluorfen (3.2) at the V5 stage compared to the nontreated plots (3.6) (Table 16). The lower LAI values following the V5 application timing may be a reflection of the early season soybean injury induced by imazethapyr and acifluorfen in study II.

Table 16. Influence of postemergence herbicides on glyphosate-resistant soybean biomass components under weed-free conditions, pooled 1997 and 1998 (Study II).

			Pod dry weight[a]		Whole plant dry weight[a]		LAI[a]	
Treatment	Rate	Application timing	21 DA-V2[a]	21 DA-V5[a]	21 DA-V2[a]	21 DA-V5[a]	21 DA-V2[a]	21 DA-V5[a]
	kg/ha		gram		gram			
PLANTING DATE 2								
Nontreated			0.2	0.7	170.2	215.7	3.2	3.6
Glyphosate + AMS[b]	1.12	V2	0.1		152.7		3.3	
Imazethapyr + MSO[c] + 28%N[d]	0.07	V2	0.1		172.3		2.9	
Acifluorfen + NIS[e]	0.42	V2	0.1		141.9		3.1	
Glyphosate + AMS	1.12	V5		0.5		202.2		3.4
Imazethapyr + MSO + 28%N	0.07	V5		0.2		186.5		3.0
Acifluorfen + NIS	0.42	V5		0.4		196.7		3.2
LSD[f]				0.1				0.3
P			NS	0.05	NS	NS	NS	0.05

[a]Pod dry weight = oven-dry weight of pods (≥5 mm) from three uniform plants in one meter row per plot; whole plant dry weight = total dry matter weight minus the three uniform soybean plants in one meter row per plot; LAI = leaf area index or leaf area per unit ground area (Welles and Norman, 1991); DA-V2 = days after V2 post application; DA-V5 = days after V5 post application.

[b]AMS = Ammonium sulfate at 2% W/W.

[c]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[d]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[e]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[f]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at P≤ 0.05.

Harvest index (HI). Despite some early season soybean injury induced by all herbicides both years, there were no differences in shell dry weight, seed dry weight, whole plant dry weight, or harvest index among the treatments regardless of application timing (Table

17). However, soybean treated with acifluorfen at the V2 stage and glyphosate at the V5 stage had lower stem dry weight (13.2 and 14.2 g, respectively) compared to the other treatments at 21 DAT.

Table 17. Influence of postemergence herbicides on glyphosate-resistant soybean components of harvest index and harvest index[a] under weed-free conditions, pooled 1997 and 1998 (Study II).

Treatment	Rate	Application timing	Stem dry weight[a]	Shell dry weight[a]	Seed dry weight[a]	Whole plant dry weight[a]	Harvest index[a]
	kg/ha		gram				
PLANTING DATE 2							
Nontreated			15.2	10.3	37.2	453.5	60
Glyphosate + AMS[b]	1.12	V2	16.0	10.8	39.4	469.7	60
Imazethapyr + MSO[c] + 28%N[d]	0.07	V2	16.1	11.0	38.8	439.8	60
Acifluorfen + NIS[e]	0.42	V2	13.2	9.5	34.3	425.0	60
Glyphosate + AMS	1.12	V5	14.2	10.3	37.9	454.2	61
Imazethapyr + MSO + 28%N	0.07	V5	16.9	11.4	41.1	445.7	60
Acifluorfen + NIS	0.42	V5	15.2	10.8	37.9	427.5	60
LSD[f]			2.0				
P			0.05	NS	NS	NS	NS

[a] Stem dry weight = oven-dry weight of stems and petioles from three uniform plants in one meter row per plot; shell dry weight = oven-dry weight of pods minus seeds from three uniform plants in one meter row per plot; seed dry weight = oven-dry weight of seed from three uniform plants in one meter row per plot; whole plant dry weight = total dry matter weight minus the three uniform soybean plants in one meter row per plot; harvest index represents the dry weight of seed per total above ground plant dry matter within a one meter row length at the end of the growing season for each plot.

[b]AMS = Ammonium sulfate at 2% W/W.

[c]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[d]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[e]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/A.

[f]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at P≤ 0.05.

Soybean maturity. In 1997 and 1998, there were no maturity differences among the treatments in study II (Table 18).

Soybean yield. Soybean yield was pooled across years and ranged from 3817 to 4067 kg/ha (Table 18). Regardless of application timing or herbicide, there were no yield differences among the treatments despite early season soybean injury both years.

Table 18. Influence of postemergence herbicides on glyphosate-resistant soybean maturity and yield under weed-free conditions (Study II).

Treatment	Rate	Application timing	Days from planting to R8 stage[a] 1997	1998	Soybean yield Pooled, 1997-1998
	kg/ha		——days after planting——		——kg/ha——
PLANTING DATE 2					
Nontreated			116	112	3922
Glyphosate + AMS[b]	1.12	V2	116	112	3970
Imazethapyr + MSO[c] + 28%N[d]	0.07	V2	116	112	3985
Acifluorfen + NIS[e]	0.42	V2	116	112	4067
Glyphosate + AMS	1.12	V5	116	112	4005
Imazethapyr + MSO + 28%N	0.07	V5	116	112	3817
Acifluorfen + NIS	0.42	V5			3987
LSD[f]					
P			NS	NS	NS

[a]R8 stage = 95% of the pods have reached their mature pod color; data represent split years when year interactions with the main effects and their interaction were significant at $P \leq 0.05$.

[b]AMS = Ammonium sulfate at 2% W/W.

[c]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[d]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[e]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[f]All data were subjected to a one-way analysis of variance after year interactions were checked. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Study III.

Environmental conditions. The POST herbicides were applied at soil moisture conditions greater than field capacity, 32 to 50% relative humidity, and an air temperature range of 26 to 29 C regardless of application timing in 1997. In 1998, the same POST herbicides were applied at soil moisture conditions greater than field capacity, 50 to 62% relative humidity, and an air temperature range of 23 to 26 C. Monthly rainfall in 1997 and 1998

was the same as in studies I and II.

Soybean injury. In study III in 1997, soybean chlorosis, stunting, necrosis, and puckering at 7 DAT among all POST treatments applied at the V2 and V4 growth stages ranged from 0 to 40% and 0 to 20%, respectively (Table 19). Glyphosate caused minimal to no soybean injury when applied at the V2 or V4 growth stage.

Crop injury from POST applications of glyphosate likely is not a concern because transgenic soybean seem to be very tolerant to rates at least twice as high as needed to control most weeds (Delannay et al. 1995). However, conventional POST and soil-applied herbicides sometimes cause substantial soybean injury. Harvey et al. (1996) reported reduced soybean yield when injury exceeded 10% from thifensulfuron , acifluorfen, and imazethapyr plus chloransulam-methyl (2-[[(5-ethoxy-7-fluoro[1,2,4]-triazolo[1,5-c]pyrimidin-2-yl)sulfonyl]amino]-3-cloro-enzoic acid). In a separate study, Owen et al. (1996) reported significant injury with POST applications of SAN-582 (2-chloro-N-[1-methyl-2-methoxy)ethyl]-N-(2,4-dimethyl-thien-3-yl)-acetamide) plus bentazon plus acifluorfen. Hart and Maxwell (1996) reported as much as 28% injury from POST applications of thifensulfuron plus sethoxidim (2-[1-(ethoxyimino)butyl-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one).

Bentazon is a herbicide considered to be a photosystem II inhibitor in photosynthesis through contact action that generally produces some pattern of chlorosis followed by necrosis in older and mature leaves of plants, and in severe cases, plant death. Chlorimuron and thifensulfuron are two sulfonylurea herbicides that frequently are marketed together as a premix. Both herbicides are systemic in plants and translocate to

meristematic regions and inhibit the acetolactate enzyme, thus blocking the production of branch-chain amino acids. Chlorimuron and thifensulfuron cause rapid inhibition of root and shoot growth, stunting, and in some instances, epinasty. Later symptoms can include mild chlorosis, purpling or anthocyanin expression, and necrosis. At this location in 1997 at the V2 stage, bentazon plus acifluorfen, chlorimuron plus thifensulfuron, acifluorfen, bentazon, and imazethapyr caused the greatest chlorosis at 40, 20, 20, 10, and 10%, respectively, 7 DAT compared to the other herbicides when applied at the V2 stage (Table 19). At the V4 stage, acifluorfen, bentazon plus acifluorfen, and bentazon were different from the other herbicides and caused 20, 18, and 9% chlorosis, respectively, 7 DAT. Injured soybean recovered from chlorosis within three weeks after treatment.

Initial stunting ranged from 0 to 19% and 0 to 9% after the V2 and V4 application timings, respectively, 7 DAT (Table 19). Visual height differences were greater and more persistent with imazethapyr or bentazon plus acifluorfen, but the final recovery among all POST treatments regardless of herbicide or stage occurred by 28 DAT.

Necrosis at 7 DAT was more severe when acifluorfen (40%), bentazon and acifluorfen (40%), imazethapyr (15%), and chlorimuron plus thifensulfuron (8%) were applied at the V2 stage compared to the V4 stage (Table 19). However, puckering prompted by acifluorfen or bentazon plus acifluorfen was different compared to the nontreated and other herbicides 7 DAT regardless of application timing in 1997. Acifluorfen applied at the V2 and V4 stage caused 20% puckering, and bentazon plus acifluorfen applied at the V2 and V4 stages caused 25 and 15% puckering, respectively, 7 DAT. Injured soybean recovered from necrosis and puckering within 3 weeks after

treatment.

Table 19. Effect of selected postemergence herbicides on glyphosate-resistant soybean tolerance under weed-free conditions, 1997 (Study III).

Treatment	Rate	Application timing	Soybean, days after postemergence application													
			Chlorosis			Stunting				Necrosis			Puckering			
			7	14	21	7	14	21	28	7	14	21	7	14	21	
	kg/ha		%													
PLANTING DATE 1																
Nontreated			0	0	0	0	1	0	0	0	0	0	0	0	0	
Pendimethalin & imazaquin	0.84 & 0.14	PPI	0	0	0	0	1	0	0	0	0	0	0	0	0	
Metribuzin & chlorimuron	0.27 & 0.04	PPI	0	1	0	0	0	0	0	0	0	0	0	0	0	
Glyphosate + AMS[a]	1.12	V2	0	0	0	0	1	0	0	0	0	0	0	0	0	
Imazethapyr + MSO[b] + 28%N[c]	0.07	V2	10	5	0	19	14	6	3	15	0	0	0	0	0	
Bentazon + COC[d]	1.12	V2	10	6	0	0	0	0	0	0	0	0	5	0	0	
Acifluorfen + NIS[e]	0.42	V2	20	11	0	0	1	0	0	40	0	0	20	8	0	
Bentazon & acifluorfen + COC[d]	0.56 & 0.28	V2	40	14	0	6	9	5	3	40	0	0	25	8	0	
Chlorimuron & thifensulfuron + COC[d]	0.02 & 0.006	V2	20	6	0	0	1	0	0	8	0	0	0	0	0	
Glyphosate + AMS	1.12	V4	0	0	0	0	1	0	0	0	0	0	0	0	0	
Imazethapyr + MSO + 28%N	0.07	V4	4	0	0	9	4	4	1	0	0	0	1	0	0	
Bentazon + COC	1.12	V4	9	0	0	1	1	0	0	9	0	0	1	0	0	
Acifluorfen + NIS	0.42	V4	20	10	0	6	1	4	1	20	10	0	20	5	0	
Bentazon & acifluorfen + COC	0.56 & 0.28	V4	18	10	0	4	3	3	1	18	10	0	15	5	0	
Chlorimuron & thifensulfuron + COC	0.02 & 0.006	V4	1	0	0	1	0	0	0	0	0	0	0	0	0	
LSD[f]			8	4		7	5	3		5	1		6	1		
P			0.05	0.05	NS	0.05	0.05	0.05	NS	0.05	0.05	NS	0.05	0.05	NS	

[a]AMS = Ammonium sulfate at 2% W/W.

[b]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[c]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[d]COC = Prime Oil crop oil concentrate, a petroleum based additive with 17% emulsifier from Riverside/Terra, Sioux City, IA. COC with bentazon and bentazon plus acifluorfen at 2240 ml/ha and COC with chlorimuron plus thifensulfuron at 1680 ml/ha.

[e]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[f]The variance and degrees of freedom associated with the differences between the check treatments and the crossed main effects were included in the calculation of the probability of F for either the HERB or HERB by STAGE effects. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

In a similar study pertaining to weed-free soybean responses to POST herbicides from 1979 to 1982, Kapusta et al. (1986) found that bentazon, acifluorfen, naptalam/dinoseb {2-[(1-naphthalenylamino)carbonyl]benzoic acid}/ [2-(1-methylpropyl)-4,6-dinitrophenol] alone or in combination with 2,4-DB [4-(2,4-dichlorophenoxy) butyric acid] applied to soybean at the V3 (two trifoliolate) and V5 (four trifoliolate) growth stages caused early crop injury, but the plants outgrew most of the injury by 21 days and there was no effect on yield. Further, bentazon plus 2,4-DB, with or without adjuvant, did not affect the yield of five soybean cultivars (Kapusta et al. 1986).

In 1998, initial soybean injury among all POST treatments applied at the V2 and V4 growth stages ranged from 0 to 20% for both application timings (Table 20). Glyphosate caused minimal to no soybean injury when applied at the V2 or V4 growth stage. Acifluorfen or bentazon plus acifluorfen caused the greatest chlorosis and puckering at 10% 7 DAT compared to the other herbicides when applied at the V2 and V4 stages.

Necrosis was 20% with both acifluorfen or bentazon plus acifluorfen when applied at the V2 stage, and 20 and 10%, respectively, when applied at the V4 stage at 7 DAT (Table 20). In 1998, initial stunting ranged from 0 to 10% and 0 to 3% after the V2 and V4 application timings, respectively, 7 DAT. Soybean stunting was most severe with imazethapyr (10%), acifluorfen (10%), bentazon plus acifluorfen (10%), and bentazon (5%) applied at the V2 stage compared to glyphosate (3%) or imazethapyr (3%) applied at the V4 stage 7 DAT. Complete to almost complete soybean recovery from all herbicides occurred approximately 14 DAT in 1998.

Table 20. Effect of selected postemergence herbicides on glyphosate-resistant soybean tolerance under weed-free conditions, 1998 (Study III).

Treatment	Rate	Application timing	Soybean, days after postemergence application							
			Chlorosis		Stunting		Necrosis		Puckering	
			7	14	7	14	7	14	7	14
	kg/ha		%							
PLANTING DATE 1										
Nontreated			0	0	0	0	0	0	0	0
Pendimethalin & imazaquin	0.84 & 0.14	PPI	0	0	0	0	0	0	0	0
Metribuzin & chlorimuron	0.27 & 0.04	PPI	0	0	0	0	0	0	0	0
Glyphosate + AMS[a]	1.12	V2	0	0	0	0	0	0	0	0
Imazethapyr + MSO[b] + 28%N[c]	0.07	V2	0	0	10	5	0	0	0	0
Bentazon + COC[d]	1.12	V2	0	0	5	3	0	0	0	0
Acifluorfen + NIS[e]	0.42	V2	10	0	10	5	20	0	10	0
Bentazon & acifluorfen + COC[d]	0.56 & 0.28	V2	10	0	10	4	20	0	10	0
Chlorimuron & thifensulfuron + COC[d]	0.02 & 0.006	V2	0	0	0	0	0	0	0	0
Glyphosate + AMS	1.12	V4	0	0	3	1	0	0	0	0
Imazethapyr + MSO + 28%N	0.07	V4	0	0	3	1	0	0	0	0
Bentazon + COC	1.12	V4	0	0	1	1	0	0	0	0
Acifluorfen + NIS	0.42	V4	10	0	1	1	20	0	10	0
Bentazon & acifluorfen + COC	0.56 & 0.28	V4	10	0	0	0	10	0	10	0
Chlorimuron & thifensulfuron + COC	0.02 & 0.006	V4	0	0	1	0	0	0	0	0
LSD[f]			1		3	2	1		1	
P			0.05	NS	0.05	0.05	0.05	NS	0.05	NS

[a]AMS = Ammonium sulfate at 2% W/W.

[b]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[c]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[d]COC = Prime Oil crop oil concentrate, a petroleum based additive with 17% emulsifier from Riverside/Terra, Sioux City, IA. COC with bentazon and bentazon plus acifluorfen at 2240 ml/ha and COC with chlorimuron plus thifensulfuron at 1680 ml/ha.

[e]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[f]The variance and degrees of freedom associated with the differences between the check treatments and the crossed main effects were included in the calculation of the probability of F for either the HERB or HERB by STAGE effects. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Soybean population. At 14 DAE and EOS, there were no differences in soybean population per 6 m of row pooled across years (Table 21).

Soybean height. At 14 days after V2 application (DA-V2), soybean height in plots treated with metribuzin plus chlorimuron and bentazon was higher compared to the nontreated and other POST treatments (Table 21). Soybean treated with imazethapyr at the V2 stage was shorter than soybean treated with most other herbicides and the nontreated. At 14 days after the V4 application (DA-V4), there were no differences in soybean height regardless of herbicides. However, at the EOS, soybean in the plots treated with pendimethalin plus imazaquin (PPI), metribuzin plus chlorimuron (PPI), glyphosate (V2), and bentazon (V2) were taller compared to soybean in the nontreated control and other treated plots despite some early season soybean injury with the POST herbicides applied at the V2 and V5 stages.

Soybean maturity. There was no difference in soybean maturity regardless of herbicide or application timing in either 1997 or 1998 (Table 22).

Soybean yield. There was no difference in yield regardless of herbicide or application timing in either 1997 or 1998 (Table 22). Yield in 1997 ranged from 2688 to 3226 kg/ha. In 1998, yield ranged from 1949 to 2957. Sudden death syndrome was most pronounced in study I in 1998 compared to 1997 (Table 23). The disease index in each plot ranged from 35 to 61% in 1998 compared to 7 to 13% in 1997. The higher disease index in 1998 suggests why yield in 1998 was slightly lower than in 1997 despite less herbicide injury.

Table 21. Effect of selected postemergence herbicides on glyphosate-resistant soybean population and height under weed-free conditions, pooled 1997-1998 (Study III).

Treatment	Rate	Application timing	Soybean population		Soybean height		
			14 DAE[a]	EOS[a]	14 DA-V2[a]	14 DA-V4[a]	EOS[a]
	kg/ha		000/ha		cm		
PLANTING DATE 1							
Nontreated			299	244	37	58	101
Pendimethalin & imazaquin	0.84 & 0.14	PPI	306	262	39	59	106
Metribuzin & chlorimuron	0.27 & 0.04	PPI	306	261	41	61	107
Glyphosate + AMS[b]	1.12	V2	299	263	38		105
Imazethapyr + MSO[c] + 28%N[d]	0.07	V2	290	251	34		102
Bentazon + COC[e]	1.12	V2	310	261	40		105
Acifluorfen + NIS[f]	0.42	V2	297	248	37		102
Bentazon & acifluorfen + COC[e]	0.56 & 0.28	V2	296	261	35		103
Chlorimuron & thifensulfuron + COC[e]	0.02 & 0.006	V2	289	251	37		101
Glyphosate + AMS	1.12	V4	288	251		59	100
Imazethapyr + MSO + 28%N	0.07	V4	301	262		55	102
Bentazon + COC	1.12	V4	297	254		58	103
Acifluorfen + NIS	0.42	V4	282	236		56	101
Bentazon & acifluorfen + COC	0.56 & 0.28	V4	309	255		59	103
Chlorimuron & thifensulfuron + COC	0.02 & 0.006	V4	294	250		61	104
LSD[g]					3		4
P			NS	NS	0.05	NS	0.05

[a]DAE = days after emergence; EOS = end of season; DA-V2 = days after V2 post application; DA-V4 = days after V4 post application.

[b]AMS = Ammonium sulfate at 2% W/W.

[c]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[d]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[e]COC = Prime Oil crop oil concentrate, a petroleum based additive with 17% emulsifier from Riverside/Terra, Sioux City, IA. COC with bentazon and bentazon plus acifluorfen at 2240 ml/ha and COC with chlorimuron plus thifensulfuron at 1680 ml/ha.

[f]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[g]The variance and degrees of freedom associated with the differences between the check treatments and the crossed main effects were included in the calculation of the probability of F for either the HERB or HERB by STAGE effects. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Table 22. Effect of selected postemergence herbicides on glyphosate-resistant soybean maturity and yield under weed-free conditions, 1997 and 1998 (Study III).

Treatment	Rate	Application timing	Days from planting to R8 stage[a]		Soybean yield	
			1997	1998	1997	1998
	kg/ha				kg/ha	
PLANTING DATE 1						
Nontreated			135	127	3226	2554
Pendimethalin & imazaquin	0.84 & 0.14	PPI	135	127	2890	2957
Metribuzin & chlorimuron	0.27 & 0.04	PPI	134	127	2822	2822
Glyphosate + AMS[b]	1.12	V2	135	127	2890	2621
Imazethapyr + MSO[c] + 28%N[d]	0.07	V2	136	127	2822	2957
Bentazon + COC[e]	1.12	V2	135	127	2755	2688
Acifluorfen + NIS[f]	0.42	V2	136	127	2688	2352
Bentazon & acifluorfen + COC[e]	0.56 & 0.28	V2	136	127	2822	2352
Chlorimuron & thifensulfuron + COC[e]	0.02 & 0.006	V2	136	127	2957	2285
Glyphosate + AMS	1.12	V4	136	127	3091	1949
Imazethapyr + MSO + 28%N	0.07	V4	137	127	3024	2419
Bentazon + COC	1.12	V4	136	127	3091	2688
Acifluorfen + NIS	0.42	V4	136	127	2822	2285
Bentazon & acifluorfen + COC	0.56 & 0.28	V4	136	127	3158	2285
Chlorimuron & thifensulfuron + COC	0.02 & 0.006	V4	136	127	3024	2419
LSD[g]						
P			NS	NS	NS	NS

[a]R8 stage = 95% of the pods have reached their mature pod color.

[b]AMS = Ammonium sulfate at 2% W/W.

[c]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[d]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[e]COC = Prime Oil crop oil concentrate, a petroleum based additive with 17% emulsifier from Riverside/Terra, Sioux City, IA. COC with bentazon and bentazon plus acifluorfen at 2240 ml/ha and COC with chlorimuron plus thifensulfuron at 1680 ml/ha.

[f]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[g]The variance and degrees of freedom associated with the differences between the check treatments and the crossed main effects were included in the calculation of the probability of F for either the HERB or HERB by STAGE effects. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Table 23. Sudden death syndrome (*Fusarium solani*, Type A) index on glyphosate-resistant soybean tolerance under weed-free conditions, 1997 and 1998 (Study III).

Treatment	Rate	Application timing	Disease index[a] 1997	1998
	kg/ha			
PLANTING DATE 1				
Nontreated			11	49
Pendimethalin & imazaquin	0.84 & 0.14	PPI	11	39
Metribuzin & chlorimuron	0.27 & 0.04	PPI	12	49
Glyphosate + AMS[b]	1.12	V2	13	45
Imazethapyr + MSO[c] + 28%N[d]	0.07	V2	10	35
Bentazon + COC[e]	1.12	V2	13	43
Acifluorfen + NIS[f]	0.42	V2	13	50
Bentazon & acifluorfen + COC[e]	0.56 & 0.28	V2	12	52
Chlorimuron & thifensulfuron + COC[e]	0.02 & 0.006	V2	11	45
Glyphosate + AMS	1.12	V4	8	61
Imazethapyr + MSO + 28%N	0.07	V4	8	49
Bentazon + COC	1.12	V4	8	40
Acifluorfen + NIS	0.42	V4	9	53
Bentazon & acifluorfen + COC	0.56 & 0.28	V4	7	60
Chlorimuron & thifensulfuron + COC	0.02 & 0.006	V4	9	61
LSD[g]				
P			NS	NS

[a]Disease index = disease incidence (percent of plot showing leaf symptoms) * disease severity (severity of leaf symptoms) ÷ 9 (total number of score values used to rate disease severity) when soybean were at the 6.0 to 6.2 R-stage (pod containing a green seed that fills the pod cavity at one of the four uppermost nodes on the main stem with a fully developed leaf).

[b]AMS = Ammonium sulfate at 2% W/W.

[c]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[d]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[e]COC = Prime Oil crop oil concentrate, a petroleum based additive with 17% emulsifier from Riverside/Terra, Sioux City, IA. COC with bentazon and bentazon plus acifluorfen at 2240 ml/ha and COC with chlorimuron plus thifensulfuron at 1680 ml/ha.

[f]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[g]The variance and degrees of freedom associated with the differences between the check treatments and the crossed main effects were included in the calculation of the probability of F for either the HERB or HERB by STAGE effects. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Study IV.

Environmental conditions. In study IV, the POST herbicides were applied at soil moisture conditions greater than or at field capacity, 32% relative humidity, and an air temperature range of 29 to 30 C regardless of application timing in 1997. In 1998, the same POST herbicides were applied at soil moisture conditions greater than field capacity, 62 to 98% relative humidity, and an air temperature range of 21 to 29 C. Monthly rainfall in 1997 and 1998 was the same as aforementioned in studies I, II, and III.

Soybean injury. In study IV in 1997, soybean chlorosis, stunting, necrosis, and puckering at 7 DAT among all POST treatments applied at the V2 and V4 growth stages ranged from 0 to 18% and 0 to 20%, respectively, (Table 24). Glyphosate caused no soybean injury when applied at the V2 or V4 growth stage. Acifluorfen, bentazon plus acifluorfen, chlorimuron plus thifensulfuron, bentazon, and imazethapyr caused the greatest chlorosis at 18, 18, 9, 8, and 6%, respectively, 7 DAT compared to the other herbicides when applied at the V2 stage. Acifluorfen, bentazon plus acifluorfen, and bentazon applied at the V4 stage caused more chlorosis at 7 DAT than the other herbicides.

Stunting ranged from 0 to 6% and 0 to 5% 1 week after the V2 and V4 application timings, respectively (Table 24). Complete to almost complete soybean recovery from all POST treatments occurred by 14 DAT.

Necrosis at 7 DAT was more severe when acifluorfen (18%), bentazon plus acifluorfen (18%), and bentazon (5%) were applied at the V2 stage compared to 20, 10,

and 0%, respectively, at the V4 stage (Table 24). Acifluorfen applied at the V2 and V4 stages caused 15 and 10% puckering, respectively, and bentazon plus acifluorfen caused 10 and 5%, respectively, 7 DAT.

In 1998, soybean chlorosis, stunting, necrosis, and puckering among all POST treatments applied at the V2 and V4 growth stages ranged from 0 to 18% and 0 to 20%, respectively , 7 DAT (Table 25). Glyphosate caused no soybean injury when applied at the V2 or V4 growth stage. Bentazon, acifluorfen, or bentazon plus acifluorfen caused the greatest chlorosis 7 DAT compared to the other herbicides when applied at the V2 stage. Following the V4 application timing, acifluorfen, bentazon plus acifluorfen, and imazethapyr caused 18, 10, and 5% chlorosis, respectively, 7 DAT.

In 1998, there was no initial soybean stunting 7 DAT when the herbicides were applied at the V2 stage (Table 25). However, imazethapyr (8%), bentazon plus acifluorfen (5%), and acifluorfen (4%) stunted soybean when applied at the V4 stage.

Soybean necrosis was most pronounced with acifluorfen (18%), bentazon plus acifluorfen (13%), and bentazon (10%) 7 days after the V2 application timing (Table 25). Acifluorfen, bentazon plus acifluorfen, and imazethapyr when applied at the V4 stage caused 20, 13, and 4% necrosis, respectively.

Acifluorfen (10%) and bentazon plus acifluorfen (6%) caused puckering 5 to 7 days after the V2 application timing, whereas no puckering was observed 7 DAT when the herbicides were applied at the V4 stage. Complete to almost complete soybean recovery of chlorosis, necrosis, and puckering from all herbicides occurred approximately 14 DAT and soybean stunting recovery occurred 1 week later.

Table 24. Effect of selected postemergence herbicides on glyphosate-resistant soybean tolerance under weed-free conditions, 1997 (Study IV).

Treatment	Rate	Application timing	Soybean, days after postemergence application							
			Chlorosis		Stunting		Necrosis		Puckering	
			7	14	7	14	7	14	7	14
	kg/ha		%							
PLANTING DATE 2										
Nontreated			0	0	0	0	0	0	0	0
Pendimethalin & imazaquin	0.84 & 0.14	PPI	0	0	5	1	0	0	0	0
Metribuzin & chlorimuron	0.27 & 0.04	PPI	0	0	0	0	0	0	0	0
Glyphosate + AMS[a]	1.12	V2	0	0	0	0	0	0	0	0
Imazethapyr + MSO[b] + 28%N[c]	0.07	V2	6	1	6	1	0	0	0	0
Bentazon + COC[d]	1.12	V2	8	0	3	2	5	0	0	0
Acifluorfen + NIS[e]	0.42	V2	18	0	4	0	18	0	15	1
Bentazon & acifluorfen + COC[d]	0.56 & 0.28	V2	18	0	4	1	18	0	10	0
Chlorimuron & thifensulfuron + COC[d]	0.02 & 0.006	V2	9	1	3	1	0	0	0	0
Glyphosatem + AMS	1.12	V4	0	0	0	0	0	0	0	0
Imazethapyr + MSO + 28%N	0.07	V4	0	0	5	4	0	0	0	0
Bentazon + COC	1.12	V4	3	0	0	0	0	0	0	0
Acifluorfen + NIS	0.42	V4	20	0	5	3	20	0	10	0
Bentazon & acifluorfen + COC	0.56 & 0.28	V4	10	0	3	1	10	0	5	0
Chlorimuron & thifensulfuron + COC	0.02 & 0.006	V4	0	0	0	0	0	0	0	0
LSD[f]			3		2		3		2	
P			0.05	NS	0.05	NS	0.05	NS	0.05	NS

[a]AMS = Ammonium sulfate at 2% W/W.

[b]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[c]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[d]COC = Prime Oil crop oil concentrate, a petroleum based additive with 17% emulsifier from Riverside/Terra, Sioux City, IA. COC with bentazon and bentazon plus acifluorfen at 2240 ml/ha and COC with chlorimuron plus thifensulfuron at 1680 ml/ha.

[e]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[f]The variance and degrees of freedom associated with the differences between the check treatments and the crossed main effects were included in the calculation of the probability of F for either the HERB or HERB by STAGE effects. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Table 25. Effect of selected postemergence herbicides on glyphosate-resistant soybean tolerance under weed-free conditions, 1998 (Study IV).

Treatment	Rate	Application timing	Soybean, days after postemergence application								
			Chlorosis		Stunting			Necrosis		Puckering	
			7	14	7	14	21	7	14	7	14
	kg/ha		%								
PLANTING DATE 2											
Nontreated			0	0	0	0	0	0	0	0	0
Pendimethalin & imazaquin	0.84 & 0.14	PPI	0	0	0	0	0	0	0	0	0
Metribuzin & chlorimuron	0.27 & 0.04	PPI	0	0	0	0	0	0	0	0	0
Glyphosate + AMS[a]	1.12	V2	0	0	0	0	0	0	0	0	0
Imazethapyr + MSO[b] + 28%N[c]	0.07	V2	0	0	0	0	0	0	0	0	0
Bentazon + COC[d]	1.12	V2	10	0	0	0	0	10	0	0	0
Acifluorfen + NIS[e]	0.42	V2	10	0	0	0	0	18	0	10	0
Bentazon & acifluorfen + COC[d]	0.56 & 0.28	V2	10	0	0	0	0	13	0	6	0
Chlorimuron & thifensulfuron + COC[d]	0.02 & 0.006	V2	0	0	0	0	0	0	0	0	0
Glyphosate + AMS	1.12	V4	0	0	0	0	0	0	0	0	0
Imazethapyr + MSO + 28%N	0.07	V4	5	0	8	6	0	4	0	0	4
Bentazon + COC	1.12	V4	0	0	0	0	0	0	0	0	0
Acifluorfen + NIS	0.42	V4	18	0	4	1	0	20	0	0	0
Bentazon & acifluorfen + COC	0.56 & 0.28	V4	10	0	5	3	0	13	0	0	0
Chlorimuron & thifensulfuron + COC	0.02 & 0.006	V4	0	0	1	0	0	0	0	0	0
LSD[f]			3		3	2		4		1	1
P			0.05	NS	0.05	0.05	NS	0.05	NS	0.05	0.05

[a]AMS = Ammonium sulfate at 2% W/W.

[b]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[c]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[d]COC = Prime Oil crop oil concentrate, a petroleum based additive with 17% emulsifier from Riverside/Terra, Sioux City, IA. COC with bentazon and bentazon plus acifluorfen at 2240 ml/ha and COC with chlorimuron plus thifensulfuron at 1680 ml/ha.

[e]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[f]The variance and degrees of freedom associated with the differences between the check treatments and the crossed main effects were included in the calculation of the probability of F for either the HERB or HERB by STAGE effects. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Soybean population. At 14 DAE and EOS, there were no differences in soybean population per 6 m of row pooled across years (Table 26).

Soybean height. At 14 DA-V2, soybean treated with imazethapyr or bentazon plus acifluorfen was shorter than the nontreated soybean (Table 26). At 14 DA-V4, soybean treated with acifluorfen, bentazon plus acifluorfen, or imazethapyr was shorter than the nontreated soybean. However, at the EOS, there was no difference in soybean height despite early season soybean injury and regardless of herbicide, stage, herbicide by stage, or year in study IV.

Soybean maturity. There was no difference in soybean maturity regardless of herbicide or application timing in 1997 or 1998 (Table 27).

Soybean yield. There was no difference in yield regardless of herbicide or application timing in 1997 or 1998 (Table 27). Yield ranged from 3024 to 3427 kg/ha in 1997 and from 2486 to 3226 in 1998.

Table 26. Effect of selected postemergence herbicides on glyphosate-resistant soybean population and height under weed-free conditions, pooled 1997-1998 (Study IV).

Treatment	Rate	Application timing	Soybean population		Soybean height		
			14 DAE[a]	EOS[a]	14 DA-V2[a]	14 DA-V4[a]	EOS[a]
	kg/ha		000/ha		cm		
PLANTING DATE 2							
Nontreated			346	304	41	56	104
Pendimethalin & imazaquin	0.84 & 0.14	PPI	342	306	39	54	102
Metribuzin & chlorimuron	0.27 & 0.04	PPI	345	311	42	55	101
Glyphosate + AMS[b]	1.12	V2	325	295	38		103
Imazethapyr + MSO[c] + 28%N[d]	0.07	V2	337	305	37		102
Bentazon + COC[e]	1.12	V2	339	296	38		103
Acifluorfen + NIS[f]	0.42	V2	344	303	39		104
Bentazon & acifluorfen + COC[e]	0.56 & 0.28	V2	335	304	36		101
Chlorimuron & thifensulfuron + COC[e]	0.02 & 0.006	V2	338	312	40		101
Glyphosate + AMS	1.12	V4	331	300		58	103
Imazethapyr + MSO + 28%N	0.07	V4	338	298		51	102
Bentazon + COC	1.12	V4	344	310		55	105
Acifluorfen + NIS	0.42	V4	332	298		53	103
Bentazon & acifluorfen + COC	0.56 & 0.28	V4	333	301		52	101
Chlorimuron & thifensulfuron + COC	0.02 & 0.006	V4	340	311		57	105
LSD[g]					4	3	
P			NS	NS	0.05	0.05	NS

[a]DAE = days after emergence; EOS = end of season; DA-V2 = days after V2 post application; DA-V4 = days after V4 post application.

[b]AMS = Ammonium sulfate at 2% W/W.

[c]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[d]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[e]COC = Prime Oil crop oil concentrate, a petroleum based additive with 17% emulsifier from Riverside/Terra, Sioux City, IA. COC with bentazon and bentazon plus acifluorfen at 2240 ml/ha and COC with chlorimuron plus thifensulfuron at 1680 ml/ha.

[f]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[g]The variance and degrees of freedom associated with the differences between the check treatments and the crossed main effects were included in the calculation of the probability of F for either the HERB or HERB by STAGE effects. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

Table 27. Effect of selected postemergence herbicides on glyphosate-resistant soybean maturity and yield under weed-free conditions, 1997 and 1998 (Study IV).

Treatment	Rate	Application timing	Days from planting to R8 stage[a]		Soybean yield	
			1997	1998	1997	1998
	kg/ha		days after planting		kg/ha	
PLANTING DATE 2						
Nontreated			127	116	3360	2688
Pendimethalin & imazaquin	0.84 & 0.14	PPI	127	116	3024	3226
Metribuzin & chlorimuron	0.27 & 0.04	PPI	127	116	3293	2822
Glyphosate + AMS[b]	1.12	V2	127	116	3226	3091
Imazethapyr + MSO[c] + 28%N[d]	0.07	V2	127	116	3226	2822
Bentazon + COC[e]	1.12	V2	127	116	3158	3024
Acifluorfen + NIS[f]	0.42	V2	127	116	3360	2890
Bentazon & acifluorfen + COC[e]	0.56 & 0.28	V2	127	116	3360	2890
Chlorimuron & thifensulfuron + COC[e]	0.02 & 0.006	V2	127	116	3360	2621
Glyphosate + AMS	1.12	V4	127	116	3226	2957
Imazethapyr + MSO + 28%N	0.07	V4	127	116	3226	2486
Bentazon + COC	1.12	V4	127	116	3293	2621
Acifluorfen + NIS	0.42	V4	127	116	3360	2755
Bentazon & acifluorfen + COC	0.56 & 0.28	V4	127	116	3360	2621
Chlorimuron & thifensulfuron + COC	0.02 & 0.006	V4	127	116	3427	2621
LSD[g]						
P			NS	NS	NS	NS

[a]R8 stage = 95% of the pods have reached their mature pod color.

[b]AMS = Ammonium sulfate at 2% W/W.

[c]MSO = Sun-It II, a methylated crop origin oil from Agsco, Inc., Grand Forks, ND at 1753 ml/ha.

[d]28%N = Chem-N 28% urea ammonium nitrate from United Suppliers, Inc., Eldora, IA at 2338 ml/ha.

[e]COC = Prime Oil crop oil concentrate, a petroleum based additive with 17% emulsifier from Riverside/Terra, Sioux City, IA. COC with bentazon and bentazon plus acifluorfen at 2240 ml/ha and COC with chlorimuron plus thifensulfuron at 1680 ml/ha.

[f]NIS = Activator 90, a nonionic surfactant from Loveland Industries, Inc., Greely, CO at 2338 ml/ha.

[g]The variance and degrees of freedom associated with the differences between the check treatments and the crossed main effects were included in the calculation of the probability of F for either the HERB or HERB by STAGE effects. Means were separated using Fisher's Protected LSD Test at $P \leq 0.05$.

DIRECTIONS FOR FUTURE RESEARCH

The adoption of glyphosate-resistant soybean as a new weed management tool affords growers the option to wait longer to control their weeds and ensure crop safety. But, is there a yield penalty associated with belated applications of selected POST herbicides on soybean that is more vegetatively and reproductively developed later in the growing season? It would be interesting to further investigate how selected POST herbicides affect soybean phenology and yield of weed-free indeterminate and determinate glyphosate-resistant soybean when applied at the V2, V5, and R2 stages at early and late planting timings. Also, as an innovative alternative to greenhouse screening, it would be imperative to closely analyze and interpret soybean responses to POST herbicides by using field subplot growth chambers to improve and broaden our understanding on how soybean responds to current herbicide chemistry in the field.

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