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Crop Response and Weed Control With Glufosinate in Rice.

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CROP RESPONSE AND WEED CONTROL WITH GLUFOSINATE IN RICE

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ABSTRACT

Studies were conducted to evaluate crop tolerance and yield of glufosinate-resistant rice lines treated with glufosinate throughout the season. In addition, studies were conducted using seed harvested from rice treated with glufosinate to evaluate seed weights, germination, and seedling vigor. Weed control with glufosinate alone and in combination with other herbicides was evaluated. Red rice control with various glufosinate rates and timings in rice with established 5, 10, and 20 cm permanent flood depths was also evaluated.

In the tolerance study, CPRS PB-13 injury was less than 10% for all timings and no differences in yield were detected when compared with the nontreated. In contrast, BNGL HC-11/62 injury was less than 15% for all timings and yield was reduced at the 3- to 5-lf, pre-boot, and boot timings compared with the nontreated. Glufosinate did not affect CPRS PB-13 seed weights, germination, and seedling vigor. No differences occurred for BNGL HC-11/62 seed weights and seedling vigor expressed as a percent of nontreated; however, germination was reduced 14 d after initiation at 22 C with a pre-boot glufosinate application.

Tank-mixing 0.42 kg/ha glufosinate with other herbicides resulted in antagonism when compared with an increased rate of glufosinate at 0.84 kg/ha with the same combinations. At 14 d after treatment, 0.42 kg/ha glufosinate controlled barnyardgrass and broadleaf signalgrass 85 and 86%, respectively. The addition of propanil and triclopyr enhanced annual sedge control over a single application of glufosinate. At 14 DAT, a synergistic response for spreading dayflower occurred for all tank-mix combinations with the exception of halosulfuron and triclopyr; however, at 28 DAT, spreading dayflower control was less than 80% with all treatments.

Red rice was controlled 87 to 98% with glufosinate, but response varied with flood depth, application timings, and years. Red rice control at both 2 and 3 weeks after treatment was reduced at the 20 cm flood depth for the 2- to 3-lf application timing compared with the 5 and 10 cm flood depths. Late season application resulted in variable red rice control.

CHAPTER 1

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important crops in the world and is a major source of nutrition for people living in developing countries (Rathore et al. 1993). This crop is grown in over 100 countries on every continent except Antartica, extending from 53° north latitude to 40° south latitude and from sea level to an altitude of 3,000 m (Juliano 1985). As the world's population increases, rice will become more important in the future. It is predicted rice will be the chief energy source for the world, thereby surpassing wheat (*Triticum aestivum* L.) (Chang and Luh 1991). Because of this, it is necessary that rice yields be enhanced through improved cultural practices, efficient breeding, and effective pest management. In 1998, 567.3 million metric tons (mmt) of rice were produced worldwide and 8.2 mmt in the United States. About 34% of U.S. production was exported in 1998, accounting for 15% of the total world trade in rice (Johnson et al. 1999).

Weeds can reduce crop yields through competition, interference, and reduced harvest efficiency (Smith et al. 1977). Weeds also harbor insects and pathogens that can potentially infest the crop (Smith 1983). Determining the time during which competition most negatively affects crop yield permits optimum timing of herbicide application to prevent losses. However, good stands, vigorous plants, and adequate soil moisture throughout the growing season, and high levels of nitrogen tend to minimize competitive effects of weeds on crops (Blackman and Templeman 1938).

Weeds reduce yield and quality by an estimated 17% in the United States (Chandler 1981), compared with about 8 and 7% for insects and

diseases, respectively (James 1981; Schwartz and Klassen 1981). In 1983, losses due to weeds were estimated at 34% in Texas, 12% in California and Missouri, and 17% in Arkansas, Louisiana, and Mississippi; total losses for the United States were 1.4 mmt valued at $269 million (Chandler et al. 1984).

More than 70 weed species infest direct-seeded rice in the U.S. (Barrett 1983), but some are more competitive and cause greater losses than others (Smith 1983). Seven plant species frequently reported as weeds in rice production are grouped into three categories of 4 grasses, 2 broadleaves, and 1 sedge (Chandler 1981). The seven plants or groups of plants most frequently reported as weeds of rice fields are *Echinochloa* species, broadleaf signalgrass [*Bracharia platyphylla* (Griseb.) Nash], ducksalad (*Heteranthera limosa* L.), hemp sesbania [*Sesbania exaltata* (Raf.) Rydb. Ex A. W. Hill], red rice (*Oryza sativa* L.), various sprangletops (*Leptochloa spp.*) and various sedges (*Cyperus spp.*) (Smith 1988).

Red rice is one of the most noxious weeds that infests rice (Askew et al. 1998; Cohn and Hughs 1981; Kwon et al. 1991; Noldin et al. 1998; Rao and Harger 1981; Smith 1981). Red rice, an annual species, is a problem weed in the southern U.S. as well as in Central and South America (Cohn and Hughes 1981). Red rice was recognized as a weed of rice in 1846 in North and South Carolina (Craigmiles 1978), and it was the most distributed and most difficult weed to control in Louisiana rice fields in 1900 (Dodson 1900). Several rice fields had to be abandoned because of heavy infestations of red rice in Louisiana and Texas by 1907 (Nelson 1907). In 1979, yield and quality losses from red rice were estimated at about $50 million in the southern U.S. (Smith 1981). Diarra et al. (1985), reported yield reductions from

season-long interference of red rice can be as high as 82% and red rice populations as low as 5 plants per/m^2 reduced grain yield 22%.

Red rice infestations, pose a long-term weed control problem (Croughan et al. 1996), because the seed heads shatter at maturity and seed can remain dormant in the soil for as long as 15 years (Cohn and Hughs 1981). Effective methods to eliminate reinfestation because the conditions that promote and break dormancy in red rice are not understood. It is very difficult to control red rice during the rice growing season due to its genetic and physiological similarities to cultivated rice (Craigmiles 1978). Traditionally, partial red rice control is achieved through preplant application of molinate (*S*-ethyl hexahydro-1*H*-azepine-1-carbothioate) or thiobencarb {*S*-[(4-chlorophenyl)methyl] diethylcarbamothioate} in combination with pinpoint water management in water-seeded rice (Baker et al. 1986; Forner 1995; Smith 1981). Currently, no postemergence herbicides are available that can effectively control red rice (Baldwin et al. 1997; Kwon et al. 1991; Rao and Harger 1981; Smith 1979).

The most recent developments in red rice control are from genetic modification of rice cultivars rendering them tolerant to specific classes of herbicide chemistry such as glufosinate [2-amino-4-(hydroxymethylphosphinyl)butanoic acid], glyphosate [*N*-(phosphonomethyl)glycine], and imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid} (Dillon et al. 2000; Jiang et al. 2000; Webster and Lanclos 2000; Wheeler et al. 2000). These new chemistries will give producers added flexibility to control problem weeds in rice.

Use of glufosinate-resistant rice will allow postemergence applications of glufosinate to a wide range of weeds including red rice (Braverman and Linscombe 1993, 1994; Lanclos et al. 2000; Sankula

et al. 1997a, 1997b; Wheeler et al. 1997, 2000). Historically, glufosinate has been used as a herbicide in minimum tillage systems, orchards, vineyards, and as a preharvest desiccant (Ellis et al. 1998; Mersey et al. 1990). It is slower acting than paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) but much faster than glyphosate in controlling weeds (Tachibana and Kaneko 1986). Glufosinate appears to be a phosphinic acid analog of L-glutamate and a potent competitive inhibitor of glutamine synthetase a key enzyme of nitrogen metabolism in plants (Bayer et al. 1972; Lea et al. 1984). After the herbicide is applied, a rapid accumulation of ammonia (Kocher 1983; Tachibana et al. 1986), a deficiency in glutamine, and inhibition of photosynthesis can be observed (Sauer et al. 1987). Sources of ammonia in treated plants include nitrate reduction, general nitrogen compound catabolism, and the glycine to serine conversion occurring during photorespiration (Mersey et al. 1990). The herbicide action results in death of the plant cells due to ammonia toxicity (Bayer et al. 1972; Tachibana et al. 1986).

Glufosinate has been evaluated for weed control in glufosinate-resistant rice for several years (Braverman and Linscombe 1994; Sankula et al. 1997a, 1997b; Wheeler et al. 1999). Glufosinate is effective for the control of red rice and other weeds in rice. However, several factors including crop tolerance, herbicide compatibility, and performance in flooded conditions need to be evaluated to achieve maximum benefits from this technology.

Herbicide-resistant crops have shown varying levels of tolerance to the compound to which resistance was developed (Baughman and Webster 1998; Blackley et al. 1999; File et al. 1998; Prochaska and Griffin 1994). Glyphosate-resistant cotton (*Gossypium hirsutum* L.) is resistant to glyphosate when applied postemergence (POST) over-the-top

of cotyledon to 4 node cotton (Blackley et al. 1999; File et al. 1998). Baughman and Webster (1998) reported that seed cotton yields were reduced with an over-the-top application at the 9- and 12-node cotton growth stage when compared with a nontreated. Other herbicide-resistant crops have been evaluated for tolerance and timing of the herbicide to which resistance was developed. Researchers in Louisiana reported slight chlorosis shortly after glyphosate application to glyphosate-resistant soybean [*Glycine max* (L.) Merr.] but yields were not reduced when compared with a nontreated (Prochaska and Griffin 1994). Peters et al. (1999) reported no yield reduction of glyphosate-resistant or glufosinate-resistant corn (*Zea mays* L.) when treated with the respective herbicide.

Pantone and Baker (1992) reported that the tolerance of rice to bromoxynil (3, 5-dibromo-4-hydroxybenzonitrile) and triclopyr {[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid} was dependent on growth stage. Rice is tolerant to 2,4-D [(2,4-dichlorophenoxy)acetic acid] during the late tillering to early jointing stages, but may be severely injured prior to tillering or in the boot stage (Smith et al. 1977). Glufosinate-resistant rice lines have been reported to differ in tolerance to glufosinate application. Transformed 'Gulfmont' rice was more resistant to glufosinate than transformed 'Koshihikari' rice when treated with 2.24 kg/ha glufosinate (Braverman and Linscombe 1994). Wheeler et al. (1999) reported Gulfmont was injured up to 50% with a POST-flood application of 0.84 kg/ha glufosinate.

Information is not available on the effects of glufosinate applications during the growing season on seed weights, seed germination, and seedling vigor from seed harvested from glufosinate-resistant rice. In Louisiana, it is imperative that rice seed have excellent germination and seedling vigor potential in order to survive

early planting dates and to maximize production in water-seeded culture (Dunand 1988). Seeds germinate and develop into seedlings under favorable environmental conditions (Anderson 1962; Gibson and Mullen 1996; Holm and Miller 1972). Seedling vigor determines the potential for rapid, uniform emergence, and development of seedlings under a wide range of field conditions (Association of Official Seed Analysts, 1985). Low vigor may result in slower germination, seedling growth rate, greater susceptibility to seed-rotting organisms, poor stand establishment, and lower yields (Edje and Burris 1971; Fehr et al. 1973; Grabe 1966).

Plant species have different temperature ranges within which their seed will germinate (Crowley and Buchanan 1980). The optimum seeding dates for rice vary from year to year because of variation in environmental conditions (Linscombe et al. 1999). Average daily temperature at seeding is important in stand establishment, and temperatures 0 to 16 C result in minimal rice seed germination. The average daily temperature must be above 18 C to insure adequate germination and rice growth in Louisiana.

Seed production and seed viability have been reduced by herbicide applications to many weed species (Fawcett and Slife 1978; Taylorson 1966) especially when herbicides were applied at or near flowering (Biniak and Aldrich 1986; Brommer et al. 1998; Fawcett and Slife 1978; Isaccs et al. 1989). Herbicide applications may affect the control mechanisms of germination, germination rate utilization of stored food, and seedling growth (Koller et al. 1962; Milborrow 1965; Vieira et al. 1992). Issacs et al. (1989) reported sicklepod (*Senna obtusifolia* L.) seedling emergence was greater when herbicides were applied at the early bloom and early fruit compared to applications at the late fruit stage.

Preliminary results indicate that glufosinate is effective for controlling grass and broadleaf weeds. Wheeler et al. (1997) evaluated glufosinate in Louisiana and Arkansas in drill-seeded rice production. Treatments in the Arkansas studies were applied at early POST on 2- to 3- leaf (lf) rice and prior to flooding, and treatments in Louisiana were applied before flood and POST flood. Two applications of glufosinate at 0.42 kg/ha and higher controlled red rice 100% and broadleaf signalgrass, hemp sesbania, and morningglory species (*Ipomoea spp.*) above 90%. Sequential applications of 0.375 kg/ha glufosinate increased control of red rice compared with 0.84 kg/ha glufosinate as a single treatment. Although glufosinate controls a broad spectrum of broadleaf weeds, it is less effective on grasses (Thompson 1997). Sankula et al. (1997b) reported that glufosinate does not adequately control ducksalad and alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.], indicating that a tank-mix partner may be needed for overall effective weed control.

Tank-mixing herbicides may aid producers by reducing application costs and increasing the spectrum of weed control and herbicide combinations may delay the development of resistant biotypes (Bruff and Shaw 1992; Hatzios and Penner 1985; Hydrick and Shaw 1995; Zhang et al. 1995). This approach is based on the assumption that herbicides would act independently when applied simultaneously or sequentially (Zhang et al. 1995). However, it has been demonstrated that herbicides may interact before or after entering the plant and the outcome can be synergistic, antagonistic, or additive (Colby 1967; Hydrick and Shaw 1994, 1995; Webster and Shaw 1997; Zhang et al. 1995).

When herbicides are applied in combination with other herbicides, control can vary (Zhang et al. 1995). Hydrick and Shaw (1994)

employed Colby's to test for synergism or antagonism in a greenhouse study using tank-mixtures between non-selective foliar applied and selective soil-applied herbicides on three weeds. Glufosinate at 0.21 kg/ha alone reduced sicklepod fresh weight by 49%; however, only an additive response was noted with the addition of 0.09 kg/ha metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one] plus 0.015 kg/ha chlorimuron-ethyl {2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid}. There were no antagonistic or synergistic responses for either rate of glufosinate for reductions of sicklepod fresh weight. In two separate field studies, Hydrick and Shaw (1995) evaluated interactions on sicklepod and pitted morningglory (*Ipomoea lacunosa* L.) control between selective and non-selective herbicide tank-mixtures in stale-seedbed soybean production. Synergism occurred for sicklepod control with 0.42 kg/ha glufosinate plus 0.14 kg/ha imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methyethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid} was tank-mixed and synergism also occurred with 0.42 kg/ha glufosinate was tank-mixed with 0.36 metribuzin plus 0.06 chlorimuron. Similar synergistic responses were reported for pitted morningglory with 0.42 kg/ha glufosinate tank-mixed with 0.14 kg/ha imazaquin or 0.36 kg/ha metribuzin plus 0.06 kg/ha chlorimuron.

Webster and Shaw (1997), reported glufosinate tank-mixed with other herbicides could be an effective burndown and residual combination for hard to control cotton weeds in a cotton stale seedbed system. Sicklepod control was above 85% with 1.68 kg/ha fluometuron {*N*,N-dimethyl-*N'*-[3-(trifluoromethyl)phenyl]urea} or 1.68 kg/ha diuron [*N'*-(3,4-dichlorophenyl)-*N*,-*N*-dimethylurea] plus 0.84 kg/ha glufosinate compared with 62% with 0.84 kg/ha glufosinate alone; however, these responses were additive. Pitted morningglory control

was additive with 1.68 kg/ha diuron, 2.02 kg/ha cyanazine {2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile} or 2.24 kg/ha MSMA (monosodium salt of MAA) tank-mixed with 0.84 kg/ha glufosinate compared with a single glufosinate application.

Little is known about the effects of flood depth in conjunction with glufosinate application timings on red rice control in glufosinate-resistant rice. Flood depth may be a concern with glufosinate-resistant rice because as a contact herbicide efficacy may be affected by foliage exposure, which can be reduced as flood depth increases (Sankula et al. 1997b). Sankula and Braverman (1996) reported that red rice control increased with glufosinate when no more than 25 to 50% of red rice foliage is under the flood. Red rice control was affected by flooding and glufosinate rates 21 DAT in both field and greenhouse studies. In field studies, a permanent flood reduced the efficacy of glufosinate by 29, 28, 46, 18, and 34% with glufosinate at 0.28, 0.42, 0.56, 0.84, 1.12 kg/ha, respectively, compared with no flood. In a greenhouse study, red rice control was 96 to 100% with glufosinate under dry soil conditions; however, red rice control was reduced to less than 78% when floods were established to cover at least 50% of the exposed red rice foliage. Plant height and dry matter production of red rice increased as flood depth increased, indicating reduced herbicide activity. However, information is limited on the combination effect of glufosinate rates and timings as well as flood depth on rice growth and weed control in glufosinate-resistant rice.

This research addresses the crop response of glufosinate-resistant rice when treated with glufosinate throughout the season as reflected by growth parameters and grain yield as well as seed

germination and seedling vigor; in addition, weed control with glufosinate was evaluated in tank-mixes with other rice herbicides or under different flooding regimes. Results of this research will help producers make effective use of glufosinate-resistant rice technology.

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CHAPTER 2

RESPONSE OF GLUFOSINATE-RESISTANT RICE TO GLUFOSINATE APPLICATION TIMINGS

Introduction

Recent advances in genetic engineering have allowed the development of crops to be resistant to specific herbicides (Braverman and Linscombe 1994; Mersey et al. 1990; Rathore et al. 1993). This technology has led to the development of glufosinate [2-amino-4-(hydroxymethylphosphinyl)butanoic acid] -resistant rice (*Oryza sativa* L.) (Christou et al. 1991). Even though the term "resistance" is used in describing crop response to the herbicide, increased tolerance does not always infer complete resistance. Glyphosate [*N*-(phosphonomethyl) glycine] resistant cotton (*Gossypium hirsutum* L.) is resistant to glyphosate when applied postemergence (POST) over-the-top of cotyledon to 4 node cotton (Blackley et al. 1999; File et al. 1998). Vargas et al. (1998) reported 0.56, 0.84, and 1.12 kg/ha glyphosate reduced boll retention when applied to 6, 9, and 12 node cotton and yield was reduced with the 12 node application. Baughman and Webster (1998) reported that seed cotton yields were reduced with over-the-top applications at the 9- and 12-node stages compared with a nontreated. Matthews et al. (1998) reported glyphosate did not affect fruit retention or yield of glyphosate-resistant cotton when applied according to the label and up to the 6-leaf (lf) stage. Blair et al. (1999), evaluated application timing of glufosinate on glufosinate-resistant cotton and reported no crop injury, differences in plant height, number of nodes per plant, number of first position bolls, or seed cotton yield. Fiber quality, which included micronaire, length, strength, and color grade were not affected by glufosinate application timings.

Other herbicide-resistant crops have been evaluated for tolerance to the respective herbicide. Researchers in Louisiana reported slight chlorosis shortly after glyphosate application to glyphosate-resistant soybean [*Glycine* max (L.) Merr.], but yields were not reduced (Prochaska and Griffin 1994). Peters et al. (1999) reported no yield reduction of glyphosate-resistant or glufosinate-resistant corn (*Zea mays* L.) when treated with the respective herbicide regardless of rate.

Injury has also been reported for herbicide-resistant rice. Masson et al. (1999), reported water-seeded imidazolinone-tolerant rice injury was at least 25% for a 1-lf application of 0.14 kg/ha imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid} and a 1-lf application of 0.105 kg/ha or 0.14 kg/ha followed by 0.07 kg/ha imazethapyr on 2- to 3-lf rice. Steele et al. (2000) reported similar injury in imazethapyr-resistant drill-seeded rice with a single POST application of 0.07 kg/ha imazethapyr. Webster and Masson (2000), reported 15% imidazolinone-rice injury with a 2- to 5-lf application of 0.07 kg/ha imazethapyr at two locations.

Glufosinate-resistant rice lines have been reported to differ in tolerance to glufosinate applications. Transformed 'Gulfmont' rice was more resistant to glufosinate than transformed 'Koshihikari' rice when treated with 2.24 kg/ha glufosinate (Braverman and Linscombe 1994). Wheeler et al. (1999), reported Gulfmont injury as high as 50% with a POST-flood application of 0.84 kg/ha glufosinate. Sankula et al. (1997), reported that glufosinate at 2.2 kg/ha injured glufosinate-resistant rice 23 to 26% treated at the 1- to 2-lf stage compared with 13 to 19% treated at the 3- to 4-lf stage and 3 to 14% with a boot stage application; however, the boot stage application

resulted in a 16% yield reduction. The objective of this research was to evaluate response of two glufosinate-resistant rice lines for potential commercial release to 0.84 kg/ha glufosinate applied at different rice growth stages.

Materials and Methods

Two studies were established in 1998 through 2000 at the Rice Research Station near Crowley, Louisiana on a Crowley silt loam (fine montmorillonitic, thermic Typic Albaqualf) with pH 5.5 and 1.2% organic matter. Seedbed preparation consisted of a fall disking followed by a spring disking and two passes with a two-way bed conditioner equipped with rolling baskets and S-tine harrows. The study area was laser-leveled to a slope gradient of 0.2% each year in the winter following initial disking. Glufosinate-resistant rice 'CPRS PB-13' (long grain transformant from 'Cypress') and a 'BNGL HC-11' and 'BNGL-62' (medium grain transformants from 'Bengal') was drill-seeded at 112 kg/ha on April 24, 1998, May 5, 1999, and May 24, 2000. BNGL HC-11 was used in 1998 and BNGL-62 in 1999 and 2000 due to the seed availability of BNGL HC-11. BNGL HC-11 and BNGL-62 will be referred to as BNGL HC-11/62.

After seeding, the study was surface irrigated within 24 hours and again at the 1- to 2-lf and 3- to 4-lf rice stage. Permanent flood was established on 4- to 5-lf rice on May 22, 1998, June 2, 1999, and June 8, 2000. Glufosinate at 0.84 kg/ha was applied using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L/ha spray volume at 186 Kpa. The area was maintained weed free with two applications of 1.7 kg/ha propanil plus 1.7 kg/ha molinate on 2- to 3-lf and 4- to 5-lf rice. Soil fertility management consisted of 340 kg/ha of 7-21-21 fertilizer pre-plant and 225 kg/ha 46-0-0 urea nitrogen prior to permanent flood establishment. Standard agronomic

practices were employed during the growing season to maximize yield. Experiments were conducted independently for the glufosinate-resistant lines. The experimental design for each was a randomized complete block with four replications. A nontreated CPRS PB-13 and BNGL HC-11/62 and conventional Cypress and Bengal lines were added for comparison purposes.

Visual ratings of rice injury were recorded 7 days after each herbicide application and continued weekly until 35 DAT. Injury was based on a scale of 0 = no injury and 100 = complete plant death. Injury symptoms consisted of leaf chlorosis and in some cases necrosis however, most injury did not persist for more than 10 to 14 DAT. Days to 50% heading was recorded and plant height at harvest was determined by measuring the plant from the ground level to the tip of the extended panicle. Rice was harvested with a small-plot combine and rough rice yield was adjusted to 12% moisture.

Data were subjected to analysis of variance, testing all possible interactions of herbicide application timing and year. Tables appropriate for the interactions present were constructed and means were separated using Fisher's protected LSD test at the 0.05% probability level.

Results and Discussion

At 14 d after treatment (DAT), a year by treatment interaction occurred for CPRS PB-13 injury (Table 2.1). In 1998, rice was injured 8 to 9% when treated at the 1-lf and 3- to 5-lf stage, and at the 1-lf, 1- to 2-lf, pre-boot, and boot stages in 1999. Injury was less than 4% for all application timings in 2000. Injury symptoms consisted of leaf chlorosis or leaf tip burning shortly after glufosinate application and did not persist for more than 14 DAT. No year by treatment interaction occurred for rice injury at 35 DAT;

Table 2.1. Glufosinate-resistant rice injury at 14 and 35 days after treatment (DAT) with 0.84 kg/ha glufosinate at different rice growth stages.

Rice growth stage	14 DAT[ab] 1998	14 DAT[ab] 1999	14 DAT[ab] 2000	35 DAT[c]
	CPRS PB-13 injury, %			
1 leaf	8	8	2	2
1-2 leaf	1	9	1	1
3-5 leaf	9	3	3	3
2-3 tiller	4	4	0	0
4-5 tiller	5	0	0	0
5-6 tiller	3	0	0	0
Green Ring	3	3	0	0
Pre Boot	1	9	0	0
Boot	0	8	0	0
LSD (0.05)		6		1
	BNGL HC-11/62 injury, %			
1 leaf	9	1	9	1
1-2 leaf	4	0	4	2
3-5 leaf	1	3	1	2
2-3 tiller	4	0	4	1
4-5 tiller	4	0	4	0
5-6 tiller	0	0	0	1
Green Ring	0	0	0	1
Pre Boot	1	13	1	1
Boot	1	4	1	0
LSD (0.05)		3		2

[a]Abbreviations: days after emergence (DAE); days after treatment (DAT).

[b]A year by treatment interaction occurred for rice injury 14 days after treatment.

[c]Data averaged over 1998, 1999, and 2000.

therefore, data were averaged over year. Injury was 0 to 3% across all treatments. These results are similar to those observed for glyphosate or glufosinate-resistant soybean where injury consisted of leaf tip burning or chlorosis, but did not persist more than 7 to 14 DAT (Culpepper et al. 2000; Pline et al. 2000; Prochaska and Griffin 1994).

No year by treatment interaction occurred for d to 50% heading, plant height at maturity, and yield for CPRS PB-13; therefore, data are averaged over years. CPRS PB-13 reached 50% heading at 98 to 105 days for all timings (Table 2.2). The nontreated CPRS PB-13 and conventional Cypress reached 50% heading at 91 and 90 days, respectively. This data indicates that a glufosinate application delays heading. Plant heights were 94 to 95 cm for all treatments. These results are consistent with those reported by Sankula et al. (1997) on plant height. However, the nontreated CPRS PB-13 was 106 cm tall at harvest, which was 10 to 11 cm taller than all other treatments indicating that glufosinate applications may reduce plant height. CPRS PB-13 yield was 5370 to 5900 kg/ha. The 1- to 2-lf and 3- to 5-lf application timings were reduced when compared with the 2- to 3-tiller application timing. No differences in yield were detected when compared with the nontreated. CPRS PB-13 yield was reduced compared with conventional Cypress regardless of glufosinate timing.

At 14 DAT, a year by treatment interaction occurred for BNGL HC-11/62 injury (Table 2.1). In 1998 and 2000, injury was similar and was less than 10% regardless of glufosinate application timing. Injury was 9% when the rice was treated at the 1-lf application timing in 1998 and 2000. In 1999, injury was 13% when rice was treated at the pre-boot stage which was the highest injury reported compared with less than 5% injury for all other treatments. No year by treatment

Table 2.2. Days to 50% heading, total plant height, and yield of glufosinate-resistant rice treated with 0.84 kg/ha glufosinate at different rice growth stages averaged over 1998 through 2000.

Rice growth stage	50% heading (days)	Plant height (cm)	Rough rice yield (kg/ha)
		CPRS PB-13	
1 leaf	101	95	5520
1-2 leaf	98	94	5370
3-5 leaf	99	94	5450
2-3 tiller	100	95	5900
4-5 tiller	105	95	5680
5-6 tiller	99	94	5580
Green Ring	101	95	5510
Pre Boot	99	94	5550
Boot	103	95	5560
Nontreated	91	106	5620
Conv. Cypress	90	95	6910
LSD (0.05)	4	1	440
		BNGL HC-11/62	
1 leaf	92	89	7860
1-2 leaf	94	89	7795
3-5 leaf	95	90	7475
2-3 tiller	93	88	7935
4-5 tiller	93	89	7800
5-6 tiller	94	90	7950
Green Ring	95	91	7660
Pre Boot	95	90	7440
Boot	94	90	6395
Nontreated	90	98	8080
Conv. Bengal	90	101	7655
LSD (0.05)	3	1	460

interaction occurred at 35 DAT, therefore, data were averaged over years. Rice injury was less than 3% for all treatments, which was consistent with injury reported by Wheeler et al. (1998).

No year by treatment interaction occurred for d to 50% heading, plant height, and yield for BNGL HC-11/62; therefore, data were averaged over year. BNGL HC-11/62 reached 50% heading at 92 to 95 d regardless of application timings (Table 2.2). BNGL HC-11/62 reached 50% heading 3 d earlier when treated at the 1-lf stage compared with rice treated at the 3- to 5-lf, green ring, and pre-boot timings. Maturity was delayed in BNGL HC-11/62 with all application timings with the exception of the 1-lf timing compared with the nontreated BNGL HC-11/62 and the conventional Bengal. Rice plant height was reduced regardless of glufosinate timing compared with the conventional Bengal and the nontreated BNGL HC-11/62. Nontreated BNGL HC-11/62 and conventional Bengal were 8 to 11 cm taller than rice treated with glufosinate. Yield was 6395 to 7935 kg/ha. BNGL HC-11/62 yield was reduced when rice was treated at the 3- to 5-lf, pre-boot, and boot stage compared with the nontreated BNGL HC-11/62. BNGL HC-11/62 yield for the boot application timing was reduced compared with rice yield from all other treatments and this was consistent with previous research (Sankula et al. 1997).

In conclusion, CPRS PB-13 days to 50% heading and plant height did differ from the nontreated. The CPRS PB-13 nontreated and conventional Cypress reached 50% heading 8 to 15 days earlier than CPRS PB-13 regardless of glufosinate timing. This information is important to a producer because with glufosinate-resistant rice heading later than a conventional rice crop, this will increase water costs, delay harvesting, and increase difficulty in producing a ratoon crop. Nontreated CPRS PB-13 was taller at harvest compared with rice

heights from other glufosinate timings. Due to agronomic concerns, glufosinate-resistant CPRS PB-13 will no longer be evaluated as a potential commercial line. If glufosinate-resistant rice technology is accepted globally, the initial release will be BNGL-62. Therefore, results indicate that BNGL-62 yield reductions occur when the line is treated at early and late season growth stages. Yield reductions can occur with glyphosate applications on glyphosate-resistant cotton (Baughman and Webster 1998; Murdock 1999) and these results agree with other research reporting that rice may be more sensitive to herbicides at certain growth stages (Pantone and Baker 1992; Smith et al. 1977). In a glyphosate-resistant cotton system, Baughman and Webster (1998) reported that cotton yields were reduced with over-the-top glyphosate applications at the 9- and 12- node stages compared with a nontreated. Vargas et al. (1998) reported 0.56, 0.84, and 1.12 kg/ha glyphosate reduced boll retention when applied to 6, 9, and 12 node cotton and yield was reduced with the 12 node application. BNGL HC-11/62 yield was maximized when glufosinate was applied at the 2- to 3-tiller through the 5- to 6-tiller stage indicating that glufosinate applications should be made after the 3- to 5-lf stage and before green ring to minimize injury and maximize yield.

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CHAPTER 3

INFLUENCE OF GLUFOSINATE ON GLUFOSINATE-RESISTANT RICE SEED WEIGHT, SEED GERMINATION, AND SEEDLING VIGOR

Introduction

Seeds germinate and develop into seedlings under favorable environmental conditions (Anderson 1962; Gibson and Mullen 1996; Holm and Miller 1972). Seedling vigor determines the potential for rapid, uniform emergence, and development of seedlings under a wide range of field conditions (Association of Official Seed Analysts, 1985). Low vigor may result in slower germination and seedling growth rate, greater susceptibility to seed-rotting organisms, poor field stands, and lower yields (Edje and Burris 1971; Fehr et al. 1973; Grabe 1966).

Plant species have different temperature ranges for seed germination (Crowley and Buchanan 1980). The optimum seeding dates for rice (*Oryza sativa* L.) vary from year to year because of variation in environmental conditions, and in particular temperature (Linscombe et al. 1999). Average daily temperature at seeding is important in rice stand establishment, and temperatures of 0 to 16 C result in minimal rice seed germination. The average daily temperature must be above 18 C to insure adequate germination and rice growth in Louisiana.

Seed production and seed viability have been reduced by herbicide applications to many weed species especially when applied at or near flowering (Biniak and Aldrich 1986; Fawcett and Slife 1978; Taylorson 1966). Herbicide applications may affect the control mechanisms of germination and later utilization of stored food and have a negative impact on seedling growth (Koller et al. 1962; Milborrow 1965; Vieira et al. 1992). Issacs et al. (1989) reported sicklepod (*Senna obtusifolia* L.) seed emergence was greater with herbicides applied at

the early bloom and early fruit compared with applications at the late fruit stage. Brommer et al. (1998), reported that postemergence (POST) applications of clethodim, {(*E*,*E*)-(±)-2-[1-[[3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one}, fluazifop {(±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid}, quizalofop {(±)-2-[4-[6-chloro-2-quinoxalinyl)oxy]phenoxy]propanoic acid}, imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid}, and glyphosate [*N*-(phosphonomethyl)glycine], reduced seed germination of red rice (*Oryza sativa* L.) regardless of timing. Glyphosate at 0.32 and 1.5 kg/ha POST on red rice in the boot stage reduced seed weight 77 and 90%, respectively. Imazethapyr and glyphosate applied at the boot or bloom stage reduced red rice seed head emergence by 80%. Clay and Griffin (2000), reported similar results with 0.56 kg/ha glyphosate or 0.07 kg/ha clethodim applied to red rice at the boot stage. Baur et al. (1977) reported seed harvested from the glyphosate treated grain sorghum [*Sorghum bicolor* (L.) Moench] produced a high percentage of abnormal seedlings with reduced chlorophyll content. Bovey et al. (1999) reported no adverse effects on grain sorghum germination and seedling growth following glufosinate, [2-amino-4-(hydromethylphosphinyl)butanoic acid] as a preharvest desiccant. Glufosinate has been reported to be an excellent preharvest desiccant when used in soybean [*Glycine max* (L.) Merr.](Ellis et al. 1998) and reduced the level of normal sicklepod seedlings, but did not have a negative effect on other growth parameters such as seed production and weight (Bennett and Shaw 2000).

No information is available on the effects of glufosinate applications during the growing season on seed weights, seed germination, and seedling vigor from seed harvested from glufosinate-

treated rice. In Louisiana, it is imperative that rice seed have excellent germination and seedling vigor potential in order to survive early planting and to maximize production in water-seeded culture (Dunand 1988). Many producers grow rice as seed stock and with the development of glufosinate-resistant rice it is imperative to know what effects glufosinate applications can have on seed germination and seedling vigor the following year after treatment to the crop during the growing season. The objectives of this study were to evaluate the effects of glufosinate application timings throughout the growing season on seed weights, seed germination and seedling vigor, from seed harvested from two glufosinate-resistant rice lines.

Materials and Methods

Seeds used for 100 count seed weights and both germination and seedling vigor studies were collected from glufosinate-resistant field studies treated with 0.84 kg/ha glufosinate applied at 1-leaf (lf), 1- to 2-lf, 3- to 5-lf, 2- to 3-tiller, 4- to 5-tiller, 5- to 6-tiller, green ring, pre-boot, and boot growth stages to two glufosinate-resistant rice lines. The rice lines were CPRS PB-13, a long grain Cypress transformant, and BNGL HC-11 and BNGL 62, medium grain Bengal transformants. Each glufosinate-resistant line was treated as an individual study. Each field study had a randomized complete block design with four replications. After harvesting, 4.4 kg of seed were collected from each plot and dried in an open air forced dryer to 12% moisture, and then stored at 7 C.

Germination Study. Growth chamber experiments were conducted in 1998 through 2000 to evaluate germination of glufosinate-resistant seed under various temperatures. The temperatures used in the study were 13, 16, 19, 22, and 25 C. The selection of the temperatures was based

on 19 C as the mean 10 cm soil temperature for the past 10 years in Crowley, Louisiana on April 1, which corresponds to 50% of the rice being planted across the state (Bell 1998[1]). Two additional temperatures above and below the mean were included to represent a range of temperatures that may occur during rice planting.

Standard germination procedures recommended by the Association of Official Seed Analysts (AOSA) were used for the study (Association of Official Seed Analysts 1985). One hundred seed from each field replication were soaked for 30 minutes in a 50:50 (v/v) solution of chlorine bleach and distilled water to decrease seedling diseases. After soaking, seeds were triple rinsed with distilled water. Seed were placed in a 9 cm diameter plastic petri dish between two sheets of nontreated Anchor®[2] germination paper. Ten ml of 0.001 ml solution of carbathiin (5,6,-dihydro-2-methyl-*N*-phenyl-1,4-oxathiin-3-carboxamide) plus lindane (1,2,3,4,5,6-hexachlorocyclohexane) and distilled water added to each petri dish to reduce seedling diseases. Petri dishes were then placed in a constant temperature germinator in total darkness. Germination counts were taken at 5, 9, and 14 days after initiation (DAI) of the study. A seed was considered germinated if the radicle reached a length of 1 mm.

Seedling Vigor Study. The assessment of seedling vigor has many important implications to the seed industry and seed consumers. Seedling vigor comprises those properties which determine the potential for rapid, uniform emergence, and development of normal

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[1] Chris Bell, 1998. Personal Communication. Louisiana Office of State Climatology, Louisiana State University, Baton Rouge, LA 70803.

[2] Anchor Paper Co. 480 Broadway Street, St. Paul, MN 55101.

seedlings under a wide range of field conditions as defined by the AOSA (Association of Official Seed Analysts 1992). Seed producers use seedling vigor information to monitor seed quality during the various conditioning phases of seed production. Producers recognize seedling vigor as being important in making economic decisions regarding seed cost, planting date, seeding rate, quantity of seeds to plant, and the anticipated uniformity of stand.

A growth chamber study was conducted in 1998 through 2000 to evaluate the seedling vigor of the harvested glufosinate-resistant rice seeds as described for the germination study. Since the AOSA (1992) has not accepted an official rice vigor test, standard vigor procedures recommended by Dr. Steve Linscombe[3] were used in this study. Vigor expression of the rice seedling can be predicted by measuring growth parameters of seedlings at early phases of the germination process (Chen et al. 1986; Lee et al. 1986; Yang and Sung 1980). Vigor estimates were based on shoot length since shoot expansion is indicative of higher seedling vigor. Since environmental conditions were uniform, any differences in vigor would be attributed to the glufosinate application. Seeds were first prepared using the procedures described for the germination study. Seeds were soaked for approximately 24 hours in distilled water to pre-germinate. Approximately 10 pre-germinated seed from each treatment and replication were placed on a single sheet of Anchor® nontreated germination paper. The germination paper was placed on a plastic 12 x 23 x 0.3 cm plate. A one-ply paper towel strip was placed over the

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[3]Dr. Steve Linscombe, Rice breeder, Louisiana Rice Research Station, Crowley, LA. Louisiana State University AgCenter.

seed and 5 ml of diluted mancozeb [ethylene (bis) dithiocarbamate] fungicide was applied on top of the paper towel strip to reduce seedling diseases. The plated seeds were then placed in 30 x 51 x 5 cm glass dishes with 1420 ml of distilled water to allow for evaporation and prevent desiccation. The glass dishes were wrapped in plastic wrap and placed in a double liquid cooled incubator at 21 C for 12 days in total darkness. At the end of 12 days, shoot lengths were measured. The study was repeated each year.

Data were subjected to analysis of variance testing all possible interactions of treatment by year. Means were separated using Fisher's protected LSD at the 0.05% level of probability. All data were averaged over years and appropriate tables for treatment interactions were constructed.

Results and Discussion

CPRS PB-13 one-hundred count seed weights were not significantly different for all application timings when expressed as a percent of the nontreated (Table 3.1). Seed germination was not affected by glufosinate application timing or temperature when expressed as percent of the nontreated when evaluated at 5 and 9 DAI (Data not shown) and at 14 DAI (Table 3.2). This information is useful to producers because is demonstrates that over a wide range of growth stages glufosinate applications did not affect the germination of harvested seed. Differences were not detected for seedling vigor when expressed as a percent of the nontreated (Table 3.1).

BNGL HC-11/62 one-hundred count seed weights were not affected by any glufosinate application when expressed as a percent of the nontreated (Table 3.3). Seed germination was not affected by glufosinate application timing or temperature when expressed as

Table 3.1. Glufosinate-resistant application timing on seed weight and seedling vigor of CPRS PB-13 as a percent of the nontreated.[a]

Glufosinate Timing	100 seed weights	Seedling Vigor
	% of nontreated	
1 leaf	106	98
1-2 leaf	105	101
3-5 leaf	103	102
2-3 tiller	107	95
4-5 tiller	103	103
5-6 tiller	108	95
Green Ring	102	98
Pre Boot	104	98
Boot	99	100
LSD (0.05)	NS	NS

[a]Data averaged over years.

Table 3.2. Effect of glufosinate application timing on seed germination of CPRS PB-13 under various temperatures 14 days after initiation (DAI) as a percent of the nontreated.[a]

Glufosinate Timing[b]	Temperatures				
	13 C	16 C	19 C	22 C	25 C
	germination, % of nontreated				
1 leaf	104	101	100	101	100
1-2 leaf	103	108	101	102	98
3-5 leaf	354	101	104	98	106
2-3 tiller	94	109	103	104	103
4-5 tiller	385	102	102	99	102
5-6 tiller	221	106	102	98	102
Green Ring	130	108	103	98	103
Pre Boot	247	108	103	100	102
Boot	193	101	104	102	98
LSD (0.05)	NS	NS	NS	NS	NS

[a]Data were averaged over year.

[b]Application timings of 0.84 kg/ha glufosinate applied POST.

Table 3.3. Glufosinate-resistant application timing on seed weight and seedling vigor of BNGL HC-11/62 as a percent of the nontreated.[a]

Glufosinate Timing	100 seed weights	Seedling Vigor
	—— % of nontreated ——	
1 leaf	107	103
1-2 leaf	101	102
3-5 leaf	91	106
2-3 tiller	96	102
4-5 tiller	98	107
5-6 tiller	100	99
Green Ring	100	103
Pre Boot	99	96
Boot	94	98
LSD (0.05)	NS	NS

[a]Data averaged over years.

percent of the nontreated when evaluated at 5 and 9 DAI (Data not shown). Percent germination at 13, 16, and 19 C at 14 DAI when expressed as percent of the nontreated was not significant (Table 3.4). However, at 22 C, a treatment interaction occurred. The pre-boot application timing correlated to an 8% reduction in germination when expressed as a percent of the nontreated. There were also differences that occurred among treatments, the 5- to 6-tiller, pre-boot and boot timings were reduced when compared with the 4- to 5-tiller application timing. At 25 C, there were no differences when compared with the nontreated; however, there was a reduction in germination for the 1- to 2-lf, 5- to 6-tiller, green ring, and pre-boot application timings when compared with the 2- to 3-tiller timing. Seedling vigor was not affected by glufosinate application timings (Table 3.3).

In conclusion, CPRS PB-13 seed weights, seed germination, and seedling vigor regardless of temperature was not affected by glufosinate application. In addition, BNGL HC-11/62 seed weights were unaffected and germination was not reduced with the exception of the pre-boot application timing at the 22 C germination temperature compared with the nontreated. Seedling vigor was not affected regardless of glufosinate application timing.

The CPRS PB-13 is no longer a candidate for release as a commercially available glufosinate-resistant line; however, the medium grain BNGL-62 will be used as the line available for release if the technology is globally approved. To ensure proper germination of seed, glufosinate should not be applied after rice has reached the 5- to 6-tiller growth stage. At this stage, rice is entering reproductive growth and applying glufosinate could have a negative

Table 3.4. Effect of glufosinate application timing on seed germination of BNGL HC-11/62 under various temperatures 14 days after initiation (DAI) as a percent of the nontreated.[a]

Glufosinate Timing[b]	Temperatures 13 C	16 C	19 C	22 C	25 C
	germination, % of nontreated				
1 leaf	144	97	104	102	101
1-2 leaf	60	111	103	98	100
3-5 leaf	88	109	104	101	102
2-3 tiller	167	88	99	101	107
4-5 tiller	115	94	101	103	105
5-6 tiller	125	97	97	97	98
Green Ring	45	106	97	101	98
Pre Boot	28	90	96	92	94
Boot	163	96	101	97	104
LSD (0.05)	NS	NS	NS	6	7

[a]Data were averaged over year.

[b]Application timings of 0.84 kg/ha glufosinate applied POST.

impact on the following years crop by potentially reducing germination.

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CHAPTER 4

WEED CONTROL WITH GLUFOSINATE PLUS HERBICIDE COMBINATIONS IN GLUFOSINATE-RESISTANT RICE

Introduction

Applying two or more herbicides sequentially or as a tank-mixture to crop production systems is a common practice aimed to improve the spectrum of weed control, reduce production costs, and prevent the development of resistant weeds to certain herbicides (Bruff and Shaw 1992; Hydrick and Shaw 1995; Zhang et al. 1995). This approach is based on the assumption that herbicides would act independently when applied simultaneously or sequentially. However, it has been demonstrated that herbicides may interact before or after entering the plants and the outcome can be synergistic, antagonistic, or additive (Colby 1967).

Glufosinate [2-amino-4-(hydroxymethylphosphinyl)butanoic acid] is an effective non-selective herbicide that controls many grass and broadleaf weeds (Ahrens 1994). It has been used as a herbicide in minimum tillage systems, orchards, vineyards, and as a preharvest desiccant (Ellis et al. 1998; Mersey et al. 1990). Presently, glufosinate is being evaluated to be used as a postemergence herbicide in genetically transformed corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], cotton (*Gossypium hirsutum* L.), canola (*Brassica napus* L.) sugar beet (*Beta vulgaris* L.) and rice (*Oryza sativa* L.) (Ahrens 1998; Bertges et al. 1994; Wheeler et al. 2000).

Combinations of contact herbicides with herbicides having foliar and soil residual activity can enhance initial weed control, provide residual activity, and reduce the number of herbicide applications (Bruce and Kells 1990; Minton et al. 1989). A common practice in minimum or no-till soybean production is to tank-mix non-selective

foliarly applied herbicides with selective soil-applied herbicides prior to or at planting (Brown et al. 1987; Connell and Derting 1973; Hydrick and Shaw 1994; Kapusta 1979; Kapusta and Strieker 1976; Stougaard et al. 1984). This allows the burndown of existing vegetation, and a herbicide with residual activity is applied to control latter germinating weeds, and it is more economical to the producer.

When herbicides are applied in combination with other herbicides, control can vary (Zhang et al. 1995). Hydrick and Shaw (1994) employed Colby's to test for synergism or antagonism in a greenhouse study using tank-mixtures between non-selective foliar applied and selective soil-applied herbicides on three weeds. Glufosinate at 0.21 kg/ha alone reduced sicklepod (*Senna obtusifolia* L.) fresh weight by 49%; however, only an additive response was noted with the addition of 0.09 kg/ha metribuzin [4-amino-6-(1,1-dimrthyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one] plus 0.015 kg/ha chlorimuron-ethyl {2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid}. There were no antagonistic or synergistic responses for either rate of glufosinate for reductions of sicklepod fresh weight.

Webster and Shaw (1997), reported in a cotton stale seedbed system, that glufosinate tank-mixed with other herbicides could be an effective burndown combination for hard to control weeds in cotton. Sicklepod control was above 85% with 1.68 kg/ha fluometuron {N,N-dimethyl-N'-[3-(trifluoromethyl)phenyl]urea} or 1.68 kg/ha diuron [N'-(3,4-dichlorophenyl)-*N*-N-dimethylurea] tank-mixed with 0.84 kg/ha glufosinate compared with 62% with 0.84 kg/ha glufosinate alone; however, these responses were only additive. Pitted morningglory (*Ipomoea lacunosa* L.) control was above 90% with 1.68 kg/ha diuron, 2.02 kg/ha cyanazine {2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-

yl]amino]-2-methylpropanenitrile} or 2.24 kg/ha MSMA (monosodium salt of MAA) tank-mixed with 0.84 kg/ha glufosinate compared with 87% for a single glufosinate application with no synergism or antagonism occurring for any of these tank-mixes.

Sankula et al. (1997) reported a single application of 0.6 kg/ha glufosinate controlled red rice (*Oryza* sativa L.) 80%; however, red rice control was 92% with the addition of 3.4 kg/ha propanil [N-(3,4-dichlorophenyl)propanamide] or 0.6 kg/ha acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid}. The objective of this study was to determine if glufosinate tank-mixed with other herbicides used in rice control programs could improve weed control compared to glufosinate alone in glufosinate-resistant rice while at the same time testing potential antagonism and synergism of these combinations.

Materials and Methods

A study was conducted at the Rice Research Station near Crowley, LA in 1998 and 1999 on a Crowley silt loam (fine montmorillonitic, thermic Typic Albaqualf), with pH 5.5 and 1.2% organic matter. Seedbed preparation consisted of a fall disking followed by a spring disking and two passes in opposite directions with a two-way bed conditioner equipped with rolling baskets and S-tine harrows set to operate at a 6 cm depth. The study area was laser-leveled to a slope gradient of 0.2% both years in the winter following initial disking. Plot size was 1.5 by 6 m. A glufosinate-resistant medium grain rice 'BNGL HC-11' was drill-seeded on May 13, 1998 and 'BNGL-62'on May 19, 1999 at 112 kg/ha. After seeding, the study was flushed within 24 hours and at the 2- to 3- and 3- to 4-leaf (lf) stage of rice. The area received 224 kg/ha 46-0-0 urea nitrogen prior to permanent flood. In 1998 and 1999, a 5 cm permanent flood was established on June 12 and June 28, respectively. The experimental design was a randomized

complete block with a two factor-factorial arrangement of treatments with four replications. Factor A was glufosinate applied at 0, 0.42, and 0.84 kg/ha. Factor B was 0.4 kg/ha bensulfuron {2-[[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]methyl] benzoic acid}, 0.05 kg/ha halosulfuron {3-chloro-5-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-1-methyl-1*H*-pyrazole-4-carboxylic acid}, 4.48 kg/ha propanil, 1.7 kg/ha propanil plus 1.7 kg/ha molinate (*S*-ethyl hexahydro-1*H*-azepine-1-carbothioate), 0.42 kg/ha quinclorac (3,7-dichloro-8-quinolinecarboxylic acid), and 0.28 kg/ha triclopyr {[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid} and no herbicide.

Herbicides were applied to 3-to 4-lf rice. Herbicide applications were made on June 3, 1998 and June 14, 1999 with a CO_2-pressurized backpack sprayer in 140 L/ha spray volume at 186 kPa. Weed control and crop injury was evaluated at 7, 14, and 28 days after treatment (DAT). Visual control and injury ratings were based on a scale 0 = no control or injury and 100% = complete plant death. Weed species evaluated included barnyardgrass (*Echinochloa crus-galli* L. Beauv.), broadleaf signalgrass (*Brachiaria platyphylla* Griseb.), annual sedge (*Cyperus iria L.)*, and spreading dayflower (*Commelina diffusa* Burm. f.). Injury symptoms included chlorosis, necrosis, and stunting. All data were subjected to analysis of variance testing all possible interactions of glufosinate rate, tank-mix herbicide, and year. Arcsine transformations of visual evaluations were not used, since it provided no additional delineation of the data. Means were separated using Fisher's protected LSD at the 5% probability level and tables for the appropriate interactions were developed.

Interactions between herbicide combinations were calculated by the mathematical method described by Colby (1967). An expected value

was calculated as follows: the product of the percent reduction provided by the two herbicides applied individually was divided by 100; this value was then subtracted from the sum of the control obtained with the two herbicides applied alone. Expected and observed values were compared by Fisher's protected LSD at the 5% level of significance. If the observed response for the herbicide combination was significantly greater than the expected value, the combination was declared synergistic; if significantly less than the expected value, the combination was declared antagonistic; the combination was additive when there was not a significant difference between the observed and the expected responses.

Results and Discussion

At 7 DAT, a single application of 0.42 kg/ha glufosinate controlled barnyardgrass 82% (Table 4.1). Antagonism occurred for all combination treatments with the exception of an additive response with propanil and propanil plus molinate. Barnyardgrass control was 85% with 0.84 kg/ha glufosinate and a synergistic response occurred with the addition of propanil. Enhanced control with propanil has been observed with propanil tank-mixes compared with propanil alone (Baltazar and Smith 1994; Sankula et al. 1997; Street and Snipes 1989). Street and Snipes (1989), reported that control of barnyardgrass increased two-fold when 3.4 kg/ha propanil was mixed with 2.2 kg/ha tridiphane [2-(3,5-dichlorophenyl)-2-(2,2,2-trichloroethyl)oxirane. Increased barnyardgrass control was reported with propanil combined with quinclorac, thiobencarb {*S*-[(4-chlorophenyl)methyl] diethylcarbamothioate}, or pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] compared with a single application of propanil (Baltazar and Smith 1994).

Table 4.1. Barnyardgrass control 7, 14, and 28 days following application to three- to four-leaf transgenic rice, averaged over years.[abc]

Combination Herbicide	Rate	glufosinate (kg/ha) 0	0.42		0.84	
	(kg/ha)	% control, 7 DAT				
None		0	82		85	
Bensulfuron	0.4	8	75 -	(83)	88	(86)
Halosulfuron	0.05	21	81 -	(86)	84	(88)
Propanil	4.48	39	91	(89)	96 +	(91)
Propanil/Molinate	1.7 + 1.7	60	90	(93)	94	(94)
Quinclorac	0.42	32	83 -	(88)	89	(90)
Tricolpyr	0.28	16	76 -	(85)	88	(87)
LSD (0.05)		4				
		% control, 14 DAT				
None		0	85		92	
Bensulfuron	0.4	23	48 -	(88)	82 -	(94)
Halosulfuron	0.05	24	45 -	(89)	95	(94)
Propanil	4.48	53	66 -	(93)	94	(96)
Propanil/Molinate	1.7 + 1.7	15	77 -	(87)	90	(93)
Quinclorac	0.42	71	68 -	(96)	96	(98)
Triclopyr	0.28	7	48 -	(86)	77 -	(93)
LSD (0.05)		8				
		% control, 28 DAT				
None		0	70		91	
Bensulfuron	0.4	8	61 -	(72)	76 -	(92)
Halosulfuron	0.05	3	60 -	(71)	89	(91)
Propanil	4.48	6	48 -	(72)	84	(92)
Propanil/Molinate	1.7 + 1.7	6	49 -	(72)	87	(92)
Quinclorac	0.42	16	51 -	(75)	90	(92)
Triclopyr	0.28	3	60 -	(71)	65 -	(91)
LSD (0.05)		8				

[a]A negative sign (-) denotes an antagonistic response; a positive sign (+) denotes a synergistic response.

[b]Abbreviations: DAT, days after treatment.

[c]Values in parentheses are Colby's calculated (expected) level of percent control for the herbicide combinations.

At 14 DAT, a single application of 0.42 kg/ha glufosinate controlled barnyardgrass 85%, which was 8 to 40% higher than all herbicide combinations (Table 4.1). Antagonism occurred with all 0.42 kg/ha glufosinate combinations; however antagonism was overcome by increasing the rate of glufosinate to 0.84 kg/ha, with the exception of bensulfuron and triclopyr. No synergism occurred and similar results occurred at 28 DAT. These results were consistent with previous research, which reported that increasing the rate of non-selective herbicide while keeping the selective herbicide rate constant can overcome antagonism (O'Donovan and O'Sullivan 1982; Rhodes and Coble 1984). Hydrick and Shaw (1994), reported antagonism with 0.21 kg/ha glufosinate tank-mixed with 0.18 kg/ha metribuzin plus 0.03 kg/ha chlorimuron {2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino] carbonyl]amino]sulfonyl]benzoic acid}, or 0.07 kg/ha imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid}, for control of entireleaf morningglory (*Ipomoea hederacea* var. integriuscula L.) and control increased with 0.42 kg/ha glufosinate plus 0.035 kg/ha imazaquin compared with a single application of 0.42 kg/ha glufosinate.

No synergism occurred for broadleaf signalgrass control across all rating dates and treatments (Table 4.2). Antagonism occurred with 0.84 kg/ha glufosinate plus all combination herbicides at some point over the three ratings with the exception of an additive response from propanil and propanil plus molinate. No herbicide was beneficial to glufosinate at either rate when applied in a tank-mix for control of broadleaf signalgrass compared with a single application of glufosinate indicating that no additional herbicide is needed for broadleaf signalgrass control.

Table 4.2. Broadleaf signalgrass control 7, 14, and 28 days following application to three- to four-leaf transgenic rice, averaged over years.[abc]

Combination Herbicide	Rate	glufosinate (kg/ha) 0	0.42	0.84
	(kg/ha)	% control, 7 DAT		
None		0	74	91
Bensulfuron	0.4	13	71 - (77)	85 - (92)
Halosulfuron	0.05	18	78 (79)	86 - (93)
Propanil	4.48	80	89 - (95)	94 (98)
Propanil/Molinate	1.7 + 1.7	58	92 (89)	95 (96)
Quinclorac	0.42	42	83 (85)	86 - (95)
Tricolpyr	0.28	23	71 - (80)	84 - (93)
LSD (0.05)		4		
		% control, 14 DAT		
None		0	86	94
Bensulfuron	0.4	4	67 - (87)	86 - (94)
Halosulfuron	0.05	6	68 - (87)	95 (94)
Propanil	4.48	68	92 (96)	95 (98)
Propanil/Molinate	1.7 + 1.7	11	81 (88)	94 (95)
Quinclorac	0.42	73	90 (96)	81 - (98)
Triclopyr	0.28	13	88 (88)	89 (95)
LSD (0.05)		7		
		% control, 28 DAT		
None		0	88	93
Bensulfuron	0.4	3	46 - (88)	85 (93)
Halosulfuron	0.05	0	48 - (88)	85 (93)
Propanil	4.48	41	65 - (93)	89 (96)
Propanil/Molinate	1.7 + 1.7	8	81 (89)	87 (94)
Quinclorac	0.42	20	41 - (90)	83 - (94)
Triclopyr	0.28	1	29 - (88)	78 - (93)
LSD (0.05)		9		

[a]A negative sign (-) denotes an antagonistic response; a positive sign (+) denotes a synergistic response.

[b]Abbreviations: DAT, days after treatment.

[c]Values in parentheses are Colby's calculated (expected) level of percent control for the herbicide combinations.

Annual sedge control was 68 and 82% with a single application of glufosinate at 0.42 and 0.84 kg/ha, respectively, at 7 DAT (Table 4.3). The only combination that resulted in a synergistic response across all rating dates was 0.42 kg/ha glufosinate plus quinclorac. At 14 and 28 DAT, no synergistic responses occurred for any herbicide combination; however, control of annual sedge did increase with several tank-mixes. Although no synergism occurred at the final rating date, the addition of bensulfuron, propanil, and triclopyr did significantly enhance annual sedge control over a single application of glufosinate at 0.42 or 0.84 kg/ha. The addition of a herbicide with glufosinate may be needed if annual sedge is present at time of application.

At 7 DAT, a single application of 0.42 and 0.84 kg/ha glufosinate resulted in 63 and 81% control of spreading dayflower (Table 4.4). The additions of bensulfuron, halosulfuron, or triclopyr to 0.42 kg/ha glufosinate were synergistic for annual sedge control. All combinations resulted in increased control of spreading dayflower compared with 0.42 kg/ha glufosinate alone. The addition of triclopyr to 0.84 kg/ha glufosinate was not synergistic however control increased compared with glufosinate alone. At 14 DAT, the addition of bensulfuron, propanil, propanil plus molinate, and quinclorac to 0.84 kg/ha glufosinate resulted in synergism for control of spreading dayflower. The addition of halosulfuron was only additive and increased control of spreading dayflower from 59% with 0.84 kg/ha glufosinate to 95%. By 28 DAT, control of spreading dayflower dropped to less than 80% with all treatments. The addition of halosulfuron to 0.84 kg/ha glufosinate was additive and resulted in increased control of spreading dayflower compared with a single application of 0.84 kg/ha glufosinate. The drop in control was due to regrowth and later

Table 4.3. Annual sedge control 7, 14, and 28 days following application to three- to four-leaf transgenic rice, averaged over years.[abc]

Combination Herbicide	Rate	glufosinate (kg/ha) 0	0.42		0.84	
	(kg/ha)	% control, 7 DAT				
None		0	68		82	
Bensulfuron	0.4	6	66	(70)	84	(83)
Halosulfuron	0.05	22	75	(75)	71 -	(86)
Propanil	4.48	53	76 -	(85)	94	(92)
Propanil/Molinate	1.7 + 1.7	48	80	(83)	93	(91)
Quinclorac	0.42	11	80 +	(72)	79	(84)
Tricolpyr	0.28	7	70	(70)	89	(83)
LSD (0.05)		7				
		% control, 14 DAT				
None		0	76		78	
Bensulfuron	0.4	84	88	(96)	81 -	(96)
Halosulfuron	0.05	83	48 -	(74)	94	(96)
Propanil	4.48	61	80 -	(91)	84	(91)
Propanil/Molinate	1.7 + 1.7	21	71 -	(81)	82	(83)
Quinclorac	0.42	26	49 -	(82)	91	(84)
Triclopyr	0.28	6	86	(77)	64 -	(79)
LSD (0.05)		9				
		% control, 28 DAT				
None		0	61		50	
Bensulfuron	0.4	54	89	(82)	80	(77)
Halosulfuron	0.05	61	62 -	(85)	82	(81)
Propanil	4.48	75	81	(90)	89	(79)
Propanil/Molinate	1.7 + 1.7	66	71 -	(87)	79	(83)
Quinclorac	0.42	71	62 -	(89)	73 -	(86)
Triclopyr	0.28	43	88	(78)	61	(72)
LSD (0.05)		11				

[a]A negative sign (-) denotes an antagonistic response; a positive sign (+) denotes a synergistic response.

[b]Abbreviations: DAT, days after treatment.

[c]Values in parentheses are Colby's calculated (expected) level of percent control for the herbicide combinations.

Table 4.4. Spreading dayflower control 7, 14, and 28 days following application to three- to four-leaf transgenic rice, averaged over years.[abc]

Combination Herbicide	Rate	glufosinate (kg/ha) 0	0.42	0.84
	(kg/ha)	% control, 7 DAT		
None		0	63	81
Bensulfuron	0.4	4	82 + (65)	85 (82)
Halosulfuron	0.05	12	84 + (67)	70 - (83)
Propanil	4.48	38	73 (77)	85 (88)
Propanil/Molinate	1.7 + 1.7	31	81 (75)	85 (87)
Quinclorac	0.42	16	72 (69)	83 (84)
Tricolpyr	0.28	14	82 + (68)	88 (84)
LSD (0.05)			7	
		% control, 14 DAT		
None		0	41	59
Bensulfuron	0.4	46	42 - (68)	96 + (78)
Halosulfuron	0.05	73	62 - (84)	95 (89)
Propanil	4.48	5	64 + (44)	94 + (61)
Propanil/Molinate	1.7 + 1.7	6	42 (45)	95 + (51)
Quinclorac	0.42	10	48 (47)	89 + (63)
Triclopyr	0.28	49	52 - (70)	38 - (79)
LSD (0.05)			9	
		% control, 28 DAT		
None		0	58	63
Bensulfuron	0.4	11	49 - (62)	53 - (67)
Halosulfuron	0.05	31	48 - (71)	77 (74)
Propanil	4.48	14	48 - (64)	68 (68)
Propanil/Molinate	1.7 + 1.7	14	48 - (64)	60 - (68)
Quinclorac	0.42	18	46 - (66)	61 - (70)
Triclopyr	0.28	26	47 - (69)	58 - (72)
LSD (0.05)			7	

[a]A negative sign (-) denotes an antagonistic response; a positive sign (+) denotes a synergistic response.

[b]Abbreviations: DAT, days after treatment.

[c]Values in parentheses are Colby's calculated (expected) level of percent control for the herbicide combinations.

germination of spreading dayflower resulting in a late season infestation (Smith 1988). The addition of bensulfuron, halosulfuron, propanil, propanil plus molinate or quinclorac to glufosinate can be beneficial on a short term basis; however, a second application will be needed in glufosinate-resistant rice to adequately control spreading dayflower season long.

No differences occurred for rice injury across the three rating dates (Data not shown). At 7 DAT, injury was less than 15% for all treatments. At 14 and 28 DAT, injury was less than 10% for all treatments evaluated.

This research indicates that applying glufosinate in combination with a selective herbicide can result in interactions, and many times these interactions occur in the form of antagonism. By increasing the rate of glufosinate antagonism was generally overcome. This agrees with previous research reported by O'Donovan and O'Sullivan (1982) and Rhodes and Coble (1984) when applying contact plus residual herbicide combinations. However, for the weeds evaluated in this study, annual sedge and spreading dayflower control was enhanced by additional selective herbicides with glufosinate indicating that glufosinate alone may not provide adequate control of these weeds. The addition of triclopyr with 0.84 kg/ha glufosinate at 14 DAT resulted in a decrease in control of annual sedge and a similar result was observed with the addition of halosulfuron at 7 DAT on spreading dayflower. This was probably due to one herbicide reducing the rate of penetration of the other herbicide into the plant (Richard and Baker 1979; Richard et al. 1984; Sundara et al. 1983). This is evident by the high rate of glufosinate rapidly desiccating foliage of target plants effectively reducing the amount of triclopyr and halosulfuron absorbed. At 7 DAT, spreading dayflower control was enhanced with the

addition of any of the herbicides evaluated when compared with a single application of 0.84 kg/ha glufosinate. Spreading dayflower control was enhanced at the 14 DAT evaluation; however, control dropped at 28 DAT, indicating another application would be needed for adequate control. This agrees with Sankula et al. (1997) for lack of control of ducksalad (*Heteranthera limosa* Willd.) and alligatorweed (*Alternanthera philoxeroides* Griseb.) with glufosinate alone. No synergistic response was gained by tank-mixing glufosinate with other herbicides to control barnyardgrass and broadleaf signalgrass when evaluated 28 DAT. Glufosinate alone will control these grasses with no tank mix partner, which from an economic standpoint, will benefit producers by saving money on additional herbicide costs. However, if a producer has annual sedge and/or a spreading dayflower infestation, an application of 0.84 kg/ha glufosinate plus bensulfuron, halosulfuron, propanil, propanil plus molinate, or quinclorac will be needed for adequate control.

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CHAPTER 5

IMPACT OF PERMANENT FLOOD DEPTH ON GLUFOSINATE ACTIITY ON RED RICE

Introduction

Red rice (*Oryza sativa* L.) is a problem weed for rice (*Oryza sativa* L.) production in the southern U. S. as well as Central and South America (Cohn and Hughes 1981; Fischer and Ramirez 1993; Pantone and Baker 1991). In 1846, red rice was first recognized as a weed of rice in the United States in North and South Carolina (Craigmiles 1978). It is estimated that grain yield, grade, and quality reductions in commercial rice due to red rice cost producers millions of dollars annually (Diarra et al. 1985; Eastin 1978). Red rice is difficult to control during the rice growing season due to its biochemical and physiological similarity to cultivated rice (Hoagland 1978; Matsunaka 1970).

Traditionally, partial red rice control is achieved through preplant application of molinate (*S*-ethyl hexahydro-1*H*-azepine-1-carbothioate) or thiobencarb {*S*-[(4-chlorophenyl)methyl] diethylcarbamothioate} in combination with pinpoint water management in water-seeded rice (Anonymous 1992; Baker et al. 1986; Forner 1995; Smith 1981). Rice has been grown in flooded conditions for many years to aid in weed control (Adair and Engler 1955; Smith 1988). Currently, postemergence herbicides are not available that can effectively control red rice (Baldwin et al. 1997; Kwon et al. 1991; Rao and Harger 1981; Smith 1979). The most recent developments in red rice control are from genetic modification of rice cultivars rendering them tolerant to specific classes of herbicide chemistry (Dillon et al. 2000; Jiang et al. 2000; Webster and Lanclos 2000; Wheeler et al. 2000). Use of glufosinate [2-amino-4-(hydroxymethylphosphinyl)

butanoic acid] -resistant rice will allow over the top applications of glufosinate to a wide range of weeds including red rice (Braverman and Linscombe 1993, 1994; Sankula et al. 1997).

Little is known about the effects of flood depth in conjunction with glufosinate application timings on red rice in glufosinate-resistant rice. Flood depth may be a concern with glufosinate-resistant rice because as a contact herbicide efficacy may be affected by foliage exposure, which can be reduced as flood depth increases. Aquatic weeds such as ducksalad (*Heteranthera limosa* Willd.) and alligatorweed (*Alternanthera philoxeroides* Griseb.), which are not controlled with glufosinate, may need additional herbicides when rice is under flooded conditions (Sankula et al. 1997).

Sankula and Braverman (1996) reported red rice control was affected by flooding and glufosinate rates 21 DAT in both field and greenhouse studies. In field studies, floodwater reduced the efficacy of glufosinate by 29, 28, 46, 18, and 34% with glufosinate at 0.28, 0.42, 0.56, 0.84, 1.12 kg/ha, respectively, compared with no flood. In a greenhouse study, red rice control was 96 to 100% with glufosinate under dry soil conditions at 21 d after treatment (DAT); however, red rice control was reduced to less than 78% when the permanent flood covered at least 50% of the red rice foliage. Plant height and dry matter production of red rice increased as flood depth increased, indicating reduced herbicide activity. However, information is limited on the combination effect of glufosinate rates and timings as well as flood depth on rice growth and weed control in glufosinate-resistant rice production. Therefore, the objective of this study was to evaluate the effect of glufosinate applied at different rates and timings on glufosinate-resistant rice and red rice under specific flood depths.

Materials and Methods

A study was conducted in 1998 and 1999 to evaluate red rice control and crop response to glufosinate applied at different rates and timings as well as flood depths in drill-seeded glufosinate-resistant rice. The study was conducted at the Rice Research Station near Crowley, LA in 1998 and a producer location near Eunice, LA in 1999. At both locations, the soil was a Crowley silt loam (fine montmorillonitic, thermic Typic Albaqualf) with a pH 5.5 to 5.7 and 1.0 to 1.2% organic matter. Field preparation at each location consisted of a fall disking followed by a spring disking and two passes in opposite directions with a two-way bed conditioner equipped with rolling baskets and S-tine harrows set to operate at a 6 cm depth. The glufosinate-resistant rice line 'BNGL HC-11' (medium grain transformant) was drill-seeded on May 19, 1998 in Crowley. In 1999, the glufosinate-resistant rice line 'BNGL-62' (medium grain transformant) was drill-seeded on July 2, 1999 near Eunice. The planting delay in 1999 was due to a mechanical problem with the irrigation pump at the Crowley location and as the season progressed, the decision was made to move the location to a producer field. Plots consisted of eight 19 cm rows, 6 m long.

The study was a factorial arrangement of treatments in a randomized complete block design with four replications. Factor A was glufosinate rate was 0, 0.42, and 0.84 kg/ha. Factor B was glufosinate application timing to 2- to 3-leaf (lf) rice, 4- to 5-lf rice, and 5-lf to 1-tiller rice. Factor C was flood depth at 5, 10, or 20 cm. Individual galvanized steel rings, 20 to 36 cm tall with a diameter of 0.9 meters, were placed in the center of each plot to allow for flood adjustment. Flood depth was maintained in individual plots on 0.82 m^2 area, on a daily basis by physically adjusting the

water level within the ring to the desired flood level. Herbicide applications were made with a CO_2-pressurized backpack sprayer set to deliver 140 L/ha. At the 2- to 3-lf application timing rice was not tall enough to establish true 5, 10, and 20 cm floods, therefore proportional flood depths were established (Table 5.1). Flood depths were 3, 6, and 12 cm for the 5, 10, and 20 cm flood depths, respectively, for the initial glufosinate timing. Flood depth was raised daily until desired flood depth was established. There was no variation in flood depth for the 4- to 5-lf and 5-lf to 1-tiller application timings (Table 5.1). Red rice density was 3 to 150 plants/m^2 and 5 to 50 plants/m^2 at the Crowley and Eunice locations, respectively. Permanent flood was established three days prior to the 2- to 3-lf application timing in both years. Standard agronomic and pest management practices were employed during the growing season.

Red rice control and rice injury was visually evaluated at 2 and 3 WAT using a scale of 0 = no control or injury and 100 = complete plant death. All data were subjected to analysis of variance testing all possible interactions of glufosinate rate, timing, flood depth, and year. Arcsine transformations were not used since it provided no additional delineation of the data. Means were separated using Fisher's Protected LSD at the 0.05% probability level and tables for appropriate interactions were developed.

Results and Discussion

An application timing by flood depth by year interaction occurred for red rice control at 2 and 3 WAT; therefore, data were averaged over glufosinate rates (Table 5.2). Control of red rice with glufosinate was 87 to 98% for the 2 and 3 WAT control evaluations. Red rice control with a 2- to 3-lf glufosinate application at 2 and 3 WAT was reduced with a 20 cm flood depth when compared with the 5 and

Table 5.1. Rice growth stages, flood depths, and corresponding percent foliage exposed above water level at glufosinate application timings.

Growth stage	Shallow flood	Medium flood	Deep flood
	cm/% foliage exposed[a]		
2-3 lf	3/82	6/64	12/29
4-5 lf	5/90	10/80	20/59
5 lf-1 till	5/92	10/84	20/67

[a]Flood depth and percent foliage exposed above water level at time of glufosinate application.

Table 5.2. Effect of flood depth and glufosinate application timing on red rice control 2 and 3 weeks after treatment in 1998 and 1999, averaged over glufosinate rate.

Glufosinate	1998[a]			1999		
Timing	5	10	20	5	10	20
	% control, 2 WAT[b]					
2-3 lf	92	92	90	96	95	87
3-4 lf	98	97	95	95	94	94
5 lf-1 till	93	92	93	89	93	94
LSD (0.05)	2					
	% control, 3 WAT					
2-3 lf	97	97	92	93	93	89
3-4 lf	93	93	95	93	92	91
5 lf-1 till	96	96	95	87	89	94
LSD (0.05)	2					

[a]Permanent flood depth: 5, 10, 20 cm.

[b]Abbreviations: WAT, weeks after treatment.

10 cm flood depths in 1998 and 1999. The reduced control was due to over 70% coverage of the red rice foliage with the flood water and this reduced the coverage of the herbicide spray. Sankula et al. (1997), reported increased red rice control with glufosinate when 75% of the foliage was above the water level. In 1998, red rice control with a 3- to 4-lf glufosinate application was increased at 5 and 10 cm flood depths when compared with the 20 cm flood depth at 2 WAT. In 1999, at the 3- to 4-lf timing, no difference in control was observed at 2 WAT, but control was greater at 5 cm compared with the 20 cm flood depth at 3 WAT. However, control was 91 to 93% with all glufosinate timings regardless of flood depth. In 1999, when glufosinate was applied at the 5-lf to 1-tiller stage, increased red rice control was observed at 10 and 20 cm compared with 5 cm depth at 2 WAT. At 3 WAT, red rice control was increased with a 20 cm flood compared with the 5 and 10 cm flood depths. Rice injury was 0-2% for all application timings and flood depths with no differences observed (Table 5.3).

The results indicate a glufosinate application to 2- to 3-lf red rice with a 5 to 10 cm flood depth resulted in the highest control or was equilvalent to the highest control in three of the four rating evaluations. In 1999, at 2 and 3 WAT, a shallow flood in conjunction with a 5-lf to 1-tiller glufosinate application reduced red rice control however, this did not occur in 1998 indicating that an increased flood depth may aid in control of red rice.

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Table 5.3. Effect of flood depth and glufosinate application timing on glufosinate-resistant rice injury 2 and 3 weeks after treatment averaged over glufosinate rate and years.

Glufosinate timing	Permanent Flood Depth, cm		
	5	10	20
	——— % injury, 2 WAT[a] ———		
2-3 lf	2	1	0
3-4 lf	1	0	0
5 lf-1 till	0	0	0
LSD (0.05)	——— NS ———		
	——— % injury, 3 WAT ———		
2-3 lf	0	0	0
3-4 lf	0	0	0
5 lf-1 till	0	0	0
LSD (0.05)	——— NS ———		

[a]Abbreviations: WAT, weeks after treatment

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CHPATER 6

SUMMARY

Technological advances in genetic engineering have allowed the development of crops to be resistant to herbicides, specifically glufosinate [2-amino-4-(hydroxymethylphosphinyl)butanoic acid] in rice (*Oryza sativa* L.). These advances will allow the use of glufosinate to be applied postemergence to control red rice (*Oryza sativa* L.) and many other weeds in rice production.

Studies were conducted to evaluate crop response and yield to glufosinate applied at intervals during the growing season. At 14 d after treatment (DAT), CPRS PB-13 was injured 8 to 9% when treated at the 1-leaf (lf) and 3- to 5-lf stage in 1998 and pre-boot and boot stage in 1999. Averaged over three years, injury symptoms at 35 DAT were less than 3% when rice was treated at various growth stages. Differences in yield were not detected for all application timings when compared with the nontreated. For BNGL HC-11/62 at 14 DAT, 9% crop injury resulted when glufosinate was applied at the 1-lf timing in 1998 and 2000. In 1999, injury was 13% when rice was treated at the pre-boot timing with all other treatments having less than 5% injury. Rice yield was 6395 to 7935 kg/ha. Rice yield was reduced when treated at the 3- to 5-lf, pre-boot, and boot timings compared with the nontreated BNGL HC-11/62. Since CPRS PB-13 is no longer a viable candidate for commercial release, this research indicates that glufosinate applications to the BNGL HC-11/62 line should be made from the 2- to 3-tiller to the 5- to 6-tiller stage to minimize injury and maximize yield.

Currently, information is not available on the effects of glufosinate applications during the growing season on harvested seed weights, seed germination, and seedling vigor. Therefore, seed weights were evaluated from harvested seed from two glufosinate-resistant rice lines. In addition to seed weights, growth chamber studies evaluating seed germination and seedling vigor were conducted.

CPRS PB-13 seed weights were not significantly different for all application timings when expressed as a percent of the nontreated. Seed germination was not affected by glufosinate application timing or temperature when expressed as percent of the nontreated when evaluated at 5, 9, and 14 d after initiation (DAI). No differences were detected for seedling vigor when expressed as a percent of the nontreated.

BNGL HC-11/62 seed weights were not affected by any glufosinate application when expressed as a percent of the nontreated. Seed germination was not affected by glufosinate application timing or temperature when expressed as percent of the nontreated when evaluated at 5 and 9 DAI. At 14 DAI, percent germination at 13, 16, and 19 C when expressed as percent of the nontreated was not significant. However, at 22 C, a treatment interaction occurred. The pre-boot application timing correlated to an 8% reduction in germination when expressed as a percent of the nontreated. Seedling vigor was not affected by glufosinate application timings. If glufosinate-resistant rice is globally accepted BNGL-62 will be the line commercially released. This research indicates that seed weights and seedling vigor will not be adversely affected by a glufosinate application the

previous year; however, germination may be adversely affected under certain growing conditions.

Applying two or more herbicides as a tank-mixture is a common practice that can aid weed control and reduce herbicide costs. However, when herbicides are tank-mixed, interactions may occur in the form of additive, antagonistic, or synergistic responses. Field studies were established to evaluate weed control with glufosinate alone and in tank-mix combinations. Glufosinate was applied at 0, 0.42, or 0.84 kg/ha as a single application or tank-mixed with 0.4 kg/ha bensulfuron {2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl] amino]sulfonyl]methyl]benzoic acid}, 0.05 kg/ha halosulfuron {3-chloro-5-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino] sulfonyl]-1-methyl-1*H*-pyrazole-4-carboxylic acid}, 4.48 kg/ha propanil [*N*-(3,4-dichlorophenyl) propanamide], 1.7 kg/ha propanil plus 1.7 kg/ha molinate (*S*-ethyl hexahydro-1*H*-azepine-1-carbothioate), 0.42 kg/ha quinclorac (3,7-dichloro-8-quinolinecarboxylic acid) and 0.28 kg/ha triclopyr {[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid} on 3- to 4-lf rice. At 14 DAT, 0.42 kg/ha glufosinate controlled barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] and broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash] 85 and 86%, respectively. Antagonism occurred for barnyardgrass control with all 0.42 kg/ha glufosinate combinations; however, antagonism was overcome by increasing the rate of glufosinate to 0.84 kg/ha, with the exception of bensulfuron and triclopyr. At 14 DAT, no herbicide was beneficial with glufosinate at either rate when applied in a tank-mix for control of broadleaf signalgrass compared with glufosinate alone. Annual sedge (*Cyperus iria* L.) control was 68 and 82% with a single

application of glufosinate at 0.42 and 0.84 kg/ha, respectively, 7 DAT. The addition of propanil and triclopyr enhanced annual sedge control over a single application of glufosinate at 0.42 or 0.84 kg/ha. At 7 DAT, all herbicide combinations resulted in increased control of spreading dayflower (*Commelina diffusa* Burm. f.) compared with glufosinate at 0.42 kg/ha. By 28 DAT, control of spreading dayflower dropped to less than 80% with all treatments.

This research indicates that applying glufosinate in combination with a selective herbicide can result in interactions, and many times these interactions occur in the form of antagonism. However, by increasing the rate of glufosinate, antagonism was generally overcome. For the weeds evaluated in this study, annual sedge and spreading dayflower control was enhanced by the addition of selective herbicides with glufosinate indicating that glufosinate alone may not provide adequate control of these weeds. Glufosinate alone will control barnyardgrass and broadleaf signalgrass alone and it will benefit producers by saving money on additional herbicide costs. However if a producer has an annual sedge and/or a spreading dayflower infestation, an application of 0.84 kg/ha glufosinate plus bensulfuron, halosulfuron, propanil, propanil plus molinate, or quinclorac will be needed for adequate control.

Little is known about the effects of flood depths in conjunction with glufosinate application timings; therefore, a study was established to evaluate the influence of 5, 10, and 20 cm water depths on red rice control with glufosinate at 0.42 and 0.84 kg/ha. Overall, red rice control was 87 to 98% and responded differently to flood depth, glufosinate application timings, and years. Red rice control

at both 2 and 3 WAT was lower at the 20 cm for the 2- to 3-lf stage in 1998 and 1999. In 1999, a 5-lf to 1-tiller glufosinate application increased red rice control 5 and 7% with a 20 cm flood depth compared with a 5 cm flood depth at 2 and 3 WAT, respectively. These results indicate that a glufosinate application on 2- to 3-lf red rice with a 5 to 10 cm flood depth resulted in the highest control or was equivalent to the highest control in three of the four rating evaluations. In 1999, at 2 and 3 WAT, a shallow flood in conjunction with a 5-lf to 1-tiller glufosinate application reduced red rice control; however, this did not occur in 1998 indicating that an increased flood depth may aid in control of red rice.

In conclusion, this research indicates that glufosinate-resistant rice technology will be beneficial to Louisiana rice producers. This technology will allow producers to control red rice and a broad spectrum of other rice weeds under different environmental conditions. The flexibility in this production system will be valuable to rice producers in the U. S.

VITA

David Yves Lanclos was born on February 5, 1972, the second of three children to Dean and Gene Lanclos in Opelousas, Louisiana. He was reared between Opelousas and Leonville, Louisiana, a small rural farming community. He attended Opelousas Catholic High School and graduated in 1990. David attended the University of Louisiana at Lafayette and received his bachelor of science degree in agricultural business in December of 1994. While an undergraduate, he was active in collegiate Future Farmers of America, served as president of Alpha Zeta fraternity for two years, and was a member of the soil and livestock judging teams. During his senior year, David was an intern with the Natural Resource Conservation Service in Lafayette and St. Martin parish.

In January of 1995, David entered the Agronomy Department at Louisiana State University in Baton Rouge, Louisiana as a full-time teaching assistant. He soon began his master's program under the direction of Dr. James E. Board working on a research project predicting yield of late-planted soybean in Louisiana. After a year, David accepted a Research Associate position in the Wheat and Oat Breeding project where he worked full-time for two years. While working on his master's, David was involved in the American Society of Agronomy and was inducted into the Louisiana State University chapter of Gamma Sigma Delta. His thesis research was published in Louisiana Agriculture, a semi-technical bulletin published by the Louisiana State University AgCenter. David graduated with his master's degree in agronomy in December of 1997.

In January of 1998, David began working on his doctorate in weed science in the Department of Plant Pathology and Crop Physiology under the direction of Dr. Eric P. Webster and Dr. James L. Griffin. His dissertation evaluated glufosinate-resistant rice response and weed control with glufosinate in Louisiana.

As a graduate student, David had the opportunity to represent Louisiana State University as a member of the weed team for two years. He was also a member of the Louisiana Plant Protection Association, Weed Science Society of America, Southern Weed Science Society of America and the Rice Technical Working Group. He has authored or co-authored eighteen abstracts, five annual reports, and he is in the process of submitting his dissertation research for refereed publication. David married Nicole A. Francingues from New Orleans in January of 1998. He expects to receive the degree of Doctor of Philosophy in Plant Health on May 18, 2001.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: David Yves Lanclos

Major Field: Plant Health

Title of Dissertation: Crop Response and Weed Control with Glufosinate in Rice

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

23 March 2001