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**GLYPHOSATE- AND GLUFOSINATE-RESISTANT
TECHNOLOGIES: WEED MANAGEMENT AND OFF-TARGET
CROP RESPONSE**

A Dissertation

**Submitted to the Graduate Faculty
of the Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy**

in

The Department of Plant Pathology and Crop Physiology

by

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B. S., Mississippi State University, 1995

M. S., Mississippi State University, 1997

May 2001

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ABSTRACT

Utility of preemergence soil-applied herbicides at full and half label rates were evaluated in glyphosate-resistant soybean. In most instances, differences in early season weed density and height were not noted when rates were reduced. None of the herbicides provided complete weed control, but some delayed weed growth providing an extra 3 to 7 days before the first postemergence glyphosate application was needed. Based on weed control and soybean yield, use of glyphosate alone was as effective as when preemergence herbicides were followed by glyphosate. In another study, barnyardgrass control with glyphosate at 0.84 and 1.12 kg ai/ha was not antagonized when applied with reduced rates of chlorimuron, acifluorfen, fomesafen, lactofen, or CGA-277476. Improved control with the combinations was noted only when pitted morningglory and hemp sesbania were large at application. When weeds were effectively controlled with glyphosate alone, soybean yield was not improved with the herbicide combinations.

Soybean, cotton, rice, and corn response to simulated drift representing 0.125, 0.063, 0.032, 0.016, and 0.008 of the use rates of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate was evaluated using a constant spray volume. Injury and height reductions occurred in most cases only for the two highest rates. Initially, soybean was more sensitive to glyphosate and cotton more sensitive to glufosinate, but both crops rapidly recovered from injury and yields were not affected. In contrast, the highest rate of glyphosate reduced rice yield as much as 99% when applied at 2- to 3-leaf and 54% when applied at panicle differentiation with a 30% reduction for glufosinate. Corn yield was reduced by as much as 78% for glyphosate, but no more than 13% for glufosinate.

In subsequent drift studies, corn and soybean were exposed to glyphosate applied in constant carrier volume of 234 L/ha and in proportional carrier volumes to include 29.3 and 14.7 L/ha for the 0.125 and 0.063 respective rates. Corn height reduction 14 days after treatment was 1.6 times greater and visual injury approximately twice as high, and yield reduction 1.6 times greater when glyphosate was applied in proportional spray volume.

CHAPTER 1

LITERATURE REVIEW

Glyphosate [*N*-(phosphonomethyl) glycine]] and glufosinate [2-amino-4-(hydroxymethylphosphinyl) butanoic acid] are nonselective herbicides that control many annual and perennial weeds. Development of glyphosate- and glufosinate-resistant crops will increase use of the respective herbicides along with potential problems associated with off-target movement to sensitive crops. Availability of herbicide resistant crops will allow producers to use nonselective herbicides to control weeds comparable to conventional herbicides and tillage (Baldwin 1995; York 1995). Glyphosate and glufosinate use in resistant crops can lead to a reduction in both number of herbicide applications and in cost of weed control programs. Additionally, herbicide resistant crops will promote the use of herbicides with different modes of action to counter weed resistance problems (Burnside 1992).

The primary mode of action of glyphosate is inhibition of the shikimate acid pathway. Glyphosate works by inhibiting 5-enolpyruvylshikimate-3-phosphate synthase (EPSP), the enzyme responsible for the binding of shikimate-3-phosphate (S3P) and phosphoenolpyruvate (PEP) to yield enolpyruvyl shikimate phosphate and an organic phosphate (Cole 1985; Devine et al. 1993). Glyphosate attaches to the specific area of EPSP synthase where PEP binds, thus glyphosate inhibition is competitive with respect to PEP (Cole 1985; Devine et al. 1993; Duke 1988; Kishore and Shah 1988). Glyphosate binding to the EPSP synthase-S3P complex is 115 times tighter and 20 times slower than PEP binding to this complex, while dissociation rate is 2,300 times slower than PEP (Anderson et al. 1988). Due to the inhibition of EPSP synthase, the

activity of 3-deoxy-D-arabinoheptulosonate-7-phosphate synthase (DAHP, EC 4.1.2.1.5) is significantly increased. DAHP synthase catalyzes the condensation of erythrose-4-phosphate with PEP. Lyndon and Duke (1988) reported once the shikimate pathway is disrupted, large concentrations of shikimate may accumulate. In sink tissues, shikimate and shikimate-3-phosphate may account for up to 16% of the dry weight (Schulz et al. 1990). As the plant tries to compensate for the disrupted shikimate pathway, more carbon is shunted into this pathway, thereby limiting the amount of carbon available for the Calvin cycle (Killmer et al. 1981).

The shikimate pathway occurs only in plants, fungi, and bacteria and the end products of this pathway are the aromatic amino acids phenylalanine, tyrosine, and tryptophan (Stryer 1995; Taiz and Zeiger 1998). Secondary plant compounds produced by this pathway include flavonoids, lignins, anthocyanins, and coumarins (Taiz and Zeiger 1998). Besides the production of phenolic compounds, up to 20% of the carbon fixed during photosynthesis in plants flows through the shikimate pathway (Floss 1986). Consequently, the shikimate pathway is vital for the survival of plants. Plants resistant to glyphosate are encoded for an additional enolpyruvylshikimate phosphate synthase (EPSP synthase, E. C. 2.5.1.19) enzyme derived from *Agrobacterium tumefaciens* strain CP4 (Johnson 1996). This gene was transferred to the plants by the use of gene gun technology (Horsch et al. 1988). The EPSP synthase derived from the bacterium is not affected by glyphosate while EPSP synthase produced naturally by the plant is inhibited (Bradshaw et al. 1997; Johnson 1996).

Glyphosate is particularly efficacious on a number of troublesome weeds, including sicklepod [*Senna obtusifolia* (L.) Irwin and Barnaby], johnsongrass [*Sorghum*

halepense (L.) Pers.], annual grasses, red rice [*Oryza sativa* (L.)], common cocklebur [*Xanthium strumarium* (L.)], and various pigweeds (Jordan et al. 1997; Krausz et al. 1996; Steckel et al. 1997). Krausz et al. (1996) reported 100% control of giant foxtail (*Setaria faberi* Herrm.), fall panicum (*Panicum dichotomiflorum* L.), redroot pigweed (*Amaranthus retroflexus* L.), jimsonweed (*Datura stramonium* L.), velvetleaf (*Abutilon theophrasti* Medik.), and common cocklebur with glyphosate. Glyphosate controlled redroot pigweed and velvetleaf 100% (Jordan et al. 1997). Chandler and Prostko (1996) reported 98% johnsongrass control with sequential glyphosate applications. However, glyphosate is not as effective on hemp sesbania [*Sesbania exaltata* (Raf.) Rydb. Ex A. W. Hill], morningglories, prickly sida (*Sida spinosa* L.), spreading dayflower (*Commelina diffusa* Brum. f.), and nutsedges (Anonymous 2000).

Several postemergence herbicides effectively control velvetleaf (Cantwell et al. 1988; Kapusta et al. 1994) and several morningglory species (Elmore et al. 1990). Tank mixtures of glyphosate with selective broadleaf herbicides could potentially provide an economical postemergence herbicide program for broad-spectrum weed control. The addition of chlorimuron to glyphosate increased control of hemp sesbania, Palmer amaranth (*Amaranthus palmeri* S.Wats.), and entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray) over that of glyphosate applied alone (Starke and Oliver 1998; Vidrine et al. 1997). Greater control of common lambsquarters (*Chenopodium album* L.) and velvetleaf was reported when bentazon or CGA-248757 was applied with glyphosate compared with glyphosate alone (Lich et al. 1997). Fomesafen increased tall morningglory [*Ipomoea purpurea* (L.) Roth] control when tank mixed with glyphosate (Culpepper, et al. 2000). Other selective herbicides

effective on weeds that are not adequately controlled with glyphosate should be evaluated to determine their use potential.

In contrast to glyphosate, glufosinate inhibits glutamine synthetase (GS, EC 6.3.1.2) in susceptible plants (Altenburger et al. 1995; Bellinder et al. 1987). The GS enzyme catalyzes the conversions of glutamate plus ammonia to glutamine, an essential reaction for nitrogen metabolism. Upon inhibition of this enzyme, the decoupling of photophosphorylation by accumulated ammonia ultimately results in membrane disruption, inhibition of photosynthesis, and plant death. In glufosinate resistant plants, the bialaphos resistance (BAR) gene encodes for the phosphinothricin acetyl transferase (PAT) enzyme which acetylates ammonia, thereby detoxifying the ammonia, and allowing for the continuation of normal plant processes (Murakami et al. 1986).

Glufosinate is effective on numerous grass and broadleaf weeds. Pankey et al. (1997) reported control of barnyardgrass (*Echinochloa crus-galli* L. Beauv.) and hemp sesbania of at least 89% when glufosinate was applied early postemergence. Sicklegod and pitted morningglory (*Ipomoea lacunosa* L.) were controlled at least 80% (Pankey et al. 1997; Tingle et al. 1996). Hill et al. (1997) reported that Palmer amaranth was controlled at least 89% and entireleaf morningglory at least 92% when glufosinate was applied following metolachlor preemergence.

The availability of transgenic crops will increase herbicide alternatives for weed control, but also will raise questions as to how this new technology will fit into current management programs. The manufacture of glyphosate¹ recommends that use of soil-applied residual herbicides be eliminated and that only glyphosate be used in

¹ Monsanto Company, 800 North Linbergh Boulevard, St. Louis, MO 63167.

glyphosate-resistant cotton (*Gossypium hirsutum* L.) and soybean [*Glycine max* (L.) Merr.]. Their stance is that a total postemergence program with glyphosate can be very effective if applied in a timely manner and that yield loss associated with weeds emerging with the crop should not occur. However, if no soil residual herbicide is used, weeds emerge along with the crop promoting early season competition. Sicklegod competition for 4 weeks or longer after soybean emergence reduced soybean yield at least 17% (McWhorter and Sciumbato 1988; Shaw et al. 1991). Common cocklebur competition for 4 weeks or longer after soybean emergence reduced soybean yield at least 10% (Barrentine 1974). These studies clearly show that if weeds are removed prior to 4 weeks, yield is not negatively affected, thereby questioning the value of a soil-applied herbicide. An effective soil-applied residual herbicide can eliminate early season competition of weeds to secure crop yield and allow the grower flexibility in timing a postemergence application. Ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.] plants that escaped soil treatment of imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-quinolinecarboxylic acid} or chlorimuron {2-[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid} plus metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one] were less vigorous and produced less leaf area and biomass compared with nontreated plants (Holloway and Shaw 1995; Holloway and Shaw 1996a; 1996b). This suggests that competitiveness of weeds exposed to soil-applied herbicides, but not controlled, is reduced and that growth rate is diminished such that the time period for making an application is extended. Little information is available on how residual herbicides impact weed populations, weed growth and development, and subsequent susceptibility

to postemergence herbicides. Such information would be important in developing effective weed control programs using glyphosate and glufosinate.

Consequences of repeated use of glyphosate and glufosinate in resistant crops could include weed population shifts toward those less susceptible to the herbicides (Harvey 2001) along with the possibility of resistance development (Lorraine-Colwill et al. 2001; Simarmata et al. 2001). Another problem associated with the use of herbicide resistant crops is the potential for misapplication and crop injury. Proliferation of herbicide resistant crops will increase likelihood of off-target movement to adjacent crops.

Herbicide drift occurs when wind causes spray droplets to be displaced from their intended flight path. Wolf et al. (1992) reported drift from unshielded sprayers ranged from 2 to 16% depending on nozzle size and wind velocity. Herbicide drift is especially prevalent when herbicides are applied under windy conditions or when environmental conditions favor volatilization and redistribution (Hanks 1995; Wall 1994), but often herbicide drift is the result of improper application (Wauchope et al. 1982).

Wind speed and boom height above the intended target are primary contributors to herbicide drift (Hatterman-Valenti et al. 1995). Droplet size can influence drift, especially when herbicides are applied by air as ultra low volume sprays with spray droplets less than 105 microns in size (Hanks 1995; Hanks 1997). Droplet size can be altered with nozzle selection and drift retardants specifically designed to reduce spray drift (Bouse et al. 1976; Johnson et al. 2001). Low drift nozzles include Greenleaf

TurboDrop², Turbo Teejet³, AI (Air Induction) Teejet³, and DG (Drift Guard) Teejet³.

The Turbo Teejet and DG Teejet nozzles use a preorifice system to produce a larger droplet size range without a reduction in flow rate when compared with standard flat fan spray nozzles at equal spray pressure. The AI Teejet and Greenleaf TurboDrop are venturi type nozzles that use a pre-orifice system to create a high velocity liquid stream and then draw air into the stream through a side opening. This mixture of air and liquid is then discharged at a low exit velocity thus creating very coarse droplets. These larger droplets are much less susceptible to drift, however, target coverage may be sacrificed due to a reduction in the total number of droplets. This factor should be considered especially when using nontranslocated herbicides (Anonymous 1998a; Anonymous 1998b).

Herbicide application during a temperature inversion can encourage herbicide drift (Baldwin 1998). Under ambient conditions, air is warmest at the soil surface and cooler with increasing altitude. However, during a temperature inversion, a layer of cool air forms at the soil surface capturing fine spray droplets that are displaced when wind velocity increases. Temperature inversions are most common at dawn, dusk, and when winds are calm. Ideally, to avoid drift due to temperature inversions, some wind movement should occur.

Simulated drift of MSMA (monosodium salt of MAA) in rice (*Oryza sativa* L.) (Richard et al. 1981), quinclorac (3,7-dichloro-8-quinolinecarboxylic acid) (Snipes et al.

² Greenleaf Technologies, P. O. Box 1777, Covington, LA 70434.

³ Spraying Systems Co., North Avenue at Schmale Rd., Wheaton, IL 60189.

1992) and triclopyr [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid] (Snipes et al. 1991) in cotton; pyriithobac {2-chloro-6-[(4,6-dimethoxy-2-pyrimidinyl)thio]benzoic acid} (Ghosheh et al. 1994) in corn (*Zea mays* L.), and nicosulfuron {2-[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide} and primisulfuron {2-[[[[[4,6-bis(difluoromethoxy)-2-pyrimidinyl] amino] carbonyl] amino]sulfonyl]benzoic acid} (Bailey and Kapusta 1993) in soybean has been investigated. Injury symptoms from herbicide drift are usually worse when drift occurs to the susceptible crop early in its development (Ghosheh et al. 1994; Hurst 1982). In addition to initial foliar damage, herbicide drift can be manifested as loss of tuber quality in potatoes (*Solanum tuberosum* L.) (Eberlein and Guttieri 1994), delays in fruit maturity in sweet cherries (*Prunus avium* L.) (Al-Khatib et al. 1992b), reduced boll production in cotton (Snipes et al. 1991), straighthead symptoms in rice (Richard et al. 1981), and stand reductions in alfalfa (*Medicago sativa* L.) (Al-Khatib et al. 1992a), and reduced yield in corn and rice (Ellis et al. 1999a, 1999b).

Most simulated drift research in the past has consisted of dose-response studies where carrier volume remained constant. In a field situation, however, drift occurring from aerial or ground equipment would decrease with movement away from the point of application and herbicide rate and spray volume would diminish proportionally. Banks and Schroeder (2000) conducted studies with 2,4-D [(2,4-dichlorophenoxy)acetic acid] on cotton and glyphosate on sweet corn (*Zea mays* var. *rogusa* Bonaf) to compare crop response to herbicide delivery in constant carrier volume compared with carrier volume varied proportionally with herbicide dosage. For both crops, visual injury and reduction in crop yield were greater for the variable carrier volume compared with

constant carrier volume. Based on their results, simulated herbicide drift research where spray volume was constant over a rate range may underestimate the negative effect on susceptible crops.

The popularity of glyphosate- and glufosinate-resistant crops will increase the potential for herbicide drift to nontransgenic crops. Determining the sensitivity of nontransgenic crops to glyphosate and glufosinate drift would be of keen importance especially in the South where multiple crops are grown in close proximity.

Research for this dissertation specifically addressed: the effect of soil-applied herbicides on weed population, weed growth and development, and subsequent timing of glyphosate postemergence application; glyphosate rates, tank-mixture partners, and weed species sensitivity; the effect of glyphosate and glufosinate simulated drift on growth parameters and yield of soybean, cotton, rice, and corn; and the effect of carrier volume on corn and soybean response to simulated drift of glyphosate and glufosinate.

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CHAPTER 2

VALUE OF SOIL-APPLIED HERBICIDES IN GLYPHOSATE-RESISTANT SOYBEAN (*GLYCINE MAX*)

Introduction

Glyphosate [*N*-(phosphonomethyl)glycine] is a postemergence (POST) nonselective herbicide that controls many annual and perennial weeds. In the U. S., soybean with the glyphosate-resistance gene (Bradshaw et al. 1997) was introduced in 1996 and cotton (*Gossypium hirsutum* L.) in 1997. More than 60% of the soybean [*Glycine max* (L.) Merr.] and 70% of cotton hectareage in 1999 in Louisiana was planted to glyphosate-resistant varieties (Anonymous 1999) and is expected to increase. Availability of glyphosate-resistant crops allows producers flexibility to use glyphosate to control weeds equal to or greater than conventional herbicides and tillage (Culpepper and York 1997, 1998, 1999). Use of glyphosate in resistant crops can lead to a reduction in both number of herbicide applications needed and in cost of weed control programs. Herbicide resistant crops that allow use of glyphosate will also help to counter weed resistance problems (Burnside 1992).

The level of activity of glyphosate depends on the weed species growth stage at time of application, and weather conditions during and after application (Vangessel et al. 2000). Glyphosate is particularly efficacious on a number of troublesome weeds, including sicklepod [*Senna obtusifolia* (L.) Irwin and Barnaby], johnsongrass [*Sorghum halepense* (L.) Pers.], annual grasses to include red rice [*Oryza sativa* (L.)] (Askew et al. 1998), common cocklebur [*Xanthium strumarium* (L.)], and various pigweeds (Jordan et al. 1997; Krausz et al. 1996). Glyphosate provided 100% control of giant foxtail (*Setaria faberi* Herrm.), fall panicum (*Panicum dichotomiflorum* L.), common

cocklebur , and jimsonweed (*Datura stramonium* L.) (Krausz et al. 1996), as well as velvetleaf (*Abutilon theophrasti* Medik.) and redroot pigweed (*Amaranthus retroflexus* L.) (Jordan et al. 1997; Krausz et al. 1996). McKinley et al. (1999) reported 98% johnsongrass control with sequential glyphosate applications. However, glyphosate is not as effective on hemp sesbania [*Sesbania exaltata* (Raf.) Rydb. Ex A. W. Hill], morningglory species (*Ipomoea* spp.), prickly sida (*Sida spinosa* L.), spreading dayflower (*Commelina diffusa* Brum. f.), and nutsedge species (Anonymous 2000).

The availability of transgenic crops will provide herbicide alternatives for weed control, but also will raise questions as to how this new technology will fit into current management programs. The manufacturer of glyphosate¹ recommends that use of soil-applied residual herbicides be eliminated and that only glyphosate be used in glyphosate-resistant cotton and soybean. When a soil-applied herbicide is not used, weeds emerge along with the crop (Holloway and Shaw 1996a). The manufacturer's stance is that a program using only glyphosate POST can be effective if glyphosate is applied in a timely manner. However, weeds not adequately controlled or allowed to compete with the crop for too long can have a negative effect on yield. Sicklepod competition for 4 weeks or longer after soybean emergence reduced soybean yield at least 17% (McWhorter and Sciumbato 1988; Shaw et al. 1991). Common cocklebur competition for 4 weeks or longer after soybean emergence reduced soybean yield by as much as 57% (Mosier and Oliver 1995). These studies clearly show that if weeds are removed prior to 4 weeks, yield is not negatively affected, thereby questioning the value of using soil-applied residual herbicides.

¹ Roundup Ultra, Monsanto Company, 800 North Linbergh Boulevard, St. Louis, MO 63167.

An effective soil-applied herbicide can eliminate or reduce early season competition of weeds to secure crop yield and allow the grower flexibility in timing a POST application if needed. Additionally, use of soil-applied herbicides can change the composition of weeds that emerge with the crop (Corrigan and Harvey 2000).

Preemergence (PRE) herbicide with grass activity may eliminate annual grasses, but release broadleaf weeds. Likewise, use of a herbicide without grass activity in fields with heavy annual grass pressure may prevent emergence and competition from broadleaf weeds due to space limitation. Soil-applied herbicides although not providing complete control of certain weeds may impact their growth. Ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.] plants exposed to imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid} or chlorimuron {2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid} plus metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one] were not completely controlled but were less vigorous and produced less leaf area and biomass compared with nontreated plants and were less competitive with the crop (Holloway and Shaw 1995, 1996a). A reduction in weed growth rate may provide a larger window in which to apply glyphosate, extending the period critical to application timing. This advantage to use of soil-applied herbicides followed by a POST herbicide, however, may not result in crop yield greater than when only a timely application of POST herbicide is used. The flexibility gained from using a soil-applied herbicide may be particularly advantageous for growers with diversified operations.

Little information is available on how residual herbicides impact weed populations, weed growth and development, and subsequent susceptibility of weeds to POST

herbicides. Such information would be important in developing effective and economical weed control programs especially in herbicide-resistant crops where growers are assessed an additional technology fee. Therefore, the objectives of this research were to determine if soil-applied herbicides used in glyphosate-resistant soybean: 1) affect weed density and growth rate, 2) extend the number of days between weed emergence and glyphosate application, 3) affect weed control with glyphosate, and 4) eliminate the need for a sequential glyphosate application.

Materials and Methods

Field experiments were conducted at the Ben Hur Research Farm near Baton Rouge, LA, over three years to evaluate the value of PRE herbicides in a glyphosate-resistant soybean system. 'Asgrow 5901 RR' soybean was planted on June 2, 1998, May 18, 1999, and May 9, 2000. The original plan was to plant in early May, but planting was delayed in 1998 because of weather conditions.

The experimental design was a randomized complete block with four replications. The soil type was a Mhoon silty clay loam (fine-silty, mixed, nonacid, thermic Typic Fluvaquent) with a pH of 5.7 and 2.2% organic matter. Soil-applied PRE treatments included half rates and labeled rates of pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] plus imazaquin (0.42 + 0.07 kg ai/ha and 0.84 + 0.14 kg/ha), pendimethalin (0.56 and 1.12 kg/ha), metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] (0.84 and 1.68 kg ai/ha), SAN 582 (proposed common name dimethenamid) [2-chloro-*N*-(2,4-dimethyl-3-thienyl)-*N*-(2-methoxy-1-methylethyl)] plus imazaquin (0.5 + 0.07 kg ai/ha and 1.0 + 0.14 kg/ha), sulfentrazone {*N*-[2,4-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-

1,2,4-triazol-1-yl]phenyl]methanesulfonamide} plus chlorimuron (0.11 + 0.02 kg ai/ha and 0.22 + 0.04 kg/ha), and metribuzin plus chlorimuron (0.18 + 0.03 kg ai/ha and 0.36 + 0.06 kg/ha). All treatments were applied in 140 L/ha spray volume with a CO₂ pressurized backpack sprayer at 166 kPa the same day soybean was planted. Plots were overhead irrigated (1.9 cm) within 3 days after application of PRE treatments to ensure herbicide activation. The reasoning behind this was to place herbicides under the best case scenario so that meaningful conclusions could be drawn as to their effect on weed emergence and growth. If plots had not been irrigated and rainfall for activation had not been received shortly after herbicide application, weeds would have emerged along with soybean since soil moisture was adequate for seed germination. With this situation PRE herbicides would have had little influence on weed emergence and their value could not have been adequately determined. Irrigation was continued as needed throughout the growing season.

Plots consisted of four 76 cm rows, 7.6 m in length with the two inside rows treated and used for data collection. Weed height and density were determined from three 0.1 m² areas randomly selected in each plot at 14, 20, and 24 days after planting (just prior to the initial glyphosate application) in 1998, 1999, and 2000, respectively. These dates varied due to growing conditions which affected weed growth rate. Weed species each year included barnyardgrass, ivyleaf morningglory, prickly sida, hemp sesbania, and redweed. After initial weed height and density data were collected, weeds were monitored at 2 d intervals to determine number of days from soybean planting required to reach the selected treatment stage of 10.2 cm. Glyphosate was applied at 1.12 kg ai/ha when the largest weeds reached 10.2 cm, which in most cases were barnyardgrass

or hemp sesbania depending on PRE herbicide used. Treatment dates in 1998 were June 19 for the no PRE plots, June 22 for the half and full rates of pendimethalin plus imazaquin, pendimethalin and metolachlor, and June 24 for the half and full rates of SAN 582 plus imazaquin, sulfentrazone plus chlorimuron, and metribuzin plus chlorimuron. In 1999, all plots were treated June 8 except those that received a full rate of metribuzin plus chlorimuron which were treated June 14. Glyphosate was applied in 2000 to all plots on June 3 except those receiving a full rate of sulfentrazone plus chlorimuron or metribuzin plus chlorimuron, which were treated June 10. Weed control was evaluated 14 days after glyphosate was applied. Visual weed control ratings were based on a scale of 0 to 100% where 0 = no control and 100 = complete control. A sequential application of glyphosate was made in the no PRE plots in 1998, but the followup application was not needed in the other years. The experimental area was cultivated. Since hemp sesbania was not completely controlled with any of the treatments, 0.28 kg ai/ha acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid} was applied in mid July to facilitate harvest. Soybeans were harvested on October 16, 1998, October 14, 1999, and September 28, 2000, and yield was adjusted to 13% moisture. Data were subjected to analysis of variance and means separated using Fisher's protected LSD at the 5% level of probability. Where treatment by year interactions were not observed, data were averaged across years.

Results and Discussion

Weed Density

Reducing the rate of only sulfentrazone plus chlorimuron increased barnyardgrass density in 1998 (Table 2.1). However, reducing the rate of the PRE herbicides did not

affect barnyardgrass densities in 1999 and 2000. When compared to the nontreated control, barnyardgrass densities were lower for both rates of all PRE herbicides in 1998, but not in 1999 or 2000. In 1998, barnyardgrass density in the nontreated control was 8.6 times higher than in 1999, and in 2000 no barnyardgrass was present in the experimental area. These differences among years for barnyardgrass density were reflected in differences observed among the herbicide treatments in respect to change in weed composition.

Reducing the rate of the individual preemergence herbicides did not affect ivyleaf morningglory densities in any year and differences among herbicide treatments and the nontreated control were not observed (Table 2.1). Averaged across all treatments, ivyleaf morningglory density was 41 per m². Results for ivyleaf morningglory, however, do not suggest that PRE herbicides did not control ivyleaf morningglory when compared with the nontreated control, but rather show interspecific competition from barnyardgrass on ivyleaf morningglory emergence when herbicide was not applied. In 1998, barnyardgrass density was at least 1.8 to 175 times greater in the nontreated control than in the plots treated with PRE herbicides. Other research has documented the change in weed composition associated with use of soil-applied herbicides (Corrigan and Harvey 2000). Prickly sida density decreased when only the rate of metolachlor was increased in 1998 and reducing the rate of the herbicides did not affect prickly sida densities in 1999 and 2000.

In 1998, reducing the rate of pendimethalin plus imazaquin increased hemp sesbania density 64% (Table 2.1). The full rate of sulfentrazone plus chlorimuron and the half

Table 2.1. The effect of preemergence herbicides applied at half and full labeled rates on densities of barnyardgrass (ECHCG), ivyleaf morningglory (IPOHE), prickly sida (SIDSP), hemp sesbania (SEBEX), and redweed (MEOCO) 14 to 24 days after planting.^a

		Weed density										
Preemergence herbicide	Rate	ECHCG			IPOHE	SIDSP			SEBEX			MEOCO
		1998	1999	2000	Average	1998	1999	2000	1998	1999	2000	Average
	kg ai/ha	no./m ²										
None	—	1924	225	0	65	333	32	11	473	322	107	129
Pendimethalin + imazaquin	0.42 + 0.07	86	32	0	26	11	11	0	828	301	54	38
	0.84 + 0.14	32	11	0	41	11	11	0	505	387	75	12
Pendimethalin	0.56	151	65	0	58	86	43	11	516	312	65	110
	1.12	204	54	0	49	118	22	11	516	333	32	53
Metolachlor	0.84	22	32	0	62	398	43	11	441	183	54	80
	1.68	11	32	0	51	161	11	11	398	312	75	32
SAN 582 + imazaquin	0.50 + 0.07	54	22	0	59	11	22	0	441	247	65	19
	1.0 + 0.14	22	11	0	19	11	0	0	333	194	65	5

(Table continued)

Sulfentrazone + chlorimuron	0.11 + 0.02	1054	129	0	5	75	0	11	430	247	86	12
	0.22 + 0.04	151	22	0	6	11	0	0	280	237	43	12
Metribuzin + chlorimuron	0.18 + 0.03	194	140	0	58	11	11	0	97	150	22	0
	0.36 + 0.06	54	43	0	33	11	0	0	32	43	32	0
LSD (0.05)		———— 340 ————			NS	———— 80 ————			———— 169 ————			70

*Experimental area was watered (1.9 cm) within 3 d after herbicide application to ensure activation. Density data were collected 14, 20, and 24 d after planting in 1998, 1999, and 2000, respectively, and varied due to time of weed emergence and growth rate.

and full rates of metribuzin plus chlorimuron were the only herbicide treatments in 1998 that reduced hemp sesbania density when compared with the nontreated control (41 to 93% reduction). In 1999 and 2000, increasing the rate for individual herbicides did not further reduce hemp sesbania density. In 1999, only metribuzin plus chlorimuron reduced hemp sesbania density compared to the nontreated control. There were no differences in hemp sesbania density among the treatments evaluated in 2000. In comparing years for the nontreated control, hemp sesbania density was 1.5 times greater in 1998 than in 1999 and 3 times greater in 1999 than in 2000.

Reducing the rate of the individual preemergence herbicides did not affect redweed densities (Table 2.1). However, redweed densities were lower for all PRE herbicide treatments compared to the nontreated control, except for half rates of pendimethalin and metolachlor. Other research has shown little or no difference in densities of velvetleaf, ivyleaf morningglory, and common cocklebur between half and full labeled rates of metribuzin plus chlorimuron, clomazone {2-[(2-chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidionone}, and imazaquin when applied preplant incorporated (PPI) in soybean (Corrigan and Harvey 2000).

Weed Height

Increasing the rate of individual PRE herbicides did not significantly reduce height of barnyardgrass or redweed, and in no cases did herbicide treatments reduce height of these weeds when compared with the nontreated control (Table 2.2). For only sulfentrazone plus chlorimuron and metribuzin plus chlorimuron was there a decrease in ivyleaf morningglory height when the application rate was decreased. Compared with the nontreated control, ivyleaf morningglory height was reduced with both rates of

Table 2.2. The effect of preemergence herbicides applied at half and full labeled rates on height of barnyardgrass (ECHCG), ivyleaf morningglory (IPOHE), prickly sida (SIDSP), hemp sesbania (SEBEX), and redweed (MEOCO) 14 to 24 days after planting.^a

Preemergence herbicide	Rate	Weed height				
		ECHCG	IPOHE	SIDSP	SEBEX	MEOCO
	kg ai/ha	cm				
None	—	13.7	6.1	8.2	13.7	5.9
Pendimethalin + imazaquin	0.42 + 0.07	11.4	4.6	2.3	13.7	2.5
	0.84 + 0.14	7.8	4.3	1.4	12.8	1.8
Pendimethalin	0.56	11.4	5.8	4.1	14.6	3.2
	1.12	11.4	4.8	4.1	12.8	3.7
Metolachlor	0.84	11.0	6.6	7.3	13.3	4.1
	1.68	11.0	7.6	6.4	14.2	3.7
SAN 582 + imazaquin	0.50 + 0.07	7.8	5.3	3.7	13.7	3.2
	1.0 + 0.14	13.7	4.1	1.4	12.8	1.8
Sulfentrazone + chlorimuron	0.11 + 0.02	13.3	5.1	3.2	13.7	4.1
	0.22 + 0.04	11.9	3.3	5.0	11.9	4.1

(Table continued)

Metribuzin + chlorimuron	0.18 + 0.03	10.1	5.8	3.2	11.9	2.5
	0.36 + 0.06	11.9	3.8	6.9	9.1	2.5
LSD (0.05)		NS	1.3	2.7	1.8	NS

^aData represent average across three years. Height data was collected 14, 20, and 24 d after planting in 1998, 1999, and 2000, respectively, and varied due to time of weed emergence and growth rate.

pendimethalin plus imazaquin (25 to 30%), and for the high rate of pendimethalin alone (21%), San 582 plus imazaquin (33%), sulfentrazone plus chlorimuron (46%), and metribuzin plus chlorimuron (38%). These decreases in weed growth delayed application of glyphosate and would be considered a positive benefit in situations where growers are under time constraints.

Increasing the rate of individual PRE herbicides did not reduce height of prickly sida (Table 2.2). However, compared to when no PRE herbicide was used, prickly sida height was reduced 39 to 83% for all PRE herbicide treatments except for metolachlor at both rates and for the full rate of metribuzin plus chlorimuron. For hemp sesbania, increasing the application rate decreased height for pendimethalin (12%), sulfentrazone plus chlorimuron (13%), and metribuzin plus chlorimuron (24%). Hemp sesbania height was less for both rates of metribuzin plus chlorimuron and for the high rate of sulfentrazone plus chlorimuron when compared to no PRE herbicide.

Glyphosate Application Timing

Under conditions where moisture was not a limiting factor, the PRE herbicides extended the initial glyphosate application an extra 3 to 5 days in 1998 when compared to no PRE treatment (Table 2.3). Both rates of pendimethalin alone or plus imazaquin, and metolachlor extended the glyphosate application 3 d and both rates of SAN 582 plus imazaquin, chlorimuron plus sulfentrazone, and metribuzin plus chlorimuron an extra 5 d. This extension in the application window for glyphosate could be extremely important especially in diversified farming operations. Corrigan and Harvey (2000) reported that a soil-applied herbicide can be beneficial when early season weed competition reduces soybean yield or when glyphosate application is delayed by

Table 2.3. The effect of preemergence herbicides applied at half and full labeled rates on the number of days from soybean planting until largest weeds reached the 10.2 cm treatment stage for glyphosate application.

Preemergence herbicide	Rate	1998	1999	2000
	kg ai/ha	no. of days		
None	--	17	21	25
Pendimethalin + imazaquin	0.42 + 0.07	20	21	25
Pendimethalin	0.56	20	21	25
	1.12	20	21	25
Metolachlor	0.84	20	21	25
	1.68	20	21	25
SAN 582 + imazaquin	0.50 + 0.07	22	21	25
Sulfentrazone + chlorimuron	0.11 + 0.02	22	21	25
Metribuzin + chlorimuron	0.18 + 0.03	22	21	25

adverse weather or time constraints. When a PRE herbicide was not used in 1998, a second glyphosate application was made 10 days after the first application to control weed escapes.

In 1999, only the full rate of metribuzin plus chlorimuron extended the glyphosate application window (6 d) and was probably related to the control of hemp sesbania (Table 2.1). In 2000, only the full rates of sulfentrazone plus chlorimuron and metribuzin plus chlorimuron extended the glyphosate application window (7 d) beyond that needed where no preemergence herbicide was used. For both 1999 and 2000, a second glyphosate application was not needed.

The number of days for weeds to reach the treatment stage for glyphosate when no PRE herbicide was used was 17, 21, and 25 d for 1998, 1999, and 2000, respectively (Table 2.3). The more rapid growth of weeds the first year may have been related to the later planting date in early June. It should be noted that for all years glyphosate application was made when the largest weeds reached 10.2 cm. This timing would, therefore, be dependent on the efficacy of the herbicide and its effect on weed composition due to interspecific competition.

Weed Control

There were no differences in control of barnyardgrass, prickly sida, or redweed among the herbicide treatments evaluated 14 d after glyphosate was applied (Table 2.4). These weeds were controlled 93 to 100% and results show that use of PRE herbicide was not beneficial. When only glyphosate was applied, ivyleaf morningglory was controlled 77%. Morningglory control was increased to 86 to 93% when glyphosate followed the high rate of SAN 582 plus imazaquin and both rates of sulfentrazone plus

Table 2.4. Barnyardgrass (ECHCG), ivyleaf morningglory (IPOHE), prickly sida (SIDSP), hemp sesbania (SEBEX), and redweed (MEOCO) control 14 days after glyphosate was applied following various preemergence herbicides at half and full labeled rates.^a

Preemergence herbicide ^b	Rate	Control				
		ECHCG	IPOHE	SIDSP	SEBEX	MEOCO
	kg ai/ha	%				
None	--	99	77	93	73	94
Pendimethalin + imazaquin	0.41 + 0.06	99	80	97	78	97
	0.82 + 0.12	99	82	96	73	96
Pendimethalin	0.54	99	83	97	81	97
	1.1	99	83	96	78	97
Metolachlor	0.84	99	77	95	78	95
	1.68	99	81	96	78	98
SAN 582 + imazaquin	0.49 + 0.06	81	100	95	78	95
	0.98 + 0.12	86	99	96	81	96
Sulfentrazone + chlorimuron	0.10 + 0.01	87	100	96	77	96
	0.20 + 0.02	89	100	97	83	97

(Table continued)

Metribuzin + chlorimuron	0.17 + 0.02	83	100	96	85	97
	0.34 + 0.04	93	100	98	95	98
LSD (0.05)		NS	5	NS	6	NS

^aData represent an average across years.

^bAll preemergence herbicide treatments (to include none) were followed by a single glyphosate application at 1.12 kg ai/ha.

chlorimuron and metribuzin plus chlorimuron. When compared to glyphosate alone, hemp sesbania control was increased when glyphosate followed the high rate of SAN 582 plus imazaquin (81%), sulfentrazone plus chlorimuron (83%), and both rates of metribuzin plus chlorimuron (85 and 95%). Regardless, half or full rates of preemergence herbicides followed by glyphosate did not completely control hemp sesbania, necessitating an acifluorfen application each year.

Soybean Yield

There were no differences in soybean yield among the herbicide treatments evaluated and yield averaged 2,540 kg/ha (Table 2.5). Other research has shown equivalent yield when POST herbicides followed PRE herbicides at half and full rates (Muyonga et al. 1996).

In conclusion, density and growth rate of both annual grass and broadleaf weeds were reduced when PRE herbicides were used and in most cases half rates were as effective as full rates. Over the 3 yr use of pendimethalin plus imazaquin, pendimethalin alone, metolachlor alone, SAN 582 plus imazaquin, sulfentrazone plus chlorimuron, and metribuzin plus chlorimuron extended the time period to make glyphosate application from 3 to 7 days when compared with no PRE. In only 1 of 3 yr did all PRE herbicide treatments extend the application window for glyphosate and only the high rate of metribuzin plus chlorimuron consistently proved beneficial over all years (5 to 7 d extension). For only morningglory and hemp sesbania was control increased when glyphosate followed a PRE herbicide and even so, a followup treatment of acifluorfen was needed to control hemp sesbania. In only 1 of 3 yr did use of PRE herbicides eliminate the need for a sequential application of glyphosate.

Table 2.5. Yield of 'Asgrow 5901 RR' soybean as influenced by various weed control programs.^a

Preemergence herbicide ^b	Rate	Soybean yield
	kg ai/ha	kg/ha
None	—	2,570
Pendimethalin + imazaquin	0.42 + 0.07	2,550
Pendimethalin	0.56	2,390
	1.12	2,740
Metolachlor	0.84	2,230
	1.68	2,350
SAN 582 + imazaquin	0.50 + 0.07	2,750
Sulfentrazone + chlorimuron	0.11 + 0.02	2,610
Metribuzin + chlorimuron	0.18 + 0.03	2,410
LSD (0.05)		NS

^aData represent an average across years.

^bAll preemergence herbicide treatments (to include none) were followed by a single glyphosate application at 1.12 kg ai/ha.

It is clear from this research that any benefit to use of PRE herbicides in glyphosate-resistant soybean should be based on economics and grower preference rather than differences in weed control and crop yield. The extension in the time period to make a glyphosate application due to use of some PRE herbicides, however, may be extremely important in diversified operations where application timing is critical.

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CHAPTER 3

GLYPHOSATE AND BROADLEAF POSTEMERGENCE HERBICIDE COMBINATIONS IN SOYBEAN (*GLYCINE MAX*)

Introduction

Availability of glyphosate-resistant soybean has provided additional options for management of troublesome weed in the soybean growing regions of the U. S. This technology allows producers to use glyphosate [*N*-(phosphonomethyl) glycine)], a nonselective herbicide, to control weeds equal to or greater than conventional herbicides and tillage (York 1995) and also provides a different mode of action to counter weed resistance problems (Burnside 1992). Use of glyphosate for postemergence weed control in resistant crops can lead to a reduction in both number of herbicide applications and in cost of weed control programs. Other possible benefits of glyphosate programs include less use of prophylactic soil applied herbicides, more practical use of economic thresholds in treatment decisions, and reduced concerns for herbicide carryover (Burnside 1992; Culpepper and York 1997, 1998, 1999; Ellis et al. 1999; Wade et al. 1998; Wilcut et al. 1996).

Glyphosate is particularly efficacious on a number of grass and broadleaf weeds, but in general is considered more active on grasses (Anonymous 2000; Ahrens 1994). Glyphosate effectively controls johnsongrass [*Sorghum halepense* (L.) Pers.], numerous annual grasses, sicklepod [*Senna obtusifolia* (L.) Irwin and Barnaby], common cocklebur [*Xanthium strumarium* (L.)], and various pigweeds (Jordan et al. 1997; Krausz et al. 1996). Krausz et al. (1996) reported 100% control of giant foxtail (*Setaria faberi* Herrm.), fall panicum (*Panicum dichotomiflorum* L.), redroot pigweed

(*Amaranthus retroflexus* L.), jimsonweed (*Datura stramonium* L.), velvetleaf (*Abutilon theophrasti* Medik.), and common cocklebur with glyphosate. Glyphosate controlled redroot pigweed and velvetleaf 100% (Jordan et al. 1997). Ghosheh and Chandler (1998) reported 98% johnsongrass control with sequential glyphosate applications. However, glyphosate is less effective on hemp sesbania [*Sesbania exaltata* (Raf.) Rydb. Ex A. W. Hill], morningglories, prickly sida (*Sida spinosa* L.), spreading dayflower (*Commelina diffusa* Brum. f.), and nutsedges (Anonymous 2000).

There are, however, several broadleaf postemergence herbicides that effectively control velvetleaf (Cantwell et al. 1988; Kapusta et al. 1994) and morningglory species (Elmore et al. 1990). Tank-mixtures of glyphosate with these selective broadleaf herbicides could potentially provide a benefit in enhancing overall weed control in glyphosate programs. Addition of chlorimuron {2-[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl] amino]sulfonyl]benzoic acid} to glyphosate increased control of hemp sesbania, Palmer amaranth (*Amaranthus palmeri* S.Wats.), and entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray) over that of glyphosate alone (Starke and Oliver 1998; Vidrine et al. 1997). Greater control of common lambsquarters (*Chenopodium album* L.) and velvetleaf was reported when bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] was applied with glyphosate (Lich et al. 1997). Fomesafen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-*N*-(methylsulfonyl)-2-nitrobenzamide} increased tall morningglory [*Ipomoea purpurea* (L.) Roth] control when tank-mixed with glyphosate (Culpepper, et al. 2000).

Producers who choose to use glyphosate-resistant soybean, particularly in the South, realize the weakness of glyphosate alone on certain broadleaf weeds. Selection of glyphosate-resistant varieties involves an additional seed cost to support the technology. Therefore, producers must consider the potential benefit in weed control of adding a tank-mix partner versus the impact that the mixture may have on reducing grass control and ultimately economics.

The objectives of this research were to evaluate grass and broadleaf control with glyphosate alone and in combination with reduced rates broadleaf herbicides chlorimuron, acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid}, fomesafen, lactofen {(±)-2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate}, and CGA-277476 {2-[[[(4,6-dimethyl-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid} and to determine possible interactions that could impact their utility in soybean production systems.

Materials and Methods

Field studies were conducted at the Ben Hur Research Farm near Baton Rouge, LA, on a Mhoon silty clay loam (fine-silty, mixed, nonacid, thermic Typic Fluvaquent) with a pH of 5.7 and 2.2% organic matter. 'Asgrow 5901 RR' (glyphosate-resistant) soybean was planted June 8, 1998, May 17, 1999, and June 15, 2000 at a seeding rate of 130,000 seeds/ha.

Herbicide treatments included glyphosate at 840 and 1120 g ai/ha applied alone and in combination with the following broadleaf herbicides: chlorimuron (4.5 and 6.7 g ai/ha), acifluorfen (210 and 315 g ai/ha), fomesafen (210 and 315 g ai/ha), lactofen (112 and 168 g ai/ha), and CGA-277476 (39 and 59 g ai/ha). Application rates of the

broadleaf herbicides represented one-half and three-fourths of the recommended field use rates. Treatments were arranged in a randomized complete block with four replications. Plots consisted of four 76.2 cm rows, 7.6 m in length with the two inside rows treated. Herbicide treatments were applied with a CO₂ pressurized backpack sprayer calibrated to deliver 140 L/ha spray volume at 166 kPa. Weed species evaluated included barnyardgrass [*Echinochloa crus-galli* L. (Beauv.)], wild poinsettia (*Euphorbia heterophylla* L.), prickly sida, pitted morningglory (*Ipomoea lacunosa* L.), and hemp sesbania. Weed density and size at application are shown in Table 3.1. Attempts were made to standardize timings of applications over years, but weather conditions resulted in some variability.

Weed control and soybean injury were evaluated 14 and 28 days after treatment (DAT). Visual ratings were based on a scale of 0 to 100% where 0 = no control and 100 = complete control of all weeds. Rating dates were selected to allow for comparisons of initial control and subsequent weed recovery and regrowth. Soybeans were not harvested in 1998 because of very low yields due to inadequate rainfall, but were harvested in 1999 and 2000 in mid-October. Data were subjected to analysis of variance and means were separated using Fisher's protected LSD at the 5% level of probability. Where treatment by year interactions occurred, data are presented for individual years.

Results and Discussion

Barnyardgrass

Of concern in this study was the possible antagonism that might occur with the herbicide combinations. Previous research has shown reduced grass control when grass

Table 3.1. Barnyardgrass, wild poinsettia, prickly sida, pitted morningglory, and hemp sesbania density and height when glyphosate was applied alone and in combination with other herbicides.

Weed species	Weed density ^a			Weed height ^a		
	1998	1999	2000	1998	1999	2000
	no./m ²			cm		
Barnyardgrass	88	215	108	20	15	10
Wild poinsettia	108	108	--	15	8	--
Prickly sida	25	--	108	8	--	6
Pitted morningglory	18	22	22	15	8	10
Hemp sesbania	45	86	54	18	10	10

^aWild poinsettia was not present in the experimental area in 2000 and prickly sida was not present in 1999.

specific herbicides were applied with broadleaf herbicides (Corkern et al. 1998). In the present study, addition of chlorimuron, acifluorfen, fomesafen, lactofen, or CGA-277476 did not negatively influence barnyardgrass control with glyphosate in any year (Tables 3.2 and 3.3). Barnyardgrass control 14 and 28 DAT averaged 96%. Other research has shown excellent grass control with glyphosate (Jordan et al. 1997; Krausz et al. 1996).

Wild Poinsettia

Wild poinsettia was evaluated in 1998 and 1999, but was not present in the experimental area in 2000. At 14 DAT, glyphosate alone controlled wild poinsettia at least 96% (Table 3.2). Addition of broadleaf herbicides provided 95 to 99% control. At 28 DAT, wild poinsettia control varied between years. Weed regrowth occurred in 1998 and control with glyphosate was no more than 80%. This was in contrast to the second year when control was 100% with glyphosate alone at both rates. Greater weed regrowth the first year can be explained by the taller weeds at the time of application when compared to the second year, (Table 3.1) along with adequate rainfall received within two weeks after application (6.6 cm). Consequently, addition of certain broadleaf herbicides in the present study was beneficial for control of wild poinsettia only in 1998. Addition of chlorimuron in 1998 did not improve wild poinsettia control when compared with glyphosate applied at the high rate alone and was also not antagonistic. In contrast, combinations of CGA-277476 at both rates with the high rate of glyphosate that year reduced wild poinsettia control when compared with glyphosate alone 12 to 20 percentage points. The reason for this response is not apparent. Addition of acifluorfen, fomesafen, or lactofen regardless of rate increased wild poinsettia control

Table 3.2. Barnyardgrass, wild poinsettia, prickly sida, pitted morningglory, and hemp sesbania control 14 days after treatment with glyphosate applied alone and in combination with other herbicides.

Herbicide	Rate g ai/ha	Barnyardgrass ^a	Wild poinsettia ^a	Prickly sida ^a	Pitted morningglory			Hemp sesbania		
					1998	1999	2000	1998	1999	2000
					%					
Glyphosate	840	95	98	95	66	75	88	50	78	58
	1120	96	96	93	75	75	95	55	87	85
Glyphoate + chlorimuron	840 + 4.5	97	95	92	66	93	95	91	100	84
	1120 + 4.5	97	97	91	75	93	93	93	97	87
	840 + 6.7	94	95	92	65	95	90	88	100	86
	1120 + 6.7	97	97	93	79	93	93	92	98	88
Glyphoate + acifluorfen	840 + 210	97	99	94	88	80	96	97	97	89
	1120 + 210	98	99	95	89	91	95	97	100	94
	840 + 315	95	97	90	89	96	94	93	99	88
	1120 + 315	95	99	91	94	89	95	95	100	88
Glyphosate + fomesafen	840 + 210	94	99	91	87	93	93	89	100	90
	1120 + 210	97	99	92	90	89	97	97	100	95

(Table continued)

Glyphosate + lactofen	840 + 315	96	98	94	85	91	94	96	100	97
	1120 + 315	98	99	96	93	93	94	96	100	93
	840 + 112	98	98	93	85	85	97	88	98	97
	1120 + 112	98	99	94	90	88	97	94	98	98
	840 + 168	96	98	94	86	96	94	83	98	95
	1120 + 168	96	97	94	84	98	97	81	100	94
	Glyphosate + CGA-277476									
	840 + 39	96	98	90	65	82	96	70	100	92
	1120 + 39	96	98	95	73	93	93	70	100	90
LSD (0.05)	840 + 59	97	96	90	70	87	91	69	100	85
	1120 + 59	97	98	90	78	88	96	97	100	95
LSD (0.05)		NS	3	9	— 10 —			— 11 —		

^a Data averaged across years. Wild poinsettia present only in 1998 and 1999 and prickly sida only in 1998 and 2000.

Table 3.3. Barnyardgrass, wild poinsettia, prickly sida, pitted morningglory, and hemp sesbania control 28 days after treatment with glyphosate alone and in combination with other herbicides.

Herbicide	Rate g ai/ha	Barnyardgrass ^a	Wild poinsettia		Prickly sida		Pitted morningglory			Hemp sesbania		
			1998	1999	1998	2000	1998	1999	2000	1998	1999	2000
			%									
Glyphosate	840	96	60	100	33	93	28	94	89	26	98	85
	1120	100	80	100	43	94	30	98	91	23	100	88
Glyphosate + chlorimuron	840 + 4.5	99	67	100	40	91	43	100	90	62	100	76
	1120 + 4.5	98	73	99	40	95	49	99	88	61	99	84
	840 + 6.7	97	69	98	35	95	46	99	85	63	99	85
	1120 + 6.7	96	75	98	50	94	48	99	93	64	99	84
Glyphosate + acifluorfen	840 + 210	96	93	99	60	95	73	95	91	91	98	88
	1120 + 210	96	92	99	63	94	66	94	94	93	100	85
	840 + 315	95	92	98	83	93	73	97	89	91	99	88
	1120 + 315	97	95	100	73	95	79	96	90	91	99	86
Glyphosate + fomesafen	840 + 210	96	92	100	60	96	53	99	93	70	99	88
	1120 + 210	96	91	100	60	95	63	96	94	83	99	91

(Table continued)

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Glyphosate + lactofen	840 + 315	97	92	100	70	96	60	98	95	85	100	90
	1120 + 315	95	91	100	75	97	66	100	92	88	100	94
	840 + 112	96	94	100	78	95	70	95	90	84	98	89
	1120 + 112	97	93	100	80	95	70	97	93	86	96	93
	840 + 168	96	92	100	78	94	70	100	90	88	98	91
	1120 + 168	95	95	100	78	94	66	94	93	83	97	91
	840 + 39	97	64	100	41	95	46	100	93	18	100	89
	1120 + 39	97	60	100	38	97	35	100	91	20	100	89
	840 + 59	95	70	100	33	94	43	98	91	20	98	83
	1120 + 59	95	68	100	48	94	43	98	93	26	99	86
LSD (0.05)		NS	— 7 —		— 9 —		— 9 —			— 9 —		

*Data averaged across years.

to 91 to 95%. Ellis et al. (2000) has reported inconsistent results in improvement of wild poinsettia control when glyphosate was applied with either chlorimuron or fomesafen.

Prickly Sida

Prickly sida was evaluated only in 1998 and 2000. At 14 DAT both years (Table 3.2) and 28 DAT in 2000 (Table 3.3), addition of chlorimuron, acifluorfen, fomesafen, lactofen, or CGA-277476 to either rate of glyphosate did not in most cases increase control compared to glyphosate applied alone, and control was at least 91%.

Regrowth of prickly sida occurred in 1998 and by 28 DAT control with glyphosate alone was no more than 43% (Table 3.3). Weed size was similar for the two years (Table 3.1) and regrowth was probably related to excellent growing conditions as discussed previously for wild poinsettia. Addition of acifluorfen, fomesafen, or lactofen regardless of rate increased prickly sida control 28 DAT when tank-mixed with either rate of glyphosate (60 to 83%). Control was at least 80% for acifluorfen at 315 g/ha or lactofen at 112 g/ha plus the high rate of glyphosate. Increases in prickly sida control associated with addition of acifluorfen or fomesafen was not expected since these herbicides do not effectively control this weed (Anonymous, 2000). Weed control was not increased with the addition of chlorimuron to glyphosate. Ellis et al. (2000) reported little or no increase in prickly sida control when fomesafen or chlorimuron was tank-mixed with glyphosate.

Pitted Morningglory

Year by treatment interactions were observed for pitted morningglory control. In none of the years did increasing the glyphosate rate when applied alone result in

increased weed control 14 DAT (Table 3.2). For the three years, glyphosate applied alone controlled pitted morningglory 66 to 88% at 840 g ai/ha and 75 to 95% at 1120 g/ha. Addition of acifluorfen, fomesafen, or lactofen regardless of rate generally increased pitted morningglory control when applied with either rate of glyphosate at 14 DAT in 1998 compared to glyphosate alone. That year, addition of chlorimuron or CGA-277476 was not beneficial. In 1999 14 DAT, all broadleaf herbicides in most cases increased pitted morningglory control compared with glyphosate alone. The addition of a broadleaf herbicide to 840 or 1120 g/ha of glyphosate, however, did not increase control of pitted morningglory in 2000, but in that year, control with glyphosate alone was 88 and 95%, greater than observed for the previous two years.

By 28 DAT, pitted morningglory control with glyphosate alone was 89 to 98% in 1999 and 2000, but no more than 30% in 1998 (Table 3.3). Addition of all broadleaf herbicides regardless of rate increased pitted morningglory control in 1998 28 DAT, but the magnitude of increase varied among herbicides. Pitted morningglory control ranged from 35 to 49% when glyphosate was tank-mixed with either chlorimuron or CGA-277476. Addition of acifluorfen, fomesafen, or lactofen to glyphosate increased pitted morningglory control to 53 to 79%. Chlorimuron, acifluorfen, fomesafen, and lactofen control pitted morningglory (Anonymous 2000) and it would be expected that control levels in the present study would have been greater. At application, however, pitted morningglory was 15 cm in height (Table 3.1), which combined with the reduced rates of the herbicides probably attributed to the lower control in 1998 compared with the other years. Bennett et al. (1999) reported that tank-mixing fomesafen or acifluorfen with glyphosate did not improve pitted morningglory control over that for glyphosate

applied alone. When pitted morningglory in the present study was no more than 10 cm at application (Table 3.1), control 28 DAT for the herbicide treatments ranged from 94 to 100% in 1999 and 85 to 95% in 2000.

Hemp Sesbania

Interaction with years was also observed for hemp sesbania control. For glyphosate applied alone at 840 g/ha, control was lowest in 1998 and 2000 (50 and 58%, respectively) and higher in 1999 (78%) (Table 3.2). In contrast, control with glyphosate alone at 1120 g/ha was 55% in 1998, but 87 and 85% in 1999 and 2000, respectively. Increasing rate of glyphosate increased hemp sesbania control 14 DAT in only 2000 (58 to 85%). At 14 DAT in 1998, addition of chlorimuron, acifluorfen, fomesafen, lactofen, or CGA-277476 to either rate of glyphosate increased hemp sesbania control (69 to 97%) compared to glyphosate applied alone. The most consistent responses across herbicide rates were observed with the acifluorfen or fomesafen and glyphosate combinations (89 to 97% control). In 1999, hemp sesbania control with the broadleaf herbicide and glyphosate combinations was 97 to 100% and greater in most cases than glyphosate applied alone. In 2000, all combinations provided greater control than the low rate of glyphosate alone, but not for the high rate of glyphosate. Mulkey et al. (1998) also observed increased hemp sesbania control when chlorimuron was tank-mixed with reduced rates of glyphosate.

By 28 DAT, hemp sesbania control had decreased to no more than 26% in 1998, but had improved to at least 98% in 1999 (Table 3.3). Plant height at application in 1998 was 1.8 times greater than in 1999 or 2000 (Table 3.1), which may explain the regrowth that occurred the first year. Hemp sesbania control 28 DAT in 1998 was not improved

when CGA-277476 was applied with glyphosate. Addition of chlorimuron to glyphosate controlled hemp sesbania 61 to 64% compared with 91 to 93% for acifluorfen, and 70 to 88% for fomesafen and lactofen. Acifluorfen has been shown to be highly effective on hemp sesbania, even at reduced rates (Vidrine et al. 1992). In contrast, in 1999 in the present study none of the combinations improved hemp sesbania control when glyphosate alone was effective. In 2000, glyphosate alone controlled hemp sesbania 85 and 88% 28 DAT. Even though control was less than observed the previous year, in most cases none of the combinations in 2000 were any more effective than glyphosate alone. Glyphosate normally does not provide adequate control of hemp sesbania (Anonymous 2000), however, under humid conditions and high temperatures herbicide diffusion rate through the cuticle and cell membranes can be increased (Wanamarta and Penner 1989). Results clearly show that control of hemp sesbania with glyphosate alone can be severely reduced, however, if plants are large at application as observed in this study in 1998 (Table 3.1). This supports other research that places emphasis on the early timing of herbicide applications for optimum weed control (DeFelice et al. 1989; Lee and Oliver 1982).

Soybean Injury and Yield

Soybean injury 14 DAT for all treatments evaluated was no more than 9% in 1998 and no more than 2% in 1999 and 2000 (Table 3.4). In 1998, at 28 DAT, soybean injury ranged from 6 to 13% for chlorimuron, 12 to 14% for acifluorfen, and 18 to 23% for lactofen, but soybean was injured no more than 6% with fomesafen and CGA-277476. Other studies have shown less injury with fomesafen compared with acifluorfen or lactofen (Harris et al. 1991; Higgins et al. 1988) and excellent soybean

Table 3.4. Soybean injury 14 and 28 days after treatment (DAT) and soybean yield as influenced by glyphosate applied alone and in combination with other herbicides.

		Soybean injury						
Herbicide	Rate	14 DAT			28 DAT			Soybean yield ^a
		1998	1999	2000	1998	1999	2000	
	g ai/ha	%						kg/ha
Glyphosate	840	0	0	0	0	0	0	2,620
	1120	0	0	0	4	0	0	2,290
Glyphosate + chlorimuron	840 + 4.5	0	0	0	6	0	0	2,490
	1120 + 4.5	1	0	0	7	0	0	2,490
	840 + 6.7	0	0	0	10	0	0	2,290
	1120 + 6.7	3	0	0	13	0	0	2,560
Glyphosate + acifluorfen	840 + 210	7	0	0	14	0	0	2,220
	1120 + 210	7	0	0	14	0	0	2,220
	840 + 315	5	0	0	12	0	0	2,490
	1120 + 315	9	0	0	14	0	0	2,150
Glyphosate + fomesafen	840 + 210	0	0	0	3	0	0	2,150

(Table continued)

	1120 + 210	3	0	0	5	0	0	2,350
	840 + 315	0	0	0	6	0	0	2,620
	1120 + 315	1	0	0	5	0	0	2,690
Glyphosate + lactofen	840 + 112	5	0	0	19	0	0	2,220
	1120 + 112	3	2	0	23	0	0	2,490
	840 + 168	6	0	0	20	0	0	2,350
	1120 + 168	7	0	0	18	0	0	2,150
Glyphosate + CGA-277476	840 + 39	0	0	0	0	0	0	2,560
	1120 + 39	0	0	0	3	0	0	2,420
	840 + 59	2	0	0	4	0	0	2,560
	1120 + 59	1	0	0	6	0	0	2,690
LSD (0.05)		0	0	0	0	0	0	2,620
		————— 2 —————			————— 2 —————			NS

*Data averaged for 1999 and 2000. Yield of the nontreated control was 1,010 kg/ha.

tolerance to CGA-277476 (Palmer and Shaw 2000). Soybean injury was not observed 28 DAT in 1999 and 2000. For soybean yield, herbicide treatments responded similarly for 1999 and 2000, even though differences between years were observed for control of some of the weeds. Yield differences were not observed where glyphosate was applied alone or in combination with various broadleaf herbicides, but yield was more than twice that of the nontreated control (Table 3.4). The similarity in yield among herbicide treatments is not unexpected since in few cases was weed control 28 DAT increased where combinations were used compared with glyphosate alone in 1999 and 2000 (Table 3.3). It is possible that if yields could have been determined the first year where differences in weed control were most apparent, yield differences among the treatments may have been detected.

Results indicate that tank-mixtures of glyphosate plus the broadleaf herbicides chlorimuron, acifluorfen, fomesafen, lactofen, or CGA-277476 can increase control of wild poinsettia, prickly sida, pitted morningglory, and hemp sesbania, especially when weeds are too large to be effectively controlled with glyphosate alone. Increasing the rate of either the broadleaf herbicides or glyphosate did not in most cases increase weed control and in no instances was barnyardgrass control antagonized with the herbicide combinations. The variation in control of some of the weed species from year to year was related in part to weed size at application combined with excellent growing conditions following application. Yield differences were not observed where glyphosate was applied alone or in combination with various broadleaf herbicides, but yield was more than twice that of the nontreated control. Results emphasize the importance of early applications, especially when glyphosate is used as a stand alone

product. In previous research improvement in pitted morningglory or hemp sesbania control was observed when broadleaf herbicides were applied with glyphosate (Ellis et al. 2000; Mulkey et al. 1998; Vidrine et al. 1992). However, in those studies glyphosate rate was lower than the highest rate of 1120 g/ha evaluated in the present study. It would be expected that an advantage would be seen when efficacious broadleaf herbicides are applied with glyphosate when glyphosate rate is insufficient to consistently control problem weeds. Even though in this study yield differences among treatments were not detected even though some differences in weed control occurred, weed regrowth and emergence through the soybean canopy in late season could impact harvest efficiency and crop quality (Ellis et al. 1998; Willard and Griffin 1993).

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CHAPTER 4

RICE (*ORYZA SATIVA*) AND CORN (*ZEA MAYS*) RESPONSE TO SIMULATED DRIFT OF GLYPHOSATE AND GLUFOSINATE

Introduction

Glyphosate [*N*-(phosphonomethyl) glycine)] and glufosinate [2-amino-4-(hydroxymethylphosphiny) butanoic acid] are non-selective herbicides used to control annual and perennial weeds in reduced tillage systems and in herbicide-resistant, transgenic crops. Glyphosate-resistant soybean [*Glycine max* (L.) Merr.], cotton (*Gossypium hirsutum* L.), and corn (*Zea mays* L.) and glufosinate-resistant soybean and corn are marketed in the South. The expected expansion in acreage of these crops will increase the likelihood of off-target movement of glyphosate and glufosinate. It is also possible that rice (*Oryza sativa* L.) resistant to glyphosate and glufosinate will be on the market in the near future. Since aerial application is common in rice culture, this may further magnify the problem. With the diversity in cropping systems in the South it is not uncommon for rice, corn, soybean, and cotton to be grown adjacent to one another. All these factors point to greater problems associated with herbicide drift.

Herbicide drift occurs when wind causes spray droplets to be displaced from their intended flight path. Wolf et al. (1992) reported drift from unshielded sprayers ranged from 2 to 16% depending on nozzle size and wind velocity. Herbicide drift is especially prevalent when herbicides are applied under windy conditions or when environmental conditions favor volatilization and redistribution (Hanks 1995; Wall 1994).

Herbicide application during a temperature inversion can encourage herbicide drift¹. Under ambient conditions, air is warmest at the soil surface and cooler with increasing altitude. However, during a temperature inversion, a layer of cool air forms at the soil surface capturing fine spray droplets that are displaced when wind velocity increases. The droplets eventually encounter a down draft, which propels them back to the soil surface. Temperature inversions are most common at dawn, dusk, and when winds are calm. Therefore, contrary to what one would expect, herbicide drift would be reduced when herbicides are applied under slightly windy conditions.

Herbicide drift is most often the result of improper application (Wauchope et al. 1982). However, wind speed and boom height above the intended target are also primary contributors to herbicide drift (Hatterman-Valenti et al. 1995). Environmental conditions can have a negative effect on herbicide drift (Bouse et al. 1976). Besides windy conditions at application, wet fields can delay timely herbicide application, which can increase the risk associated with off-target movement of herbicides applied aerially (Martin and Green 1995).

Droplet size can influence drift, especially when herbicides are applied by air as ultra low volume sprays with spray droplets less than 100 microns in size (Hanks 1995, 1997). To reduce herbicide drift, formation of spray droplets less than 100 microns during application should be avoided. Droplet size can be altered with nozzle selection and drift retardants specifically designed to reduce spray drift (Bouse et al. 1976).

¹ Anonymous. 1994. Herbicide Application Management. Sandoz Crop Protection. Des Plaines, IL. 60016. 27 p.

Simulated drift of MSMA (monosodium salt of MAA) in rice (Richard et al. 1981), quinclorac (3,7-dichloro-8-quinolinecarboxylic acid) (Snipes et al. 1992) and triclopyr [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid] (Snipes et al. 1991) in cotton, pyriithobac {2-chloro-6-[(4,6-dimethoxy-2-pyrimidinyl)thio]benzoic acid} in corn (Ghosheh et al. 1994), and nicosulfuron {2-[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide} and primisulfuron {2-[[[[4,6-bis (difluoromethoxy)-2-pyrimidinyl]amino]carbonyl]mino]sulfonyl]benzoic acid} in soybean (Bailey and Kapusta 1993) has been investigated. Injury symptoms from herbicide drift are usually worse when drift occurs to the susceptible crop early in its development (Ghosheh et al. 1994; Hurst 1982). In addition to initial foliar damage, herbicide drift can be manifested as loss of tuber quality in potatoes (*Solanum tuberosum* L.) (Eberlein and Guttieri 1994), delays in fruit maturity in sweet cherries (*Prunus avium* L.) (Al-Khatib et al. 1992b), reduced boll production in cotton (Snipes et al. 1991), straighthead symptoms in rice (Richard et al. 1981), and stand reductions in alfalfa (*Medicago sativa* L.) (Al-Khatib et al. 1992a).

Of concern from the standpoint of drift is that glyphosate has been shown to affect vigor of seeds produced from treated plants. Glyphosate treatment of wild oat (*Avena fatua* L.) at or near anthesis inhibited seed development and reduced seed germination (Shuma et al. 1995; Shuma and Raju 1993). Clay and Griffin (2000) reported reductions in seedling emergence of 82% for common cocklebur (*Xanthium strumarium* L.) and 94% for hemp sesbania [*Sesbania exaltata* (Raf.) Rybd. ex A. W. Hill] when glyphosate was applied at initial seed set. Low vigor seed may result in slower germination and seedling growth rate, greater susceptibility to seed-rotting

organisms, poor stands, and reduced yield (Edje and Burris 1971). The implications would be important when considering the effect of drift of glyphosate on commercial seed production fields.

The objectives of this research were to determine the effect of simulated drift of glyphosate and glufosinate on growth and yield of conventional non-herbicide resistant rice and corn, and to evaluate the subsequent effect of simulated drift on rice seed germination and vigor.

Materials and Methods

Rice Field Study

Field experiments were conducted at the Rice Research Station in Crowley, LA over three years to evaluate response of 'Cypress' non-herbicide resistant rice to simulated drift rates of glyphosate and glufosinate. Rice was drill planted (18 cm row spacing) April 24, 1998, May 5, 1999, and April 25, 2000 at a seeding rate of 112 kg/ha. The experimental area was tilled and the seedbed packed prior to planting. The soil type was a Crowley silt loam (fine, montmorillonitic, thermic Typic Albaqualf) with a pH of 5.5 and 1.4% organic matter. The fertilizer program consisted of 8-24-24 kg/ha (N-P₂O₅-K₂O) preplant incorporated and 104-0-0 kg/ha broadcast 4 weeks after planting. Plots were maintained weed free by an application of propanil [*N*-(3,4-dichlorophenyl) propanamide] plus molinate (*S*-ethyl hexahydro-1*H*-azepine-1-carbothioate) (3.36 + 3.36 kg ai/ha) on May 17, 1998, June 3, 1999, and May 20, 2000.

Plots consisted of 7, 18 cm rows 6.1 m long. The experimental design was a randomized complete block with a three-factor factorial treatment arrangement and four replications. The first and second factors were herbicides and herbicide drift rates.

Drift rates represented 0.125, 0.063, 0.032, 0.016, and 0.008 of the use rate of 1.12 kg ai/ha glyphosate (140, 70, 35, 18, and 9 g/ha, respectively) and 0.42 kg ai/ha glufosinate (53, 26, 13, 7, and 4 g/ha, respectively). The third factor was application timing. An early postemergence application was made prior to establishment of the permanent flood when rice was at 2- to 3-leaf on May 20, 1998, May 25, 1999, and May 5, 2000 and a late postemergence application to flooded 2- to 3-tiller rice at panicle differentiation (initiation of reproductive stage) on June 19, 1998, June 30, 1999, and June 16, 2000. Herbicide treatments were applied using a CO₂ pressurized backpack sprayer calibrated to deliver 140 L/ha spray volume at 166 kPa. The permanent flood was established on May 23, 1998, June 4, 1999, and June 8, 2000. Visual injury and plant heights from the soil to the tip of the uppermost leaf of 10 plants in each plot were determined 7, 14, and 28 days after treatment (DAT). Visual injury ratings were based on a scale of 0 to 100% where 0 = no injury and 100 = complete death of the plant. Height was expressed as a percentage of the nontreated glyphosate/glufosinate control. Days from rice emergence to 50% heading were determined to document any delay in rice maturity. Plant height of 10 plants in each plot was determined just prior to harvest by measuring from the soil surface to the tip of extended seed-heads. Rice was harvested on August 27, 1998, August 30, 1998, and August 16, 2000 and yield was adjusted to 12% moisture. Data were subjected to analysis of variance with partitioning appropriate for the factorial arrangement of treatments. Means of significant main effects and interactions were separated using Fisher's protected LSD at the 5% level of probability.

Rice Germination/Vigor Study

Germination and vigor of seed are important to producers who are growing rice for commercial seed because these factors can impact emergence and development of healthy seedlings (AOSA 1985). Rice seed was saved from each plot after harvest in order to evaluate the effects of the herbicides on germination and vigor. Harvested rice seeds were cleaned to remove excess debris and seeds were dried to 12% moisture. After drying, seeds were stored at 7 C.

Germination procedures were in accordance with established guidelines (AOSA 1992). Rice seeds were soaked for 30 minutes in a 50:50 solution of sodium hypochlorite and distilled water. After soaking, seeds were triple rinsed with distilled water and one hundred seeds were placed between two sheets of germination paper and into a 8.9 cm diameter plastic petri dishes. Seeds were incubated in darkness in a liquid cooled incubator. Percent germination was evaluated 5, 9, and 14 days after seed plating (DAP). Rice seeds were counted as germinated if the radicle or shoot was 1 mm in length. Ten milliliters of distilled water was added at the beginning of the experiment and 1.5 ml of distilled water was added to the petri dish at the 9 d counting. Percent germination was calculated on the basis of 100 seeds. A completely randomized design with a factorial arrangement of treatments replicated four times was used. All data were subjected to analysis of variance and treatment means were separated using Fisher's protected LSD at the 5% level of probability.

The vigor experiment was prepared as described in the germination experiment. Seeds were soaked in a 50:50 solution of sodium hypochlorite and distilled water for 30 minutes. After soaking, seeds were triple rinsed and pre-soaked for 24 hours in distilled

water to promote germination before seedling plating. At plating, 10 pre-germinated seed from each treatment were placed on sterile germination paper. Germination paper was placed on a 12 cm wide 23 cm long sheet of plastic. A one-ply paper towel strip was placed over the seed and 5 ml of mancozeb (ethylene bisdithiocarbamate) fungicide was applied on top of the paper towel strip to eliminate seedling diseases. The plated seeds and 1.1 L of distilled water were then placed in glass containers that were 30 cm wide and 51 cm long. The glass containers were covered in plastic wrap and placed in a double liquid cooled incubator at 25 C for 12 days. At the end of 12 days, vigor was evaluated by measuring shoot lengths. Statistical analysis was as described for the germination study.

Corn Field Study

Field experiments were conducted at the R & D Research Farm, Inc., near Washington, LA in 1997, and at the Ben Hur Research Farm near Baton Rouge, LA in 1998 and 1999, to evaluate corn response to simulated drift of glyphosate and glufosinate. Non-herbicide resistant 'Dekalb 687' corn was planted March 14, 1997 at the R & D Research Farm, and March 16, 1998 and March 25, 1999 at the Ben Hur Research Farm at a seeding rate of 74,000 seed/ha with an estimated final stand of 60,000 plants/ha. The experimental areas were tilled and bedded prior to planting. The soil type at the R & D Research Farm was a Baldwin silty clay loam (fine, montmorillonitic, thermic Vertic Ochraqualf) with a pH of 5.9 and 1.4% organic matter. The fertilizer program consisted of 64-64-64 kg/ha broadcast prior to planting and 11-37-0 kg/ha in-furrow at planting. Three weeks after planting 65-0-0 was side dressed. The insecticides terbufos {*S*-[[[(1,1-dimethylethyl)thio]methyl]O,O-diethyl

phosphorodithioate} (1.12 kg ai/ha) and permethrin [(3-phenoxyphenyl)methyl(+)-*cis*, *trans*-3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate] (0.22 kg ai/ha) were applied in-furrow at planting. The soil type at the Ben Hur Research Farm in 1998 and 1999 was a Commerce silt loam (fine-silty, mixed, nonacid, thermic Aeric Fluvaquent) with a pH of 5.6 and 1.3% organic matter. The fertilizer program consisted of 200-30-30 kg/ha side dressed three weeks after planting. The insecticide chlorpyrifos [O,O-diethyl-O-(3,5,6-trichloro-2-pyridinyl)] (2.0 kg ai/ha) was applied in-furrow at planting. At both locations plots were maintained weed free by a preemergence application of atrazine plus metolachlor (2.17 + 1.79 kg ai/ha) the day of planting and mechanical cultivation as needed.

Plots consisted of four, 91.4 cm rows 7.6 m long in 1997 and three, 96.5 cm rows 7.6 m long in 1998 and 1999. The experimental design was a randomized complete block with a three-factor factorial treatment arrangement with four replications. Treatments were the same as described for the rice study with the exception of the application timings. An early application was made at 6-leaf on May 2, 1997, May 5, 1998, and April 27, 1999 and a late application at 9-leaf on May 28, 1997, May 20, 1998, and May 21, 1999. A glyphosate/glufosinate nontreated control was included for comparison. Herbicide treatments were applied as described previously. Visual injury and plant height data were collected 7, 14, and 28 DAT for the 6-leaf application and 7 DAT for the 9-leaf application. Later ratings for the 9-leaf application were not made because corn plants were tasseling 7 DAT. Corn height was based on measurement from the soil surface to the last fully developed collar and expressed as a percentage of the nontreated glyphosate/glufosinate control. Corn was harvested August 22, 1997, July 31, 1998,

and August 5, 1999 and yield was adjusted to 15% moisture. Statistical analysis was as described for the rice study.

Greenhouse Studies

Since only one corn and rice variety were evaluated in the field, greenhouse experiments were conducted to evaluate differences in sensitivity to simulated drift rates of glyphosate and glufosinate using five commonly grown rice and corn varieties. The experimental design was a randomized complete block with a three-factor factorial arrangement of treatments with four replications. The first factor was crop variety and the second and third factors were herbicide and herbicide drift rate, respectively.

Dekalb 687, 'Asgrow 897', 'Pioneer 3223', 'Mycogen 8460', and 'Terral 2930' corn varieties and Cypress, 'Bengal', 'Cocodrie', 'Drew', and 'Jefferson' rice varieties were treated with 0.125, 0.063, and 0.032 of the use rates of 1.12 kg ai/ha of glyphosate and 0.42 kg ai/ha of glufosinate at the 3-leaf stage. Rates were selected because they had caused significant crop injury in the field experiments. All treatments were applied in 140 L/ha of water at 166 kPa. Plants were grown in the greenhouse using plastic pots containing a 50:50 mix of commercial peat premix² and Olivier silt loam (fine-silty, mixed, thermic, thermic, Aeric Fluvaquent) soil. Artificial lighting was utilized to extend day length to 14 h and temperature was maintained at 31 ± 4 C. Plants were thinned after emergence to two plants per pot. At 7 and 14 DAT, plant height and injury were recorded as described previously. At 14 DAT, the above ground biomass was harvested and oven dried at 60 C for 48 h. Separate experiments and analyses were

² Jiffy Mix Plus, Jiffy Products of America Inc., Batavia, IL 60510.

conducted for each crop and experiments were repeated. Data were subjected to analysis of variance and means separated using Fisher's protected LSD at the 5% level of probability.

Results and Discussion

Rice Field Study

For rice injury, height, and yield, data are presented for individual years because of significant year by treatment interactions. In general, herbicide injury symptoms were more severe in 1998 and 2000 than in 1999. Air temperatures averaged 5 to 7 C higher during and after herbicide application in 1998 and 2000 compared to 1999, which may explain the variation observed. Greater injury under warm weather conditions was not surprising since high temperatures increase herbicide diffusion rate through the cuticle and cell membranes (Wanamarta and Penner 1989). Past simulated drift research has shown significant variation in years when evaluating sub-lethal rates of herbicides (Snipes et al. 1991; Richard 1995). It would be expected that differences in environmental conditions among years would have a greater impact on herbicide activity when reduced rates are applied (Jordan et al. 1997).

Rice symptoms varied between glyphosate and glufosinate. Visual injury from glyphosate developed slowly and consisted of stunting and a slight yellow discoloration of leaves. Symptoms caused by glufosinate developed quickly and included some stunting, however, injury mainly consisted of chlorosis and necrosis of leaves. At 7 DAT, rice height following glyphosate applied early to 2- to 3-leaf rice was reduced 16 to 37% at rates of 0.016 to 0.125 of the use rate, but injury from glufosinate at the same rates was generally not observed (data not shown). Neither herbicide reduced rice

height when applied late at panicle differentiation. Glyphosate at the 0.016 to 0.125 rates applied early injured rice 0 to 94% compared with 0 to 45% for glufosinate. In contrast, rice injury was not observed following late application of glyphosate, but was 11 to 44% for the 0.063 rate and higher for glufosinate.

At 14 DAT, glyphosate applied at the 0.125 and 0.063 rates in 1998 and the 0.032 rate and higher in 2000 reduced rice height when applied early 10 to 63% (Table 4.1). However, no reduction in rice height was observed when glyphosate was applied early in 1999 or when applied late any year. Rice height was not reduced with glufosinate. Even though height was not reduced for some of the treatments injury was observed. All rates of glyphosate applied early injured rice (5 to 78%) in 1998. Injury to rice occurred when glyphosate was applied early at the 0.125 and 0.063 rates in 1999 (11 and 5%), and at the 0.032 rate and higher in 2000 (11 to 98%). Glufosinate applied early did not injure rice in 1999, but the 0.125 and 0.063 rates injured rice 11 and 39% in 1998 and 24 and 25% in 2000. Glyphosate applied late injured rice at 0.125 and 0.063 rates in 1999 (15 and 10%) and in 2000 (8 and 6%), but only for the 0.125 rate in 1998 (10%). Glufosinate applied late injured rice at 0.032 of the use rate and higher in 1998 and 2000 (5 to 35%), but for only the two high rates in 1999 (23 and 13%).

At 28 DAT, rice height was still reduced where glyphosate at the 0.125 and 0.063 rates was applied early in 1998 and 2000 (8 to 51%), but not for glufosinate (Table 4.2). Of interest is that rice height was not reduced following either herbicide applied late 14 DAT (Table 4.1), but reductions were observed 28 DAT (Table 4.2). The 0.125 and 0.063 rates of glyphosate in 1998 and 2000 and the 0.125 rate in 1999 reduced rice

Table 4.1. Height and injury of non-transgenic 'Cypress' rice 14 days following simulated drift rates of glyphosate and glufosinate at two application timings.^a

Treatment	Rate ^b	Rice height						Rice injury					
		Early timing			Late timing			Early timing			Late timing		
		1998	1999	2000	1998	1999	2000	1998	1999	2000	1998	1999	2000
		% of nontreated						%					
Glyphosate	0.125	47	94	37	95	96	93	78	11	98	10	15	8
	0.063	91	99	61	102	96	96	41	5	61	4	10	6
	0.032	104	102	90	100	99	98	23	0	11	0	0	3
	0.016	106	97	97	105	96	95	6	0	0	0	1	0
	0.008	104	96	99	99	98	95	5	0	1	0	3	0
Glufosinate	0.125	92	98	92	100	99	98	39	3	25	35	23	21
	0.063	98	98	98	101	98	97	11	0	24	20	13	10
	0.032	107	99	92	104	98	98	4	0	4	5	3	5
	0.016	102	97	103	101	98	98	3	0	0	0	1	0
	0.008	104	95	105	103	96	100	1	1	0	0	0	0
LSD (0.05)		9						5					

^aApplication timings correspond to 2- to 3-leaf (early timing) and panicle differentiation (late timing). Rice height based on measurement from the soil to the tip of the uppermost leaf.

^bRates correspond to 0.125, 0.063, 0.032, 0.016, and 0.008 of the labeled rates of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate.

Table 4.2. Height and injury of non-transgenic 'Cypress' rice 28 days following simulated drift rates of glyphosate and glufosinate at two application timings.^a

Treatment	Rate ^b	Rice height						Rice injury					
		Early timing			Late timing			Early timing			Late timing		
		1998	1999	2000	1998	1999	2000	1998	1999	2000	1998	1999	2000
		% of nontreated						%					
Glyphosate	0.125	49	98	56	84	73	85	83	0	94	35	29	33
	0.063	92	99	79	89	98	88	19	0	40	24	19	23
	0.032	100	97	101	96	94	95	0	0	0	9	0	0
	0.016	103	95	99	102	95	96	0	0	2	0	0	0
	0.008	101	96	100	98	95	95	0	0	2	2	0	0
Glufosinate	0.125	94	96	97	85	90	87	6	0	0	28	44	16
	0.063	99	96	100	93	95	92	0	0	0	16	5	6
	0.032	104	97	94	101	96	96	0	0	0	5	0	3
	0.016	99	94	98	99	96	97	0	0	0	0	0	0
	0.008	105	96	100	103	96	100	0	0	0	0	0	0
LSD (0.05)		8						3					

^aApplication timings correspond to 2- to 3-leaf (early timing) and panicle differentiation (late timing). Rice height based on measurement from the soil to the tip of the uppermost leaf.

^bRates correspond to 0.125, 0.063, 0.032, 0.016, and 0.008 of the labeled rates of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate.

height when applied late 11 to 27%. The 0.125 rate of glufosinate in 1998 and 1999 and the 0.125 and 0.063 rates in 2000 reduced rice height when applied late 8 to 15%. Rice was injured 83 and 19% in 1998 and 94 and 40% in 2000 when the 0.125 and 0.063 rates of glyphosate were applied early, but not in 1999. By 28 DAT, rice plants had recovered from visual injury sustained from early application of glufosinate in 1998 and 2000. In contrast, rice injury 28 DAT had increased for the 0.063 and 0.125 rates from that observed at 14 DAT, and was 19 to 35%. For glufosinate, injury in some years 28 DAT following late application had increased from the earlier rating and was 5 to 44% for the two highest rates. In comparing across rating dates, it is evident that rice plants exposed to the highest rate of glyphosate were not able to recover from height reduction observed in 2 of 3 yr when glyphosate was applied early and in all years when applied late. Additionally, injury increased with time in all years when glyphosate was applied late. For glufosinate, however, plants in most cases were able to more rapidly recover from herbicide injury. This clearly shows the greater sensitivity of rice to glyphosate.

Rice height at harvest and days to 50% heading were not influenced by application timing and year. At rice harvest, height was reduced 12 and 6% where glyphosate was applied at 0.125 and 0.063 rates, respectively, but no more than 3% for the same rates of glufosinate (data not shown). Number of days to 50% heading was delayed 5 and 2 days following 0.125 and 0.063 rates of glyphosate and 1 day following glufosinate at the 0.125 rate (data not shown). Data for rice height at harvest again reflect the inability to recover from height reduction following the early and late applications (Tables 4.1 and 4.2) and the subsequent impact of this stress on delayed heading.

Glyphosate reduced rice yield when applied early at the 0.125 rate in 1998 (99%) and at 0.125 and 0.063 rates (67 and 26%, respectively) in 2000 (Table 4.3). Rice yields were reduced 29 to 54% for the two highest rates of glyphosate applied late. Yield reductions for the early or late glyphosate applications, however, were not observed in 1999. In contrast to glyphosate, only the 0.125 rate of glufosinate in 1998 (30%) reduced rice yield when applied at panicle differentiation, again supporting the greater sensitivity of rice to glyphosate.

Rice Germination/Vigor Studies

Application timings did not affect rice germination and data are averaged across the two application timings. In 1999, simulated drift of glyphosate and glufosinate did not affect rice germination evaluated at temperatures of 13, 16, 19, 22, and 25 C, however, differences were observed among seed saved from 2000 (data not shown). Rice injury was generally higher in 2000 versus 1999 (Tables 4.1 and 4.2), which may have contributed to reductions in germination observed in 2000.

In 2000, differences in germination were not observed among the treatments when evaluated at 13 C. At 16 C, differences were not observed in rice germination 5 DAP in 2000, but by 9 DAP rice germination was reduced by the 0.032 rate and higher of glyphosate and the 0.125 and 0.063 rates of glufosinate. However, at 14 DAP, all rates of glyphosate and the two highest rates of glufosinate reduced rice germination compared to the glyphosate/glufosinate nontreated control. At 19 C, only the 0.125 and 0.063 rates of glyphosate resulted in reduction of rice seed germination 14 DAP. As temperature was increased to 22 and 25 C, more favorable for rice seed germination,

Table 4.3. Yield of non-transgenic ‘Cypress’ rice following simulated drift rates of glyphosate and glufosinate at two application timings.^a

		Rice yield ^c					
Treatment	Rate ^b	Early timing			Late timing		
		1998	1999	2000	1998	1999	2000
Glyphosate	0.125	1	95	33	46	89	71
	0.063	96	102	74	67	93	70
	0.032	95	88	93	94	104	94
	0.016	98	92	91	103	98	86
	0.008	97	102	96	90	102	97
Glufosinate	0.125	89	93	85	70	97	86
	0.063	102	103	83	86	106	93
	0.032	107	94	94	104	102	98
	0.016	100	102	102	103	92	99
	0.008	98	101	101	101	98	96
LSD (0.05)		16					

^aApplication timings correspond to 2- to 3-leaf (early timing) and panicle differentiation (late timing). Rice height based on measurement from the soil to the tip of the uppermost leaf.

^bRates correspond to 0.125, 0.063, 0.032, 0.016, and 0.008 of the labeled rates of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate.

^cYield for the nontreated control was 8,770, 5,810, and 7,860 kg/ha in 1998, 1998, and 2000, respectively.

only the 0.125 rate of glyphosate reduced rice seed germination below that of the control 14 DAP (56% vs. 89% at 22 C and 65 vs. 96% at 25 C).

Differences in rice vigor based on shoot length of germinating seeds were not dependent on herbicides or application timings. Simulated drift rates did not negatively affect rice vigor in 1999 (data not shown). However, following the 0.125 rate in 2000, vigor was reduced 18% when compared to the control (data not shown). These data suggest that glyphosate at reduced rates can affect seed germination and vigor and that caution should be used when applying glyphosate near fields used for commercial seed production. In other studies glyphosate has had a negative impact on germination of seed produced from treated plants (Clay and Griffin 2000).

Corn Field Study

Corn symptoms varied between glyphosate and glufosinate. Corn visual injury from glyphosate developed slowly and consisted of stunting and yellow and red discoloration of leaves. Symptoms caused by glufosinate developed quickly and included some stunting, however, injury mainly consisted of chlorosis and necrosis of leaves.

Significant interactions occurred among years for corn injury and height 7, 14, and 28 DAT, therefore data are presented by year. At 7 DAT, glyphosate applied early to 6-leaf corn at the 0.125 and 0.063 rates in 1997 reduced height 28 and 22% and 0.125, 0.063, and 0.032 rates in 2000 reduced corn height 87, 45, and 12%, respectively (Table 4.4). Glyphosate, however, applied early did not reduce height in 1998. When glyphosate was applied late to 9-leaf corn, the highest rate reduced height 32 and 13% in 1998 and 1999, respectively. Glufosinate reduced corn height only in 1998 at 7 DAT when applied late (12%). In 1997, all rates of glyphosate applied early injured corn (10

Table 4.4. Height and injury of non-transgenic 'Dekalb 687' corn 7 days following simulated drift rates of glyphosate and Glufosinate at two application timings.^a

Treatment	Rate ^b	Corn height						Corn injury					
		Early timing			Late timing			Early timing			Late timing		
		1997	1998	1999	1997	1998	1999	1997	1998	1999	1997	1998	1999
		% of nontreated						%					
Glyphosate	0.125	72	90	13	96	68	87	78	48	64	0	40	10
	0.063	78	96	55	100	90	97	55	24	41	0	13	5
	0.032	99	101	88	94	90	96	29	13	15	0	0	0
	0.016	100	100	98	100	88	101	25	12	0	0	0	0
	0.008	107	101	99	98	96	100	10	5	0	0	0	0
Glufosinate	0.125	96	98	92	101	88	97	46	61	54	20	29	25
	0.063	104	97	98	102	88	99	20	44	24	12	23	13
	0.032	110	103	100	104	91	111	11	24	14	3	8	5
	0.016	106	106	100	103	86	103	8	15	3	0	1	0
	0.008	107	107	103	101	85	101	4	6	0	0	0	0
LSD (0.05)		12						6					

^aApplication timings correspond to 6-leaf (early timing) and 9-leaf (late timing). Corn height based on measurement from the soil to the last fully developed collar.

^bRates correspond to 0.125, 0.063, 0.032, 0.016, and 0.008 of the labeled rates of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate.

to 78%). Corn injury was observed with the 0.016 rate and higher at the early application in 1998 (12 to 48%) and 0.032 and higher in 1999 (15 to 64%). When applied early, all rates of glufosinate injured corn in 1998 6 to 61%. The 0.016 rate and higher of glufosinate applied early injured corn 8 to 46% in 1997 and injury in 1999 ranged from 14 to 54% for the 0.032 rate and higher.

Injury was not observed in 1997 when glyphosate was applied late (Table 4.4). In 1998, however, corn was injured 13 and 40% for the two highest rates and 10% for the highest rate in 1999. When glufosinate was applied early, the 0.125 and 0.063 rates injured corn 12 to 29% over the three years.

Since corn was tasseling 7 d following the late application, corn height and injury 14 and 28 DAT represents only the early application. At 14 DAT, corn height was reduced 55 and 42% in 1997 with the two highest rates of glyphosate and with the three highest rates in 1998 (14 to 61%) and in 1999 (19 to 73%) (Table 4.5). Glufosinate did not reduce corn height 14 DAT in 1997, but height was reduced 21% in 1998 and 14% in 1999 for the highest rate. All rates of glyphosate and glufosinate injured corn 14 DAT in 1997 and ranged from 13 to 79% and 10 to 36%, respectively. In 1998, corn was injured by the 0.016 rate and higher for glyphosate (14 to 58%) and glufosinate (16 to 36%). In 1999, however, the 0.032 rate and higher of glyphosate injured corn 38 to 80% and the 0.125 and 0.063 rates of glufosinate injured corn 31 and 11%, respectively.

At 28 DAT, corn height was reduced by the two highest rates of glyphosate in 1997 (63 and 36%) and 1999 (87 and 45%), but only for the highest rate in 1998 (33%) (Table 4.5). Height reduction was not apparent for glufosinate regardless of rate. In 1997, all rates of glyphosate and glufosinate injured corn 28 DAT and ranged from 9 to

Table 4.5. Height and injury of non-transgenic 'Dekalb 687' corn 14 and 28 days following simulated drift rates of glyphosate and glufosinate applied at the 6-leaf growth stage.^a

Treatment	Rate ^b	14 DAT						28 DAT					
		Corn height			Corn injury			Corn height			Corn injury		
		1997	1998	1999	1997	1998	1999	1997	1998	1999	1997	1998	1999
		% of nontreated			% ——— % ———			% of nontreated			% ——— % ———		
Glyphosate	0.125	45	39	27	79	58	80	27	67	13	81	69	61
	0.063	58	79	29	56	43	66	64	94	55	38	23	38
	0.032	97	86	81	26	25	38	91	97	87	14	8	11
	0.016	96	89	97	21	14	3	91	99	99	18	3	0
	0.008	97	91	97	13	5	6	95	99	99	9	0	3
Glufosinate	0.125	101	79	86	36	36	31	93	94	92	13	11	10
	0.063	98	89	94	25	21	11	95	100	98	13	8	1
	0.032	99	91	96	13	21	3	102	100	100	11	5	1
	0.016	96	95	95	9	16	4	97	100	99	10	0	0
	0.008	100	95	102	10	5	0	97	99	103	14	0	0
LSD (0.05)		———— 12 ————			———— 8 ————			———— 14 ————			———— 7 ————		

^aCorn height based on measurement from the soil to the last fully developed collar.

^bRates correspond to 0.125, 0.063, 0.032, 0.016, and 0.008 of the labeled rates of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate.

81% and 10 to 14%, respectively. Corn injury for the three highest rates of glyphosate was 8 to 69% in 1998 and 11 to 61% in 1999. Injury for glufosinate was no more than 11% in 1998 and 1999. As also noted for rice, corn was able to recover from height reduction associated with glufosinate at the highest rates, but not with glyphosate. The differential response again points to the greater sensitivity of corn to glyphosate.

Even though variation in crop response was observed among years this same response was not manifested in yield. Corn yield averaged across years was reduced 78, 43, and 22% following early application of 0.125, 0.063, and 0.032 rates of glyphosate, respectively (Table 4.6). However, when application was delayed, only the highest glyphosate rate reduced corn yield (33%). For glufosinate, the 0.125 rate reduced corn yield 13 and 11% when applied at the early and late timings, respectively.

Greenhouse Studies

For the greenhouse experiments, no differences in height, injury, and dry weight responses were observed among Cypress, Bengal, Cocodrie, Drew, and Jefferson rice varieties and Dekalb 687, Asgrow 897, Pioneer 3223, Mycogen 8460, and Terral 2930 corn varieties following application of simulated drift rates of glyphosate or glufosinate (data not shown). Even though experiments were not conducted in the field, results suggest that varieties would respond similarly to the negative effects of the herbicides. Greenhouse research also clearly showed the greater sensitivity of both crops to glyphosate.

Results emphasize the negative effect that both glyphosate and glufosinate can have on rice and corn when applied at the sub-lethal rates. Both crops are more sensitive to

Table 4.6. Yield of non-transgenic 'Dekalb 687' corn following simulated drift rates of glyphosate and glufosinate at two application timings.^a

Treatment	Rate ^b	Corn yield ^c	
		Early timing	Late timing
		—— % of nontreated ——	
Glyphosate	0.125	22	67
	0.063	57	104
	0.032	78	95
	0.016	92	100
	0.008	96	93
Glufosinate	0.125	87	89
	0.063	91	92
	0.032	97	101
	0.016	96	98
	0.008	97	97
LSD (0.05)		—— 11 ——	

^aApplication timings correspond to 6-leaf (early timing) and 9-leaf (late timing). Data averaged across years.

^bRates correspond to 0.125, 0.063, 0.032, 0.016, and 0.008 of the labeled rates of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha.

^cYield for the nontreated check was 9,270 kg/ha .

glyphosate than to glufosinate, this based on the ability of plants to recover from height reduction associated with the early application. In general, glyphosate controls grasses better than glufosinate and glufosinate is generally a better broadleaf herbicide than glyphosate (Anonymous 2000; Ahrens 1994).

Variation in crop response was observed among years and may be related to inability to precisely time the applications combined with weather conditions around application that may have affected herbicide uptake (Wanamarta and Penner 1989). In regard to rice, panicle differentiation can occur over several days. Based on yield reductions associated with glyphosate, rice and corn can be classified as equally sensitive. For both crops, early applications (2- to 3-leaf rice and 6-leaf corn) of glyphosate reduced yield more than the later applications (panicle differentiation in rice and 1 wk prior to corn tasseling). At the highest rate evaluated for glyphosate (0.125 of the labeled use rate), which is typical of what could be expected from herbicide drift (Wolf et al. 1992), rice yield was reduced in 2 of 3 experiments 99 and 67% when applied early and 64 and 29% when applied late. In corn, yield following the 0.125 rate of glyphosate was reduced over 3 experiments an average of 78% when applied early and 33% when applied late. For glufosinate, corn yield was reduced 13 and 11% when applications were made early and late, respectively. These studies clearly indicate that producers should use caution when applying glyphosate and glufosinate to fields adjacent to non-herbicide resistant rice and corn.

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CHAPTER 5

SOYBEAN (*GLYCINE MAX*) AND COTTON (*GOSSYPIMUM HIRSUTUM*) RESPONSE TO SIMULATED DRIFT OF GLYPHOSATE AND GLUFOSINATE

Introduction

Glyphosate [*N*-(phosphonomethyl) glycine)] and glufosinate [2-amino-4-(hydroxymethylphosphinyl) butanoic acid] are nonselective postemergence herbicides that control many annual and perennial weeds. In general, glyphosate controls grasses better than glufosinate and glufosinate is generally a better broadleaf herbicide than glyphosate (Anonymous 2000; Ahrens 1994). Glyphosate and glufosinate were initially evaluated as preplant herbicides for use in reduced tillage cropping systems (Lanie et al. 1994a, 1994b), but their role expanded with the development of herbicide-resistant crops.

Soybean [*Glycine max* (L.) Merr.] with the glyphosate-resistance gene (Bradshaw 1997) was introduced in the U. S. in 1996 and cotton (*Gossypium hirsutum* L.) in 1997. In 1999, more than 50% of the soybean and 60% of the cotton hectareage in Louisiana was planted to glyphosate-resistant varieties (Anonymous 1999). Expanded use of glyphosate-resistant and glufosinate-resistant crops will increase use of the respective herbicides and also increase the likelihood of off-target movement to adjacent crops. Because of the diversity of cropping systems in the South, it is not uncommon for herbicide resistant crops to be planted near susceptible soybean and cotton. Consequently, potential for herbicide drift is of great concern.

Most agricultural chemicals used to control pests are applied into the atmosphere as liquid spray droplets (Hanks 1995). Conversion of a liquid into spray droplets and the

ultimate fate of the droplets depend on nozzle type, spray pressure, droplet size, environmental conditions, protective shielding, boom height, and spray additives (Bode et al. 1976; Wolf et al. 1993). Research has shown that downwind drift from unshielded sprayers ranges from 1 to 16% depending on nozzle size and wind velocity (Maybank et al. 1978; Wolf et al. 1993). Drift is especially prevalent when herbicides are applied under windy conditions or when environmental conditions favor volatilization and redistribution (Hanks 1995). Besides windy conditions at application, wet fields can delay timely herbicide application, which can increase the risk associated with off-target movement of herbicides applied aerially (Martin and Green 1995). Herbicide drift may also be the result of improper application (Wauchope et al. 1982).

Herbicide application during a temperature inversion can encourage herbicide drift (Anonymous 1993). Under ambient conditions, air is warmest at the soil surface and cooler with increasing altitude. However, during a temperature inversion, a layer of cool air forms at the soil surface capturing fine spray droplets that are displaced when wind velocity increases. The droplets eventually encounter a down draft, which propels them back to the surface. Temperature inversions are most common at dawn, dusk, and when winds are calm. To alleviate herbicide drift due to inversions, formation of spray droplets less than 100 microns during application should be avoided.

Droplet size can influence drift, especially when herbicides are applied by air as ultra low volume sprays with spray droplets less than 105 microns in size (Hanks 1995, 1997). Droplet size can be altered with nozzle selection and drift retardants specifically designed to reduce spray drift (Bouse et al. 1976). While herbicides vary in their relative drift potential (Hanks 1997; Mueller and Womac 1997), use of venturi-type

nozzles and other drift reducing nozzles may minimize their overall drift potential (Etheridge et al. 1999). However due to the larger droplet size, weed control with certain herbicides could be compromised.

Research has shown that off-target movement of herbicide during application is somewhere between 1/10 and 1/100 of the applied rate (Al-Khatib and Peterson 1999; Bailey and Kapusta 1993; Snipes et al. 1991, 1992). Even though the herbicide rates would be considered sub-lethal, response can be quite severe for susceptible crops. Previous research has investigated simulated drift of quinclorac (3,7-dichloro-8-quinolinecarboxylic acid) (Snipes et al. 1992) and triclopyr {[3,5,6-trichloro-2-pyridinyl]oxy]acetic acid} (Snipes et al. 1991) in cotton and nicosulfuron {2-[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide} and primisulfuron {2-[[[[4,6-bis(difluoromethoxy)-2-pyrimidinyl]amino]carbonyl]amino]sulfonyl]benzoic acid} in soybean (Bailey and Kapusta 1993). Injury from herbicide drift is usually worse when drift occurs early in the development of susceptible plants or when plants are in the early reproductive growth stage (Ghosheh et al. 1994; Hurst 1982; Snipes et al. 1991, 1992). However, significant injury from exposure to simulated drift rates of certain herbicides does not always result in yield losses. Levels of soybean injury were similar after exposure to simulated drift of nicosulfuron and primisulfuron, but significant yield losses occurred only for primisulfuron-treated plants (Bailey and Kapusta 1993). Weidenhammer et al. (1989) reported significant soybean injury and yield reductions when exposed to simulated drift of dicamba (3,6-dichloro-2-methoxybenzoic acid). Snipes et al. (1991) reported delayed cotton maturity and yield reduction when triclopyr was applied at early

bloom. Cotton yield was also reduced when quinclorac was applied at the cotyledon stage or at pinhead square (Snipes et al. 1992).

The objective of this research was to determine the effect of simulated drift of glyphosate and glufosinate on growth and yield of conventional, non-herbicide resistant soybean and cotton.

Materials and Methods

Soybean Field Study

Field experiments were conducted at the Ben Hur Research Farm near Baton Rouge, LA, to evaluate response of 'DPL 3588' non-herbicide resistant soybean to simulated drift rates of glyphosate and glufosinate. Soybean was planted May 26, 1998 and May 18, 1999 at a seeding rate of 130,000 seeds/ha. The experimental area was tilled and the seedbed packed prior to planting. The soil type was a Commerce silt loam (fine-silty, mixed, nonacid, thermic Aeric Fluvaquent) with a pH of 5.6 and 1.3% organic matter. Plots were maintained weed free by a preemergence application of metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] plus imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid} (1.7 + 0.14 kg ai/ha) and a postemergence application of 0.28 kg ai/ha fomesafen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-*N*-(methylsulfonyl)-2-nitrobenzamide} in early June followed by mechanical cultivation as needed.

Plots consisted of 3, 76 cm rows 7.6 m in length. The experimental design was a randomized complete block with a three-factor factorial treatment arrangement with four replications. The first and second factor was herbicide and herbicide rates. Drift rates represented 0.125, 0.063, 0.032, 0.016, and 0.008 of the use rates of 1.12 kg ai/ha

glyphosate (140, 70, 35, 18, and 9 g/ha, respectively) and 0.42 kg ai/ha glufosinate (53, 26, 13, 7, and 4 g/ha, respectively). The range of drift rates was chosen because it represents what could typically occur under field conditions (Al-Khatib and Peterson 1999; Ghosheh et al. 1994; Hurst 1982; Snipes et al. 1991, 1992). The third factor was application timing. An early postemergence application was made to soybean at 2- to 3-trifoliolate on June 17, 1998 and June 9, 1999 and a late postemergence application at first flower on July 13, 1998 and July 7, 1999. A glyphosate/glufosinate nontreated control was included for comparison. Herbicide treatments were applied using a CO₂ pressurized backpack sprayer calibrated to deliver 140 L/ha spray volume at 166 kPa. Visual injury and plant height data were collected 7, 14, and 28 days after treatment (DAT). Soybean height was based on measurement from the soil to the terminal of each plant and expressed as a percentage of the nontreated control. Height measurements 28 DAT for the first flower application were not made because DPL 3588 is a determinant variety and main stem growth had ceased shortly after flowering began. Visual injury ratings were based on a scale of 0 to 100% where 0 = no injury and 100 = complete death of the plant. Soybean was harvested October 16, 1998 and October 7, 1999 and yield was adjusted to 13% moisture. Data were subjected to analysis of variance with partitioning appropriate for the factorial arrangement of treatments. Means of significant main effects and interactions were separated using Fisher's protected LSD at the 5% level of probability.

Cotton Field Study

Non-herbicide resistant 'Delta Pine 33B' cotton was planted at the R & D Research Farm near Washington, LA, on May 8, 1998 and May 21, 1999 at a seeding rate of

130,000 seeds/ha. The experimental area was tilled and bedded prior to planting. The soil type was a Baldwin silty clay loam (fine, montmorillonitic, thermic Vertic Ochraqualf) with a pH of 5.9 and 1.4% organic matter. The fertilizer program consisted of 64-64-64 kg/ha (N-P₂O₅-K₂O) broadcast prior to planting. Three weeks after planting 65-0-0 kg/ha. The insecticide aldicarb [2-methyl-2-(methylthio) propionaldehyde O-(methylcarbamoyl)oxime] at 0.67 kg ai/ha was applied in-furrow at planting. Plots were maintained weed free by a preemergence application of 0.06 kg ai/ha pyriithobac {2-chloro-6-[(4,6-dimethoxy-2-pyrimidinyl)thio]benzoic acid} and postemergence applications of 0.28 kg ai/ha sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} followed by a postemergence-directed application of 1.1 kg ai/ha fluometuron [*N,N*-dimethyl-*N'*-[3-(trifluoromethyl) phenyl]urea] plus 2.2 kg ai/ha MSMA (monosodium salt of MAA).

Plots consisted of 3, 91.4 cm rows 7.6 m long. The experimental design was a randomized complete block with a three-factor factorial treatment arrangement with four replications. A glyphosate/glufosinate nontreated control was included for comparison. Treatments were the same as described for the soybean study with the exception of the application timings. An early postemergence application was made at 3- to 4-leaf on May 29, 1998 and June 14, 1999, a mid-postemergence application at pinhead square June 9, 1998 and June 28, 1999, and a late postemergence application at early bloom on June 30, 1998 and July 19, 1999. Visual injury and plant height data were collected 7, 14, and 28 DAT as described previously for the soybean study. Plots were monitored twice weekly for appearance of first square (flower bud) and first flower to document any delay in cotton maturity. Monitoring was based on the normal

cotton development where a square is produced every three days. When approximately 50% of the plants reached first square or first flower in the glyphosate/glufosinate nontreated control plots, days to first-square and first flower were determined. Also at flowering, nodes above white flower (NAWF) were determined from 10 plants in the center two rows of each plot each week until NAWF was less than 5 (near end of flowering period). Cotton was mechanically harvested on September 19, 1998 and September 21, 1999 and seed cotton yield was determined. Statistical analysis was as described for the soybean study.

Greenhouse Study

Since only one soybean and cotton variety was evaluated in the field, greenhouse experiments were conducted to evaluate differences in sensitivity to simulated drift of glyphosate and glufosinate using five commonly grown soybean and cotton varieties. The experimental design was a randomized complete block with a three-factor factorial arrangement of treatments with four replications. The first factor was crop variety and the second and third factors were herbicide and herbicide drift rate, respectively. DPL 3588, 'Asgrow 5959', 'Terral 5893', 'Pioneer 9594', and 'Dekalb 5850' soybean varieties and DPL 33B, 'Stoneville 474', 'Suregrow 125', 'Suregrow 747', and 'Paymaster 1560B' cotton varieties were treated with 0.125, 0.063, and 0.032 of the use rates of 1.12 kg/ha of glyphosate and 0.42 kg/ha of glufosinate at the 3-leaf stage. Rates were selected because they had caused significant crop injury in the field experiments. All treatments were applied in a spray volume of 140 L/ha at 166 kPa. Plants were grown in the greenhouse using plastic pots with a 50:50 mix of commercial potting mix¹

¹Jiffy Mix Plus, Jiffy Products of America Inc., Batavia, IL 60510.

and Olivier silt loam (fine-silty, mixed, thermic, Aeric Fluvaquent) soil. Artificial lighting was utilized to extend day length to 14 hours and temperature was maintained at 31 ± 4 C. Plants were thinned after emergence to two plants per pot. At 7 and 14 DAT, plant height and injury were recorded as described previously. At 14 DAT, above ground biomass was harvested and oven dried at 60 C for 48 h. Separate experiments and analyses were conducted for each crop and experiments were repeated. Data were subjected to analysis of variance with partitioning appropriate for the factorial arrangement of treatments. Means of significant main effects and interactions were separated using Fisher's protected LSD at the 5% level of probability.

Results and Discussion

Soybean Field Study

Soybean height was influenced only by herbicide rate and data were averaged across herbicides and application timings. At both 7 and 28 DAT, the two highest rates (0.125 and 0.063) reduced soybean height 11 and 9%, respectively (Table 5.1). Soybean height was reduced 14 DAT by only the highest rate (11%). Plant symptoms varied between glyphosate and glufosinate. Visual injury from glyphosate applied early at 2- to 3-trifoliolate consisted of stunting and chlorosis of youngest leaves. When applied late at first flower, injury was manifested as chlorosis. Injury from glufosinate consisted of some stunting, but predominantly chlorosis and necrosis of contacted leaves.

For soybean, injury 7 and 14 DAT is presented for individual years because of significant year by treatment interactions. Injury was most evident for the two highest rates of the herbicides (Table 5.2). At 7 DAT, glyphosate at 0.125 and 0.063 rates

Table 5.1. Height of non-transgenic ‘DPL 3588’ soybean 7, 14, and 28 days following simulated drift rates of glyphosate and glufosinate at two application timings.^a

Rate ^b	Soybean height ^c		
	7 DAT	14 DAT	28 DAT ^d
	% of nontreated		
0.125	89	89	89
0.063	91	95	91
0.032	98	100	102
0.016	98	101	98
0.008	98	100	92
LSD (0.05)	7	8	9

^aAveraged across years and application timings of 2- to 3-trifoliolate (early timing) and first flower (late timing).

^bRates correspond to 0.125, 0.063, 0.032, 0.016, and 0.008 of the labeled rates of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate.

^cSoybean height based on measurement from the soil to the terminal of each plant.

^dHeight was not measured 28 DAT for the late timing.

Table 5.2. Injury of non-transgenic 'DPL 3588' soybean 7, 14, and 28 days following simulated drift rates of glyphosate and glufosinate at two application timings.^a

		Soybean injury					
Herbicide	Rate ^b	7 DAT		14 DAT		28 DAT ^c	
		Early timing	Late timing	Early timing	Late timing	Early timing	Late timing
		%					
Glyphosate	0.125	29 (21) ^d	25 (17)	35 (5)	3 (0)	8	0
	0.063	18 (8)	3 (5)	9 (1)	0 (0)	0	0
	0.032	3 (4)	0 (0)	1 (0)	0 (0)	0	0
	0.016	0 (0)	3 (0)	0 (0)	0 (0)	1	0
	0.008	0 (0)	0 (0)	0 (0)	0 (0)	0	0
Glufosinate	0.125	14 (19)	40 (17)	4 (6)	14 (0)	1	0
	0.063	9 (6)	16 (5)	0 (0)	6 (0)	1	0
	0.032	0 (1)	0 (0)	0 (3)	0 (0)	0	0
	0.016	0 (0)	0 (0)	0 (1)	3 (0)	0	0
	0.008	0 (0)	0 (0)	0 (0)	0 (0)	0	0
LSD (0.05)		5		4		4	

^aApplication timings correspond to 2- to 3-trifoliolate (early timing) and first flower (late timing).

^bRates correspond to 0.125, 0.063, 0.032, 0.016, and 0.008 of the labeled rates of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate.

^cData averaged across years.

^dData are for 1998 and for 1999 in parentheses.

applied early injured soybean 29 and 18%, respectively in 1998, which was greater than in 1999 (21 and 8%, respectively). In 1998, injury from glyphosate 7 DAT was greater than observed for glufosinate (no more than 14%). The second year, injury from the two highest rates of glufosinate (19 and 6%) was equivalent to that of glyphosate. When applied late the high rate of glyphosate injured soybean 7 DAT 25% in 1998, however, in 1999, the two highest rates injured soybean 17 and 5%. The 0.125 and 0.063 rates of glufosinate injured soybean 40 and 16% in 1998 and 17 and 5% in 1999. Unlike for the early timing, glufosinate applied late in 1998 injured soybean 7 DAT more than glyphosate.

At 14 DAT, glyphosate applied at the 0.125 and 0.063 rates in 1998 injured soybean when applied early 35 to 9%, respectively, with injury at least 7 times greater than for the same rate the second year (Table 5.2). The high rate of glufosinate injured soybean in 1998 and 1999 when applied early no more than 6%. Late application of glyphosate injured soybean both years no more than 3% compared with no more than 14% for glufosinate.

At 28 DAT averaged across years, only the high rate of glyphosate applied early injured soybean (8%) (Table 5.2). The ability of soybean to recover within 28 days after early or late application of glyphosate and glufosinate was reflected in yields equal for all treatments (Table 5.3). Other research has shown the ability of soybean to recover from herbicide injury from drift rates (Bailey and Kapusta 1993). Al-Khatib and Peterson (1999) reported no reductions in soybean yield when 0.01 to 0.3 of the use rates of 1.12 kg/ha glyphosate and 0.42 kg/ha glufosinate injured 2- to 3-trifoliolate soybean 15 to 40%.

Table 5.3. Yield of non-transgenic 'DPL 3588' soybean following simulated drift rates of glyphosate and glufosinate at two application timings.^a

Herbicide	Rate ^b	Soybean yield ^c	
		Early timing	Late timing
		———— % of nontreated ————	
Glyphosate	0.125	92	91
	0.063	91	93
	0.032	97	102
	0.016	91	97
	0.008	95	91
Glufosinate	0.125	91	90
	0.063	98	99
	0.032	92	99
	0.016	92	92
	0.008	95	96
LSD (0.05)		———— NS ————	

^aApplication timings correspond to two to three trifoliate (early timing) and first flower (late timing).

^bRates correspond to 0.125, 0.063, 0.032, 0.016, and 0.008 of the labeled rates of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate.

^cData averaged across years. Yield for the nontreated check was 3,830 kg/ha.

Cotton Field Study

Cotton injury from glyphosate consisted of slight stunting from the high rate and a chlorosis of leaves. Symptoms caused by glufosinate included stunting but mostly chlorosis and necrosis of leaves.

Differences in cotton height response were not herbicide dependent, but could be attributed to herbicide rate and application timing. Height reductions were noted only for the highest herbicide rate (Table 5.4). Averaged across herbicides, cotton height was reduced 15% for the mid timing (pinhead square) 7 DAT in 1998; 20% for the early timing (2- to 3-leaf) 14 DAT in 1999; 21% for the mid timing 14 DAT in 1998; and 17% for the early timing 28 DAT in 1999.

Cotton injury data are presented for individual years because of significant year by treatment interactions. At 7 DAT, glyphosate injured cotton only at the late timing in 1998 for the 0.125 (16%) and 0.063 (5%) rates (Table 5.5). In contrast, glufosinate at the 0.032 rate and higher applied early in 1999 injured cotton 4 to 36%. For the mid timing, glufosinate at the two highest rates injured cotton 8 to 29% over the two years. Injury was 5 to 39% when the same rates were applied at the late timing over the two years.

Glyphosate at the highest rate injured cotton 0 to 13% 14 DAT and 0 to 21% 28 DAT when applied at the various timings over the years (Table 5.5). This compares with 0 to 20% 14 DAT and 0 to 9% 28 DAT for the two highest rates of glufosinate applied at the various timings. When comparing individual rates of the herbicides inconsistency in response between years was evident and in some cases injury would be higher at a specific timing for the first year with the reverse occurring for another

Table 5.5. Injury of non-transgenic 'DPL 33B' cotton 7, 14, and 28 days following simulated drift rates of glyphosate and glufosinate at three application timings.^a

		Cotton injury								
		7 DAT			14 DAT			28 DAT		
Herbicide	Rate ^b	Early timing	Mid timing	Late timing	Early timing	Mid timing	Late timing	Early timing	Mid timing	Late timing
		%								
Glyphosate	0.125	0 (5) ^c	0 (3)	16 (0)	0 (13)	4 (5)	10 (0)	0 (18)	16 (0)	21 (0)
	0.063	0 (0)	0 (0)	5 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	5 (0)
	0.032	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	0.016	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	0.008	0 (0)	0 (0)	0 (0)	0 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Glufosinate	0.125	3 (36)	29 (20)	39 (7)	0 (20)	6 (0)	19 (1)	0 (6)	3 (0)	9 (0)
	0.063	0 (20)	11 (8)	24 (5)	0 (16)	0 (0)	14 (0)	0 (4)	0 (0)	9 (0)
	0.032	0 (4)	3 (1)	5 (0)	0 (1)	0 (0)	4 (0)	0 (0)	0 (0)	0 (0)
	0.016	0 (0)	3 (0)	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	0.008	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
LSD (0.05)		4			4			4		

^aApplication timings correspond to 2- to 3-leaf (early timing), pinhead square (mid timing), and early bloom (late timing).

^bRates correspond to 0.125, 0.063, 0.032, 0.016, and 0.008 of the labeled rates of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate.

^cData for 1998 and for 1999 in parentheses.

Table 5.4. Height of 'DPL 33B', non-transgenic cotton 7, 14, and 28 days following simulated drift rates of glyphosate and glufosinate at three application timings.^a

Rate ^b	Cotton height								
	7 DAT			14 DAT			28 DAT		
	Early timing	Mid timing	Late timing	Early timing	Mid timing	Late timing	Early timing	Mid timing	Late timing
	%								
0.125	98 (88) ^c	85 (100)	97 (93)	102 (80)	79 (93)	95 (102)	93 (83)	88 (87)	95 (103)
0.063	103 (89)	100 (81)	92 (102)	103 (92)	95 (92)	92 (103)	97 (92)	97 (86)	92 (103)
0.032	96 (100)	94 (103)	94 (107)	97 (107)	89 (111)	92 (111)	94 (89)	93 (103)	93 (111)
0.016	94 (100)	92 (107)	101 (99)	91 (111)	88 (116)	101 (99)	89 (109)	94 (112)	101 (99)
0.008	98 (104)	100 (98)	97 (88)	95 (113)	96 (98)	98 (98)	95 (113)	95 (90)	98 (98)
LSD (0.05)	13			15			15		

^aApplication timings correspond to 2- to 3-leaf (early timing), pinhead square (mid timing), and early bloom (late timing).

^bRates correspond to 0.125, 0.063, 0.032, 0.016, and 0.008 of the labeled rates of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate.

^cData are for 1998 and 1999 in parentheses.

timing the second year. Variation in cotton injury observed between years may be related to inability to precisely time the applications, combined with environmental conditions around application that may have affected herbicide uptake (Wanamarta and Penner 1989). Previous research has shown significant variation in years when evaluating crop response to sub-lethal rates of herbicides (Richard 1981; Snipes et al. 1991). This may very well explain the variability in injury often observed among plants within fields suspected of exposure to sub-lethal herbicide rates due to drift.

Conclusions can be drawn from the present study that cotton was more sensitive to glufosinate than glyphosate 7 DAT, but with time, differences between herbicides were less apparent due to the ability of cotton to quickly recover (Tables 5.4 and 5.5). The fact that there were no differences in number of days to first square or flower and NAWF (data not shown), demonstrates that cotton maturity was not delayed due to drift rates of glyphosate and glufosinate. Additionally, early season injury from the herbicides (Tables 5.4 and 5.5) was not manifested in yield reductions (Table 5.6). Snipes et al. (1991) reported cotton maturity was delayed and yield was reduced when triclopyr was applied at early bloom. Also, cotton yield was reduced when quinclorac was applied at either cotyledon or pinhead square (Snipes et al. 1992).

Greenhouse Study

For the greenhouse experiments, no differences in height, injury, or dry weight were observed among the soybean or cotton varieties following simulated drift rates of glyphosate and glufosinate (data not shown). Even though these experiments were not conducted in the field, results suggest that varieties should respond similarly to the

Table 5.6. Yield of non-transgenic ‘DPL 33B’ cotton following simulated drift rates of glyphosate and glufosinate at three application timings.^a

Herbicide	Rate ^b	Yield ^c		
		Early timing	Mid timing	Late timing
		% of nontreated		
Glyphosate	0.125	105	94	108
	0.063	108	101	105
	0.032	95	106	108
	0.016	110	109	107
	0.008	108	102	95
Glufosinate	0.125	99	98	107
	0.063	105	97	107
	0.032	100	102	107
	0.016	108	110	104
	0.008	110	108	109
LSD (0.05)		NS		

^aApplication timings correspond to 2- to 3-leaf (early timing), pinhead square (mid timing), and early bloom (late timing).

^bRates correspond to 0.125, 0.063, 0.032, 0.016, and 0.008 of the labeled rates of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate.

^cData averaged across years.

negative effects of the herbicides. Greenhouse research also clearly showed the tolerance of soybean and cotton to sub-lethal rates of glyphosate and glufosinate.

In contrast to previous research evaluating corn and rice response to simulated drift of glyphosate and glufosinate (Ellis et al. 1999a, 1999b), soybean and cotton appear to be more tolerant to these herbicides. Glyphosate is very effective on grasses (Anonymous 2000; Ahrens 1994; Lanie 1994a, 1994b), which may explain the greater sensitivity of corn and rice to glyphosate. Based on injury 7 DAT, cotton was more sensitive to glufosinate than to glyphosate, but was able to recover with no ill effect on maturity or yield. The early sensitivity of cotton to glufosinate can be explained by its excellent broadleaf activity (Anonymous 2000; Ahrens 1994; Lanie 1994a, 1994b). In these studies attempts were made to apply herbicides at sub-lethal rates typical of what would be expected under drift conditions. Even though only one soybean and cotton variety was evaluated, greenhouse experiments indicate that similar response should be expected with other non-herbicide resistant varieties. Application at rates higher than evaluated in this study could be very detrimental to both soybean and cotton. Precautions should be used to prevent off-target movement of glyphosate and glufosinate to sensitive crops.

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CHAPTER 6

EFFECT OF CARRIER VOLUME ON CORN (*ZEA MAYS*) AND SOYBEAN (*GLYCINE MAX*) RESPONSE TO SIMULATED DRIFT OF GLYPHOSATE AND GLUFOSINATE

Introduction

Development of herbicide resistant crops has offered novel weed management options with economical advantages to growers (Burnside 1992; Culpepper and York 1998, 1999; Wyse 1992). In particular, availability of crops with resistance to glyphosate [*N*-(phosphonomethyl) glycine]] and glufosinate [2-amino-4-(hydroxymethylphosphinyl) butanoic acid] has increased. A major concern associated with proliferation of herbicide resistant crops, however, is potential for misapplication and likelihood of increased incidence of off-target herbicide movement to sensitive crops. Herbicide drift occurs when wind causes spray droplets to be displaced from their intended flight path. Wolf et al. (1992) reported drift from unshielded sprayers ranged from 2 to 16% depending on nozzle size and wind velocity. Herbicide drift is especially prevalent when herbicides are applied under windy conditions or when environmental conditions favor volatilization and redeposition (Hanks 1995; Wall 1994).

Herbicide drift is most often the result of improper application (Wauchope et al. 1982). Wind speed and boom height above the intended target are primary contributors to herbicide drift (Hatterman-Valenti et al. 1995). Environmental conditions can also have an effect on herbicide drift (Bouse et al. 1976). Besides windy conditions and temperature inversions at application, wet fields can delay timely herbicide application,

which can increase the risk associated with off-target movement of herbicides applied aerially (Martin and Green 1995).

Simulated drift of MSMA (monosodium salt of MAA) in rice (*Oryza sativa* L.) (Richard et al. 1981), quinclorac (3,7-dichloro-8-quinolinecarboxylic acid) (Snipes et al. 1992) and triclopyr [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid] (Snipes et al. 1991) in cotton, pyriithiobac {2-chloro-6-[(4,6-dimethoxy-2-pyrimidinyl)thio]benzoic acid} (Ghosheh et al. 1994) in corn (*Zea mays* L.), and nicosulfuron {2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide} and primisulfuron {2-[[[[(4,6-bis(difluoromethoxy)-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid} (Bailey and Kapusta 1993) in soybean has been investigated. Injury symptoms from herbicide drift are usually worse when drift occurs to the susceptible crop early in its development (Ghosheh et al. 1994; Hurst 1982). In addition to initial foliar damage, herbicide drift can be manifested as loss of tuber quality in potatoes (*Solanum tuberosum* L.) (Eberlein and Guttieri 1994), delays in fruit maturity in sweet cherries (*Prunus avium* L.) (Al-Khatib et al. 1992b), reduced boll production in cotton (Snipes et al. 1991), straighthead symptoms in rice (Richard et al. 1981), stand reductions in alfalfa (*Medicago sativa* L.) (Al-Khatib et al. 1992a), and reduced yield in corn and rice (Ellis et al. 1999a, 1999b).

In previous research, simulated drift was accomplished by varying herbicide rate with application in a constant carrier volume (Bailey and Kapusta 1993; Ellis et al. 1999a, 1999b; Ghosheh et al. 1994; Snipes et al. 1991, 1992). In these studies, carrier volumes ranged from 140 to 187 L/ha. Using this methodology, though providing dose response information, does not reflect what occurs in typical field situations. In the

field, drift occurring from aerial or ground equipment would decrease with movement away from the point of application and herbicide rate and spray volume would diminish proportionally. Research conducted in New Mexico by Banks and Schroeder (2000) addresses this concern and evaluated the effect of varying the carrier volume proportionally with rates of glyphosate on sweet corn (*Zea mays* var. *rogusa* Bonaf) and 2,4-D [2,4-(dichlorophenoxy)acetic acid] on cotton. For both crops and for the same herbicide rate, greater injury and height and yield reductions were observed for the variable carrier volume compared with constant carrier volume.

Drift of glyphosate to sensitive crops in the South has increased in recent years and observations have been that crop injury at sub-lethal rates was much greater than has been reported in the literature for simulated drift studies (Griffin, personal communication). These differences may be due to carrier volume. Of interest is that environmental conditions in the mid-South (high soil moisture and humidity) may result in even greater differences between constant and proportional spray volume than has been reported by Banks and Schroeder (2000) in New Mexico.

It is already established that weed control with glyphosate can be significantly influenced by carrier volume (Buhler and Burnside 1983a, 1983b; Stahlman and Phillips 1979). At a reduced rate of glyphosate (0.1 to 0.4 kg ai/ha), phytotoxicity to oats (*Avena sativa* L. 'Stout') was increased when carrier volume was decreased from 190 to 24 L/ha (Buhler and Burnside 1983b). The objective of this research was to evaluate the effect of carrier volume on corn and soybean response to sub-lethal simulated drift rates (1/8 and 1/16 of the labeled rates) of glyphosate and glufosinate under mid-South environmental conditions.

Materials and Methods

Field experiments were conducted in 2000 at the R & D Research Farm near Washington, LA, and at the Ben Hur Research Farm near Baton Rouge, LA, to determine if varying the carrier volume proportionally to rates of glyphosate and glufosinate would change corn and soybean response compared to maintaining a constant carrier volume. The soil type at the R & D Research Farm was a Baldwin silty clay loam (fine, montmorillonitic, thermic Vertic Ochraqualf) with pH of 5.9 and 1.4% organic matter. The soil type at the Ben Hur Research Farm was a Commerce silt loam (fine-silty, mixed, nonacid, thermic Aeric Fluvaquent) with pH of 5.6 and 1.3% organic matter. Both soils are representative of corn and soybean producing areas of Louisiana. Separate studies were conducted for corn and soybean and the experimental design for each was a randomized complete block with a three-factor factorial treatment arrangement with four replications. The first and second factors were herbicide and herbicide drift rate. Drift rates represented 0.125 (1/8) and 0.063 (1/16) of the use rates of 1.12 kg ai/ha glyphosate¹ (140 and 70 g/ha, respectively) and 0.42 kg ai/ha glufosinate² (53 and 26 g/ha, respectively). A glyphosate/glufosinate nontreated control was included for comparison. The third factor was carrier volume. Rates for each herbicide were applied in constant carrier volume of 233.9 L/ha and in proportional carrier volumes of 29.3 L/ha for the 0.125 rate and 14.7 L/ha for the 0.063. Only two rates of each herbicide were evaluated because of the difficulty of obtaining carrier

¹ Roundup Ultra™ (479 g/L of glyphosate), Monsanto Company, St. Louis, MO 63167.

² Liberty™ (200 g/L of glufosinate), Aventis CropScience, Research Triangle Park, NC 27709.

volumes below 14.7 L/ha with the equipment used. Also, previous research in Louisiana has shown that injury from drift rates of glyphosate and glufosinate on corn and soybean was not observed at less than 0.063 of the labeled rates (Ellis et al. 1999a, 1999b).

Herbicide treatments were applied using a tractor mounted compressed air sprayer with a spray pressure of 186 kPa. A TurboTeejet³ 110005 nozzle was used for all treatments and tractor speed was adjusted to obtain the desired carrier volumes. Tractor speed was 1.0 km/h for the constant carrier volume and 8.1 and 16.1 km/h for the 29.3 and 14.7 L/ha proportional carrier volumes, respectively.

Corn Study

Nontransgenic 'Dekalb 687' corn was planted at 74,000 seeds/ha at the Ben Hur Research Farm on April 3 and on March 26 at the R & D Research Farm. The experimental area was tilled and bedded prior to planting. The fertilizer program at the Ben Hur Research Farm consisted of 64-64-64 kg/ha (N-P₂O₅-K₂O) broadcast prior to planting and 11-37-00 kg/ha in-furrow at planting. Three weeks after planting 65-0-0 was side dressed. The insecticides terbufos {S-[[[(1,1-dimethylethyl)thio]methyl]O,O-diethyl phosphorodithioate} (1.12 kg ai/ha) and permethrin [(3-phenoxyphenyl)methyl(+)-*cis, trans*-3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate] (0.22 kg ai/ha) were applied in-furrow at planting. The fertilizer program at the R & D Research Farm consisted of 200-30-30 side dressed three weeks after planting. The insecticide chlorpyrifos [O,O-diethyl-O-(3,5,6-trichloro-2-pyridinyl)] (2.0 kg ai/ha) was applied in-furrow at planting. At both locations plots were maintained weed free by a

³ Teejet Agricultural Spray Products. Spraying Systems Co. Wheaton, IL. 60189.

preemergence application of atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] plus metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] (2.17 + 1.79 kg ai/ha) the day of planting and mechanical cultivation as needed.

Corn plots consisted of four, 91.4 cm rows 12.2 m long at the R & D Research Farm and four, 96.5 cm rows 7.6 m long at the Ben Hur Research Farm. Herbicide treatments were applied to the two center rows when corn was at the 6-leaf growth stage on May 4 at the Ben Hur Research Farm and on April 27 at the R & D Research Farm. Visual injury and plant height data were collected 7, 14, and 28 days after treatment (DAT). Visual injury was based on a scale of 0 to 100% with 0 = no plant injury and 100% = complete death of the plant. Chlorosis, necrosis, and plant stunting were used when making visual estimates. Corn height was based on measurement from the soil to the last fully developed collar and was expressed as a percentage of the nontreated glyphosate/glufosinate control. Corn was harvested on August 17 at the R & D Research Farm and August 15 at the Ben Hur Research Farm. Seed corn yield was adjusted to 15% moisture and expressed as a percentage of the control. Data were subjected to analysis of variance with partitioning appropriate for the factorial arrangement of treatments. Means of significant main effects and interactions were separated using Fisher's protected LSD at the 5% level of probability.

Soybean Study

'DPL 3588', a nontransgenic soybean variety, was planted at 130,000 seeds/ha at the Ben Hur Research Farm on May 5 and at the R & D Research Farm on May 20. Plots at the Ben Hur Research Farm were maintained weed free by a preemergence

application of 1.7 kg/ha metolachlor plus 0.14 kg ai/ha imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-quinolinecarboxylic acid}. Plots were maintained weed free at the R & D Research Farm by a postemergence application of 0.28 kg ai/ha fomesafen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-*N*-(methylsulfonyl)-2-nitrobenzamide} on June 30 followed by 0.28 kg ai/ha sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} on July 10.

Soybean plots consisted of four, 96.5 cm rows 9 m long at the Ben Hur Research Farm and four, 91.4 cm rows 12 m long at the R & D Research Farm. Herbicide treatments were applied to the two center rows when soybean was at the two to three trifoliate growth stage on June 6 at the Ben Hur Research Farm and on July 5 at the R& D Research Farm. Visual injury and plant height data were collected 7, 14, and 28 DAT. Soybean height was measured from the soil to the terminal of each plant and expressed as a percentage of the nontreated glyphosate/glufosinate control. Soybean was harvested on September 28 at the Ben Hur Research Farm and on October 23 at the R & D Research Farm. Soybean seed yield was adjusted to 13% moisture and expressed as a percentage of the nontreated control. Statistical analysis was as described for the corn study.

Results and Discussion

Corn Study

Differences in corn height and injury, and yield reductions were not herbicide dependent; therefore, data were averaged across herbicides. At 7 DAT, corn height was reduced more when the 0.125 rate was applied in proportional carrier volume of 29.3

L/ha compared to the constant carrier volume of 233.9 L/ha, but in both cases height was reduced at least 23% (Table 6.1). For the 0.063 rate, corn height was reduced no more than 9% for the carrier volumes. Even though a significant portion of corn injury was from height reduction, injury was also manifested as leaf chlorosis and necrosis. Corn injury increased from 32 to 45% for the 0.125 rate and 18 to 36% for the 0.063 rate when the carrier volume was adjusted proportionally with herbicide rate.

At 14 DAT, corn height continued to be reduced more when the 0.125 rate was applied in proportional carrier volume (45%) compared to constant carrier volume (28%) (Table 6.1). The 0.063 rate reduced corn height 38% when applied in proportional carrier volume, but not when the same rate was applied in constant carrier volume. Corn injury at 14 DAT changed little from that observed 7 d earlier and was only 18% when the 0.063 rate was applied in the constant spray volume.

At 28 DAT, corn height reduction and injury was still apparent and most severe for both herbicide rates when applied in proportional rather than a constant spray volume (Table 6.1). Corn height was reduced only 10% when the 0.063 rate was applied in constant carrier volume, however height reduction increased to 38% when applied in proportional carrier volume. Corn injury when the 0.125 rate was applied in proportional carrier volume was 46%, 13 percentage points higher than for the constant carrier volume. Corn injury for the 0.063 rate doubled when the carrier volume was adjusted proportionally to the herbicide drift rate (18 to 37%).

Corn symptoms varied between glyphosate and glufosinate. Visual injury from glyphosate developed slowly and consisted of severe stunting of plants and a yellow to red discoloration of stems and leaves. Symptoms caused by glufosinate developed

Table 6.1. Corn height and injury 7, 14, and 28 days after treatment and yield following simulated drift rates of glyphosate and glufosinate applied at 6-leaf growth stage.^a

Herbicide rate ^b	Application carrier volume ^c	Corn height ^d			Corn injury			Yield ^d
		7	14	28	7	14	28	
	L/ha	— % of nontreated —			— % —			% of nontreated
0.125	233.9	77	72	82	32	33	33	59
	29.3	71	55	58	45	51	46	38
0.063	233.9	91	93	90	18	18	13	87
	14.7	93	62	62	36	38	37	48
LSD (0.05)		5	8	12	4	5	12	10

^aData averaged across herbicides and locations.

^bRates correspond to 0.125 and 0.063 of the labeled rate of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate.

^cThe constant carrier volume was 233.9 and variable carrier volumes, adjusted proportionally with the simulated drift rate, were 29.3 and 14.7 L/ha for the 0.125 and 0.063 rates, respectively.

^dCorn height was measured from the soil to the last fully developed collar. Yield for the nontreated glyphosate/glufosinate control was 9,820 kg/ha.

quickly and included slight stunting, however, injury mainly consisted of chlorosis followed by necrosis of treated leaves. Even though the herbicides responded similarly when carrier volume was adjusted, injury and height reductions when averaged across all other factors were twice as severe for glyphosate compared to glufosinate. The fact that herbicide response to carrier volume was consistent is noteworthy due to differences in uptake and translocation for glyphosate and glufosinate. Glyphosate is readily translocated throughout the plant; therefore symptoms appear later when compared to glufosinate, which is more of a contact type herbicide, with little or no translocation occurring in the plant (Ahrens 1994).

Corn yield was reduced only 13% when the 0.063 rate was applied in constant carrier volume compared with 52% when the same rate was applied in proportional volume (Table 6.1). As expected, when rate was increased, greater yield reduction was observed. The 0.125 rate applied in constant carrier volume reduced corn yield 41%, but 62% when applied in proportional carrier volume. These results showing differences in response due to carrier volume agree with those reported in New Mexico with 2,4-D on cotton and glyphosate on sweet corn (Banks and Schroeder 2000).

Of interest is that when comparing herbicide rates, yield reduction was 36 and 45% greater for the proportional compared with the constant spray volume for the 0.125 and 0.063 rates, respectively. In reality, in a field situation where drift occurs, rate diminishes as distance away from the application site increases. As rate decreases, spray volume also decreases proportionally to one another. Results clearly show a greater negative impact of herbicide rate as spray volume is adjusted proportionally when compared with a constant spray volume. This obvious differential response may

explain why higher yield reductions from sub-lethal glyphosate rates have been observed where actual drift occurred (Griffin, personal communication).

Possible explanations for the differences in response between carrier volumes for glyphosate and glufosinate may be related to water hardness, surfactant concentration, and spray droplet dynamics. Researchers have shown that the activity of glyphosate can be reduced when carrier volume is increased (Sanberg et al. 1978; Stahlman and Phillips 1979). Most believe this is attributed to water hardness (Hatzios and Penner 1985; Nalewaja and Matysiak 1991, 1993). Water is determined to be “hard” if total hardness is 100 ppm or higher. When glyphosate is applied in hard water Ca, Mg, and other cations interact with the glyphosate molecule forming a complex that is less readily absorbed by the plant. This situation has been overcome by adding ammonium sulfate to the spray solution (Thelen et al. 1995). For the two experiments conducted in the present study, analysis of water showed only one source to be hard-water (281 ppm). Since a location by experiment interaction was not observed, water hardness was ruled out as an explanation. Also, there were no reports in the literature showing that glufosinate is susceptible to decreased activity in hard-water. Both glyphosate and glufosinate responded the same in this study, also ruling out hard-water as a culprit.

Both the glyphosate and glufosinate formulations used in our research were formulated with a surfactant, and no surfactant was added to the spray solution. A plausible explanation for the difference in response due to carrier volume may be related to spray droplet number and herbicide/surfactant concentration in individual spray droplets. At the 29.3 and 14.7 L/ha spray volumes in this study, spray droplets would have been more concentrated with herbicide and surfactant compared to the

233.9 L/ha spray volume, which may have enhanced herbicide uptake. Research has shown greater activity of glyphosate at lower spray volumes (Buhler and Burnside 1983a, 1983b; Sandberg et al. 1978; Stahlman and Phillips 1979). Ambach and Ashford (1982) reported glyphosate applied in ultra low volumes had a greater phytotoxic effect on barley at a given rate than a high diluent volume application. It could be speculated that the high spray volume (233.9 L/ha) used to make comparisons in the present study was atypical of field situations and may have actually decreased herbicide activity due to surfactant dilution. If so, then differences in response between carrier volumes would have been even greater. Furthermore, yield reductions in corn in the present study where a constant spray volume of 233.9 L/ha was used mirror those reductions observed in previous research where the same rates were applied in 140.3 L/ha (Ellis et al. 1999a).

Soybean Study

Unlike corn, differences in soybean response were not affected by carrier volume, but could be attributed to the herbicides. Soybean height was reduced by the 0.125 rate of glyphosate 23, 20, and 16% at 7, 14, and 28 DAT, respectively (Table 6.2). Neither of the rates of glufosinate or the 0.063 rate of glyphosate reduced soybean height at the three evaluation dates. Ellis et al. (1999b) reported that simulated drift rates of glufosinate (3 to 51 g/ha) did not significantly reduce soybean height and that height reductions with glyphosate were rate dependent. At 7 and 14 DAT in the present study, both rates of glyphosate and glufosinate injured soybean, clearly indicating that injury was more related to chlorosis/necrosis than to height reduction (Table 6.2). The 0.125 and 0.063 rates of glyphosate injured soybean 31 and 19%, respectively, 7 DAT, but

Table 6.2. Soybean height and injury 7, 14, and 28 days after treatment and yield following simulated drift rates of glyphosate and glufosinate applied at the 2- to 3-trifoliolate growth stage.^a

Herbicide	Rate ^b	Soybean height ^c			Soybean injury			Yield ^c
		7	14	28	7	14	28	
		—— % of nontreated ——			—— % ——			% of nontreated
glyphosate	0.125	77	80	84	31	23	13	87
	0.063	95	95	97	19	8	7	92
glufosinate	0.125	92	92	96	26	13	3	91
	0.063	91	93	92	16	12	1	93
LSD (0.05)		10	9	11	7	5	3	NS

^aData averaged across application carrier volumes (233.9 L/ha for constant and 29.3 and 14.7 L/ha adjusted proportionally to herbicide rate) and locations.

^bRates correspond to 0.125 and 0.063 of the labeled rate of 1.12 kg ai/ha glyphosate and 0.42 kg ai/ha glufosinate.

^cSoybean height measured from the soil to the terminal. Yield for the nontreated glyphosate/glufosinate control was 2,290 kg/ha.

injury was reduced to 23 and 8%, respectively at 14 DAT. Glufosinate at the 0.125 and 0.063 rates injured soybean 26 and 16%, respectively, 7 DAT and 13 and 12%, respectively, at 14 DAT. By 28 DAT, injury was 13% for the 0.125 rate of glyphosate, but was no more than 7% for the other herbicide rates.

Soybean symptoms varied between glyphosate and glufosinate. Visual injury from glyphosate consisted of some stunting of plants at the high rate and yellowing in the terminals of treated plants. Symptoms caused by glufosinate consisted of chlorosis followed by necrosis of treated leaves. No stunting of plants was observed following glufosinate application.

Even though soybean injury was significant at all rating intervals, soybean recovered rapidly and no negative effect on yield was observed (Table 6.2). Findings agree with those of Al-Khatib and Peterson (1999) who reported no reductions in soybean yield when exposed to 0.01 to 0.3 of the use rates of 1.12 kg/ha glyphosate and 0.42 kg/ha glufosinate at the two to three trifoliolate growth stage. The fact that differences in soybean height, injury, and yield were carrier volume independent in the present study shows that soybean are inherently less sensitive than corn to these two herbicides.

This research clearly shows that adjusting carrier volume from constant to proportional based on herbicide rate increases the negative effects of glyphosate and glufosinate on corn injury and yield. This response however, was not observed when herbicides were applied to soybean, a less sensitive crop. Traditional simulated herbicide drift research where dose response is evaluated over a constant spray volume does not represent what would occur under field situations and results may

underestimate yield reductions. Results clearly demonstrate the importance of using caution when applying glyphosate or glufosinate near non-target, sensitive crops.

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CHAPTER 7

SUMMARY

Field studies were conducted to evaluate weed control in glyphosate-resistant soybean and implications off-target movement of glyphosate [*N*-(phosphonomethyl) glycine] and glufosinate [2-amino-4-(hydroxymethylphosphinyl) butanoic acid] to susceptible crops.

Research conducted 3 yr evaluated the utility of preemergence (PRE) soil-applied herbicides in glyphosate-resistant soybean. Soil-applied herbicide treatments at full label rates included pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] plus imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid} (0.84 + 0.14 kg ai/ha), pendimethalin (1.12 kg/ha), metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] (1.68 kg ai/ha), SAN 582 [2-chloro-*N*-(2,4-dimethyl-3-thienyl)-*N*-(2-methoxy-1-methylethyl)] plus imazaquin (1.0 + 0.14 kg ai/ha), sulfentrazone {*N*-[2,4-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1*H*-1,2,4-triazol-1-yl]phenyl]methanesulfonamide} plus chlorimuron {2-[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid} (0.22 + 0.04 kg ai/ha), and metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one] plus chlorimuron (0.36 + 0.06 kg ai/ha). In most instances, differences in weed density and height (14 to 28 days after soybean planting) were not noted when preemergence herbicide rates were reduced from the full to half rates and none of the treatments provided complete weed control. In 1998, all soil-applied herbicide treatments provided an extra 3 to 5 days before the first glyphosate

application was needed compared to no preemergence herbicide. For 1999, the full rate of metribuzin plus chlorimuron extended the application time for glyphosate 6 d and in 2000, 7 d for the full rates of sulfentrazone plus chlorimuron and metribuzin plus chlorimuron. Where soil applied herbicide was not used, a second glyphosate application was needed only in 1998. Soybean yield was equivalent for all herbicide treatments further showing a total postemergence program using glyphosate was as effective as when PRE herbicides are applied at half or full rates and followed by glyphosate.

Research conducted over 3 yr evaluated grass and broadleaf weed control in soybean with glyphosate alone and in combination with reduced rates of the broadleaf herbicides chlorimuron, acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid}, fomesafen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-*N*-(methylsulfonyl)-2-nitrobenzamide}, lactofen {(±)-2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate}, or CGA-277476 {2-[[[[(4,6-dimethyl-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid}. Barnyardgrass control was at least 94% with glyphosate at 0.84 and 1.12 kg ai/ha and was not antagonized with any of the combinations. At 14 days after treatment (DAT) wild poinsettia and prickly sida control in most cases was greater than 90% when glyphosate was applied alone or in the combinations. By 28 DAT, in 1 of 2 experiments wild poinsettia was controlled 80% and prickly sida 43% with the high rate of glyphosate and addition of acifluorfen or fomesafen (0.21 and 0.32 kg ai/ha), or lactofen (1.12 and 1.68 kg ai/ha) increased control of wild poinsettia to 91 to 95% and prickly sida to 60 to 80%. For pitted morningglory and hemp sesbania, control 14 DAT in most cases was improved with the

addition of chlorimuron (0.0045 and 0.0067 kg/ha) or CGA-277476 (0.39 and 0.59 kg/ha). By 28 DAT, improved control with the combinations was noted in only 1 of 3 experiments when pitted morningglory and hemp sesbania were larger at application. In the other two experiments, pitted morningglory was controlled 91 to 98% and hemp sesbania 88 to 100% with glyphosate alone at 1.12 kg/ha. Soybean injury 28 DAT was as high as 13, 15, and 23% for the chlorimuron, acifluorfen, and lactofen treatments, respectively, but no more than 6% for fomesafen and CGA-277476. Soybean yield was determined only for the experiments where glyphosate alone provided good to excellent weed control and the combinations did not improve yield.

Results indicate that tank-mixtures of glyphosate plus the broadleaf herbicides can increase control of wild poinsettia, prickly sida, pitted morningglory, and hemp sesbania, especially when weeds are too large to be effectively controlled with glyphosate alone. Increasing the rate of either the broadleaf herbicides or glyphosate did not in most cases increase weed control and in no instances was barnyardgrass control antagonized with the herbicide combinations. The variation in control for some of the weed species from year to year was related in part to weed size at application combined with excellent growing conditions following application. Results emphasize the importance of early applications, especially when glyphosate is used as a stand alone product. It would be expected that an advantage would be seen when efficacious broadleaf herbicides are applied with glyphosate when glyphosate rate is insufficient to consistently control problem weeds. Even though in this study yield differences among treatments were not detected even though some differences in weed control occurred,

weed regrowth and emergence through the soybean canopy in late season could impact harvest efficiency and crop quality.

Field studies were conducted to evaluate response of rice, corn, soybean, and cotton to simulated drift rates representing 0.125, 0.063, 0.032, 0.016, and 0.008 of the use rates of 1.12 kg/ha glyphosate and 0.42 kg ai/ha glufosinate. Early applications were made to 2- to 3-leaf rice, 6-leaf corn, 2- to 3-trifoliolate soybean, and 2- to 3-leaf cotton and late applications to rice at panicle differentiation, corn at 9-leaf (one week prior to tasseling), soybean at first flower, and cotton at early bloom. A mid-postemergence application was also made to cotton at pinhead square (first flower bud). Crop injury was generally higher for the 0.125 and 0.063 rates for both herbicides when applied early. Little to no reduction in rice, corn, soybean, or cotton height was observed with glufosinate.

For rice, glyphosate consistently reduced plant height when the two highest rates were applied early and heading was delayed 5 and 2 days, respectively. In two of three year, the highest rate of glyphosate reduced rice yield 99 and 67% when applied early and 54 and 11% when applied late. Germination of rice seed from glyphosate-treated plants was reduced in one of two yr and with only the highest rate. For glufosinate, rice yield was reduced 30% and in only one year when applied late at the highest rate.

Early applications of glyphosate reduced corn yield an average of 22 to 78% for the three highest rates, but only for the highest rate at the late timing. Corn yield was reduced an average of 13 and 11% for the highest rate of glufosinate at the early and late timing, respectively. Soybean height was reduced no more than 11% regardless of herbicide rate or timing. Based on visual injury, soybean was more sensitive to

glyphosate when applied early in 1998, but equal for the herbicides in 1999. When herbicides were applied late, soybean was more sensitive to glufosinate the first year. Cotton was more sensitive to glufosinate 7 d after application both years regardless of timing, but by 28 d differences between herbicides were less apparent. Cotton maturity was not delayed by either herbicide based on days to first square or flower, and nodes above white flower. Both soybean and cotton were able to rapidly recover from herbicide injury and yields were not negatively affected. In greenhouse studies, five rice, corn, soybean, and cotton varieties were equally sensitive to reduced rates of glyphosate and glufosinate.

Variation in crop response observed among years may be related to inability to precisely time the applications combined with weather conditions around application that may have affected herbicide uptake. Based on yield reductions associated with glyphosate, rice and corn can be classified as equally sensitive. For both crops, early applications of glyphosate reduced yield more than the later applications. In contrast, soybean and cotton appear to be more tolerant to these herbicides. Based on injury 7 DAT, cotton was more sensitive to glufosinate than to glyphosate, but was able to recover with no ill effect on maturity or yield.

In these studies attempts were made to apply herbicides at sub-lethal rates typical of what would be expected under drift conditions. Application at rates higher than evaluated in this study could be very detrimental.

In traditional simulated herbicide drift research, dose-response is evaluated using a constant carrier volume. Typically when drift occurs under field conditions, spray volume and dose vary proportionally. In field experiments, the influence of carrier

volume was evaluated with drift rates representing 0.125 and 0.063 of the use rates of 1.12 kg/ha glyphosate and 0.42 kg/ha glufosinate. Corn and soybean were exposed to herbicide rates applied in constant carrier volume of 234 L/ha and in proportional carrier volumes to include 29.3 and 14.7 L/ha for the 0.125 and 0.063 rates, respectively. Differences in corn response were not herbicide dependent. Averaged across herbicides, corn height reduction 14 DAT was greater for the 0.125 rate when applied in proportional carrier volume (45%) compared to constant carrier volume (28%). The 0.063 rate reduced corn height 38% when applied in proportional carrier volume, but not when applied in constant carrier volume. When carrier volume was changed from constant to proportional, injury 14 DAT increased from 33 to 51% for the 0.125 rate and 18 to 38% for the 0.063 rate. Compared to constant spray volume, corn yield reduction was about 1.6 times greater when spray volume was varied proportionally to the herbicide rates. Differential response due to carrier volume was not observed when herbicides were applied to soybean, a less sensitive crop. Soybean was injured more by glyphosate than glufosinate, but recovery was rapid and yield was not negatively affected.

This research clearly shows that adjusting carrier volume from constant to proportional based on herbicide rate increases the negative effects of glyphosate and glufosinate on corn injury and yield. This response however, was not observed when herbicides were applied to soybean, a less sensitive crop. Traditional simulated herbicide drift research where dose response is evaluated over a constant spray volume does not represent what would occur under field situations and yield reductions may be underestimated.

The research described in this dissertation is significant in that it provides information critical to making sound weed management decisions in glyphosate-resistant soybean. Also, information on the effects of glyphosate and glufosinate drift on rice, corn, soybean, and cotton is important since use of both herbicides will increase along with potential for off-target movement.

VITA

Jeffrey Mark Ellis was born in Greenville, Mississippi, on April 27, 1972. He attended Washington School and graduated in May, 1990. He then attended Mississippi Delta Community College for two years before transferring to Mississippi State University. He graduated *cum laude* from Mississippi State University in May 1995, with a bachelor of science degree in Agricultural Pest Management. Upon graduation, he accepted an assistantship in the Department of Plant Soil Science at Mississippi State University in weed science under the direction of Dr. David R. Shaw. He graduated with a master of science in weed science in May, 1997. Before graduating, he accepted a research associate position in the Department of Plant Pathology and Crop Physiology in weed science under the direction of Dr. James L. Griffin. He is currently a candidate for the degree of Doctor of Philosophy in plant health with an educational and research emphasis in weed science.

While at Louisiana State University, Jeff received the Louisiana Agricultural Consultant's Association scholarship in 1998 and 2001 and the American Society of Sugarcane Technologist Scholarship in 2001. Jeff presented numerous papers and posters at professional meetings and won first place for the best paper – Soil and Environmental Aspects of Weed Science Section at the Southern Weed Science Society meeting in 2001 and second place in the poster section in 1998. Jeff has also been an active participant in the Southern Weed Science Society Annual Weed Contest where he was a second place team member in 1997 and 1999 and a coach of the third place team in 2000. He was also seventh place individual at the 1999 contest.


DOCTORAL EXAMINATION AND DISSERTATION REPORT

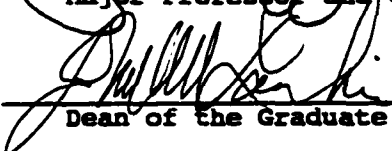
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Major Field: Plant Health

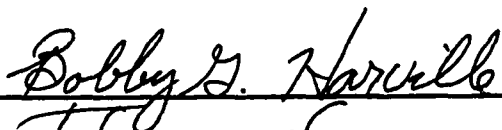
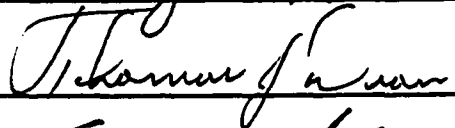

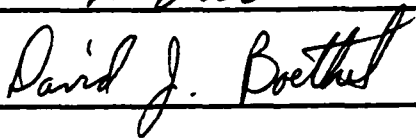
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