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Wheat (Triticum aestivum) response to simulated drift of glyphosate

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WHEAT (*TRITICUM AESTIVUM*) RESPONSE TO SIMULATED DRIFT OF GLYPHOSATE

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TABLE OF CONTENTS

ABSTRACT

Field research evaluated response of ‘USG 3209’ wheat to glyphosate drift representing 12.5, 6.3, and 1.6% of the usage rate of 1,120 g ai/ha (140, 70, and 18 g/ha, respectively). Applications in 140 L/ha spray volume were made at first node in late February/late March, boot stage in late March/early April, and early flowering in early to mid-April. Bleaching of leaf foliage was observed for all glyphosate rates regardless of application timing. Height 28 days after treatment (DAT) was reduced 47% with glyphosate applied at 140 g/ha at first node and around 26% for 70 g/ha applied at first node or 140 g/ha applied at boot stage. Yield was reduced 72% when glyphosate was applied at 140 g/ha at first node, 45% when applied at boot stage, and 54% when applied at flowering. For 70 g/ha wheat yield was reduced 25 to 30% for the three application timings, but yield was not reduced for 18 g/ha. In another study, response of six wheat varieties to glyphosate was the same as that observed for USG 3209.

The influence of carrier volume was evaluated where glyphosate at drift rates representing 12.5 and 6.3% of 1,120 g/ha was applied to USG 3209 wheat at first node in late February/late March and at heading in early to mid-April. Glyphosate was applied in constant carrier volume of 234 L/ha where herbicide concentration declined with reduction in dosage and in carrier volumes adjusted proportionally to glyphosate rate to include 30 L/ha for 12.5% rate and 15 L/ha for 6.3% rate. Glyphosate applied at first node in proportional carrier volume reduced height 42% 28 DAT, 2.8 times the reduction for glyphosate applied in 234 L/ha. Height reduction was no more than 15% when glyphosate was applied at heading regardless of carrier volume. Yield was reduced 42% when glyphosate at 140 g/ha was applied in 234 L/ha, but was reduced 54% when applied in proportional carrier volume. For 70 g/ha glyphosate applied in 234 L/ha yield

was reduced 11%, but yield reduction was almost 4 times greater when applied in proportional carrier volume.

CHAPTER 1

INTRODUCTION

Wheat (*Triticum* spp.), the world's most widely cultivated crop, in 2000, world wheat production was approximately 572 million metric tons on 205 million hectares (Anonymous 2002, Stoskopf 1985). Of the cereal crops, wheat accounts for the greatest volume of international trade. Wheat is the staple food for about 40% of the world's population (Wiese 1987). Common bread wheat (*T. aestivum,* L.) and durum wheat (*T . durum* Desf.) make up 90% of the world's wheat crop. Wheat is further classified as winter or spring, hard or soft, red or white, and by protein content (Briggle and Curtis 1987). The majority of wheat produced is used for human consumption. Bread wheats are used in making bread, rolls, cakes, cookies, and pastries. Durum wheats are used for making pasta products (Wiese 1987). Wheat is also used on a limited basis for animal feed (Briggle and Curtis 1987). Processing wheat produces by-products which have proven especially useful in poultry rations.

Nearly two-thirds of the wheat produced in the United States is exported, making this country the largest wheat exporter (Briggle and Curtis 1987). Wheat acreage has shown a substantial increase in Louisiana since 1970, but grain yields have remained relatively constant (Harrison et al. 1987). In Louisiana wheat production has increased from 33,608 hectares grown by 440 producers in 1998 averaging 1,174 kg/ha, to 83,581 hectares in 2002 averaging 1,252 kg/ha in 2002 (Anonymous 2005). In the humid mid-south, wheat yields are often low because of high temperature and excess rainfall. Wet fields frequently delay planting beyond optimum dates, resulting in reduced tillering, delayed maturity, and decreased yields.

Inability to plant at the optimum date (October 1 – October 31) is an important yield-limiting factor for winter wheat production in the mid-South. Wheat planted at an optimum date has greater yield potential than late-planted wheat because of increased tillers, heads, and kernel weight (Darwinkel et al. 1977; Thill et al. 1978). Harrison et al. (1987) reported a 363 kg/ha decrease in grain yield when planting was delayed 28 d beyond mid-November in southern Louisiana. Gardner et al. (1993) reported that in the southern U.S., spring-type cultivars are adapted to a wider range of planting dates than winter types and early planting of winter-type wheat cultivars are recommended because of their vernalization requirement (Shah et al. 1994).

Yield potential is defined as the yield of a cultivar attainable when grown in adapted environments, with non-limiting nutrients and water and with pests, diseases, weeds, lodging, and other stresses effectively eliminated (Evans and Fischer 1999). Cultivar selection is a major contributing factor to grain yield, weed suppression, and disease resistance. Wheat grain yield is affected by the number of fertile heads per square meter, the number of kernels per head, and/or individual kernel weight (Frederick et al. 2001). Environmental factors also play a key role. Potential for yield compensation occurs early in the plant life cycle through adjustment in the number of panicles per square meter and kernels per panicle (Maman et al. 2004). Variation in kernel weight allows for a degree of yield compensation later in the life cycle. Increases in kernels per panicle and in kernel weight may help compensate for low plant populations or limited tillering.

Wheat grain quality is determined by the chemical and physical constituents of the kernels themselves. Those chemical constituents are assembled following anthesis in a manner dependent on the genetic makeup of the cultivar and the environment. Past research has indicated that genotype, environment and genotype x environment interaction all influence the milling and baking quality of classes of wheat (Baenziger et al. 1985; Basset et al. 1989; Peterson et al. 1992).

Cultivars are classified in the U.S. on the basis of kernel hardness (soft or hard), bran color (red or white), and growth habit (spring or winter). Each grain class is expected to function as an ingredient in a broad range of class-specific end-use products. The products made from soft wheat are numerous and include cakes, cookies, crackers, noodles, pastries, and pie crusts (Faridi et al. 1994). Quality criteria evaluated during cultivar development include milling yield, protein content, kernel hardness, rheological properties, and volume and texture of actual end-use products (Hazen et al. 1997).

Test weight is the weight of dockage-free grain per unit volume. Wheat is traded on the basis of U.S. no. 2 grade quality standards that require, among other criteria, a minimum test weight of 746 kg/m^3 *748 g/l (USDA 1977, The Official United States Standards for Grain). Yamazaki and Briggle (1969) described the components of test weight as kernel volume (size and shape) and kernel weight. Kernel volume affects the packing efficiency or the percent volume of a given container that is occupied by grain (Schuler et al. 1994).

Crops respond differently to herbicides and herbicide rates and cultivar tolerance must be established for a herbicide to be labeled. For some crops that are very sensitive to certain herbicides extremely low (sublethal) doses can cause stunting, chlorosis, necrosis, reduced seed weight, deformed head development and reduced seed viability. Wheat grown in Louisiana is susceptible to drift from glyphosate coinciding with burndown applications for spring corn production. Glyphosate is a non-selective, translocated, foliage-absorbed herbicide that controls a wide spectrum of annual and perennial weed species. Glyphosate is especially active on grass species. Attempts to enhance glyphosate phytotoxicity by reducing the carrier volume (Buhler and Burnside 1983; Jordan 1981; O'Sullivan et al. 1981; Van et al. 1986) or by using various additives (Buhler and Burnside 1983; O'Sullivan et al 1981; Stahlman and Phillips 1979) or chelating agents (Shea and Tupy 1984) have allowed for the use of reduced herbicide dosages, resulting in lower cost while maintaining effective weed control.

Off-target movement of herbicide as drift is a problem in many areas, especially when herbicides are applied under windy conditions or other environmental conditions. Recent developments in sprayer shields and drift retardants have helped reduce herbicide drift potential, but have not eliminated the problem (Wall 1994). 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 environmental conditions favor volatilization and redesposition (Hanks 1995; Wall 1994), but often herbicide drift is the result of improper application (Wauchope et al. 1982).

Herbicide drift can injure plants a considerable distance downwind depending on the susceptibility of plants to the herbicide. In south central Washington, injury to grape (*Vitis siuitera* L.) vineyards from alleged 2,4-D drift from wheat producing regions several km away has occurred regularly since 2,4-D was introduced in 1947 (Al-Khatib et al. 1992a). Glyphosate was reregistered in the United States in 1993. According to the United States Environmental Protection Agency glyphosate and its associated formulations would not pose unreasonable risks or adverse effects if used according to the label. Herbicides containing the active ingredient glyphosate are used extensively throughout all aspects of agricultural production. Formulations of glyphosate for nonselective weed management were first commercialized in 1974, and, currently, glyphosate-based herbicides are among the most widely used herbicides in the world (Franz et al. 1997).

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 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 4.12.1.5) 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 to survival of plants. Plants developed to be resistant to glyphosate are encoded for an additional enolpryuvylshikimate phosphate synthase (EPSP synthase, E.D.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 annual grasses, red rice [*Oryza* sativa L], johnsongrass [*Sorghum* halepense (L.) Pers.], sicklepod [*Senna obtusifolia* (L.) Irvin and Barnaby], and various pigweeds (Jordan et al. 1997; Krausz et al. 1996). Krausz et al. (1996) reported 100% control of common cocklebur, fall panicum (*Panicum dichotomiflorum* L.), giant foxtail (*Setaria faberi* Herrm.), jimsonweed (*Datura stramoniuim* L.), redroot pigweed (*Amaranthus retroflexus* L.), and velvetleaf (*Abutilon theophrasti* Medik.) 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. Exa. W. Hill], morningglories, nutsedges (*Cyperus spp*) , prickly sida (*Sida spinosa* L.), and spreading dayflower (*Commelina diffusa* Brum. F.) (Anonymous 2000).

The increased glyphosate phytotoxicity observed when carrier volume is decreased may be related to spray droplets. The fewer spray droplets associated with lower spray volume would result in higher herbicide and surfactant concentration per droplet which could increase herbicide absorption into the plant. Decreasing carrier volume would also reduce impurities in the water carrier that could inhibit glyphosate activity. Buhler and Burnside (1983) reported that decreasing carrier volume from 190 to 24 l/ha eliminated phytotoxicity when hard water with

122 ppm calcium was used. Increased spray retention is another possible factor in increasing glyphosate activity when carrier volume is decreased. Sandberg et al. (1978) reported that loss of glyphosate due to runoff became significant in tall morningglory [*Ipomea purpurea* (L.) Roth] when carrier volume was increased above 190 l/ha.

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). Wet and dry deposition of dispersed aerosols carried by regional atmospheric transport may also cause visible morphological responses (Felsot et al 1996). In most cases, off-target herbicide movement rates range between 1/100 and 1/10 of the recommended use rates (Al-Khatib and Peterson, 1999; Al-Khatib et al. 1993a; Bode 1987; Maybank et al. 1978).

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 TurboDrop[2], Turbo Teejet[3], AI (Air Induction) Teejet[3], and DG (Drift Guard) Teejet[3]. 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 contact 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 inversion is most common at dawn, dusk, and when winds are calm. Ideally to avoid drift due to temperature inversions, some wind movement should occur.

Although herbicides cause a wide range of symptoms, herbicide within the same chemical families usually display characteristic symptoms. Environmental conditions, species, stage of growth, and herbicide rate also can affect the degree of symptomology caused by herbicides. For example, at a low rate, some herbicides cause chlorosis, but at high rates can cause leaf desiccation and necrosis. Also, young plants are usually more sensitive to herbicides than older plants (Al-Khatib et al. 1992b).

Although visual injury from herbicide drift can be quite distinct, it may not always adequately indicate the effect on physiological processes and overall growth of the plant (Bhatti et al. 1998). Root (Chen et al. 1972) and leaf (Friesen et al. 1963) abnormalities, delayed maturity and plant height reductions (Quimby and Nalewaja 1966), straw weakness (Scragg 1952), and seed protein increases (Martin et al. 1989) have been described. Spike abnormalities such as the development of oppositely arranged spikelets instead of placement in the usual alternate configuration, elongated spike internodes, branched spikes, multiple spikelets at one node, and decreases in spikelet number have occurred (Edwards and Miller 1978; Tottman 1982). Seed weight increases (Schroeder and Banks 1989) and decreases (Edwards and Miller 1978) and decreases in seed number due to floret sterility (Tottman 1982) have also been reported.

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), and reduced yield in corn and rice (Ellis et al 1999b).

The popularity of glyphosate-resistant crops will increase the potential for herbicide drift to nontransgenic crops. Determining the sensitivity of nontransgenic crops to glyphosate drift would be of keen importance especially in the South where multiple crops are grown in close proximity. This thesis evaluates the response of wheat to simulated drift of sublethal rates of glyphosate applied at various growth stages and also evaluates the response of several soft red winter wheat varieties.

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CHAPTER 2

WHEAT (*TRITICUM AESTIVUM*) RESPONSE TO SIMULATED GLYPHOSATE DRIFT

Introduction

Glyphosate is a non-selective postemergence herbicide 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.) are marketed in the southern U.S. The expected expansion in acreage of transgenic varieties or hybrids has increased the use of glyphosate and the complaints of off-target movement to sensitive crops.

Herbicide drift is most often the result of improper application (Wauchope et al. 1982). Wind speed and spray nozzle height above the intended target are primary contributors to herbicide drift (Hatterman-Valenti et al. 1995). Besides windy conditions during 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 ultralow-volume sprays with spray droplets less than 105 microns in size (Hanks 1995). Droplet size can be altered using different nozzles and drift retardants specifically designed to reduce spray drift (Bouse et al. 1976).

Research has shown that off-target movement of herbicide during application can be 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). Although these herbicide rates would be considered sub-lethal, response can be quite severe for susceptible crops. Simulated drift research with glyphosate has been conducted on rice (*Oryza sativa* L.), corn, soybean, and cotton. Based on yield reductions, rice and corn can be classified as equally sensitive to glyphosate (Ellis et al.

2003). For both crops, early glyphosate application (2- to 3-leaf rice and 6-leaf corn) reduced yield more than the later application (panicle differentiation in rice and l wk prior to corn tasseling). Glyphosate at 140 g/ha or 12.5% of the labeled use rate, which is typical of what could be expected from herbicide drift (Wolf et al. 1992), reduced rice yield in 2 of 3 yr 99 and 67% when applied early and 54 and 29% when applied late. In corn, yield following 140 g/ha glyphosate was reduced over 3 yr an average of 78% when applied early and 33% when applied late. Visual injury based on height reduction and discoloration of foliage to both rice and corn associated with the lower glyphosate rates in some cases was minimal, but the negative effect on yield was significant. In contrast, soybean and cotton were more tolerant to glyphosate (Ellis and Griffin 2002). Injury and height reductions occurred in most cases when glyphosate was applied at 140 g/ha to 2- to 3-trifoliate soybean and 2- to 3-leaf cotton. Cotton maturity was not delayed and both crops were able to recover rapidly from herbicide injury, and yields were not affected negatively.

Wheat would be susceptible to drift from glyphosate applied as a preplant burndown in corn, cotton, or soybean from February through April. At this time of the year in the South wheat growth stage could range from late tillering to flowering. At the jointing stage when the wheat seedhead primordia are formed plants would be especially sensitive to glyphosate because of its systemic nature. Additionally at flowering, glyphosate may have a negative effect on spiklets produced per head and on seed weight which could impact yield. Deeds et al. (2006) reported wheat injury and yield loss in Kansas generally greater from glyphosate applied at jointing than at flowering. They also reported that visual injury was an accurate indicator of yield reduction. Injury, however, was not a reliable indicator of yield reduction from sub lethal rates of glyphosate applied to rice or corn in Louisiana (Ellis et al. 2003). The objectives of this research were to determine the effect of simulated drift of glyphosate from jointing through flowering on winter wheat growth, yield, and yield components.

Materials and Methods

Timing x Rate Study. 'USG 3209' wheat was seeded in rows spaced 18 cm apart at 100 kg/ha at the Central Research Station, Ben Hur Farm near Baton Rouge, LA, on December 4, 2000 and December 5, 2001; at the Dean Lee Research Station, Alexandria, LA, on December 6, 2000 and December 5, 2001; and at the Northeast Research Station, St. Joseph, LA, on December 5, 2000 and December 6, 2001. The experimental area was tilled and the seedbed packed prior to planting. The soil type at Baton Rouge was a Commerce silt loam (fine-silty, mixed, nonacid, thermic Aeric Fluvaquents) with a pH of 5.6 and 1.3% organic matter. The soil at Alexandria was a Norwood silt loam (fine-silty, mixed, superactive, hyperthermic Fluventic Eurtrudepts) with a pH of 7.8 and 0.75% organic matter. The soil at St. Joseph was a Commerce silt loam (fine-silty, mixed, nonacid, thermic Aeric Fluvaquents) with a pH of 6.1 and 1.6% organic matter. The fertilizer program at the locations consisted of 18:54:54 kg/ha (N-P_20_5-K_2O) broadcast prior to planting and 100:0:0 kg/ha broadcast between February 5 and 14 over the two years.

Plots consisted of seven rows spaced 18-cm apart and 9.1 m long. The experimental design for the six experiments was a randomized complete block with a two-factor factorial treatment arrangement and four replications. The first factor was herbicide drift rates representing 12.5, 6.3, and 1.6% of the usage rate of 1,120 g ai/ha glyphosate (140, 70, and 18 g/ha, respectively). Herbicide treatments were applied to an area 1.5 m wide. The second factor was application timings. The first node application was made between February 27 and March 27. The month difference in application timing among the experiments was due to variation in planting dates and environmental conditions. The boot stage application was made between March 23 and April 3, and the early flowering application was made between April 6 and April 12.

Herbicide treatments were applied using a CO_2 -pressurized backpack sprayer calibrated to deliver 140 L/ha spray volume at 166 kPa. Visual estimates of percent injury and plant height from the soil to the top of the wheat canopy using three subsamples in each plot were determined 14 and 28 d after treatment (DAT). Visual injury ratings were based on height reduction and discoloration of foliage using a scale of 0 to 100%, where 0 = no injury, and 100 = plant death. Wheat was harvested between May 16 and May 24 and yield was adjusted to 13% moisture. Yield was not determined the first year at the St. Joseph location because of damage from glyphosate application to an adjacent field. Wheat yield components including spike density, number of spikelets per spike, and 100-seed weight were determined. All data collected are expressed as percent reduction compared with the nontreated control.

Data were subjected to the Mixed Procedure in SAS[1]. Years or locations, replications (nested within years or location), and all interactions containing either of these effects were considered random effects (Carmer et al. 1989). All other variables (herbicide drift rate and application timing) were considered fixed effects. Considering years as environmental or random effects permit inferences about treatments to be made over a range of environments (Carmer et al. 1989; Hager et al. 2003). Least square means were calculated and mean separation was performed using Fisher's protected LSD at P= 0.05. Letter groupings were converted using the PDMIX800 macro in SAS (Saxton 1998).

Timing x Rate x Variety Study. An additional study was conducted at Baton Rouge in 2001 and 2002 to evaluate wheat varietal response to simulated drift of glyphosate. Wheat varieties

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[1] SAS institute. 2003. SAS User's Guide: Statistics. Version 9.1. SAS Institute. Cary, NC.

included Coker 9663, Mason, LA 422, AGS 2000, Pioneer/26R61, and USG 3209. Wheat was planted as described for the timing x rate study at the Ben Hur Farm near Baton Rouge, LA, on December 4, 2000 and December 5, 2001 and was harvested on May 16, 2001 and May 24, 2002. The soil type at Baton Rouge was a Commerce silt loam with a with a pH of 5.6 and 1.3% organic matter. The fertilizer program was the same as described for the timing x rate study and N was top-dressed on February 5, 2001 and February 14, 2002.

The experimental design was a randomized complete block with a three-factor factorial treatment arrangement and four replications. The first factor was wheat variety. The second factor was herbicide drift rates representing 12.5 and 6.3% of the usage rate of 1,120 g/ha glyphosate (140 and 70 g/ha, respectively). Only two glyphosate rates were evaluated in this study because of space limitation. The third factor was application timings. The first node application was made February 26, 2001 and March 3, 2002. The early flowering application was April 1, 2001 and April 16, 2002.

Plot size, spray application information, and data collection and methodology were the same as described for the timing x rate study. Data are expressed as percent reduction compared with the nontreated control. Statistical analysis of data was as described for the timing x rate study.

Results and Discussion

Timing x Rate Study. A glyphosate application timing by rate interaction was observed for wheat injury and height reduction 14 and 28 DAT, and data are averaged across locations/years (Table 2.1). Visual injury from glyphosate appeared within 3 to 5 days after application as bleaching of leaf foliage followed by some level of growth cessation beginning 7 to 10 days after application. At 14 DAT, wheat injury when glyphosate was applied at 140 g/ha at first node was 55%, which was greater than when applied at the same rate at boot stage or early flowering

Table2. 1. Wheat injury and height 14 and 28 days after treatment (DAT) as influenced by glyphosate application timing and simulated drift rates.[a]

Application timing[b]	Rate[c]	Injury 14 DAT	Injury 28 DAT	Height 14 DAT[d]	Height 28 DAT[d]
	g a.i./ha	%		% reduction	
First node	140	55 a[e] *	74 a *	23 a *	47 a *
	70	40 b *	49 b *	12 bc *	26 b *
	18	16 d *	16 d *	4 de	3 d
Boot stage	140	42 b *	54 b *	16 b *	27 b *
	70	30 c *	33 c *	9 c *	14 c *
	18	18 d *	17 d *	4 de	4 d
Early flowering	140	43 b *	67 a *	5 d *	3 d
	70	27 c *	51 b *	4 de	3 d
	18	15 d *	24 cd *	1 de	1 d

[a]Data averaged across six experiments for 'USG 3209' wheat.

[b]Application timings correspond to first node in late February/late March, boot stage in late March/early April, and at early flowering in early to mid-April.

[c]Glyphosate rates represent 12.5, 6.3, and 1.6% of the labeled rate of 1120 g ai/ha (140, 70, and 18 g/ha).

[d]Data expressed as percent reduction compared with the nontreated control. For the nontreated control height at first node 14 and 28 DAT was 82.2 and 84.3 cm, respectively; at boot stage 14 and 28 DAT height was 87.1 and 85.8 cm, respectively; and at early flowering 14 and 28 DAT height was 76.7 and 83.0 cm, respectively.

[e]Application timing x herbicide rate interaction means within a column followed by the same lower case letter are not significantly different (P = 0.05). Asterisks (*) indicate that means are significantly different from the nontreated control.

(42 to 43%). Injury 14 DAT was reduced when glyphosate was applied at 70 g/ha compared with 140 g/ha at all timings and was still greater at first node than at boot stage or early flowering (40 vs. 27 to 30%). Wheat injury was no more than 18% when glyphosate was applied at 18 g/ha regardless of timing. At 28 DAT, injury for glyphosate applied at first node at 140 g/ha increased to 74% and was 54 and 67% when applied at the same rate at boot stage or early flowering, respectively. Injury 28 DAT was 33 to 51% when applied at 70 g/ha and 16 to 24% when applied at 18 g/ha. Much of the injury observed on wheat was due to reduction in plant height. At the highest glyphosate rate wheat height reduction 14 DAT was greatest when applied at first node (23%) followed by boot stage (16%) and early flowering (5%). For all application timings as glyphosate rate was reduced height reduction 14 DAT decreased. Height reduction, however, was not different from the nontreated for the lowest glyphosate rate at all timing and for the middle rate of glyphosate applied at the early flowering.

By 28 DAT wheat height reductions were still evident and for 140 g/ha glyphosate height was reduced 47% for the first node application and 27% for the boot stage application. At both these growth stages height reduction was less when glyphosate rate was reduced. Wheat height was not reduced when compared with the nontreated for the 18 g/ha rate applied at first node and boot stage and for all glyphosate rates when applied at early flowering. Height reduction would not be expected with the early flowering application since plants would have already reached maximum plant height when application was made.

Wheat yield was reduced 72% when glyphosate was applied at 140 g/ha at first node, which was greater than the 45 and 54% reduction for the same rate applied at boot stage and early flowering, respectively (Table 2.2). At the 70 or 18 g/ha rate wheat yield reduction was equivalent for the three application timings (25 to 30% for 70 g/ha and 8 to 13% for 18 g/ha).

Table 2.2. Wheat yield and yield components as influenced by glyphosate application timing and simulated drift rates.[a]

Application timing[b]	Rate[c]	Yield[d]	Spike density[d]	Spikelets /spike[d]	Seed weight[d]
	g a.i./ha	% reduction			
First node	140	72 a[e] *	42 a *	19 a *	35 *
	70	29 c *	5 cd	7 bc *	5
	18	8 e	4 cd	4 cd	4
Boot stage	140	45 b *	24 b *	12 b *	30 *
	70	30 c *	7 cd	2 cd	3
	18	13 de	5 cd	2 cd	7
Early flowering	140	54 b *	14 c *	6 bcd	36 *
	70	25 cd *	5 cd	2 cd	16 *
	18	2 e	6 cd	3 cd	3

[a]Data averaged across five experiments for 'USG 3209' wheat.

[b]Application timings correspond to first node in late February/late March, boot stage in late March/early April, and early flowering in early to mid-April.

[c]Glyphosate rates represent 12.5, 6.3, and 1.6% of the labeled rate of 1120 g ai/ha (140, 70, and 18 g/ha).

[d]Data expressed as percent reduction compared with the nontreated control. For the nontreated control for the first node, boot stage, and early heading treatments yield was 3570, 3340, and 3490 kg/ha, respectively; spike density was 642, 677, and 645 spikes/m^2, respectively; spikelets per spike was 14.2, 14.6, and 14.7, respectively; and seed weight represented 33.3, 33.8, and 33.0 mg/seed, respectively.

[e]Application timing x herbicide rate interaction means within a column followed by the same lower case letter are not significantly different (P = 0.05). Asterisks (*) indicate that means are significantly different from the nontreated control.

For 18 g/ha wheat yield regardless of glyphosate timing was equal to that of the nontreated control. Of interest was that although wheat injury with 18 g/ha was clearly evident 28 DAT (16 to 24%) (Table 2.1), injury was not sufficient to reduce yield. This is contrary to what was observed with rice and corn where visual injury associated with the lower herbicide rates in some cases was minimal, but the negative effect on yield was significant (Ellis et al. 2003). Visual injury alone in corn and rice, therefore, was not a good indicator of potential yield loss from sub lethal rates of glyphosate. In other research visual injury to wheat from sub-lethal glyphosate rates was a reliable indicator of wheat yield reduction in Kansas (Deeds et al. 2006).

In the present study the reduction in yield was reflected in spike density, spikelets per head, and seed weight data (Table 2.2). Spike density was reduced when glyphosate was applied at 140 g/ha at all growth stages. A reduction in spike density of 42% occurred when glyphosate was applied at first node, which was greater than the reduction observed when applied at 140 g/ha at boot stage (24%) or early flowering (14%). When glyphosate was applied at 70 or 18 g/ha spike density was reduced equally regardless of application timing and ranged from 4 to 7%, and in all cases reduction in spike density was less than for 140 g/ha. For 70 and 18 g/ha, regardless of glyphosate timing, spike density was equal to the nontreated control.

Spikelets per spike was reduced 19% when glyphosate was applied at 140 g/ha at first node, a greater reduction than for 70 g/ha applied at first node (7% reduction) and 140 g/ha at B (12%) and early flowering (6%). Spikelets per spike were equal to the nontreated control for 18 g/ha glyphosate applied at first node, 70 and 18 g/ha applied at boot stage, and for all rates applied at early flowering. For seed weight a significant application timing x glyphosate rate interaction was not observed, however, there was a significant glyphosate rate effect (Table 2.2). Averaged across application timings, seed weight was reduced 34% when glyphosate was applied at 140 g/ha. This reduction was greater than that observed for 70 (8% reduction) and 18 (4% reduction). The reduction for the 18 g/ha rate was not different from the nontreated control. Data clearly show that yield reduction from glyphosate applied at 140 g/ha is associated with reduced number of spikes per unit area, spikelets per spike, and seed weight. However, yield reduction associated with the 70 g/ha rate could not be explained based on individual yield components measured, but rather is probably due to the additive effects of the yield components.

Timing x Rate x Variety Study. This study was conducted to determine if there were differences in response to glyphosate among wheat varieties. The six wheat varieties responded the same to glyphosate application. In other studies differences in response among rice and corn varieties (Ellis et al. 2003) and soybean and cotton (Ellis and Griffin 2002) varieties to sub-lethal rates of glyphosate were not observed. A glyphosate application timing by rate interaction was observed for wheat injury and height reduction 14 and 28 DAT and data are averaged across varieties and years (Table 2.3). As noted for the previous study, visual injury from glyphosate appeared within 3 to 5 days after application as bleaching of leaf foliage followed by some level of growth cessation beginning 7 to 10 days after application. At 14 DAT averaged across varieties, wheat injury when glyphosate was applied at 140 g/ha at first node was 48%, which was greater than when applied at 70 g/ha at the same timing and for both rates of glyphosate applied at early flowering. Injury 14 DAT was 33% for 70 g/ha applied at first node and for 140 g/ha applied at early flowering and greater than when applied at 70 g/ha at early flowering (25%). At 28 DAT, injury increased to 61% when glyphosate was applied at first node at 140 g/ha, which was greater than when applied at the same growth stage at 70 g/ha (35%). Injury was no more than 15% when glyphosate was applied at early flowering and less than when glyphosate was applied at first node.

Table 2.3. Wheat injury and height 14 and 28 days after treatment (DAT) as influenced by glyphosate application timing and simulated drift rates.[a]

Application timing[b]	Rate[c]	Injury 14 DAT	Injury 28 DAT	Height 14 DAT[d]	Height 28 DAT[d]
	g a.i./ha	%		% reduction	
First node	140	48 a[e] *	61 a *	36 a *	34 a *
	70	33 b *	35 b *	19 b *	17 b *
Early flowering	140	33 b *	15 c *	1 c	0 c
	70	25 c *	12 c *	1 c	0 c

[a]Data averaged across two years and six wheat varieties, ‘Coker 9663’, ‘Mason’, ‘LA 422’, ‘AGS 2000’, ‘Pioneer/26R61’, and ‘USG 3209’.

[b]Application timings correspond to first node in late February/early March and early flowering in early to mid-April.

[c]Glyphosate rates represent 12.5 and 6.3% of the labeled rates of 1120 g ai/ha (140 and 70 g/ha).

[d]Data expressed as percent reduction compared with the nontreated control. For the nontreated control height at first node 14 and 28 DAT was 53.6 and 77.5 cm, respectively; at early flowering 14 and 28 DAT height was 92.5 and 85.1 cm, respectively.

[e]Application timing x herbicide rate interaction means within a column followed by the same lower case letter are not significantly different (P = 0.05). Asterisks (*) indicate that means are significantly different from the nontreated control.

Much of the injury observed on wheat at the early application was due to reduction in plant height. Wheat height reduction averaged across six varieties was 36% 14 DAT and 34% 28 DAT for glyphosate applied at 140 g/ha at first node, which was greater than when applied at 70 g/ha (19 and 17% reduction, respectively) (Table 2.3). Height reduction 14 and 28 DAT was no more than 1% when glyphosate was applied at early flowering and height reduction was not significant when compared with the nontreated. Height reduction would not be expected with the later application since plants would have already reached maximum plant height when application was made.

Wheat yield averaged across the six varieties was reduced 58% when glyphosate was applied at 140 g/ha at first node, which was greater than the 43 and 38% reduction for 70 g/ha applied at first node and 140 g/ha applied at early flowering, respectively (Table 2.4). For 70 g/ha applied at early flowering wheat yield was reduced 19%. Wheat yield for all application timings and glyphosate rates was less than the nontreated. The 58% reduction in wheat yield following glyphosate applied at 140 g/ha at first node was accompanied by a reduction in spike density, spikelets per spike , and seed weight (16, 15, and 27%, respectively) (Table 2.4). For spike density and spikelets per spike the reduction when glyphosate was applied at 70 g/ha at first node was equal to that when applied at both rates at early flowering and for both parameters, reductions were greater than that for the nontreated control. Reduction in seed weight was equivalent for 70 g/ha glyphosate applied at first node and for 140 g/ha applied at early flowering and greater than that for 70 g/ha applied at early flowering (6% reduction). The 6% reduction in seed weight for the 70 g/ha rate applied at early flowering was the only treatment not different from the nontreated.

Table2. 4. Wheat yield and yield components as influenced by glyphosate application timing and simulated drift rates.[a]

Application timing[b]	Rate[c]	Yield[d]	Spike density[d]	Spikelets /spike[d]	Seed weight[d]
	g a.i./ha	% reduction			
First node	140	58 a[e] *	16 a *	15 a *	27 a *
	70	43 b *	9 b *	7 b *	13 b *
Early flowering	140	38 b *	6 b *	5 b *	14 b *
	70	19 c *	9 b *	5 b *	6 c

[a] Data averaged across two years and six wheat varieties, 'Coker 9663', 'Mason', 'LA 422', 'AGS 2000', 'Pioneer/26R61', and 'USG 3209'.

[b]Application timings correspond to first node in late February/early March and early flowering in early to mid-April.

[c]Glyphosate rates represent 12.5 and 6.3% of the labeled rates of 1120 g ai/ha (140 and 70 g/ha).

[d]Data expressed as percent reduction compared with the nontreated control. For the nontreated control for the first node and early heading treatments yield was 3210 and 3260 kg/ha, respectively; spike density was 537 and 540 spikes/m^2, respectively; spikelets per spike was 14.3 and 14.4, respectively; and seed weight represented 30.0 and 30.7 mg/seed, respectively.

[e]Application timing x herbicide rate interaction means within a column followed by the same lower case letter are not significantly different (P = 0.05). Asterisks (*) indicate that means are significantly different from the nontreated control.

In the present study wheat was more sensitive to glyphosate applied at first node compared with boot stage or early flowering. In other grass crops early application (2- to 3-leaf rice and 6-leaf corn) of glyphosate reduced yield more than the later applications (panicle differentiation in rice and l wk prior to corn tasseling) (Ellis et al. 2003). At the highest rate evaluated for glyphosate (140 g/ha or 12.5% 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 yr 99 and 67% when applied early (Ellis et al. 2003). Corn yield at the same rate reduced yield over 3 yr an average of 78% when applied early. The yield reduction for wheat in the present study from first node application at 140 g/ha reduced yield 72% in the timing x rate study and 58% in the timing x rate x variety study. The yield reductions are comparable to what has been reported for rice and corn (Ellis et al 2003) and clearly show the negative effect that glyphosate can have on grass crops when applied at sub-lethal rates. Glyphosate is very effective on grasses (Ahrens 1994), which explains the greater sensitivity of wheat when compared with soybean and cotton (Ellis and Griffin 2002).

Even though wheat yield reduction from sub-lethal rates of glyphosate was similar to that reported for rice and corn when applied early at the same rate (Ellis et al. 2003), visual injury alone was not a good indicator of rice or corn yield loss. However, it appears from this research that visual injury would be an accurate indicator of wheat yield reduction. Visual symptoms expressed as bleaching of wheat foliage were clearly evident within 7 to 10 days after application. Bleaching was not a common visual response to glyphosate when applied at sub-lethal rates in rice and corn (Ellis et al. 2003). Deeds et al. (2006) concluded that wheat yield reduction was highly correlated with injury observed with sub-lethal glyphosate rates in Kansas. Producers should use caution when applying glyphosate to fields adjacent to wheat.

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CHAPTER 3

CARRIER VOLUME AFFECTS WHEAT (*TRITICUM AESTIVUM*) RESPONSE TO SIMULATED GLYPHOSATE DRIFT

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). A major concern of herbicide resistant crops is the potential for herbicide misapplication. Research has shown that off-target movement of herbicide during application can be 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). Although these herbicide rates would be considered sub-lethal, response can be quite severe for susceptible 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 spray nozzle height above the intended target are primary contributors to herbicide drift (Hatterman-Valenti et al. 1995).

Research to address glyphosate drift has been conducted in rice (*Oryza sativa* L.) and corn (*Zea mays* L.) (Ellis et al. 2003), soybean (*Glycine max* L. Merr.) and cotton (*Gossypium hirsutum* L.) (Ellis and Griffin 2002), and wheat (Deeds et al. 2006). In this research and in other research (Bailey and Kapusta 1993; Ghosheh et al. 1994; Snipes et al. 1991, 1992), simulated drift was accomplished by varying herbicide rate with application in a constant carrier volume. Using this method, herbicide concentration would decline and be more diluted as the dosage is reduced. In the field, drift occurring from aerial or ground equipment would decrease with movement downwind from the point of application. As water in the spray solution evaporates, remaining spray droplets would become more concentrated with herbicide and surfactant. The degree of water evaporation would depend on several variables to include relative humidity and temperature. Therefore, varying herbicide rate with application in a constant carrier volume would not simulate what happens under field conditions

Research conducted by Ellis et al (2002) in field corn and Banks and Schroeder (2002) in sweet corn (*Zea mays* var. *rogusa* Bonaf) evaluated the effect of varying the carrier volume proportionally with glyphosate rates whereby herbicide concentration in the carrier remained constant. For the same rate of glyphosate, greater injury and height and yield reductions were observed when applied in variable carrier volume compared with using a constant carrier volume. For a constant carrier volume as herbicide rate decreased herbicide concentration would be more diluted. Results from these studies suggest that previous simulated drift research in which dose response is evaluated over a constant spray volume may have underestimated yield reduction. This would be particularly applicable to systemic herbicides that are very active on either grass or broadleaf species.

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 greater than has been reported in the literature for simulated drift studies (Griffin, personal communication). These differences may be related to carrier volume. Glyphosate drift on to soft red winter wheat in the mid-South would occur in February through April from preplant burndown applications in corn, cotton, or soybean. During this time period wheat could be jointing or flowering depending on planting date and variety. At the jointing stage when wheat seedhead primordia are formed, plants would be sensitive to glyphosate because of its systemic nature. Additionally at flowering, glyphosate may have a negative effect on spikelets produced per head and on seed weight which could impact yield. Deeds et al. (2006) reported wheat injury and yield loss in Kansas generally greater from glyphosate applied at jointing than at flowering. Yield reduction with glyphosate applied at the 1/10x rate (112 g ai/ha) at jointing ranged from 83 to 98%. They also reported that visual injury 28 d after treatment (DAT) was an accurate indicator of yield reduction. Injury, however, has not been a reliable indicator of yield reduction from sub-lethal rates of glyphosate applied to rice or corn in Louisiana (Ellis et al. 2003).

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 (100 to 400 g/ha), phytotoxicity to oat (*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 wheat response to sub-lethal simulated drift rates (12.5 and 6.3% of the labeled rates) of glyphosate applied at jointing and at heading under mid-South environmental conditions.

Materials and Methods

Field experiments were conducted in 2001 and 2002 at the Central Research Station, Ben Hur Farm near Baton Rouge, LA. The soil type was a Commerce silt loam (fine-silty, mixed, nonacid, thermic Aeric Fluvaquents) with pH of 5.6 and 1.3% organic matter. 'USG 3209' wheat was seeded at 100 kg/ha on December 4, 2000 and December 5, 2001. The fertilizer program consisted of 18:54:54 kg/ha (N-P_20_5-K_2O) broadcast prior to planting and 100:0:0 kg/ha broadcast on February 5 and 14 for the two years. Plots consisted of seven rows 18 cm apart and 9.1 m long.

The experimental design was a randomized complete block with an augmented three-factor factorial treatment arrangement with four replications. Factors included glyphosate rate, spray volume, and application timing. Drift rates represented 12.5 and 6.3% of the use rates of 1,120 g ai/ha glyphosate[2] (140 and 70 g/ha, respectively). A nontreated control was included for comparison. Glyphosate was applied in a constant carrier volume of 234 L/ha and in proportional carrier volumes of 30 L/ha for the 12.5% rate and 15 L/ha for the 6.3% rate, which maintained a constant herbicide concentration in the carrier. The proportional carrier volumes were selected to evaluate changes in the ratio of herbicide to water in the spray solution that could occur under field conditions downwind from the application site (Ellis et al. 2002). Only two rates of glyphosate were evaluated because of the difficulty of obtaining carrier volumes below 15 L/ha with the equipment used. Also, previous research in Louisiana has shown that injury from drift rates of glyphosate on corn and rice was less apparent at rates less than 70 g/ha (Ellis et al. 2003). Glyphosate was applied at first node on February 27, 2000 and March 27, 2001 and at heading on April 6, 2000 and April 12, 2001.

Herbicide treatments were applied to an area 1.5 m wide using a tractor-mounted compressed air sprayer with a spray pressure of 186 kPa. A TurboDrop 005 Venturi air aspirator[3] with a TurboTeejet[4] 110015 nozzle for exit pattern 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 30 and 15 L/ha proportional carrier volumes, respectively.

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[2] Roundup Ultra™ (479 g/L glyphosate), Monsanto Company, St. Louis, MO 63167.

[3] Greenleaf Technologies. Covington, LA 70434.

[4] Teejet Agricultural Spray Products. Spraying Systems Co. Wheaton, IL 60189.

Visual estimates of percent injury and plant height from the soil to the top of the wheat canopy at 10 locations in each plot were determined 14 and 28 DAT. Visual injury ratings were based on height reduction and discoloration of foliage using a scale of 0 to 100%, where 0 = no injury, and 100 = plant death. Wheat was harvested between May 16 and May 24 and yield was adjusted to 13% moisture. Wheat yield components including spike density, number of spikelets per spike, seed weight per spike, and 100-seed weight were determined. All data are expressed as percent reduction compared with the nontreated control.

Data were subjected to the Mixed Procedure in SAS[5]. Years, replications (nested within years), and all interactions containing either of these effects were considered random effects (Carmer et al. 1989). All other variables (herbicide drift rate and application timing) were considered fixed effects. Considering years as environmental or random effects permit inferences about treatments to be made over a range of environments (Carmer et al. 1989; Hager et al. 2003). Least square means were calculated and mean separation was performed using Fisher's protected LSD at P= 0.05. Letter groupings were converted using the PDMIX800 macro in SAS (Saxton 1998).

Results and Discussion

A significant glyphosate application timing x carrier volume interaction was observed for wheat injury 14 DAT and wheat height 14 and 28 DAT. Visual injury from glyphosate appeared within 3 to 5 days after application as bleaching of leaf foliage followed by some level of growth cessation beginning 7 to 10 days after application. Averaged across glyphosate rates wheat injury 14 DAT was 55% when application was made at first node in the proportional carrier volume (carrier volume adjusted proportionally to glyphosate rate) compared with 38% when

[5] SAS institute. 2003. SAS User's Guide: Statistics. Version 9.1. SAS Institute. Cary, NC.

applied at first node in 234 L/ha constant carrier volume (Table 3.1). Application at heading resulted in around 45% injury 14 DAT regardless of carrier volume. By 28 DAT, however, wheat injury for glyphosate applied at first node or heading was the same regardless of carrier volume. Averaged across application timings, however, wheat injury 28 DAT was 39% when glyphosate was applied in 234 L/ha compared with 62% when applied in proportional carrier volume.

Although some injury was due to bleaching of plant foliage most injury was reflected in plant height reduction. Glyphosate application at first node in proportional carrier volume resulted in more than twice as much height reduction compared with application in 234 L/ha (12 vs. 27%) (Table 3.1). Height reduction was no more than 1% when glyphosate was applied at heading. At 28 DAT, glyphosate applied in proportional carrier volume reduced wheat height 42%, 2.8 times that when glyphosate was applied at the same growth stage in 234 L/ha. Height reduction for glyphosate was applied at heading in 234 L/ha (14%) and in the proportional carrier volume (13%) was equivalent to the first node application in 234 L/ha. At both 14 and 28 DAT, a significant effect due to carrier volume was observed and height reduction averaged across application timings was around twice as great when glyphosate was applied in the proportional carrier volume compared with the 234 L/ha constant carrier volume.

Glyphosate rate also affected wheat injury and height. Averaged across growth stage and carrier volume wheat was injured 38 and 43% 14 and 28 DAT, respectively, when glyphosate was applied at 70 g/ha (Table 3.2). At both ratings wheat injury was greater when glyphosate

Table 3.1. Wheat injury and height 14 and 28 days after treatment (DAT) as influenced by glyphosate application timing and carrier volume.[a]

Application Timing	Application carrier volume[b]	Injury		Height[c]	
		14 DAT	28 DAT	14 DAT	28 DAT
	L/ha	%		% reduction	
First node	234	38 c[e]	39 a	12 b	15 b
	proportional	55 a	64 a	27 a	42 a
Application timing avg.		47 A[e]	52 A	19 A	28 A
Heading	234	45 b	39 a	1 c	14 b
	proportional	48 b	59 a	0 c	13 b
Application timing avg.		47 A	49 A	0 B	14 B
Carrier volume avg.	234	42 B[e]	39 B	6 B	15 B
	proportional	52 A	62 A	13 A	27 A

[a] Data averaged across glyphosate rates corresponding to 12.5 and 6.3% of the labeled rates of 1,120 g ai/ha (140 and 70 g/ha, respectively).

[b] Carrier volumes represent 234 L/ha for constant and 30 and 15 L/ha adjusted proportionally to herbicide rate of 12.5 and 6.3%, respectively, of the labeled rates of 1,120 g/ha glyphosate.

[c] Data expressed as percent reduction compared with the nontreated control. For the nontreated control wheat height at first node 14 and 28 DAT was 54.3 and 72.1 cm, respectively. Height at heading 14 and 28 DAT was 84.6 and 84.3 cm, respectively.

[e] Application timing x carrier volume interaction means within a column followed by the same lower case letter are not significantly different (P = 0.05). Main effect means for application timing and carrier volume within a column followed by the same upper case letter are not significantly different (P = 0.05).

Table 3.2. Wheat injury and height 14 and 28 days after treatment (DAT) and wheat yield components as influenced by simulated drift rates of glyphosate.[a]

Herbicide rate[b]	Injury		Height[c]		Spike density[c]	Spikelets/ spike[c]	Seed weight/ spike[c]	Seed weight[c]
	14 DAT	28 DAT	14 DAT	28 DAT				
g ai/ha	%	%	% reduction					
140	55 a[d]	58 a	11 a	25 a	10 a	13 a	49 a	15 a
70	38 b	43 b	8 b	17 b	7 a	7 b	30 b	7 b

[a] Data averaged across application carrier volumes (234 L/ha for constant and 30 and 15 L/ha adjusted proportionally to herbicide rate) and wheat growth stages corresponding to first node and heading.

[b] Rates correspond to 12.5 and 6.3% of the labeled rates of 1,120 g ai/ha glyphosate (140 and 70 g/ha, respectively).

[c] Data expressed as percent reduction compared with the nontreated control. For the nontreated control wheat height averaged 69.4 cm 14 DAT and 78.2 cm 28 DAT. For the nontreated control spike density was 661 spikes/m^2, spikelets per spike was 13.9, seed weight per spike was 0.72 g, and seed weight represented 31 mg/seed.

[d] Main effect means for glyphosate rate within a column followed by the same lower case letter are not significantly different ($P = 0.05$).

was applied at 140 g/ha and was around 55%. When glyphosate was applied at 140 g/ha height reduction was 11% 14 DAT and 25% 28 DAT; height reduction at both rating dates was greater than when applied at 70 g/ha (8 and 17%, respectively).

A significant glyphosate rate x carrier volume interaction was observed for wheat yield. At 140 g/ha glyphosate wheat yield was reduced 42% when applied in 234 L/ha, but was reduced 54% for the same rate applied in proportional carrier volume (Table 3.3). For 70 g/ha glyphosate, wheat yield was reduced 11% when applied in 234 L/ha, but reduction in yield was almost 4 times greater when the same rate was applied in proportional carrier volume. The yield reduction for 70 g/ha applied in proportional carrier volume was equivalent to 140 g/ha applied in 234 L/ha. These results showing differences in wheat response to glyphosate due to carrier volume agree with those also reported for 2,4-D on cotton and glyphosate on sweet corn (Banks and Schroeder 2002) and for glyphosate on corn (Ellis et al. 2002). The highest yield reduction in the present study, 54% with 140 g/ha glyphosate, was considerably less than the 83 to 98% yield reduction observed with 112 g ai/ha glyphosate applied to wheat at jointing in a Kansas study (Deeds et al. 2006). The greater yield reduction in the Kansas study may be due to use of hard red winter wheat vs. the soft red winter type used in our study and to differences in environmental conditions at the time of glyphosate application. Wheat varieties differ in response to metribuzin (Wicks et al. 1987) and chlorsulfuron (Dastgheib et al. 1994). With chlorsulfuron differences in sensitivity among wheat varieties were attributed to differential rates of metabolism (Dastgheib et al. 1994).

Averaged across growth stage and carrier volume wheat yield was reduced 48% when glyphosate was applied at 140 g/ha, which was 1.8 times the average yield reduction for 70 g/ha (Table 3.3). For the wheat yield components of spike density, spikelets per spike, seed

Table 3.3. Wheat yield as influenced by glyphosate rate and carrier volume.[a]

Herbicide rate[b]	Application carrier volume[c]	Yield[d]
g ai/ha	L/ha	% reduction
140	234	42 b[e]
	proportional	54 a
Herbicide rate avg.		48 A
70	234	11 c
	proportional	42 b
Herbicide rate avg.		26 B

[a] Data averaged across wheat growth stages corresponding to first node and heading.
[b] Rates correspond to 12.5 and 6.3% of the labeled rates of 1,120 g ai/ha glyphosate.
[c] Carrier volumes represent 234 L/ha for constant and 30 and 15 L/ha adjusted proportionally to herbicide rate of 12.5 and 6.3%, respectively, of the labeled rates of 1,120 g/ha glyphosate (140 and 70 g/ha, respectively).
[d] Data expressed as percent reduction compared with the nontreated control. For the nontreated control yield was 3,920 kg/ha.
[e] Glyphosate rate x carrier volume interaction means within a column followed by the same lower case letter are not significantly different (P = 0.05). Main effect means for glyphosate rate within a column followed by the same upper case letter are not significantly different (P = 0.05).

weight per spike, and seed weight, the glyphosate rate x carrier volume interaction was not significant. However, there was a significant glyphosate rate effect on many of the yield components. Spike density was not affected by glyphosate rate (Table 3.2). Spikelets per spike were reduced 13%, seed weight per spike was reduced 49%, and seed weight was reduced 15% when glyphosate was applied at 140 g/ha (Table 3.2). These reductions were at least 1.6 times that observed when glyphosate was applied at 70 g/ha, clearly showing that yield reduction was directly attributed to reduction in spikelets per spike, seed weight per spike, and seed weight.

A significant glyphosate application timing x carrier volume interaction was also observed for wheat yield and for some of the yield components. Averaged across glyphosate rates wheat yield reduction was equivalent when application was made in 234 L/ha at first node and at heading (29 and 24%, respectively) (Table 3.4). For both application timings yield reduction was greater when glyphosate was applied in proportional carrier volume compared with 234 L/ha (2.1 times greater for the first node application and 1.5 times greater for the heading application). The 60% wheat yield reduction observed when glyphosate was applied at first node in the proportional carrier volume was 1.7 times greater than the heading application in proportional carrier volume. Other research has shown greater yield reductions in wheat from glyphosate applied at jointing rather than at heading or flowering (Deeds et al. 2006; Roider et al. 2002).

The yield response noted for the glyphosate application timing x carrier volume interaction was also apparent for seed weight per spike indicating that yield reduction was attributed primarily to decreased seed weight per spike (Table 3.4). Averaged across carrier volumes wheat yield was reduced more when glyphosate was applied at first node than at heading (Table 3.4). This same

Table 3.4. Wheat yield and yield components as influenced by glyphosate application timing and carrier volume.[a]

Application timing	Carrier volume [b]	Yield [c]	Spike density [c]	Spikelets /spike [c]	Seed weight/spike [c]	Seed weight [c]
	L/ha	% reduction				
First node	234	29 bc [d]	4 b	11 a	29 bc	3 a
	proportional	60 a	13 a	17 a	67 a	13 a
Application timing avg.		44 A [e]	9 A	14 A	48 A	8 B
Heading	234	24 c	9 ab	7 a	22 c	10 a
	proportional	36 b	7 ab	5 a	40 b	17 a
Application timing avg.		30 B	8 A	6 B	31 B	14 A
Carrier volume avg.	234	26 B [e]	6 A	9 A	26 B	7 B
	proportional	48 A	10 A	11 A	54 A	15 A

[a]Data averaged across glyphosate rates corresponding to 12.5 and 6.3% of the labeled rates of 1,120 g ai/ha (140 and 70 g/ha, respectively).

[b]Carrier volumes represent 234 L/ha for constant and 30 and 15 L/ha adjusted proportionally to herbicide rate of 12.5 and 6.3%, respectively, of the labeled rates of 1,120 g/ha glyphosate.

[c]Data expressed as percent reduction compared with the nontreated control. For the nontreated control yield was 3,920 kg/ha, spike density was 661 spikes/m2, spikelets per spike was 13.9, seed weight per spike was 0.72 g, and seed weight represented 31 mg/seed.

[d]Application timing x carrier volume interaction means within a column followed by the same lower case letter are not significantly different (P = 0.05). Main effect means for application timing and carrier volume within a column followed by the same upper case letter are not significantly different (P = 0.05).

response was also observed for spikelets per spike, seed weight per spike, and seed weight. Averaged across application timings the greater yield reduction when glyphosate was applied in proportional carrier volume compared with 234 L/ha was reflected also in greater reductions in seed weight per spike and seed weight for the proportional carrier volume.

Possible explanations for the differences in response to carrier volume for glyphosate may be related to water hardness, surfactant concentration, and spray droplet dynamics. Researchers have shown that the activity of glyphosate can be affected by carrier volume (Sanberg et al. 1978; Stahlman and Phillips 1979). Most believe this is attributed to water hardness (Hatzios and Penner 1985; Nalewaja and Matysiak 1991). 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 that water hardness was not an issue.

The glyphosate used in this research is 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 30 and 15 L/ha spray volumes, spray droplets would have been more concentrated with herbicide and surfactant compared to the 234 L/ha spray volume. 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. It could be speculated that the high spray volume (234

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.

This research clearly shows that adjusting carrier volume from a constant carrier volume where glyphosate concentration declines with each reduction in dosage to proportional carrier volume where glyphosate concentration remains constant increases the negative effects of glyphosate on wheat injury and yield. Traditional simulated herbicide drift research where dose response is evaluated over a constant spray volume does not represent what may occur under field conditions and the results may underestimate yield reductions. Results clearly demonstrate the importance of using caution when applying glyphosate near wheat particularly when wheat is near the first node growth stage. Unlike previous research with glyphosate drift to rice and corn (Ellis et al. 2003), visual injury from glyphosate was a good indicator of wheat yield loss.

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CHAPTER 4

SUMMARY

Wheat (*Triticum* spp.), the world's most widely cultivated agronomic crop, occupies over 22% of land area devoted to cereal grain production. Of the cereal crops, wheat accounts for the greatest volume of international trade. Nearly two-thirds of the wheat produced in the U.S. is exported, making the U.S. the largest wheat exporter in the world. An increase in wheat production since 1970 has occurred in Louisiana, and in 2005, 42,680 ha were grown in the state.

Glyphosate is a non-selective, translocated, foliar-absorbed herbicide that is used to control a wide spectrum of annual and perennial weed species. Widespread use of glyphosate as a preplant burndown herbicide and expanded use with the development of glyphosate-resistant crops has increased concerns of off target movement and injury to sensitive crops. Herbicide drift occurs when wind causes spray droplets to be displaced from their intended flight path. Herbicide drift is a problem in areas where herbicides are applied under windy conditions or when environmental conditions favor volatilization and redeposition. Wheat grown in the South would be most susceptible to drift from glyphosate when applied preplant burndown in corn, cotton, or soybean. This application timing in the South could extend from February through April when wheat growth stage would range from tillering to flowering. At the jointing stage when wheat seedhead primordia are formed, wheat would be especially sensitive to glyphosate because of its systemic nature. Additionally at flowering, glyphosate may have a negative effect on spiklets produced per spike and on seed weight which could impact yield.

In the first study field research was conducted over 2 years and at 3 locations to evaluate response of 'USG 3209' wheat to simulated drift rates representing 12.5, 6.3, and 1.6% of the usage rates of 1,120 g ai/ha glyphosate (140, 70, and 18 g/ha, respectively). Applications were made at first node in late February/late March; boot stage in late March/early April; and at early flowering in early to mid-April. Visual injury from glyphosate appeared within 3 to 5 days after application as bleaching of leaf foliage followed by some level of growth cessation beginning 7 to 10 days after application. At 14 days after treatment (DAT), wheat injury when glyphosate was applied at 140 g/ha at first node was 55%. At 28 DAT, injury when glyphosate at 140 g/ha was applied at first node increased to 74% and was 54 and 67% when applied at the same rate at boot stage or early flowering, respectively. At the highest glyphosate rate wheat height reduction 14 DAT was greatest when applied at first node (23%). For all application timings as glyphosate rate was reduced height reduction 14 DAT decreased. Height reduction was not observed with the early flowering application since plants had already reached maximum plant height when the application was made. Wheat yield was reduced 72% when glyphosate was applied at 140 g/ha at first node, which was greater than the 45 and 54% reduction for the same rate applied at boot stage and early flowering, respectively. A reduction in spike density of 42% occurred when glyphosate was applied at first node, which was greater than the reduction observed when applied at 140 g/ha at boot stage (24%) or early flowering (14%). Reduction in yield was reflected also in spikelets per spike and seed weight. Visual injury observed to wheat with the sub-lethal glyphosate rates was a reliable indicator of wheat yield reduction.

A second study was conducted over 2 years to evaluate response of wheat varieties to glyphosate rate and application timing. The six wheat varieties, 'Coker 9663', 'Mason', 'LA 422', 'AGS 2000', 'Pioneer/26R61', and 'USG 3209', responded similarly to glyphosate application. As noted for the previous study, visual injury from glyphosate appeared within 3 to 5 days after application as bleaching of leaf foliage followed by some level of growth cessation beginning 7 to 10 days after application. At 14 DAT averaged across varieties, wheat injury when glyphosate was applied at 140 g/ha at first node was 48%. Much of the injury observed on wheat at the early application was due to reduced plant height. Wheat height reduction averaged across varieties was 36% 14 DAT and 34% 28 DAT for glyphosate applied at 140 g/ha at first node. Wheat yield averaged across the six varieties was reduced 58% when glyphosate was applied at 140 g/ha at first node, which was greater than the 43 and 38% reduction for 70 g/ha applied at first node and 140 g/ha applied at boot stage. Wheat yield for all application timings and glyphosate rates was less than the nontreated.

For both studies application of glyphosate at first node resulted in greater yield loss compared with boot stage or early heading application. Yield reductions were comparable to what has been previously reported for rice and corn exposed to glyphosate and results clearly show the negative effect that glyphosate can have on grass crops when applied at sub-lethal rates. Even though yield reduction from sub-lethal rates of glyphosate on wheat was similar to that observed for rice and corn when applied at the same rate, visual injury alone was not a good indicator of rice or corn yield loss. However, it appears from this research that visual injury would be an accurate indicator of wheat yield reduction.

In the third study the influence of glyphosate and carrier volume on 'USG 3209' wheat was evaluated over 2 years. Glyphosate was applied in a constant carrier volume of 234 L/ha and in proportional carrier volumes of 30 L/ha for the 12.5% rate and 15 L/ha for the 6.3% rate. For the proportional carrier volume treatments a constant herbicide concentration was maintained in the carrier. Only two rates of glyphosate were evaluated because of the difficulty of obtaining carrier volumes below 15 L/ha with the equipment used. Glyphosate was applied at first node and at heading. Visual estimates of percent injury and plant height were determined 14 and 28 DAT. A significant glyphosate application timing x carrier volume interaction was observed for wheat injury 14 DAT and wheat height 14 and 28 DAT. Averaged across glyphosate rates wheat injury 14 DAT was 55% when application was made at first node in the proportional carrier volume compared with 38% when applied at first node in 234 L/ha constant carrier volume.

Glyphosate application at first node in proportional carrier volume resulted in more than twice as much height reduction compared with application in 234 L/ha (12 vs. 27%). At both 14 and 28 DAT, a significant effect due to carrier volume was observed and height reduction averaged across application timings was around twice as great when glyphosate was applied in the proportional carrier volume compared with the 234 L/ha constant carrier volume. A significant glyphosate rate x carrier volume interaction was observed for wheat yield. At 140 g/ha glyphosate, wheat yield was reduced 42% when applied in 234 L/ha, but was reduced 54% for the same rate applied in proportional carrier volume. Averaged across growth stage and carrier volume, wheat yield was reduced 48% when glyphosate was applied at 140 g/ha, which was 1.8 times the average yield reduction for 70 g/ha. For the wheat yield components of spike density, spikelets per spike, seed weight per spike, and 100-seed weight, the glyphosate rate x carrier volume interaction was not significant.

This research clearly shows that adjusting carrier volume from a constant carrier volume where glyphosate concentration declines with each reduction in dosage to proportional carrier volume where glyphosate concentration remains constant, increases the negative effect of glyphosate on wheat injury and yield. Possible explanations for the differences in response to carrier volume for glyphosate may be related to water hardness, surfactant concentration, and spray droplet dynamics. 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.

Unlike previous research with glyphosate drift to rice and corn conducted in Louisiana, visual injury from glyphosate was a good indicator of wheat yield loss. Results stress the importance of using caution when applying glyphosate to fields adjacent to wheat, particularly when wheat is near the first node growth stage.

APPENDIX: RATE X TIMING AND VARIETY X RATE MEANS FOR WHEAT RESPONSE TO SIMULATED GLYPHOSATE DRIFT STUDY

Appendix Table 1. Wheat injury and height 14 and 28 days after treatment (DAT) as influenced by glyphosate application timing and simulated drift rates.[a]

Application timing[b]	Rate[c]	Injury 14 DAT	Injury 28 DAT	Height 14 DAT[d]	Height 28 DAT[d]
	g a.i./ha	%		% reduction	
First node	140	55 a[e] *	74 a *	23.3 a *	46.5 a *
	70	40 b *	49 b *	12.2 bc *	26.2 b *
	18	16 d *	16 d *	3.9 de	2.7 d
Application timing avg.		37 A	46 A	13.1 A	24.9 A
Boot stage	140	42 b *	54 b *	15.5 b *	27.4 b *
	70	30 c *	33 c *	9.3 c *	13.8 c *
	18	18 d *	17 d *	3.6 de	3.8 d
Application timing avg.		30 B	35 B	9.5 B	15.0 B
Early flowering	140	43 b *	67 a *	4.5 d *	3.0 d
	70	27 c *	51 b *	4.2 de	2.9 d
	18	15 d *	24 cd *	1.4 de	0.6 d
Application timing avg.		28 B	47 A	3.4 C	2.2 C
Herbicide rate avg.	140	47 A *	65 A *	14.4 A *	25.6 A *
	70	32 B *	44 B *	8.6 B *	14.3 B *
	18	16 C *	19 C *	3.0 C *	2.4 C

[a]Data averaged across six experiments for ‘USG 3209’ wheat.
[b]Application timings correspond to first node in late February/late March, boot stage in late March/early April, and early flowering in early to mid-April.
[c]Glyphosate rates represent 12.5, 6.3, and 1.6% of the labeled rate of 1120 g ai/ha (140, 70, and 18 g/ha).
[d]Data expressed as percent reduction compared with the nontreated control. For the nontreated control height at first node 14 and 28 DAT was 82.2 and 84.3 cm, respectively; at boot stage 14

and 28 DAT height was 87.1 and 85.8 cm, respectively; and at early heading 14 and 28 DAT height was 76.7 and 83.0 cm.

[e]Application timing x herbicide rate interaction means within a column followed by the same lower case letter are not significantly different (P = 0.05). Main effect means for application timing and herbicide rate within a column followed by the same upper case letter are not significantly different (P = 0.05). Asterisks (*) indicate that means are significantly different from the nontreated control.

Appendix Table 2. Wheat yield and yield components as influenced by glyphosate application timing and simulated drift rates.[a]

Application timing[b]	Rate[c]	Yield[d]	Spike density[d]	Spikelets /spike[d]	Seed weight[d]
	g a.i./ha	% reduction			
First node	140	72.1 a[e] *	41.8 a *	19.1 a *	34.8
	70	29.4 c *	5.0 cd	7.1 bc *	5.2c
	18	7.6 e	4.3 cd	3.6 cd	3.5
Application timing avg.		36.4	17.0 A	9.9 A	14.5
Boot stage	140	45.0 b *	23.5 b *	11.5 b *	30.3
	70	30.2 c *	6.9 cd	2.0 cd	3.2
	18	13.2 de	4.7 cd	2.0 cd	6.9
Application timing avg.		29.5	11.7 AB	5.2 B	13.5
Early flowering	140	54.0 b *	13.6 c *	5.9 bcd	35.8
	70	24.6 cd *	4.8 cd	1.8 cd	15.6
	18	2.4 e	6.2 cd	3.3 cd	2.8
Application timing avg.		27.0	8.2 B	3.7 B	18.1
Herbicide rate avg.	140	57.0 A *	26.3 A *	12.2 A *	33.6 A *
	70	28.1 B *	5.6 B	3.6 B *	8.0 B *
	18	7.7 C	5.1 B	3.0 BC	4.4 BC

[a]Data averaged across five experiments for ‘USG 3209’ wheat.

[b]Application timings correspond to first node in late February/late March, boot stage in late March/early April, and early flowering in early to mid-April.

[c]Glyphosate rates represent 12.5, 6.3, and 1.6% of the labeled rate of 1120 g ai/ha (140, 70, and 18 g/ha).

[d]Data expressed as percent reduction compared with the nontreated control. For the nontreated control for the first node, boot stage, and early heading treatments yield was 3570, 3340, and 3490 kg/ha, respectively; spike density was 642, 677, and 645 spikes/m^2, respectively; spikelets per spike was 14.2, 14.6, and 14.7, respectively; and seed weight represented 33.3, 33.8, and 33.0 mg/seed, respectively.

[e]Application timing x herbicide rate interaction means within a column followed by the same lower case letter are not significantly different (P = 0.05). Main effect means for application

timing and herbicide rate within a column followed by the same upper case letter are not significantly different (P = 0.05). Asterisks (*) indicate that means are significantly different from the nontreated control.

Appendix Table 3. Wheat injury and height 14 and 28 days after treatment (DAT) as influenced by glyphosate application timing and simulated drift rates.[a]

Application timing[b]	Rate[c]	Injury 14 DAT	Injury 28 DAT	Height 14 DAT[d]	Height 28 DAT[d]
	g a.i./ha	%		% reduction	
First node	140	48 a[e] *	61 a *	35.9 a *	34.2 a *
	70	33 b *	35 b *	19.0 b *	16.7 b *
Application timing avg.		41 A	48 A	27.5 A	25.5 A
Early flowering	140	33 b *	15 c *	1.4 c	0.3 c
	70	25 c *	12 c *	1.4 c	0.3 c
Application timing avg.		29 B	14 B	1.4 B	0.3 B
Herbicide rate avg.	140	41 A *	38 A *	18.7 A *	17.3 A *
	70	29 B *	24 B *	10.2 B *	8.5 B *

[a]Data averaged across two years and six wheat varieties, 'Coker 9663', 'Mason', 'LA 422', 'AGS 2000', 'Pioneer/26R61', and 'USG 3209'.

[b]Application timings correspond to first node in late February/early March and early flowering in early to mid-April.

[c]Glyphosate rates represent 12.5 and 6.3% of the labeled rates of 1120 g ai/ha (140 and 70 g/ha).

[d]Data expressed as percent reduction compared with the nontreated control. For the nontreated control height at first node 14 and 28 DAT was 53.6 and 77.5 cm, respectively; at early flowering 14 and 28 DAT wheat height was 92.5 and 85.1 cm, respectively.

[e]Application timing x herbicide rate interaction means within a column followed by the same lower case letter are not significantly different (P = 0.05). Main effect means for application timing and herbicide rate within a column followed by the same upper case letter are not significantly different (P = 0.05). Asterisks (*) indicate that means are significantly different from the nontreated control.

Appendix Table 4. Wheat yield and yield components as influenced by glyphosate application timing and simulated drift rates.[a]

Application timing[b]	Rate[c]	Yield[d]	Spike density[d]	Spikelets /spike[d]	Seed weight[d]
	g a.i./ha	% reduction			
First node	140	58.2 a[e] *	15.8 a *	14.9 a *	27.3 a *
	70	43.2 b *	8.6 b *	7.0 b *	13.1 b *
Application timing avg.		50.7 A	12.2	11.0 A	20.2 A
Early flowering	140	37.7 b *	6.2 b *	5.2 b *	13.9 b *
	70	18.5 c *	8.8 b *	4.6 b *	5.6 c
Application timing avg.		28.1 B	7.5	4.9 B	9.8 B
Herbicide rate avg.	140	47.9 A *	11.0 A *	10.1 A *	20.6 A *
	70	30.8 B *	8.7 A *	5.8 B *	9.3 B *

[a] Data averaged across two years and six wheat varieties, 'Coker 9663', 'Mason', 'LA 422', 'AGS 2000', 'Pioneer/26R61', and 'USG 3209'.

[b]Application timings correspond to first node in late February/early March and early flowering in early to mid-April.

[c]Glyphosate rates represent 12.5 and 6.3% of the labeled rates of 1120 g ai/ha (140 and 70 g/ha).

[d]Data expressed as percent reduction compared with the nontreated control. For the nontreated control for the first node and early heading treatments yield was 3210 and 3260 kg/ha, respectively; spike density was 537 and 540 spikes/m^2, respectively; spikelets per spike was 14.3 and 14.4, respectively; and seed weight represented 30.0 and 30.7 mg/seed, respectively.

[e]Application timing x herbicide rate interaction means within a column followed by the same lower case letter are not significantly different (P = 0.05). Main effect means for application timing and herbicide rate within a column followed by the same upper case letter are not significantly different (P = 0.05). Asterisks (*) indicate that means are significantly different from the nontreated control.

Appendix Table 5. Wheat injury and height 14 and 28 days after treatment (DAT) and wheat yield and yield components of six wheat varieties as influenced by simulated drift rates of glyphosate. [a]

Herbicide rate [b]	Wheat variety	Injury 14 DAT	Injury 28 DAT	Height 14 DAT [c]	Height 28 DAT [c]	Yield [c]	Spike density [c]	Spikelets/ spike [c]	Seed weight [c]
g ai/ha		%	%	% reduction					
140	USG 3290	52 a [d]	49	21.2	20.4	50.9	10.4	17.3	27.6
	Mason	46 b	39	17.4	18.2	52.5	17.0	14.5	30.5
	Coker 9663	45 b	35	22.0	16.3	41.9	9.8	4.4	12.2
	Pioneer/26R61	36 c	38	16.0	15.9	55.8	17.3	9.4	29.1
	LA 422	35 cd	33	18.4	17.0	45.6	3.9	5.7	10.0
	AGS 2000	31 de	31	17.0	15.8	41.0	7.4	9.2	14.4
70	USG 3209	38 c	33	11.0	8.8	32.0	12.0	10.0	9.8
	Mason	33 cd	28	10.3	10.0	31.4	8.9	6.5	11.7
	Coker 9663	33 cd	23	10.1	8.7	22.3	9.6	5.2	7.6
	Pioneer/26R61	26 ef	22	10.2	9.2	39.8	13.5	1.8	12.6
	LA 422	23 fg	20	10.0	7.0	30.3	4.5	4.1	6.1
	AGS 2000	20 g	17	10.4	7.2	29.3	3.7	7.2	8.1

[a]Data averaged across two experiments and herbicide application at first node and early flowering.
[b]Glyphosate rates represent 12.5 and 6.3% of the labeled rates of 1120 g ai/ha (140 and 70 g/ha).
[c]Data expressed as percent reduction compared with the nontreated control. For the nontreated control for 140 and 70 g/ha height 14 DAT was 53.6 and 77.5 cm, respectively; height 28 DAT was 92.5 and 85.1 cm, respectively; yield was 3210 and 3260 kg/ha, respectively; spike density was 537 and 540 spikes/m^2, respectively; spikelets per spike was 14.3 and 14.4, respectively; and seed weight represented 30.0 and 30.7 mg/seed, respectively.
[d] Wheat injury means 14 DAT followed by the same lower case letter are not significantly different (P = 0.05). Significant differences among varieties for the other parameters were not observe

VITA

Christopher Andrew Roider is the son of Karl A. and Sue E. Roider. Born 26 October 1967, in Palo Alto, California, he grew up in Baton Rouge, Louisiana, and graduated from McKinley Senior High School. Chris is married to Emy Roider, his wife of 15 years, and they have three children Evan, Meghan and Sian. He received a Bachelor of Science degree in animal science from Louisiana State University in May 1999. Chris enrolled in the Department of Agronomy and Environmental Management graduate program under the direction of Dr. Jim Griffin and Dr. Steven Harrison in 2001 and is currently a candidate for the degree of Master of Science in agronomy with an educational and research emphasis in weed science. He is currently a Research Farm Manager at the Louisiana Agricultural Center Central Research Station Plant Science Unit and Farm Support Unit.