RED RICE (*Oryza sativa* L.) ECOTYPE TOLERANCE TO HERBICIDES AND WINTER WEED MANAGEMENT PRACTICES

A Thesis

by

WELDON DUANE NANSON

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2007

Major Subject: Agronomy

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Approved by:

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ABSTRACT

Red Rice (*Oryza sativa* L.) Ecotype Tolerance to Herbicides

and Winter Weed Management Practices. (August 2007)

Weldon Duane Nanson, B.S., Texas A&M University

Chair of Advisory Committee: Dr. J.M. Chandler

Studies were conducted in 2004, 2005, and 2006 in south Texas to evaluate fall, winter, and spring weed control for commercial rice production, study tillage intensity and herbicide rate interactions for rice production, and determine the tolerance of red rice ecotypes from Texas rice fields using selected herbicides at varying rates.

A single application of any herbicide or combination of herbicides was not adequate for weed control throughout the fall, winter, and spring. Fall applications of clomazone plus flumioxazin provided consistent weed control. Addition of flumioxazin to glyphosate provided excellent winter annual grass control with winter application. A residual herbicide, coupled with the proper contact herbicide is the key to extending control.

In 2006, all tillage by herbicide treatments in all studies provided ≥ 90% control of all weed species. The conventional tillage treatment with low herbicide input provided the highest rice grain yield in 2005 and 2006, though they were not significantly different from the spring stale seedbed program with medium or high herbicide input in 2006. In 2006, fall stale seedbed treatments were among the lowest in

yield. A stale seedbed program may be useful, but with substantial weed pressure, increasing the intensity of herbicide applications is necessary to overcome the absence of tillage.

All rice ecotypes were adequately controlled by glyphosate and only one ecotype was found to be tolerant to 2x rates of both imazethapyr and imazamox. All ecotypes were adequately controlled by 2x rates of more than two of the four herbicides which included imazethapy, imazamox, glufosinate, and glyphosate. Ecotypes from the 3.2 group, genetically similar to the ecotype TX4, appear to be the most likely to exhibit tolerance to a given herbicide. Tolerance to glufosinate was found in 70% of the group 3.2 ecotypes. Sixty percent of ecotypes from group 3.1, genetically similar to *Oryza rufipogon* were not adequately controlled by glufosinate.

DEDICATION

I would like to dedicate this thesis to my parents, Weldon and Brenda, who pushed me to succeed and put me through school. I would also like to dedicate this thesis to my wife, Casey, who stood by me through the good times and the bad. I could never have done this without you.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Chandler, and my committee members, Dr. McCauley, Dr. Senseman, and Dr. Speed for their guidance and support throughout the course of my research. Thanks also to Sam Willingham, Nyland Falkenberg, Mike Jund, Darryl Hagler, Kyle Cranek, the Eagle Lake staff and Josh Bynum without whose help this research would never have been accomplished. I would like to thank the Texas Rice Research Foundation for their support of this research. I would also like to thank my wife and my parents for their love and support throughout this endeavor. Finally, I would like to thank my friend and mentor, Cliff Mock, for all of his guidance and support over the years and for teaching me to "see" the field.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

A major goal of the rice industry is to increase efficiency of production. To achieve this, research has focused on management strategies to reduce fossil fuel use (Mannion 1995; Olofsdotter et al. 2000). Conventional, high tillage input management strategies do not adequately control all pest problems (Askew et al. 1998; Richard and Baker 1979). Contemporary conservation tillage practices such as fall and spring stale seedbeds with herbicides are part of an integrated weed management system during the off season that reduce the number and intensity of tillage operations during the production cycle. The major benefit of spring stale seedbed tillage is early red rice (*Oryza sativa* L.) control, while fall stale seedbed tillage systems allow early planting dates (McCauley 2006). With reduced tillage, new herbicides are needed. Some weeds are not adequately controlled with soil applied herbicides, forcing postemergence (POST) herbicide use (Askew et al. 1998).

Red rice is one of the most problematic weeds in the rice belt of Texas (Noldin et al. 1999b). Historically red rice is considered the same species as cultivated rice (*Oryza sativa* L.) (Vaughn 2005; Diarra et al. 1985; Kwon et al. 1992). Red rice populations are genetically diverse (Noldin et al. 1999b). Consequently, red rice is very difficult to control using conventional herbicides. The need to develop herbicide tolerant rice varieties with herbicides not typically used in rice was identified as early as 1979

This thesis follows the style of Weed Technology.

(Richard and Baker 1979). Recent rice varieties have been developed that show tolerance to selected herbicides through natural breeding or genetic modification. Emphasis has been placed in researching gene flow and outcrossing potential of herbicide tolerant varieties with red rice, which could produce a red rice type that is tolerant to the selected herbicides (Gealy et al. 2003).

Throughout the 1980's and 90's cultural and chemical suppression of red rice with crop rotation was the best mitigation strategy. The use of other herbicide families, such as the *s*-triazines, cyclohexanediones, and chloroacetamides, allowed producers to control red rice in rotation crops such as corn (*Zea mays*), grain sorghum (*Sorghum bicolor*), and soybean (*Glycine max*) (Barrentine et al. 1984). The goal was to develop management practices that minimize red rice impact on cultivated rice grade and quality while retaining high yield potential (Dunand et al. 1985).

Red rice is known to be highly competitive with cultivated rice (Ferrero et. al. 1999). Twenty red rice plants per meter^2 may cause up to a 60% loss in rice grain yield (Fischer and Ramirez 1993). For many years molinate (*S*-ethyl hexahydro- 1*H*-azepine-1-carbothioate) has been one of the best preplant incorporated (PPI) herbicides for red rice control. Red rice control of 86% has been provided with molinate plus fenoxaprop (($\pm$)-2-[4-[(6-chloro-2-benzoxazolyl)oxy] phenoxy] propanoic acid) applied PPI (Kwon et al. 1991). However, because of carcinogenicity concern of thiocarbamate chemicals, the sale of molinate will be prohibited after June 30, 2008 (Environmental Protection Agency 2003). Herbicides suggested for red rice control include glyphosate (*N*-(phosphonomethyl)glycine) (Askew et al. 1998), imazamox (2-[4,5-dihydro-4-methyl-4-

(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid) (Vasilakoglou and Dhima 2005), glufosinate (2-amino-4-(hydroxymethylphosphinyl)butanoic acid) (Sankula et al. 1997a) and imazethapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imadazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid). The possibility of incorporating tolerance to these broad spectrum herbicides into cultivated rice varieties has been a focus for red rice control.

In 1993, a cultivated rice variety was found that showed tolerance to the imidazolinone family of herbicides (Sanders et al. 1998). This plant was used to breed tolerance into new rice cultivars allowing use of imazethapyr, as a POST applied management option for red rice control. This technology was commercialized in 2002 by BASF Corporation[1] as CLEARFIELD[*] rice (Bollich et al. 2002). Imazethapyr kills susceptible plants by blocking the acetolactate synthase (ALS) enzyme responsible for the production of the branched chain amino acids isoleucine, leucine and valine (Vencill et al. 2002). Susceptible plants stop growth within one to two hours after application, but visual symptoms of plant chlorosis and necrosis usually require one to two weeks (Vencill et al. 2002). While useful for the red rice control in cultivated rice, the abundant use of ALS herbicides has led to several herbicide resistant weed species (Devine and Shukla 2000). Avila et al. (2005) reported tolerance to imazethapyr in two red rice ecotypes two times that of the susceptible cultivated variety ‘Cypress’. Steele et al. (2002) found that sequential applications of imazethapyr provided from 92 to 98% control of red rice but increasing rates of imazethapyr above 52 g/ha did not improve red rice control. Ottis et al. (2003) found that sequential POST applications improved control over that provided by a single late post (LPOST) application.

In addition to imazethapyr tolerance, imazamox may also be applied to imidizolinone tolerant cultivated varieties for red rice control. Imazamox is also an imidizolinone herbicide similar to imazethapyr. Vasilakoglou and Dhima (2005) found a number of red rice ecotypes tolerant to imazamox, and concluded that POST applications may not be effective against all red rice ecotypes.

Glufosinate has also been evaluated for red rice control in cultivated rice through the transgenic incorporation of the bialaphos resistance (BAR) gene. Thus a nonselective herbicide could be applied to a crop that would ordinarily be susceptible to the chemical (Braverman and Linscombe 1994). Glufosinate is an inhibitor of glutamine synthetase and causes plant death by buildup of ammonium inhibiting photosystem II (Vencill et al. 2002). Glufosinate has been used for broadspectrum broadleaf weed control in noncropland and as a contact herbicide prior to crop emergence in reduced tillage operations (Haas and Muller 1987). For complete red rice control sequential applications of at least 0.4 kg/ha of glufosinate was needed (Sankula et al. 1997b). When sequential applications were not used, the control of red rice decreased with decreasing rate of glufosinate. Braverman and Linscombe (1994) recommended 1.1 kg/ha of glufosinate on small red rice and lower dosage sequential applications for larger plants. In 1993, Noldin et al. (1999a) identified red rice ecotype TX4, collected at Katy, Texas, as low susceptibility to glufosinate even though this herbicide had not been used in the area. Glufosinate applied at 0.07 kg. ai/ha provided between 71 and 89% control of TX4 and increasing the rate to 1.12 kg ai/ha provided 94% control. Variability in herbicide sensitivity exists within red rice populations even in areas where a given herbicide has not been previously used (Noldin 1999a). There is no glufosinate tolerant cultivated rice variety available to producers at present.

Glyphosate is another broadspectrum herbicide that has been evaluated for red rice control. Glyphosate is an inhibitor of 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase, a key pathway for the synthesis of tryptophan, tyrosine, and phenylalanine. By blocking the EPSP synthase pathway, the production of proteins for plant growth is stopped (Vencill et al. 2002). No commercially available glyphosate tolerant cultivated rice variety has yet been released. Therefore, the use of glyphosate for red rice control must be restricted to glyphosate tolerant corn or soybeans or during the off season and weed control prior to crop emergence. Glyphosate at 0.5 kg/ha controlled red rice (Guy 1996). However, Askew et al. (1998) found that single applications of glyphosate at 1.7 kg/ha were not adequate for season long weed control. Five percent red rice escapes may not negatively impact soybean yield, but may restore the red rice seedbank (Rao and Harger 1981; Goss and Brown 1939).

Vaughan et al. (2001) found great genetic diversity within red rice populations in close proximity. Red rice ecotype TX4, identified by Noldin (1999b), was found to be genetically similar to *Oryza rufipogon* accession 105491, while other red rice ecotypes were similar to *Oryza sativa* ssp. *indica* (Vaughan et al. 2001). Red rice ecotype TX4 has low susceptibility to glufosinate (Noldin 1999a). With possible glufosinate tolerance in Texas red rice populations, these populations must be evaluated for tolerance to glufosinate, glyphosate and the imidazolinone herbicides.

With increased herbicide use in rice production, the need for high intensity tillage should diminish. In 2002, 52% of the cultivated rice acreage in Texas used some level of conservation tillage (Stansel 2003). Timely planting into a stale seedbed promoted higher yields and reduced production cost (Street 2003). Bollich et al. (2002) reported that conventional tillage provided greater weed control than stale seedbed methods with the same rate of Arrosolo, a premix herbicide containing molinate and propanil (*N*-(3,4-dichlorophenyl)propanamide).

Herbicides must be used for weed control in stale seedbeds because there is no barrier to weed growth without tillage (Itoh and Takahashi 1997). Although stale seedbeds lower the number and intensity of mechanical inputs, their main use is early planting and stand establishment (Shaw 1996). Another effect of stale seedbed programs is reduced weed germination from reduced weed seed brought to the soil surface in the absence of tillage (Shaw 1996). Talbert et al. (2003) found that cultivated rice yield in a stale seedbed treated with imazethapyr was 15% greater than rice grown in a conventional tillage program. Hydrick and Shaw (1994) found that herbicides were necessary for adequate winter weed control from either sequential applications or full label rates. Baughman et al. (1993) found that by applying glyphosate sequentially after weed emergence and prior to crop emergence, control of Italian ryegrass (*Lolium multiflorum* Lam.) was increased from $< 50\%$ to $\geq 95\%$. Halford et al. (2001) found that under no-till programs weeds emerged later and with higher density than in conventional tillage. This finding stressed the need for increased herbicide rates to control higher weed densities. Norsworthy and Frederick (2005) noted that even though conservation tillage practices may suppress weed growth, chemical control will be needed. Bond et al. (2005b) stated that one of the main roadblocks facing reduced tillage programs is vegetation management prior to planting.

The necessity of controlling weeds prior to planting with stale seedbed programs focuses on adequate chemical weed control during the winter months. Itoh and Takahashi (1997) found that winter weeds caused a reduction in straw weight when allowed to grow with the crop. Glyphosate is a broad spectrum herbicide labeled for use as a burndown. Bond et al. (2005a) found that Persian clover (*Trifolium resupinatum*) and California burclover (*Medicago polymorpha*) control were increased by adding flumioxazin (2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl-2*H*-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1*H*-isoindole-1,3(2*H*)-dione) or 2,4-D ((2,4-dichlorophenoxy)acetic acid) to glyphosate. Price et al. (2002) found that adding 105 g/ha flumioxazin to 1.12 kg/ha glyphosate provided ≥ 96% control of common chickweed (*Stellaria media* L. Vill.), common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), Palmer amaranth (*Amaranthus palmeri* S. Wats.), and smooth pigweed (*Amaranthus hybridus* L.) while glyphosate alone provided ≤ 50% control of common lambsquarters, common ragweed, large crabgrass (*Digitaria sanguinalis* L.), Palmer amaranth, and smooth pigweed. Herbicide 2,4-D is often added to glyphosate to broaden the spectrum of weeds controlled (Crawford 1992). Treatments incorporating glyphosate plus 2,4-D provided better broadleaf control than did glyphosate plus flumioxazin, which provided better control than glyphosate alone (Culpepper 2002; Bond et al. 2005a). Robinson et al. (2002) found that sequential applications of glufosinate at 0.4 kg/ha and glyphosate at 1.12 kg/ha provided 100% control of common cocklebur (*Xanthium strumarium* L.), common lambsquarters, common ragweed, Florida beggarweed (*Desmodium tortuosum* (Sw.) DC), jimsonweed (Datura stramonium L.), Palmer amaranth, redroot pigweed (*Amaranthus retroflexus* L.), smooth pigweed, and velvetleaf (*Abutilon theophrasti* Medik), while single applications of the herbicides at the same rates provided ≤ 90% control of the same weeds. Clomazone (2-[(2-chlorophenyl) methyl]-4,4-dimethyl-3-isoxazolidinone) also controls a broad spectrum of broadleaf and grass weeds (Vencill et al. 2002). Data are not available on use of clomazone for winter weed control. Meins et al (2006) evaluated prosulfuron (1-(4-methoxy-6-methyl-triazin-2-yl)-3-[2-(3,3,3-trifluoropropyl)phenylsulfonyl]urea) on cultivated rice with marginal grass activity but found hemp sesbania (*Sesbania exaltata*) and annual sedge (*Cyperus* spp.) were controlled.

The objectives of this research were 1) to identify red rice ecotypes that display a level of tolerance to existing red rice control herbicides; 2) evaluate the interaction between tillage intensity and herbicide application rates to optimize stale seedbed and conventional tillage programs; 3) evaluate existing herbicide technologies for weed control during the fall, winter, and spring months prior to rice planting.

CHAPTER II

WINTER WEED CONTROL PROGRAMS FOR TEXAS RICE PRODUCTION

Introduction

The necessity of controlling weeds prior to planting in stale seedbeds requires adequate chemical weed control during winter months. Itoh and Takahashi (1997) found that winter weeds reduced straw weight in the cultivated rice crop. Glyphosate (*N*-(phosphonomethyl) glycine) is labeled as a broad spectrum herbicide. Bond et al. (2005a) found that Persian clover (*Trifolium resupinatum* L.) and California burclover (*Medicago polymorpha* L.) control were increased by adding flumioxazin (2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl-2*H*-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1*H*-isoindole-1,3(2*H*)-dione) or 2,4-D ((2,4-dichlorophenoxy)acetic acid) to glyphosate. Price et al. (2002) found that adding 105 g/ha flumioxazin to 1.12 kg/ha glyphosate provided ≥ 96% control of common chickweed (*Stellaria media* L. Vill.), common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), Palmer amaranth (*Amaranthus palmeri* S. Wats.), and smooth pigweed (*Amaranthus hybridus* L.) while glyphosate alone provided ≤ 50% control of common lambsquarters, common ragweed, large crabgrass (*Digitaria sanguinalis* L.), Palmer amaranth, and smooth pigweed. Herbicide 2,4-D is often added to glyphosate to broaden the spectrum of weeds controlled (Crawford 1992). Treatments combining glyphosate plus 2,4-D provided better broadleaf weed control than did glyphosate plus flumioxazin, or glyphosate alone (Culpepper 2002; Bond et al. 2005a). Robinson et al. (2002) found that sequential applications of glufosinate [(2-amino-4-(hydroxymethylphosphinyl) butanoic acid)] at 0.4 kg/ha and glyphosate at 1.12 kg/ha provided 100% control of common cocklebur (*Xanthium strumarium* L.), common lambsquarters, common ragweed, Florida beggarweed (*Desmodium tortuosum* (Sw.) DC.), jimsonweed (*Datura stramonium* L.), Palmer amaranth, redroot pigweed (*Amaranthus retroflexus* L.), smooth pigweed, and velvetleaf (*Abutilon theophrasti* Medik), while single applications of the herbicides at the same rates provided ≤ 90% control of the same weeds. Clomazone (2-[(2-chlorophenyl) methyl]-4,4-dimethyl-3-isoxazolidinone) is also known to control a broad spectrum of broadleaf and grassy weeds (Vencill 2002). Data are not available on winter weed control with clomazone. Meins et al (2006) found marginal grass control with prosulfuron [(1-(4-methoxy-6-methyl-triazin-2-yl)-3-[2-(3,3,3-trifluoropropyl) phenylsulfonyl]-urea)] in rice but excellent control of hemp sesbania [*Sesbania exaltata* (Raf.) Rydb. ex A.W. Hill] and annual sedge (*Cyperus compressus* L.). The objective of this research was to evaluate available herbicides for weed control during fall, winter, and spring months prior to planting rice.

Materials and Methods

Studies were established in the fall and spring of 2004-2005 and 2005-2006 at the Texas Agricultural Experiment Station research sites, near Beaumont and Eagle Lake, Texas to evaluate winter weed control with herbicides. The soil near Beaumont is a League silty clay Fine, smectitic, hyperthermic Oxyaquic Dystruderts with a pH ranging from 5.8 - 8.1 and organic matter content between 1.2 and 1.7%. The soil near Eagle Lake is a Crowley very fine sandy loam Fine, smectitic, hyperthermic Typic Albaqualfs with a pH ranging from 5.3 - 6.1 and a 1.0% organic matter content. The herbicides evaluated were clomazone, flumioxazin, glyphosate, glufosinate, prosulfuron, and 2,4-D. Three application timings were fall (October), winter (December), and spring (February). Treatments were arranged in a randomized complete block design with plots three m wide and 12 m long with four replications. The study also contained an untreated control to evaluate weed populations. Fall treatments consisted of clomazone at 1.4 kg ai/ha plus flumioxazin at 175 g/ha and clomazone at 1.4 kg/ha plus prosulfuron at 35 g/ha. Clomazone at 1.1 kg/ha was used near Eagle Lake because of sandy soil. Winter treatments consisted of glyphosate applied at 1.1 kg/ha, glufosinate at 0.6 kg/ha, glyphosate at 1.1 kg/ha plus flumioxazin at 175 g/ha, and glyphosate at 1.1 kg/ha plus 2,4-D at 1.1 kg/ha. Spring applications included clomazone at 1.4 kg/ha plus flumioxazin at 175 g/ha applied in the fall followed by (fb) glyphosate at 1.1 kg/ha in the spring, glyphosate at 1.1 kg/ha in the winter fb glyphosate at 1.1 kg/ha in the spring, glyphosate at 1.1 kg/ha in the spring, glufosinate applied at 0.6 kg/ha in the winter fb glyphosate at 1.1 kg/ha in the spring, glufosinate applied at 0.6 kg/ha in the spring, glyphosate at 1.1 kg/ha plus flumioxazin at 175 g/ha applied in the winter fb glyphosate at 1.1 kg/ha in the spring, glyphosate at 1.1 kg/ha applied in the winter fb glyphosate at 1.1 kg/ha plus flumioxazin at 175 g/ha in the spring, glyphosate at 1.1 kg/ha plus flumioxazin at 175 g/ha in the spring, clomazone at 1.4 kg/ha plus prosulfuron at 35 g/ha applied in the fall fb glyphosate at 1.1 kg/ha in the spring, and glyphosate at 1.1 kg/ha plus 2,4-D at 1.1 kg/ha applied in the winter fb glyphosate at 1.1 kg/ha in the spring.

Weed control was visually rated on a scale of 0 to 100%, with 0 indicating no control and 100 indicating total plant death, at 2, 4, and 8 weeks after application (WAA). Data was subjected to the GLM Procedure using SAS[2] software with mean separation done by Fisher's protected LSD.

Weed populations sufficient to allow evaluation included spinyfruit buttercup, RANMU (*Ranunculus muricatus* L.); field clover TRFCA (*Trifolium campestri* Schreb.); dock RUMSS (*Rumex* spp.); annual rabbitsfoot grass POHMO (*Polypogon monspeliensis* (L.) Desf.); sand bittercress CARPA (*Cardamine parviflora var. arencicola* (Britton) O.E. Shulz); scarlet pimpernel ANGAR (*Angallis arvensis* L.); cutleaf eveningprimrose OEOLA (*Oenothera laciniata* Hill); California burclover MEDPO (*Medicago polymorpha* L.); rice ORYSA (*Oryza sativa* L.); broadleaf signalgrass BRAPP (*Brachiaria platyphylla* Griseb. Nash); barnyardgrass ECHCG (*Echinochloa crus-galli* L. Beauv.); field pennycress THLAR (*Thlaspi arvense* L.); pinnate tanseymustard DESPI (*Descurainia pinnata* (Walt.) Britt.); yellow nutsedge CYPES (*Cyperus esculentus* L.); annual sedge CCCAN (*Cyperaceae* sp.); common purslane POROL (*Portulaca oleracea* L.); and swinecress COPDI (*Coronopus didymus* (L.) Sm).

Data could not be combined between years or locations due to a divergence in the natural infestation of weeds present in the studies. Weed species differed between locations and between years at the same location. Weed control provided by a herbicide program was considered acceptable at or above 80% control.

Results and Discussion

Fall

Eight weeks after the fall application in 2004 near Eagle Lake, clomazone + prosulfuron provided 75% control of volunteer rice (ORYSA), while clomazone + flumioxazin provided 100% control (Table 1). The following year at the same location, no treatment provided > 86% of volunteer rice (ORYSA). With the exception of the volunteer rice (ORYSA) control near Eagle Lake, both clomazone + flumioxazin and clomazone + prosulfuron provided ≥ 98% control of all weed species at both locations in both years (Table 1).

Winter

All winter applications provided excellent control of both large and small barnyardgrass (ECHCG) in 2004 near Beaumont (Table 2). Annual sedge (CCCAN) was adequately controlled by all treatments except glufosinate alone. For ≥ 90% control of annual rabbitsfoot grass (POHMO), the addition of residual herbicide flumioxazin or 2,4-D was needed. Glyphosate alone provided marginal control of annual rabbitsfoot grass (POHMO) at 80%, but glufosinate did not provide adequate control.

Table 1. Fall weed control with herbicide combinations 8 WAA near Beaumont and Eagle Lake, TX in 2004 and 2005.[ab]

		Beaumont 2004				Eagle Lake 2004		
Treatment	Rate	ECHCG (L)	ECHCG (S)	CCCAN	RUMSS	ORYSA	BRAPP	THLAR
	kg ai/ha	%						
Clomazone + flumioxazin	1.4 + 0.2	100 A	100 A	100 A	100 A	100 A	100 A	100 A
Clomazone + prosulfuron	1.4 + 0.035	100 A	100 A	100 A	100 A	75 B	100 A	100 A

		Beaumont 2005				Eagle Lake 2005				
Treatment	Rate	RANMU	TRFCA	CCCAN	RUMSS	ORYSA	COPDI	POROL	CARPA	DESPI
	kg ai/ha	%								
Clomazone + flumioxazin	1.4 + 0.2	98 A	99 A	99 A	100 A	86 A	100 A	100 A	100 A	100 A
Clomazone + prosulfuron	1.4 + 0.035	99 A	100 A	99 A	100 A	70 B	100 A	100 A	100 A	100 A

[a] ECHCG, *Echinochloa crus-galli*; L, Large, 4-6 leaf; S, Small, 2-3 leaf; CCCAN, *Cyperaceae sp.*; RANMU, *Ranunculus muricatus* L.; TRFCA, *Trifolium campestri* Schreb.; RUMSS, *Rumex* spp.; ORYSA, *Oryza sativa* L.; COPDI, *Coronopus didymus* (L.) Sm.; POROL, *Portulaca oleracea* L.; CARPA, *Cardamine parviflora var. arencicola* (Britton) O.E. Shulz; BRAPP, *Brachiaria platyphylla* Griseb. Nash.; THLAR, *Thlaspi arvense* L., and DESPI, *Descurainia pinnata* (Walt.) Britt.

[b] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.1.

Table 2. Winter weed control with herbicide combinations 8 WAA near Beaumont and Eagle Lake, TX in 2004 and 2005.[ab]

		Beaumont 2004				Eagle Lake 2004			
Treatment	Rate	ECHCG (L)	ECHCG (S)	CCCAN	POHMO	ORYSA	CCCAN	BRAPP	THLAR
	kg ai/ha	%							
Glyphosate	1.1	100 A	100 A	81 AB	80 B	100 A	100 A	100 A	87 C
Glufosinate	0.6	100 A	88 A	76 B	69 C	100 A	99 B	100 A	93 BC
Glyphosate	1.1	100 A	100 A	96 A	95 A	100 A	100 A	100 A	100 A
+ flumioxazin	0.2								
Glyphosate	1.1	100 A	100 A	90 AB	90 A	100 A	100 A	100 A	99 AB
+ 2,4-D	1.1								

		Beaumont 2005						Eagle Lake 2005				
Treatment	Rate	RANMU	TRFCA	RUMSS	POHMO	CARPA	ANGAR	ORYSA	COPDI	POROL	CARPA	DESPI
	kg ai/ha	%										
Glyphosate	1.1	93 A	75 C	95 A	73 C	75 B	65 B	75 A	54 B	75 B	85 A	43 C
Glufosinate	0.6	93 A	87 B	87 B	63 D	59 C	63 B	75 A	34 C	88 A	83 A	44 C

Table 2 continued.

		Beaumont 2005						Eagle Lake 2005				
		RANMU	TRFCA	RUMSS	POHMO	CARPA	ANGAR	ORYSA	COPDI	POROL	CARPA	DESPI
		---	---	---	---	---	%	---	---	---	---	---
Glyphosate	1.1	99 A	89 B	100 A	97 A	99 A	99 A	81 A	56 B	94 A	89 A	63 B
+ flumioxazin	0.2											
Glyphosate	1.1	100 A	100 A	100 A	80 B	100 A	95 A	73 A	100 A	85 AB	85 A	88 A
+ 2,4-D	1.1											

[a] ECHCG, *Echinochloa crus-galli*; L, Large, 4- to 6- leaf; S, Small, 2- to 3- leaf; CCCAN, *Cyperaceae sp.*; BRAPP, *Bracharia platyphylla*; ORYSA, *Oryza sativa*; RANMU, *Ranunculus muricatus* L.; TRFCA, *Trifolium campestri* Schreb.; RUMSS , *Rumex* spp.; POHMO, *Polypogon monspeliensis* (L.) Desf.; CARPA, *Cardamine parviflora var. arencicola* (Britton) O.E. Shulz; ANGAR, *Angallis arvensis* L.; COPDI, *Coronopus didymus* (L.) Sm.; POROL, *Portulaca oleracea* L.; THLAR, *Thlaspi arvense* L., and DESPI, *Descurainia pinnata* (Walt.) Britt.

[b] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.1.

In the 2004, all treatments near Eagle Lake provided excellent broadleaf signalgrass (BRAPP), annual sedge (CCCAN), and volunteer rice (ORYSA) control (Table 2). Glyphosate with flumioxazin or 2,4-D provided 99 to 100% control of field pennycress (THLAR), while glufosinate provided 93% control and glyphosate provided 87%.

In 2005, all treatments near Beaumont provided excellent spinnyfruit buttercup (RANMU) control (Table 2). Control of field clover (TRFCA) was 100% with glyphosate + 2,4-D and 89 and 87% with glyphosate + flumioxazin and glufosinate, respectively. Glyphosate alone did not provide adequate control. Control of dock (RUMSS) was excellent with glyphosate alone and glyphosate + flumioxazin or 2,4-D, but significantly less with glufosinate at 87%. Annual rabbitsfoot grass (POHMO) control was excellent with glyphosate + flumioxazin and marginal with glyphosate + 2,4-D at 80% control. Glyphosate or glufosinate did not provide adequate control of annual rabbitsfoot grass (POHMO). Treatments containing residual herbicides provided excellent control of sand bittercress (CARPA) and scarlet pimpernel (ANGAR), while the non-residual treatments glyphosate and glufosinate did not provide adequate control of either species.

In 2005 near Eagle Lake, no treatment provided more than 81% volunteer rice (ORYSA) control (Table 2). Glyphosate + 2,4-D provided excellent control of swinecress (COPDI), but control was inadequate in all other treatments. Glyphosate + flumioxazin or 2,4-D, and glufosinate provided good control of common purslane (POROL) ranging from 85 to 94%, but control with glyphosate was inadequate. All treatments provided adequate control of sand bittercress (CARPA), but only glyphosate + 2,4-D provided adequate control of pinnate tanseymustard (DESPI).

Spring

In 2005 near Beaumont at eight weeks after application spring, the only treatments that provided > 80% control of barnyardgrass (ECHCG) was clomazone + flumioxazin applied in the fall and clomazone + flumioxazin applied in the fall fb glyphosate in the spring (Table 3). Treatments that included clomazone plus prosulfuron, clomazone plus flumioxazin, or a spring application of glyphosate, provided ≥ 90% control of broadleaf signalgrass (BRAPP) and annual sedge (CCCAN) eight weeks after the spring application (Table 3).

In 2005 treatments near Eagle Lake with a residual herbicide or spring application of glyphosate provided excellent annual sedge (CCCAN) control (Table 4). All other treatments did not adequately control annual sedge (CCCAN). Gyphosate applied in the winter fb glyphosate + flumioxazin and glyphosate + flumioxazin applied in the spring provided 88 and 83% control, respectively, of emerging broadleaf signalgrass (BRAPP) eight weeks after the spring application. All other treatments provided ≤ 75% control of emerging broadleaf signalgrass (BRAPP). All treatments provided excellent control of California burclover (MEDPO) except glyphosate or glufosinate applied in the winter, which did not provide adequate control. At this same timing and location, glyphosate plus flumioxazin and clomazone plus prosulfuron

Table 3. Weed control 8 WAA in the spring provided by herbicide combinations applied in the fall, winter, and spring near Beaumont, TX in 2005.[ab]

		Beaumont 2005		
Treatment	Rate	ECHCG	CCCAN	BRAPP
	kg ai/ha	-------------------%-----------------		
Clomazone + flumioxazin (F)	1.4 + 0.2	85 A	99 A	99 A
Clomazone + flumioxazin (F)	1.4 + 0.2	84 A	97 AB	97 AB
fb glyphosate (S)	1.1			
Glyphosate (W)	1.1	63 EF	73 D	38 F
Glyphosate (W)	1.1	64 EF	91 ABC	91 BC
fb glyphosate (S)	1.1			
Glyphosate (S)	1.1	64 EF	95 AB	95 AB
Glufosinate (W)	0.6	53 G	60 E	33F
Glufosinate (W)	0.6	63 EF	96 AB	90 BC
fb glyphosate (S)	1.1			

Table 3 continued.

Treatment[bc]	Rate	Beaumont 2005 ECHCG	Beaumont 2005 CCCAN	Beaumont 2005 BRAPP
	kg ai/ha	------------------%----------------		
Glufosinate (S)	0.6	68 CDE	90 ABC	71 D
Glyphosate + flumioxazin (W)	1.1 + 0.2	59 FG	83 C	51 E
Glyphosate + flumioxazin (W)	1.1 + 0.2	64 EF	94 AB	93 ABC
fb glyphosate (S)	1.1			
Glyphosate (W)	1.1	75 BC	95 AB	96 AB
fb glyphosate + flumioxazin (S)	1.1 + 0.2			
Glyphosate + flumioxazin (S)	1.1 + 0.2	66 DEF	94 AB	86 C
Clomazone + prosulfuron (F)	1.1 + 0.035	78 AB	94 AB	94 AB
Clomazone + prosulfuron (F)	1.1 + 0.035	73 BCD	89 BC	96 AB
fb glyphosate (S)	1.1			

Table 3 continued.

Treatment[bc]	Rate	Beaumont 2005 ECHCG	CCCAN	BRAPP
	kg ai/ha	-----------------%	-----------------	
Glyphosate + 2,4-D (W)	1.1 + 1.1	65 DEF	94 AB	95 AB
fb glyphosate (S)	1.1			

[a] ECHCG, *Echinochloa crus-galli*; CCCAN, Cyperaceae, annual sedge; BRAPP, *Bracharia platyphylla*; F, fall application (October); W, winter application (December); S, spring application (February).

[b] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.1.

Table 4. Weed control 8 WAA in the spring provided by herbicide combinations applied in the fall, winter, and spring near Eagle Lake, TX in 2005.[ab]

		Eagle Lake 2005			
Treatment	Rate	CCCAN	BRAPP	MEDPO	THLAR
	kg ai/ha	-----------------------	%	-----------------------	
Clomazone + flumioxazin (F)	1.1 + 0.2	93 ABC	65 CDE	100 A	56 D
Clomazone + flumioxazin (F)	1.1 + 0.2	92 ABC	70 BC	100 A	80 B
fb glyphosate (S)	1.1				
Glyphosate (W)	1.1	58 E	53 EFG	68 B	40 F
Glyphosate (W)	1.1	83 BC	48 FGH	100 A	76 BC
fb glyphosate (S)	1.1				
Glyphosate (S)	1.1	80 CD	54 DEF	98 A	55 D
Glufosinate (W)	0.6	68 DE	38 H	74 B	39 F
Glufosinate (W)	0.6	91 ABC	40 GH	100 A	78 BC
fb glyphosate (S)	1.1				

Table 4 continued.

		Eagle Lake 2005			
Treatment	Rate	CCCAN	BRAPP	MEDPO	THLAR
	kg ai/ha	-----------------------%-------------------------			
Glufosinate (S)	0.6	30 F	48 FGH	100 A	44 EF
Glyphosate + flumioxazin (W)	1.1 + 0.2	100 A	75 ABC	100 A	93 A
Glyphosate + flumioxazin (W)	1.1 + 0.2	98 A	75 ABC	100 A	98 A
fb glyphosate (S)	1.1				
Glyphosate (W)	1.1	100 A	88 A	100 A	100 A
fb glyphosate + flumioxazin (S)	1.1 + 0.2				
Glyphosate + flumioxazin (S)	1.1 + 0.2	93 ABC	83 AB	100 A	100 A
Clomazone + prosulfuron (F)	1.1 + 0.035	91 ABC	67 CD	100 A	53 DE
Clomazone + prosulfuron (F)	1.1 + 0.035	96 A	68 C	100 A	91 A
fb glyphosate (S)	1.1				

Table 4 continued.

Treatment	Rate	Eagle Lake 2005			
		CCCAN	BRAPP	MEDPO	THLAR
	kg ai/ha	------------------------%------------------------			
Glyphosate + 2,4-D (W)	1.1 + 1.1	95 AB	43 FGH	100 A	68 C
fb glyphosate (S)	1.1				

[a] CCCAN, annual sedge; BRAPP, *Bracharia platyphylla*; MEDPO, *Medicago polymorpha*; and THLAR, *Thlaspi arvense* L.; F, fall application (October); W, winter application (December); S, spring application (February).

[b] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.1.

applied in the fall fb glyphosate in the spring provided ≥ 90% control of field pennycress (THLAR).

By eight weeks after the spring application near Beaumont in 2006, all treatments containing flumioxazin, prosulfuron, 2,4-D at any timing, and glufosinate in the spring provided > 80% control of all weed species (Table 5). All treatments provided > 85% control of spinyfruit buttercup (RANMU). Glyphosate or glufosinate applied in the winter did not provide adequate control of field clover (TRFCA). Glufosinate in the winter failed to adequately control dock (RUMSS), while all other treatments provided ≥ 85% control. Annual rabbitsfoot grass (POHMO), sand bittercress (CARPA), and scarlet pimpernel (ANGAR) were all adequately controlled by treatments containing a residual herbicide (Table 5). Treatments containing glyphosate in the spring failed to provide adequate control for one or more of these weed species if not combined with a residual herbicide.

In 2006 near Eagle Lake, adequate control of California burclover (MEDPO) was provided by all treatments except glyphosate, glufosinate, or glyphosate + flumioxazin in the winter (Table 6). Adequate control of cutleaf eveningprimrose (OEOLA) was provided by glyphosate + 2,4-D in the winter fb glyphosate in the spring, glyphosate + flumioxazin in the winter fb glyphosate in the spring, glufosinate in the spring, and clomazone + flumioxazin in the fall fb glyphosate in the spring. No other treatment provided adequate control of cutleaf eveningprimrose (OEOLA). Glyphosate and glufosinate applied alone in the winter provided < 50% control of cutleaf eveningprimrose (OEOLA). The high weed density resulting from poor control after the

Table 5. Weed control 8 WAA in the spring provided by herbicide combinations applied in the fall, winter, and spring near Beaumont, TX in 2006.[ab]

		Beaumont 2006					
Treatment	Rate	RANMU	TRFCA	RUMSS	POHMO	CARPA	ANGAR
	kg ai/ha	------------------------------------%------------------------------------					
Clomazone + flumioxazin (F)	1.4 + 0.2	89 CD	88 D	100 A	98 AB	88 CD	95 A
Clomazone + flumioxazin (F)	1.4 + 0.2	100 A	100 A	100 A	100 A	96 ABC	98 A
fb glyphosate (S)	1.1						
Glyphosate (W)	1.1	90 CD	71 F	85 BC	63 F	75 E	60 BC
Glyphosate (W)	1.1	100 A	94 BC	86 B	80 DE	83 DE	65 B
fb glyphsate (S)	1.1						
Glyphosate (S)	1.1	98 AB	100 A	93 AB	75 E	88 CD	53 BC
Glufosinate (W)	0.6	93 BC	78 E	75 C	54 G	55 F	50 C
Glufosinate (W)	0.6	100 A	98 AB	85 BC	75 E	78 E	58 BC
fb glyphosate (S)	1.1						

Table 5 continued.

Treatment	Rate	Beaumont 2006					
		RANMU	TRFCA	RUMSS	POHMO	CARPA	ANGAR
	kg ai/ha	--------------------------------		%		--------------------------------	
Glufosinate (S)	0.6	85 D	91 CD	100 A	85 CD	91 A-D	93 A
Glyphosate + flumioxazin (W)	1.1 + 0.2	100 A	81 E	99 A	86 CD	98 AB	98 A
Glyphosate + flumioxazin (W)	1.1 + 0.2	100 A	100 A	100 A	98 AB	98 AB	98 A
fb glyphosate (S)	1.1						
Glyphosate (W)	1.1	100 A	99 AB	100 A	95 AB	99 A	100 A
fb glyphosate + flumioxazin (S)	1.1 + 0.2						
Glyphosate + flumioxazin (S)	1.1 + 0.2	100 A	99 AB	100 A	84 CD	90 BCD	90 A
Clomazone + prosulfuron (F)	1.4 + 0.035	100 A	100 A	100 A	100 A	100 A	100 A
Clomazone + prosulfuron (F)	1.4 + 0.035	100 A	100 A	100 A	100 A	100 A	100 A
fb glyphosate (S)	1.1						

Table 5 continued.

Treatment	Rate	Beaumont 2006					
		RANMU	TRFCA	RUMSS	POHMO	CARPA	ANGAR
	kg ai/ha	----------------------------------	-----------	------%	-------------	-------------	----------
Glyphosate + 2,4-D (W)	1.1 + 1.1	100 A	100 A	94 AB	91 BC	100 A	89 A
fb glyphosate (S)	1.1						

[a] RANMU, *Ranunculus muricatus*; TRFCA, *Trifolium campestri*; RUMSS, *Rumex* sp.; POHMO, *Polypogon monspeliensis*; CARPA, *Cardamine parviflora* var. *arenicola*; ANGAR, *Anagallis arvensis*; F, fall application (October); W, winter application (December); S, spring application (February).

[b] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.1.

Table 6. Weed control 8 WAA in the spring provided by herbicide combinations applied in the fall, winter, and spring near Eagle Lake, TX in 2006.[ab]

		Eagle Lake 2006				
Treatment	Rate	MEDPO	OEOLA	BRAPP	CYPES	ANGAR
	kg ai/ha	---%				
Clomazone+flumioxazin (F)	1.1 + 0.2	100 A	65 DE	73 CD	75 ABC	100 A
Clomazone+flumioxazin (F)	1.1 + 0.2	100 A	85 BC	48 EF	63 BC	100 A
fb glyphosate (S)	1.1					
Glyphosate (W)	1.1	43 E	20 I	100 A	73 ABC	70 C
Glyphosate (W)	1.1	85 ABC	45 H	53 EF	80 AB	93 AB
fb glyphosate (S)	1.1					
Glyphosate (S)	1.1	98 AB	48 GH	75 CD	70 ABC	100 A
Glufosinate (W)	0.6	68 CD	43 H	100 A	95 A	48 D
Glufosinate (W)	0.6	93 AB	50 FGH	43 EFG	73 ABC	100 A
fb glyphosate (S)	1.1					

Table 6 continued.

Treatment	Rate	Eagle Lake 2006				
		MEDPO	OEOLA	BRAPP	CYPES	ANGAR
	kg ai/ha	----------------------------%----------------------------				
Glufosinate (S)	0.6	93 AB	95 AB	80 BC	58 BC	63 C
Glyphosate+flumioxazin (W)	1.1 + 0.2	55 DE	45 H	95 AB	83 AB	88 B
Glyphosate+flumioxazin (W)	1.1 + 0.2	89 AB	80 C	35 FG	75 ABC	100 A
fb glyphosate (S)	1.1					
Glyphosate (W)	1.1	85 ABC	58 EFG	43 EFG	75 ABC	98 AB
fb glyphosate+flumioxazin (S)	1.1 + 0.2					
Glyphosate+flumioxazin (S)	1.1 + 0.2	80 BC	60 EF	58 DE	73 ABC	99 AB
Clomazone+prosulfuron (F)	1.1 + 0.035	100 A	43 H	85 ABC	65 BC	100 A
Clomazone+prosulfuron (F)	1.1 + 0.035	100 A	75 CD	48 EF	50 C	100 A
fb glyphosate (S)	1.1					

Table 6 continued.

		Eagle Lake 2006				
Treatment	Rate	MEDPO	OEOLA	BRAPP	CYPES	ANGAR
	kg ai/ha	------------------------------%------------------------------				
Glyphosate+2,4-D (W)	1.1 + 1.1	80 BC	100 A	28 G	73 ABC	95 AB
fb glyphosate (S)	1.1					

[a] MEDPO, *Medicago polymorpha*; OEOLA, *Oenothera laciniata*; BRAPP, *Brachiaria platyphylla*; CYPES, *Cyperus esculentus*; ANGAR, *Anagallis arvensis*; F, fall application (October); W, winter application (December); S, spring application (February).

[b] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.1.

spring application of glyphosate or glufosinate excluded broadleaf signalgrass (BRAPP) from the plot area after eight weeks (Table 6). Glyphosate + flumioxazin and clomazone + prosulfuron provided excellent control of broadleaf signalgrass (BRAPP) and glufosinate in the spring provided marginal control, no other treatment provided adequate control. Glufosinate in the winter and glyphosate + flumioxazin in the winter provided excellent control of yellow nutsedge (CYPES). Glyphosate applied in the winter fb glyphosate in the spring provided marginal control. No other treatment provided adequate control of yellow nutsedge (CYPES). Excellent control of scarlet pimpernel (ANGAR) was provided by all treatments containing a residual herbicide. A single application of glyphosate alone in winter and any treatment with glufosinate alone did not provide adequate control of scarlet pimpernel (ANGAR). In most cases at this timing, the residual action of flumioxazin, 2,4-D, or prosulfuron were needed to adequately control weeds. The single application of glyphosate in the spring was not always adequate to control all weed species, and in some cases the addition of the burndown action of glyphosate was needed for residual herbicides to provide good control of certain weed species.

A single application of any herbicide or combination of herbicides was not adequate for control throughout the fall, winter, and spring. The best herbicide programs contained a burndown application prior to planting for adequate weed control. Fall applications of clomazone plus flumioxazin provided consistent weed control in both studies and both years. One weakness of clomazone plus prosulfuron was inadequate control of volunteer rice (ORYSA). The first year winter application of flumioxazin plus glyphosate provided excellent control of all weed species at both locations. In the second year the glyphosate plus flumioxazin was inadequate for controlling all weed species present at both locations. Due to differences in weed species at each location, the applications of clomazone plus flumioxazin at Eagle Lake and clomazone plus prosulfuron at Beaumont provided the best control of all species. The burndown action of flumioxazin or prosulfuron combined with residual control of clomazone is very effective for total weed control at this timing. The residual control of clomazone appears necessary coupled with the correct burndown herbicide to kill existing vegetation. The proper burndown herbicide is required to adequately control existing vegetation or weed control is not adequate for extended time periods. One herbicide application without residual soil activity provided inadequate control for one or more weed species at each location. After the spring applications in the first year, clomazone plus flumioxazin near Beaumont and glyphosate in the winter fb glyphosate plus flumioxazin in the spring near Eagle Lake were the only treatments that approached adequate weed control. In the second year no treatment adequately controlled all weed species present at either location. The residual herbicide treatments were adequate to control many weed species through early spring, but did not provide control of emerging summer annual grasses and sedges. Summer annual grass and sedge control was poor for both years but was worse in the second year. Combining a burndown herbicide with a residual herbicide may be a viable option for controlling winter annual weeds in the off-season, but emerging summer annuals must be controlled prior to planting. The correct burndown herbicide to match weed species is essential for adequate weed control.

CHAPTER III

COMBINATIONS OF TILLAGE AND HERBICIDE INTENSITY FOR WEED CONTROL IN TEXAS RICE

Introduction

The need for high intensity tillage decreases with increased herbicide use in cultivated rice production. In 2002, 52% of the cultivated rice acreage in Texas used some conservation tillage (Stansel 2003). The major benefit of spring stale seedbed tillage is early red rice (*Oryza sativa* L.) control, while fall stale seedbed tillage allows early planting dates (McCauley 2006). Reduced tillage requires more herbicide use. Some weeds are not adequately controlled with soil applied herbicides, requiring postemergence (POST) herbicide use (Askew et al. 1998). Timely planting into a stale seedbed promoted higher yields and reduced production cost in Mississippi (Street 2003). Bollich et al. (2002) reported that conventional tillage provided greater weed control than stale seedbed methods with Arrosolo, a premix herbicide containing molinate (*S*-ethyl hexahydro-1*H*-azepine-1-carbothioate) and propanil (*N*-(3,4-dichlorophenyl)propanamide).

Herbicides must be used for weed control in stale seedbed systems because without tillage there is no barrier to weed growth (Itoh and Takahashi 1997). Although stale seedbed programs lower the number and intensity of mechanical inputs, the main reason for their use is early planting and stand establishment (Shaw 1996). Another effect of stale seedbed programs is reduced weed germination due to the reduced number of weed seed brought to the soil surface in the absence of tillage (Shaw 1996). Talbert et al. (2003) found that rice yield in a stale seedbed program treated with imazethapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imadazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid) was 15% greater than rice grown in a conventional tillage program. Hydrick and Shaw (1994) found that for adequate winter weed control either sequential applications or full label herbicide rates was necessary. Baughman et al. (1993) found that by applying glyphosate (*N*-(phosphonomethyl)glycine) sequentially prior to crop emergence, control of Italian ryegrass (*Lolium multiflorum* Lam.) was increased from < 50% to ≥ 95%. Halford et al. (2001) found that under no-till programs weeds emerge later and with higher density than conventional tillage. This finding stresses the need for increased herbicide rates to control higher weed densities. Norsworthy and Frederick (2005) noted that even though conservation tillage may suppress early weed growth, chemical control will be needed. Bond et al. (2005b) stated that one of main roadblocks facing reduced tillage programs is vegetation management prior to planting. The objective of this research was to evaluate the interaction between tillage intensity and herbicide application rates to optimize stale seedbed and conventional tillage programs.

Materials and Methods

Studies were conducted in 2005 and 2006 at Texas Agricultural Experiment Station locations, near Beaumont, Eagle Lake, and Ganado, TX. The soil near Beaumont is a League silty clay Fine, smectitic, hyperthermic Oxyaquic, Dystruderts with a pH ranging from 5.8-8.1 and organic matter content between 1.2 and 1.7%. The soil near Eagle Lake is a Crowley very fine sandy loam Fine, smectitic, hyperthermic Typic Albaqualfs with a pH ranging from 5.3-6.1 and a 1.0% organic matter content. Soil near Ganado is an Edna fine sandy loam Fine, montmorillinitic, thermic Vertic Hapludalfs with a pH of 6.1 and an organic matter content of 0.8%. One study was conducted in 2005 near Beaumont, Texas, with three identical studies established in 2006 near Beaumont, Eagle Lake, and Ganado, TX. Experimental design was a split plot with three tillage intensities as the main plots and three weed control programs as the subplots. The three tillage treatments were conventional tillage (CT), tilled as needed throughout the fall, winter, and spring; fall stale seedbed (FSS), weed free with glyphosate as needed until planting; and spring stale seedbed (SSS) with tillage to early spring and glyphosate until planting. The three herbicide programs were categorized as low herbicide input with clomazone(2-[(2-chlorophenyl) methyl]-4,4-dimethyl-3-isoxazolidinone) at 0.5 kg ai/ha followed by (fb) propanil at 3.4 kg/ha plus halosulfuron (methyl[[(4.6-dimethoxy-2-pyrimidinyl)amino]carbonylaminosulfonyl]-3-chloro-1-methyl-1-*H*-pyrazole-4-carboxylate) at 34.0 g/ha; medium herbicide input with clomazone at 0.6 kg/ha fb propanil at 4.5 kg/ha plus quinclorac (3,7-dichloro-8-quinolinecarboxylic acid) at 0.6 kg/ha; and high herbicide input with of clomazone at 0.7 kg/ha fb propanil at 4.5 kg/ha plus halosulfuron at 50.0 g/ha and quinclorac at 0.6 kg/ha. The only differences between locations were the reductions in the clomazone rates at the sites near Eagle Lake and Ganado because of the lighter soils. At these two locations, clomazone rates were adjusted to 0.3 kg/ha, 0.5 kg/ha, and 0.6 kg/ha for the low, medium and high input, respectively. The cultivated rice variety ‘Cocodrie’ was drill seeded at 78 kg/ha with a Great Plains seed drill[3]. The studies were watered and fertilized according to recommendations in the Rice Production Guidelines for Texas (Turner 2005).

Weed control in the studies was evaluated visually (0-100%) at 2, 4, and 8 weeks after the completion of each herbicide application (WAA) beginning with the PRE application of clomazone. The grain was harvested with a Kubota[4] plot combine and the yield data were recorded. Weed control and yield data were subjected to the GLM Procedure using SAS[2] software with mean separation by Fisher’s protected LSD.

Weeds present at levels that allowed evaluation in the studies were broadleaf signalgrass, BRAPP (*Brachiaria platyphylla* Griseb. Nash); barnyardgrass, ECHCG (*Echinochloa crus-galli* L. Beauv.); hemp sesbania, SEBEX, [*Sesbania exaltata* (Raf.) Rydb. ex A.W. Hill]; sprangletop, LEFSS, (*Leptochloa sp.*); common purslane, POROL (*Portulaca oleracea* L.); yellow nutsedge, CYPES, (*Cyperus esculentus* L.); and scarlet pimpernel, ANGAR (*Anagallis arvensis* L.).

Results and Discussion

Beaumont

Two WAA near Beaumont in 2005 CT treatments with all herbicide intensity inputs provided good control of barnyardgrass (ECHCG) at 91 to 93% (Table 7). The only treatment providing < 90% control of barnyardgrass (ECHCG) at this time was SSS

Table 7. Weed control with combinations of tillage and herbicide intensity 2 and 8 WAA near Beaumont, TX in 2005.[abc]

	2 WAA		8 WAA	
Treatment	ECHCG	SEBEX	ECHCG	SEBEX
	------------% ------------		--------------%------------	
Conventional tillage (CT) + low herbicide	91 AB	70 CB	96 A	95 A
Conventional tillage (CT) + medium herbicide	94 A	64 C	100 A	100 A
Conventional tillage (CT) + high herbicide	93 A	68 BC	100 A	98 A
Spring stale seedbed tillage (SSS) + low herbicide	85 B	81 AB	85 B	78 B
Spring stale seedbed tillage (SSS) + medium herbicide	96 A	89 A	100 A	100 A
Spring stale seedbed tillage (SSS) + high herbicide	98 A	88 A	95 A	100 A

Table 7 continued.

Treatment	2 WAA		8 WAA	
	ECHCG	SEBEX	ECHCG	SEBEX
	------------% ------------		--------------%------------	
Fall stale seedbed tillage (FSS) + low herbicide	94 A	89 A	85 B	78 B
Fall stale seedbed tillage (FSS) + medium herbicide	98 A	91 A	100 A	100 A
Fall stale seedbed tillage (FSS) + high herbicide	95 A	89 A	100 A	100 A

[a] ECHCG = *Echinochloa crus-galli*, SEBEX = *Sesbania exaltata*, WAA = weeks after application.

[b] Conventional tillage (CT), treatments kept weed free with tillage; spring stale seedbed tillage (SSS), fall tilled and treated with glyphosate prior to planting; fall stale seedbed tillage (FSS), kept weed free with glyphosate until planting; low herbicide, clomazone at 0.5 kg/ha followed by (fb) 3.4 kg/ha propanil + 34.0 g/ha halosulfuron; medium herbicide, clomazone at 0.6 kg/ha fb 4.5 kg/ha propanil + 0.6 kg/ha quinclorac; high herbicide, clomazone at 0.7 kg/ha fb 4.5 kg/ha propanil + 50.0 g/ha halosulfuron + 0.6 kg/ha quinclorac.

[c] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.05.

with the low herbicide intensity input at 85 % (Table 7). With CT and SSS tillage treatments that received the low herbicide intensity input barnyardgrass (ECHCG) control was slightly lower in the CT and significantly lower in SSS treatments than in medium or high herbicide input treatments. No CT treatment provided > 70% control of hemp sesbania (SEBEX) and herbicide inputs did not significantly impact control. All other treatments provided 89 to 91% control except SSS tillage with the low herbicide intensity input, which provided marginal control at 81% (Table 7). Increased herbicide intensity was needed for the best control in the SSS tillage system. Eight WAA all treatments provided ≥ 95 % control of barnyardgrass (ECHCG) and hemp sesbania (SEBEX) with the exception of SSS and FSS treatments receiving the low herbicide input. These treatments provided 10 to 15% less control of barnyardgrass (ECHCG) and 17 to 22% less control of hemp sesbania (SEBEX) than other treatments (Table 7). For good control in the SSS and FSS tillage systems increased herbicide intensity was needed.

Two WAA near Beaumont in 2006 all treatments provided ≥ 90% control of common purslane (POROL), but FSS treatments receiving the medium and high intensity herbicide inputs provided significantly less control (Table 8). All treatments provided good control of hemp sesbania (SEBEX) from 89 to 95%. All SSS and CT treatments with all herbicide intensities provided excellent control of scarlet pimpernel (ANGAR). Treatments that were not tilled in the fall or spring such as the FSS treatments did not provide adequate control of scarlet pimpernel (ANGAR) with any herbicide input (Table 8). Common purslane (POROL) and scarlet pimpernel (ANGAR)

Table 8. Weed control with combinations of tillage and herbicide intensity 2 and 8 WAA near Beaumont, TX in 2006.[abc]

	2 WAA			8 WAA		
Treatment	POROL	SEBEX	ANGAR	ECHCG	SEBEX	LEFSS
	----------------%-----------------			----------------%--------------		
Conventional tillage (CT) + low herbicide	100 A	89 A	100 A	100 A	100 A	100 A
Conventional tillage (CT) + medium herbicide	100 A	95 A	100 A	100 A	100 A	100 A
Conventional tillage (CT) + high herbicide	100 A	92 A	99 A	100 A	100 A	100 A
Spring stale seedbed tillage (SSS) + low herbicide	96 AB	94 A	96 A	100 A	100 A	100 A
Spring stale seedbed tillage (SSS) + medium herbicide	95 ABC	89 A	99 A	100 A	100 A	100 A
Spring stale seedbed tillage (SSS) + high herbicide	96 AB	91 A	100 A	100 A	100 A	100 A

Table 8 continued.

Treatment	2 WAA			8 WAA		
	POROL	SEBEX	ANGAR	ECHCG	SEBEX	LEFSS
	----------------%-----------------			----------------%--------------		
Fall stale seedbed tillage (FSS) + low herbicide	95 ABC	94 A	78 B	98 A	100 A	100 A
Fall stale seedbed tillage (FSS) + medium herbicide	93 BC	93 A	71 C	100 A	100 A	100 A
Fall stale seedbed tillage (FSS) + high herbicide	90 C	90 A	73 C	100 A	100 A	100 A

[a] POROL = *Portulaca oleracea*, SEBEX = *Sesbania exaltata*, ANGAR = *Anagallis arvensis*, ECHCG = *Echinochloa crus-galli*, LEFSS = *Leptochloa sp*., WAA = weeks after application.

[b] Conventional tillage (CT), treatments kept weed free with tillage; spring stale seedbed tillage (SSS), fall tilled and treated with glyphosate prior to planting; fall stale seedbed tillage (FSS), kept weed free with glyphosate until planting; low herbicide, clomazone at 0.5 kg/ha followed by (fb) 3.4 kg/ha propanil + 34.0 g/ha halosulfuron; medium herbicide, clomazone at 0.6 kg/ha fb 4.5 kg/ha propanil + 0.6 kg/ha quinclorac; high herbicide, clomazone at 0.7 kg/ha fb 4.5 kg/ha propanil + 50.0 g/ha halosulfuron + 0.6 kg/ha quinclorac.

[c] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.05.

are winter annuals that were present at two WAA. The reduced control provided by FSS treatments indicated that herbicides without tillage was not adequate to control scarlet pimpernel (ANGAR). CT treatments with all herbicide intensity inputs provided ≥ 99 % control of common purslane (POROL) and scarlet pimpernel (ANGAR) and 89-95 % control of hemp sesbania (SEBEX) (Table 8). By eight WAA, all tillage treatments at all herbicide input levels provided ≥ 98% control of all weeds present (Table 8).

Eagle Lake

Two WAA near Eagle Lake in 2006 CT treatments with all herbicide intensity inputs provided ≥ 99 % control of broadleaf signalgrass (BRAPP). FSS treatments provided 91% control with high herbicide input, but < 86% control with medium and low herbicide intensity (Table 9). No combination of SSS with any herbicide intensity provided adequate control of broadleaf signalgrass (BRAPP). Both CT and FSS treatments receiving low, medium, and high herbicide inputs provided 91 to 98% control of yellow nutsedge (CYPES), while SSS treatments provided significantly less control (Table 9). All treatments provided excellent control of barnyardgrass (ECHCG) except FSS treatments receiving the low and high herbicide input which provided < 92% control (Table 9). At eight WAA, all tillage treatments provided 100 % control of broadleaf signalgrass (BRAPP) except the SSS treatment receiving the low herbicide input level which provided 90% control (Table 9). Sprangletop (LEFSS) control was 98-100% for all treatments except FSS receiving the low or medium herbicide input. Control was < 94% (Table 9). Lowering the intensity of herbicide treatment in reduced

Table 9. Weed control with combinations of tillage and herbicide intensity 2 and 8 WAA near Eagle Lake,TX in 2006.[abc]

	2 WAA			8 WAA	
Treatment	BRAPP	CYPES	ECHCG	BRAPP	LEFSS
	--		%		--
Conventional tillage (CT) + low herbicide	100 A	91 ABC	100 A	100 A	98 AB
Conventional tillage (CT) + medium herbicide	99 A	95 AB	100 A	100 A	100 A
Conventional tillage (CT) + high herbicide	99 A	98 A	100 A	100 A	100 A
Spring stale seedbed tillage (SSS)+ low herbicide	56 C	66 D	100 A	90 B	100 A
Spring stale seedbed tillage (SSS) + medium herbicide	65 C	80 CD	99 A	100 A	100 A
Spring stale seedbed tillage (SSS) + high herbicide	66 C	81 BC	100 A	100 A	100 A

Table 9 continued.

Treatment	2 WAA			8 WAA	
	BRAPP	CYPES	ECHCG	BRAPP	LEFSS
	---------------------------------------%			---------------------------------------	
Fall stale seedbed tillage (FSS) + low herbicide	85 B	93 ABC	89 B	100 A	91 B
Fall stale seedbed tillage (FSS) + medium herbicide	83 B	91 ABC	94 AB	100 A	93 B
Fall stale seedbed tillage (FSS) + high herbicide	91 AB	96 A	91 B	100 A	100 A

[a] BRAPP, *Brachiaria platyphylla*, ECHCG, *Echinochloa crus-galli*, CYPES, *Cyperus esculentus*, LEFSS = *Leptochloa sp.*, WAA = weeks after application.

[b] Conventional tillage (CT), treatments kept weed free with tillage; spring stale seedbed tillage (SSS), fall tilled and treated with glyphosate prior to planting; fall stale seedbed tillage (FSS), kept weed free with glyphosate until planting; low herbicide, clomazone at 0.5 kg/ha (Beaumont), 0.3 kg/ha (Eagle Lake, Ganado) followed by (fb) 3.4 kg/ha propanil + 34.0 g/ha halosulfuron; medium herbicide, clomazone at 0.6 kg/ha (Beaumont), 0.5 kg/ha (Eagle Lake, Ganado) fb 4.5 kg/ha propanil + 0.6 kg/ha quinclorac; high herbicide, clomazone at 0.7 kg/ha (Beaumont), 0.6 kg/ha (Eagle Lake, Ganado) fb 4.5 kg/ha propanil + 50.0 g/ha halosulfuron + 0.6 kg/ha quinclorac.

[c] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.05.

tillage systems such as SSS and FSS does not provide adequate control of some weed species. For example FSS treatments with reduced sprangletop (LEFSS) control and SSS treatments with reduced broadleaf signalgrass (BRAPP) control.

Ganado

Two WAA in 2006 near Ganado, all treatments provided 90% or better broadleaf signalgrass (BRAPP) control except the FSS tillage receiving the low herbicide intensity input at 81% control (Table 10). No tillage treatment with any herbicide intensity provided adequate yellow nutsedge (CYPES) control. By eight WAA, all tillage treatments at all herbicide input levels provided > 94% control of broadleaf signalgrass (BRAPP) and < 90% control of barnyardgrass (ECHCG) (Table 10).

Yield

In 2005 near Beaumont, rice yield was significantly reduced in SSS and FSS treatments receiving the low herbicide intensity compared to yields of most other treatments or tended to be reduced. The lower yields in these treatments were caused by poor barnyardgrass (ECHCG) and hemp sesbania (SEBEX) control (Table 11). In 2006 near Beaumont, rice yield in FSS treatments receiving low herbicide inputs were significantly lower than the yields of all other treatments receiving CT or SSS tillage but not different from other FSS tillage treatments. Reduced rice yield is probably due to poor winter annual weed control from lack of tillage (Table 11).

Table 10. Weed control with combinations of tillage and herbicide intensity at 2 and 8 WAA near Ganado, TX in 2006.[abc]

Treatment	2 WAA		8 WAA	
	BRAPP	CYPES	BRAPP	ECHCG
	--------------	-------------- % --------------	--------------	--------------
Conventional tillage (CT) + low herbicide	92 A	35 BC	100 A	95 A
Conventional tillage (CT) + medium herbicide	94 A	45 AB	100 A	100 A
Conventional tillage (CT) + high herbicide	94 A	40 BC	100 A	100 A
Spring stale seedbed tillage (SSS) + low herbicide	93 A	60 A	99 A	93 A
Spring stale seedbed tillage (SSS) + medium herbicide	94 A	40 BC	98 A	100 A
Spring stale seedbed tillage (SSS) + high herbicide	93 A	38 BC	100 A	99 A

Table 10 continued.

Treatment	2 WAA		8 WAA	
	BRAPP	CYPES	BRAPP	ECHCG
	------------------------------%------------------------------			
Fall stale seedbed tillage (FSS) + low herbicide	81 B	40 BC	99 A	91 A
Fall stale seedbed tillage (FSS) + medium herbicide	91 A	33 BC	95 A	98 A
Fall stale seedbed tillage (FSS) + high herbicide	90 A	25 C	100 A	100 A

[a] ECHCG = *Echinochloa crus-galli*, CYPES = *Cyperus esculentus*, LEFSS = *Leptochloa sp*., BRAPP = *Brachiaria platyphylla*, WAA = weeks after application.

[b] Conventional tillage (CT), treatments kept weed free with tillage; spring stale seedbed tillage (SSS), fall tilled and treated with glyphosate prior to planting; fall stale seedbed tillage (FSS), kept weed free with glyphosate until planting; low herbicide, clomazone at 0.5 kg/ha (Beaumont), 0.3 kg/ha (Eagle Lake, Ganado) followed by (fb) 3.4 kg/ha propanil + 34.0 g/ha halosulfuron; medium herbicide, clomazone at 0.6 kg/ha (Beaumont), 0.5 kg/ha (Eagle Lake, Ganado) fb 4.5 kg/ha propanil + 0.6 kg/ha quinclorac; high herbicide, clomazone at 0.7 kg/ha (Beaumont), 0.6 kg/ha (Eagle Lake, Ganado) fb 4.5 kg/ha propanil + 50.0 g/ha halosulfuron + 0.6 kg/ha quinclorac.

[c] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.05.

Table 11. Rice yield with combinations of tillage and herbicide intensity in 2005 and 2006 near Beaumont, Eagle Lake, and Ganado, TX.[abc]

	Yield			
Treatment	BMT 2005	BMT 2006	EL 2006	GAN 2006
	---------------------------kg/ha---------------------------			
Conventional tillage (CT) + low herbicide	6210 A	6880 A	7360 A	3580 BC
Conventional tillage (CT) + medium herbicide	4540 ABC	6640 A	7080 AB	3440 C
Conventional tillage (CT) + high herbicide	5120 AB	6430 AB	7210 A	3230 C
Spring stale seedbed tillage (SSS) + low herbicide	2800 C	6380 AB	7290 A	3820 ABC
Spring stale seedbed tillage (SSS) + medium herbicide	5560 A	6630 A	7330 A	4170 AB
Spring stale seedbed tillage (SSS) + high herbicide	5830 A	6650 A	6960 AB	4330 A

Table 11 continued.

Treatment	Yield			
	BMT 2005	BMT 2006	EL 2006	GAN 2006
	----------------------------kg/ha----------------------------			
Fall stale seedbed tillage (FSS) + low herbicide	3330 BC	5650 C	6460 BC	3520 C
Fall stale seedbed tillage (FSS) + medium herbicide	5350 AB	6350 ABC	6720 ABC	3840 ABC
Fall stale seedbed tillage (FSS) + high herbicide	5780 A	5760 BC	6310 C	4160 AB

[a] BMT, Beaumont, TX; EL, Eagle Lake, TX; GAN, Ganado, TX; WAA, weeks after application.

[b] Conventional tillage (CT), treatments kept weed free with tillage; spring stale seedbed tillage (SSS), tilled fall and burned down with glyphosate prior to planting; fall stale seedbed tillage (FSS), kept weed free with glyphosate until planting; low herbicide, clomazone at 0.5 kg/ha followed by (fb) 3.4 kg/ha propanil + 34.0 g/ha halosulfuron; medium herbicide, clomazone at 0.6 kg/ha fb 4.5 kg/ha propanil + 0.6 kg/ha quinclorac; high herbicide, clomazone at 0.7 kg/ha fb 4.5 kg/ha propanil + 50.0 g/ha halosulfuron + 0.6 kg/ha quinclorac.

[c] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.05.

Near Eagle Lake in 2006, FSS treatments receiving the high herbicide inputs were significantly lower than all other tillage treatments (Table 11).

Near Ganado in 2006, CT treatments receiving medium and high herbicide inputs and the FSS treatment receiving the low herbicide input were significantly lower than the yields of SSS treatments with medium or high herbicide input and FSS with high herbicide input. Reduced yields in the CT treatments is most likely due to the increased tillage in light soil which may have provided a poor stand due to un-uniform seed placement and depth.

By eight WAA in 2006, all treatments in all studies provided ≥ 90% control of all weed species present at that time (Tables 8, 9, and 10). In 2005 near Beaumont, 8 WAA significant reductions in weed control were found in FSS and SSS treatments receiving low herbicide input for barnyardgrass (ECHCG) and hemp sesbania (SEBEX) (Table 7). Differences in weed control from the same treatments between 2005 and 2006 could be due to differences in weed populations. Under light weed pressure, weeds may be effectively controlled with conservation tillage practices with lower herbicide rates. Under heavy weed pressure higher herbicide rates may be needed to inhibit weed growth that would usually be provided by tillage in a conventional system. The reduced weed control in 2005 was reflected in reduced rice yield (Table 7). However, the CT treatment receiving the lower herbicide input provided the highest yield of any treatment. Although the weed control was much improved in all locations in 2006, FSS treatments tended to be among the lowest in yield (Table 11). Since the weed control was excellent in 2006 we may theorize that yield differences may be due to seedbed preparation. This particular effect may have been masked in 2005 by the higher weed pressure. Near Ganado, CT treatments tended to produce lowest rice yields (Table 11). Increased tillage in the CT treatments may have provided very loose soil for planting causing differences in planting depth as well as seed placement. The data suggests that stale seedbed programs should consider soil characteristics as well as weed pressure. A stale seedbed program may be beneficial and useful for early planting or for red rice suppression, but under increased weed pressure, increasing herbicide intensity may be necessary to overcome lack of tillage. With the exception of the Ganado study, highest yields were found in CT treatments with low herbicide intensity, though these yields were not significantly different than the SSS program with medium or high herbicide input level (Table 11). Comparable yields can be achieved through pairing a stale seedbed program with an appropriate herbicide program. With this in mind producers must decide whether the savings gained from the reduction in tillage will outweigh increased herbicide program cost

CHAPTER IV

RED RICE ECOTYPE RESPONSE TO RATES OF HERBICIDES

Introduction

Red rice is one of the most problematic weeds in the rice belt of Texas (Noldin et al. 1999b). Historically red rice is considered the same species as cultivated rice (*Oryza sativa* L.) (Vaughn 2005; Diarra et al. 1985; Kwon et al. 1992). Genetic variation has been identified in red rice populations (Noldin et al. 1999b). Consequently, red rice is very difficult to control using conventional herbicides. The need to develop herbicide tolerant rice varieties with herbicides not typically used in rice was identified as early as 1979 (Richard and Baker 1979). Recent rice varieties have been developed that show tolerance to selected herbicides by natural breeding or genetic modification. Emphasis has been placed in researching gene flow and outcrossing potential of herbicide tolerant varieties with red rice, which could produce a red rice that is tolerant to the selected herbicides (Gealy et al. 2003).

Throughout the 1980's and 90's cultural and chemical suppression of red rice with crop rotation produced the best control. The use of other herbicide families, such as the *s*-triazines, cyclohexanediones, and chloroacetamides, allowed producers to control red rice in rotation crops such as corn (*Zea mays*), grain sorghum (*Sorghum bicolor*), and soybean (*Glycine max*) (Barrentine et al. 1984). The goal was to develop control practices that minimize red rice impact on cultivated rice grade and quality while retaining high yield potential (Dunand et al. 1985).

Red rice is known to be highly competitive with cultivated rice (Ferrero et. al. 1999). Twenty red rice plants per $meter^2$ may cause up to a 60% loss in rice grain yield (Fischer and Ramirez 1993). For many years molinate (*S*-ethyl hexahydro-1*H*-azepine-1-carbothioate) has been one of the best preplant incorporated (PPI) herbicides for red rice control. Red rice control of 86% has been provided with molinate plus fenoxaprop ((±)-2-[4-[(6-chloro-2-benzoxazolyl)oxy] phenoxy] propanoic acid) applied PPI (Kwon et al. 1991). However, because of carcinogenicity concerns of thiocarbamate chemicals, the sale of molinate will be prohibited after June 30, 2008 (Environmental Protection Agency 2003). Herbicides suggested for red rice control include glyphosate (*N*-(phosphonomethyl)glycine) (Askew et al. 1998), imazamox (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid) (Vasilakoglou and Dhima 2005), glufosinate (2-amino-4-(hydroxymethylphosphinyl)butanoic acid) (Sankula et al. 1997a) and imazethapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imadazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid). The possibility of incorporating tolerance to these broad spectrum herbicides into cultivated rice varieties has been a focus for red rice control.

In 1993, a cultivated rice variety was found that showed tolerance to the imidazolinone family of herbicides (Sanders et al. 1998). This plant was used to breed tolerance into new rice cultivars allowing use of imazethapyr, as a POST applied management option for red rice control. This technology was commercialized in 2002 by BASF Corporation[1] as CLEARFIELD[*] rice (Bollich et al. 2002). Imazethapyr kills susceptible plants by blocking the acetolactate synthase (ALS) enzyme responsible for the production of the branched chain amino acids isoleucine, leucine and valine (Vencill et al. 2002). Susceptible plants stop growth within one to two hours after application, but visual symptoms of plant chlorosis and necrosis usually require one to two weeks (Vencill et al. 2002). While useful for the red rice control in cultivated rice, the abundant use of ALS herbicides has led to several herbicide resistant weed species (Devine and Shukla 2000). Avila et al. (2005) reported tolerance to imazethapyr in two red rice ecotypes two times that of the susceptible cultivated variety 'Cypress'. Steele et al. (2002) found that sequential applications of imazethapyr provided from 92 to 98% control of red rice but increasing rates of imazethapyr above 52 g/ha did not improve red rice control. Ottis et al. (2003) found that sequential POST applications improved control over that provided by a single late post (LPOST) application.

In addition to imazethapyr tolerance, imazamox may also be applied to imidizolinone tolerant cultivated varieties for red rice control. Imazamox is also an imidizolinone herbicide similar to imazethapyr. Vasilakoglou and Dhima (2005) found a number of red rice ecotypes tolerant to imazamox, and concluded that POST applications may not be effective against all red rice ecotypes.

Glufosinate has also been evaluated for red rice control in cultivated rice through the transgenic incorporation of the bialaphos resistance (BAR) gene. Thus a nonselective herbicide could be applied to a crop that would ordinarily be susceptible to the chemical (Braverman and Linscombe 1994). Glufosinate is an inhibitor of glutamine synthetase and causes plant death by buildup of ammonium inhibiting photosystem II (Vencill et al. 2002). Glufosinate has been used for broadspectrum broadleaf weed control in noncropland and as a contact herbicide prior to crop emergence in reduced tillage systems (Haas and Muller 1987). For complete red rice control sequential applications of at least 0.4 kg/ha of glufosinate was needed (Sankula et al. 1997b). When sequential applications were not used, the control of red rice decreased with decreasing rate of glufosinate. Braverman and Linscombe (1994) recommended 1.1 kg/ha of glufosinate on small red rice and lower dosage sequential applications for larger plants. In 1993, Noldin et al. (1999a) identified red rice ecotype TX4, collected at Katy, Texas, as low susceptibility to glufosinate even though this herbicide had not been used in the area. Glufosinate applied at 0.07 kg. ai/ha provided between 71 and 89% control of TX4 and increasing the rate to 1.12 kg/ha provided 94% control. Variability in herbicide sensitivity exists within red rice populations even in areas where a given herbicide has not been previously used (Noldin 1999a). There is no glufosinate tolerant cultivated rice variety available to producers at present.

Glyphosate is another broadspectrum herbicide that has been evaluated for red rice control. Glyphosate is an inhibitor of 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase, a key pathway for the synthesis of tryptophan, tyrosine, and phenylalanine. By blocking the EPSP synthase pathway, the production of proteins for plant growth is stopped (Vencill et al. 2002). No commercially available glyphosate-tolerant cultivated rice variety has been released. Therefore, the use of glyphosate for red rice control must be restricted to glyphosate tolerant corn or soybeans or during the off season and weed control prior to crop emergence. Glyphosate at 0.5 kg/ha controlled red rice (Guy 1996). However, Askew et al. (1998) found that single applications of glyphosate at 1.7 kg/ha were not adequate for season long weed control. Five percent red rice escapes may not negatively impact soybean yield, but may restore the red rice seedbank (Rao and Harger 1981; Goss and Brown 1939). Vaughan et al. (2001) found great genetic diversity within red rice populations in close proximity. Red rice ecotype TX4, identified by Noldin (1999b), was found to be genetically similar to *Oryza rufipogon* accession 105491, while other red rice ecotypes were similar to *Oryza sativa* ssp. *indica* (Vaughan et al. 2001). Red rice ecotype TX4 has low susceptibility to glufosinate (Noldin 1999a). With possible glufosinate tolerance in Texas red rice populations, these populations must be evaluated for tolerance to glufosinate, glyphosate and the imidazolinone herbicides. The objectives of this research are to identify red rice ecotypes that display a level of tolerance to existing red rice control herbicides.

Materials and Methods

Studies were conducted at the Texas Agricultural Experiment Station, near Beaumont, TX. The soil at Beaumont is a League silty clay Fine, smectitic, hyperthermic Oxyaquic, Dystruderts with a pH ranging from 5.8-8.1 and organic matter content between 1.2 and 1.7%. Research was conducted using a cross section of red rice ecotypes from across Texas. During the summer of 2003, 240 seed samples from individual plants at different locations were collected across the Texas rice belt and genetically fingerprinted (Vaughan 2005). This information was used to separate the red rice ecotypes into four genetically similar subgroups. A cross section of ecotypes from each subgroup was planted for a seed increase. During the seed increase, data were collected on the agronomic traits of each red rice ecotype, including the number of tillers per plant, the number of seeds per panicle, the number of panicles per plant, plant height, 100 seed weight, and percent germination.

Red rice samples were separated into five separate groups based on a genetic cluster analysis performed by Vaughan (2005), which separated all of the red rice samples collected into genetic similarity clusters. These clusters separated the red rice ecotypes into three main groups. Group three was separated into two subgroups which clustered around TX4 and *Oryza rufipogon* accession IRGC 105491. Selections were then made from these subgroups to adequately represent the traits of the group. Subgroup 3.1 included all ecotypes that genetically resemble *Oryza rufipogon* accession IRGC 105491. Subgroup 3.2 included all ecotypes that genetically resemble TX4. Subgroups 3.1 and 3.2 were made up of red rice ecotypes with black hulls and long awns that genetically resemble *Oryza rufipogon* (Vaughan et al. 2001). Another group consisted of intermediate ecotypes with genetic characteristics of both IRGC 105491 and TX4. Group two consisted of strawhulled ecotypes which are similar to *Oryza sativa* ssp. *indica*, and the last group consisted of four separate seed lots of TX4, which all originated with the plant from Katy, TX (Noldin 1999b). Dormancy was broken in the red rice seed using a wetting and drying process (Hessler 1999). Seed samples were placed uncovered in a dryer at 37ºC for 24 h then allowed to imbibe moisture from the air for 24 h. This cycle was repeated three times. Upon removal from the dryer the seed samples were sealed in freezer bags and placed in a freezer for 24 h at 1ºC for 24 h. After processing, the seed were planted in 118 ml. wax paper cups filled with Sun Grow Metro-mix 200 series growing medium[5] with one seed per cup and allowed to germinate in the greenhouse. Ecotypes with 40 strong, healthy seedlings were planted in May 2005 to produce the necessary quantity of seed for planting in 2006. The plants were transplanted at Beaumont in six m rows with plants spaced 15 cm apart. Each row was flanked buy two rows of the crawfish rice variety, 'Ecrevisse', a very late flowering variety used to prevent cross pollination between red rice ecotypes.

Seed dormancy was broken by the same method as in the previous year. Germination was then evaluated by placing 20 seeds of each ecotype on filter paper in a sealed dish and wetting the paper with distilled water. The dishes were then placed in a growth chamber at approximately 35ºC. At the end of one week sprouted seeds were counted and percent germination was determined.

Seed of increased red rice was planted near Beaumont in 2006. Seeding rate was correlated to % germination for each ecotype to produce 36 live plants per plot. Ecotypes with 100 % germination were planted at a rate of 14.8 kg/ha; 95% germination were planted at 15.6 kg/ha; 90% germination were planted at 16.4 kg/ha; 85 % germination were planted at 17.4 kg/ha; 75% germination were planted at 19.7 kg/ha and 70% germination were planted at 21.2 kg/ha. Red rice ecotypes were seeded with a Hege seed drill[6] on 30 cm centers using randomized drill passes of six red rice ecotypes per pass. The entire study received a PRE application of clomazone. The red rice studies were arranged in a split plot design with the main plot being 72 red rice ecotypes. Sub plots were sequential applications of glyphosate, glufosinate, imazethapyr, or imazamox at the three to five leaf stage and again at the five to six leaf stage. Glyphosate was applied at half the labeled rate 0.4 kg ai/ha (½ x), the labeled rate 0.8 kg/ha (1x) and two times the labeled rate 1.7 kg/ha (2x). The glufosinate treatments consisted of sequential applications at ½ x (0.2 kg/ha), 1x (0.4 kg/ha) and at 2x (0.8 kg/ha). Imazethapyr treatments were applied sequentially at ½ x (0.04 kg/ha), 1x (0.07 kg/ha), and 2x rate (0.14 kg/ha). Imazamox treatments consisted of sequential applications at ½ x (0.02 kg/ha), 1x (0.04 kg/ha), and 2x rate (0.07 kg/ha). The herbicide was applied perpendicular to the drill rows for a plot size of two m wide by 22 m long. The treatments in these studies were replicated four times. Two identical studies were established.

Red rice control was evaluated by percent control on a 0 to 100 scale, with zero representing no injury and 100 representing total plant death. A visual rating was taken for each ecotype within each treatment at intervals of 1, 2, 3, and 4 weeks after each application, with a live plant count at four weeks after the second application. The data was subjected to the GLM Procedure using SAS[2] with mean separation done by Fisher's protected LSD. Further comparisons were made among the means of each group with separation by Fisher's protected LSD. In evaluating the control provided by each herbicide, 80% was used as a cutoff point for red rice control that would be acceptable to a producer. Red rice ecotypes controlled ≤ 50% by a herbicide were deemed to be at risk for tolerance to that herbicide.

Results and Discussion

Imazethapyr applied at the 1.0x rate provided adequate red rice control for group 3.1 at site one with 81% control 4 WAA (weeks after application) (Table 12). All other groups were controlled between 79 and 71%. At site two, 1x imazethapyr controlled red rice groups between 80 and 90% but only 75% control of the TX4. The strawhulled group had the highest control at 90% (Table 12). Imazethapyr applied at the 2x rate at site one provided ≥ 91% control for all groups (Table 13). All groups were adequately controlled with the 2x imazethapyr at site two.

The 1x application of imazamox did not provide adequate control of any red rice group in either study 4 WAA (Table 12). At site one the highest control was group 3.1 with 71% and the lowest in the intermediate group at 56%. At site two the greatest control was group 3.1 with 63% and the lowest control in the TX4 group with 53%. Imazamox applied at the 2x rate did not provide adequate control of the intermediate group at site one, but did provide adequate control at site two with 89%. All other groups were controlled between 83 and 94% in both studies with imazamox at the 2x rate (Table 13).

Red Rice control provided by glufosinate at the 1x rate 4 WAA was at or below 80% for all genetic groups in both studies (Table 12). At site one glufosinate provided the best control in the strawhulled and 3.1 groups at 57 and 54%, respectively, with control of all other groups below 50%. The control provided at site two was better than site one. The best control was the strawhulled and 3.1 groups at 80 and 73%, respectively. All other groups fell between at 67 and 53%. In both studies glufosinate at the 1x rate provided the lowest control for groups 3.2 and TX4 with 39 and 36% at site one and 53 and 55% at site two (Table 12). Glufosinate at the 2x rate failed to provide adequate control for groups 3.2 and TX4, but provided good control of the strawhulled, intermediate, and 3.1 groups (Table 13). At site two all groups were controlled by a 2x rate of glufosinate at or above 86% control. Glyphosate applied at the 1x and 2x rates provided ≥99% control for all red rice groups in both studies (Tables 12 and 13).

No ecotype was found tolerant of glyphosate at the 1x or 2x rate. Only ecotype 205 was found to be tolerant to imazethapyr and imazamox at the 2x rates, with imazethapyr providing 29% control and imazamox providing 44% control (Table 14). Ecotype TX4-5 as well as group 3.2 ecotypes 361, 425, and 428 were not adequately controlled with the 2x rate of glufosinate. No ecotype showed tolerance to the 2x rate of glufosinate. Possible tolerance to the 1.0x rates of imazethapyr and imazamox was found in group 3.1 ecotype 205. Intermediate group ecotypes 596, 539, and 600 also showed tolerance to imazamox at the 1x rate, but not imazethapy. All TX4 ecotypes and group 3.1 ecotypes 28-2, 623, and 311 were controlled < 50% with the 1x rate of glufosinate. Intermediate group ecotypes 521, 325 as well as group 3.2 ecotypes 348, 971, 172, 728, 27-1, 425, 493, 409, 166, 428, 30, 140, 27-2, 161, 142, 356, 361, 179, and 11 were controlled < 50% with the 1x rate of glufosinate revealing a possibility for tolerance to this herbicide.

Table 12. Red rice control with herbicides at their recommended rates applied twice at two sites at 4 WAA near Beaumont, TX.[abc]

Group	Imazethapyr 1x		Imazamox 1x		Glufosinate 1x		Glyphosate 1x	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
	-----	-----	-----	-----	%	-----	-----	-----
TX4	72 C	75 D	63 BC	53 B	36 C	55 C	99 A	100 A
Strawhulled	79 AB	90 A	70 AB	62 A	57 A	80 A	100 A	100 A
Intermediate	71 C	80 CD	56 C	61 A	46 B	67 B	100 A	100 A
3.2	74 BC	82 BC	67 AB	57 AB	39 BC	53 C	99 A	100 A
3.1	81 A	86 AB	71 A	63 A	54 A	73 AB	100 A	100 A

[a] WAA = weeks after application; Group TX4 = red rice ecotypes known to be TX4; Strawhulled = red rice ecotypes genetically similar to *Oryza sativa* ssp. *indica*; Intermediate = red rice ecotypes genetically similar to *Oryza rufipogon* and TX4; 3.2 = red rice ecotypes genetically similar to TX4; 3.1 = red rice ecotypes genetically similar to *Oryza rufipogon*; Site 1 = first study planted; Site 2 = second study planted.

[b] Glufosinate 1x = 0.4 kg/ha, glyphosate 1x = 0.8 kg/ha, imazethapyr 1x = 0.07 kg/ha, and imazamox 1x = 0.04 kg/ha, first treatment applied to 3- to 4- leaf red rice, second treatment applied to 6- to 8- leaf red rice.

[c] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.05.

Table 13. Red rice control with herbicides at two times their recommended rates applied twice at two sites at 4 WAA near Beaumont, TX.[abc]

Group	Imazethapyr 2x		Imazamox 2x		Glufosinate 2x		Glyphosate 2x	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
	%							
TX4	96 A	88 B	88 A	83 B	62 B	86 B	99 A	100 A
Strawhulled	98 A	94 A	89 A	94 A	92 A	97 A	100 A	100 A
Intermediate	91 B	93 A	74 B	89 A	88 A	96 A	100 A	100 A
3.2	96 A	90 AB	87 A	85 B	64 B	87 B	100 A	100 A
3.1	96 A	90 AB	88 A	92 A	88 A	97 A	100 A	100 A

[a] WAA = weeks after application; Group TX4 = red rice ecotypes known to be TX4; Strawhulled = red rice ecotypes genetically similar to *Oryza sativa* ssp. *indica*; Intermediate = red rice ecotypes genetically similar to *Oryza rufipogon* and TX4; 3.2 = red rice ecotypes genetically similar to TX4; 3.1 = red rice ecotypes genetically similar to *Oryza rufipogon*; Site 1 = first study planted; Site 2 = second study planted.
[b] Glufosinate 2x = 0.8 kg/ha, glyphosate 2x = 1.7 kg/ha, imazethapyr 2x = 0.14 kg/ha, and imazamox 2x = 0.07 kg/ha, first treatment applied to 3- to 4- leaf red rice, second treatment applied to 6- to 8- leaf red rice.
[c] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.05.

Table 14. Red rice ecotypes controlled ≤ 80% and ≤ 50% with the herbicides imazethapyr, imazamox, and glufosinate 4 WAA near Beaumont, TX in 2006.[ab]

Group	Imazethapyr		Imazamox		Glufosinate		Glyphosate	
	1x	2x	1x	2x	1x	2x	0.5x	1x
TX4	TX4-4 (75)		TX4-3 (64)		**TX4-4 (49)**[cd]	TX4-5 (65)		
	TX4-3 (72)		TX4-2 (62)		**TX4-5 (47)**			
	TX4-5 (69)		TX4-5 (55)		**TX4-2 (47)**			
			TX4-4 (52)		**TX4-3 (42)**			
Strawhulled			2261 (72)		2261 (72)			
			279 (71)		24 (62)			
			1249 (71)		1249 (59)			
			1309 (66)		1309 (58)			
			154 (65)					
			374 (63)					
			430 (62)					

Table 14 continued.

Group	Imazethapyr		Imazamox		Glufosinate		Glyphosate	
	1x	2x	1x	2x	1x	2x	0.5x	1x
Strawhulled			471 (59)					
			304 (53)					
Intermediate	585 (72)		2 (64)		2 (62)			
	539 (69)		585 (62)		600 (60)			
	521 (63)		325 (59)		539 (58)			
	596 (62)		521 (56)		585 (54)			
			596 (47)		596 (53)			
			539 (47)		**521 (49)**			
			600 (42)		**325 (48)**			
3.2	142 (72)		172 (69)		183 (64)	361 (73)		
	27-1 (72)		728 (67)		25-2 (62)	425 (67)		
	356 (69)		493 (66)		3 (57)	428 (59)		

Table 14 continued.

Group	Imazethapyr		Imazamox		Glufosinate		Glyphosate	
	1x	2x	1x	2x	1x	2x	0.5x	1x
3.2	409 (69)		384 (66)		390 (54)			
	179 (65)		183 (65)		136 (54)			
	27-2 (76)		27-2 (65)		25-1 (52)			
	361 (70)		3 (64)		384 (52)			
	161 (72)		425 (64)		414 (52)			
			27-1 (63)		**348 (48)**			
			25-2 (63)		**971 (47)**			
			179 (63)		**172 (47)**			
			361 (63)		**728 (46)**			
			414 (63)		**27-1 (45)**			
			30 (63)		**425 (44)**			
			409 (62)		**493 (44)**			

Table 14 continued.

Group	Imazethapyr		Imazamox		Glufosinate		Glyphosate	
	1x	2x	1x	2x	1x	2x	0.5x	1x
3.2			166 (62)		**409 (43)**			
			348 (62)		**166 (42)**			
			971 (60)		**428 (42)**			
			161 (57)		**30 (42)**			
			136 (57)		**140 (40)**			
			11 (55)		**27-2 (40)**			
			356 (54)		**161 (40)**			
			390 (54)		**142 (39)**			
			140 (53)		**356 (39)**			
					361 (39)			
					179 (37)			
					11 (36)			

Table 14 continued.

Group	Imazethapyr		Imazamox		Glufosinate		Glyphosate	
	1x	2x	1x	2x	1x	2x	0.5x	1x
3.1	223 (77)	**205 (29)**	18 (73)	**205 (44)**	813 (73)			
	623 (73)		811 (73)		223 (67)			
	205 (37)		297 (73)		405 (63)			
			429 (71)		18 (62)			
			2265 (71)		5 (60)			
			23 (67)		28-1 (59)			
			5 (67)		58 (58)			
			58 (67)		2251 (57)			
			623 (64)		297 (57)			
			815 (63)		296 (54)			
			28-2 (56)		429 (52)			
			223 (54)		**28-2 (49)**			

Table 14 continued.

Group	Imazethapyr		Imazamox		Glufosinate		Glyphosate	
	1x	2x	1x	2x	1x	2x	0.5x	1x
3.1			4 (54)		**623 (47)**			
			813 (52)		**311 (45)**			
			205 (39)					

[a] WAA = weeks after application; Group TX4 = red rice ecotypes known to be TX4; Strawhulled = red rice ecotypes genetically similar to *Oryza sativa* ssp. *indica*; Intermediate = red rice ecotypes genetically similar to *Oryza rufipogon* and TX4; 3.2 = red rice ecotypes genetically similar to TX4; 3.1 = red rice ecotypes genetically similar to *Oryza rufipogon*.

[b] Glufosinate 1x = 0.4 kg/ha, 2x = 0.8 kg/ha; glyphosate 1x = 0.8 kg/ha, 2x = 1.7 kg/ha; imazethapyr 1x = 0.07 kg/ha, 2x = 0.14 kg/ha; and imazamox 1x = 0.04 kg/ha., 2x = 0.07 kg/ha, first treatment applied to 3- to 4- leaf red rice, second treatment applied to 6- to 8- leaf red rice.

[c] Ecotypes in bold are ≤ 50% control.

[d] Numbers in parenthesis are percent control averaged between the two sites.

TX4 ecotypes TX4-4, TX4-3, and TX4-5 were not adequately controlled by 1x of imazethapyr or imazamox. TX4-2 was not adequately controlled by imazamox at the 1x rate, but was controlled by the 1x rate of imazethapyr. All ecotypes in the strawhulled group were adequately controlled by a 1x rate of imazethapyr. Nine strawhulled ecotypes were not adequately controlled by imazamox, and four were not adequately controlled by glufosinate. Strawhulled ecotypes 2261, 1249, and 1309 were not adequately controlled by glufosinate or imazamox, but were controlled > 50%. Four intermediate group ecotypes were not adequately controlled by imazethapyr, four were not adequately controlled by imazamox, and five were not adequately controlled by glufosinate, but were controlled > 50%. Intermediate group ecotypes 585, 539, 521, and 596 were not adequately controlled by glufosinate, imazethapyr, or imazamox. Ecotypes 2, 585, 325, 521, 596, 539, and 600 were not adequately controlled with either imazamox or glufosinate, though ecotypes 2, 325, and 600 were controlled with imazethapyr. Eight group 3.2 ecotypes were not adequately controlled by a 1x rate of imazethapyr, sixteen were not adequately controlled by imazamox, and eight were not adequately controlled by glufosinate, but were controlled > 50%. Group 3.2 ecotypes 27-1, 356, 409, 179, 27-2, and 161 were not adequately controlled with imazethapyr, imazamox, or glufosinate at the 1x rate. Ecotype 361 was not controlled effectively by a 1x rate of imazethapyr or imazamox. Of the group 3.1 two ecotypes were not adequately controlled by a 1x rate of imazethapyr, fourteen were not adequately controlled with imazamox, and eleven were not adequately controlled with glufosinate. Ecotypes 223 and 623 were not adequately controlled by 1x rates of glufosinate, imazethapyr, or imazamox. Ecotypes from every genetic similarity group were not adequately controlled by 1x rates of glufosinate and imazamox, but ecotypes from the strawhulled group were all controlled by imazethapyr (Table 14).

Ecotypes from every region of the Texas rice belt showed possible tolerance to the 1x rate of glufosinate or were not adequately controlled by the 1x rate of imazamox (Table 15). Ecotypes from the east and west regions only, were not adequately controlled by imazethapyr (Table 15).

Only one red rice ecotype was found to be tolerant to 2x rates of both imazethapyr and imazamox. No ecotype was found tolerant to 2x rates of more than two of the four herbicides. Ecotypes from the 3.2 group appear to be the most likely to exhibit tolerance to a given herbicide with the exception of glyphosate. The 3.2 group is made up of ecotypes genetically similar to the ecotype TX4 found in Katy, TX, which has low susceptibility to glufosinate. Therefore, it is not surprising that 70% of the group 3.2 ecotypes were found to have glufosinate tolerance. Additionally, 60% of the group 3.1 ecotypes were not adequately controlled by the 1x rate of glufosinate. These results suggest that the majority of red rice ecotypes genetically similar to the awned and black hulled *Oryza rufipogon* may prove tolerant to glufosinate (Table 16). With very few exceptions red rice ecotypes genetically similar to *Oryza rufipogon* are also awned and have black hulls (Table 16). The distinct difference in proportion of ecotype tolerance to the 1x and 2x rates of glufosinate indicated that glufosinate is not a viable option for red rice control in Texas. All ecotypes were adequately controlled by glyphosate indicating the need for glyphosate use in tolerant crops or glyphosate use in fallow years on red rice. With 57% more ecotypes found less than adequately controlled with imazamox than imazethapyr, it is clear that imazamox may be best for late season treatment. Imazamox and glufosinate lack adequate control among red rice ecotypes throughout all regions of the rice belt. This research indicated that the use of full labeled rates of imazethapyr and imazamox are essential to preventing increased occurrence of tolerance to the imidizolinone herbicide family. Rotating herbicides for red rice control is essential for existing herbicide technologies to continue providing effective red rice control in cultivated rice crops and in rotational cropping systems.

Table 15. Counties of origin for red rice ecotypes controlled ≤ 80% and ≤ 50% with herbicides 4 WAA near Beaumont, TX in 2006.[ab]

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	County	Region	Ecotype	County	Region	Ecotype	County	Region
TX4	TX4-4	Waller	West	TX4-3	Waller	West	**TX4-4**[c]	**Waller**	**West**
	TX4-3	Waller	West	TX4-2	Waller	West	**TX4-5**	**Waller**	**West**
	TX4-5	Waller	West	TX4-5	Waller	West	**TX4-2**	**Waller**	**West**
				TX4-4	Waller	West	**TX4-3**	**Waller**	**West**
Strawhulled				279	Bowie	North	2261	Brazoria	West
				304	Bowie	North	24	Wharton	West
				2261	Brazoria	West	1249	Liberty	East
				374	Fort Bend	West	1309	Liberty	East
				430	Wharton	West			
				471	Wharton	West			

Table 15 continued.

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	County	Region	Ecotype	County	Region	Ecotype	County	Region
Strawhulled				1249	Liberty	East			
				1309	Liberty	East			
				154	Jefferson	East			
Intermediate	585	Liberty	East	325	Bowie	North	**325**	**Bowie**	**North**
	539	Liberty	East	2	Waller	West	2	Waller	West
	521	Liberty	East	585	Liberty	East	600	Liberty	East
	596	Liberty	East	521	Liberty	East	539	Liberty	East
				596	**Liberty**	**East**	585	Liberty	East
				539	**Liberty**	**East**	596	Liberty	East
				600	**Liberty**	**East**	**521**	**Liberty**	**East**
3.2	179	Colorado	West	183	Colorado	West	183	Colorado	West

Table 15 continued.

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	County	Region	Ecotype	County	Region	Ecotype	County	Region
3.2	27-1	Fort Bend	West	179	Colorado	West	**179**	**Colorado**	**West**
	356	Fort Bend	West	27-2	Fort Bend	West	**348**	**Fort Bend**	**West**
	27-2	Fort Bend	West	27-1	Fort Bend	West	**27-1**	**Fort Bend**	**West**
	361	Fort Bend	West	361	Fort Bend	West	**27-2**	**Fort Bend**	**West**
	409	Chambers	East	348	Fort Bend	West	**356**	**Fort Bend**	**West**
	142	Jefferson	East	11	Fort Bend	West	**361**	**Fort Bend**	**West**
	161	Jefferson	East	356	Fort Bend	West	**11**	**Fort Bend**	**West**
				25-2	Matagorda	West	25-2	Matagorda	West
				30	Matagorda	West	25-1	Matagorda	West
				3	Waller	West	**30**	**Matagorda**	**West**
				384	Chambers	East	3	Waller	West

Table 15 continued.

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	County	Region	Ecotype	County	Region	Ecotype	County	Region
3.2				425	Chambers	East	390	Chambers	East
				414	Chambers	East	384	Chambers	East
				409	Chambers	East	414	Chambers	East
				390	Chambers	East	**425**	**Chambers**	**East**
				172	Jefferson	East	**409**	**Chambers**	**East**
				166	Jefferson	East	**428**	**Chambers**	**East**
				161	Jefferson	East	136	Jefferson	East
				136	Jefferson	East	**172**	**Jefferson**	**East**
				140	Jefferson	East	**166**	**Jefferson**	**East**
				728	Liberty	East	**140**	**Jefferson**	**East**
				493	Liberty	East	**161**	**Jefferson**	**East**

Table 15 continued.

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	County	Region	Ecotype	County	Region	Ecotype	County	Region
3.2				971	Liberty	East	**142**	**Jefferson**	**East**
							971	**Liberty**	**East**
							728	**Liberty**	**East**
							493	**Liberty**	**East**
3.1	223	Colorado	West	297	Bowie	North	297	Bowie	North
	205	Colorado	West	2265	Brazoria	West	296	Bowie	North
	623	Jefferson	East	18	Colorado	West	**311**	**Bowie**	**North**
				223	Colorado	West	2251	Brazoria	West
				205	**Colorado**	**West**	223	Colorado	West
				28-2	Fort Bend	West	18	Colorado	West
				58	Matagorda	West	28-1	Fort Bend	West

Table 15 continued.

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	County	Region	Ecotype	County	Region	Ecotype	County	Region
3.1				5	Waller	West	**28-2**	**Fort Bend**	**West**
				4	Waller	West	58	Matagorda	West
				429	Wharton	West	5	Waller	West
				23	Wharton	West	429	Wharton	West
				623	Jefferson	East	405	Chambers	East

Table 15 continued.

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	County	Region	Ecotype	County	Region	Ecotype	County	Region
3.1				811	Liberty	East	**623**	**Jefferson**	**East**
				815	Liberty	East	813	Liberty	East
				813	Liberty	East			

[a] WAA = weeks after application; Group TX4 = red rice ecotypes known to be TX4; Strawhulled = red rice ecotypes genetically similar to *Oryza sativa* ssp. *Indica*; Intermediate = red rice ecotypes genetically similar to *Oryza rufipogon*; TX4, 3.2 = red rice ecotypes genetically similar to TX4, and 3.1 = red rice ecotypes genetically similar to *Oryza rufipogon*.

[b] Glufosinate 1x = 0.4 kg/ha; glyphosate 1x = 0.8 kg/ha; imazethapyr 1x = 0.07 kg/ha; and imazamox 1x = 0.04 kg/ha, first treatment applied to 3- to 4- leaf red rice, second treatment applied to 6- to 8- leaf red rice.

[c] Ecotypes in bold are ≤ 50% control.

Table 16. Hull color and awning of red rice ecotypes controlled ≤ 80% and ≤ 50% with the herbicides imazethapyr, imazamox, and glufosinate 4 WAA near Beaumont, TX in 2006.[ab]

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn
TX4	TX4-4	BL	A	TX4-3	BL	A	**TX4-4**[c]	**BL**	**A**
	TX4-3	BL	A	TX4-2	BL	A	**TX4-5**	**BL**	**A**
	TX4-5	BL	A	TX4-5	BL	A	**TX4-2**	**BL**	**A**
				TX4-4	BL	A	**TX4-3**	**BL**	**A**
Strawhulled				279	S	N	2261	S	N
				304	S	N	24	BL	A
				2261	S	N	1249	S	N
				374	S	N	1309	S	N
				430	S	N			
				471	S	N			

Table 16 continued.

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn
Strawhulled				1249	S	N			
				1309	S	N			
				154	S	N			
Intermediate	585	S	A	325	S	N	**325**	**S**	**N**
	539	BL	A	2	BL	A	2	BL	A
	521	BL	A	585	S	A	600	BL	A
	596	BL	A	521	BL	A	539	BL	A
				596	**BL**	**A**	585	S	A
				539	**BL**	**A**	596	BL	A
				600	**BL**	**A**	**521**	**BL**	**A**
3.2	179	BL	A	183	BL	A	183	BL	A

Table 16 continued.

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn
3.2	27-1	BL	A	179	BL	A	**179**	**BL**	**A**
	356	BL	A	27-2	BL	A	**348**	**BL**	**A**
	27-2	BL	A	27-1	BL	A	**27-1**	**BL**	**A**
	361	BL	A	361	BL	A	**27-2**	**BL**	**A**
	409	BL	A	348	BL	A	**356**	**BL**	**A**
	142	BL	A	11	BL	A	**361**	**BL**	**A**
	161	BL	A	356	BL	A	**11**	**BL**	**A**
				25-2	BL	A	25-2	BL	A
				30	BL	A	25-1	BL	A
				3	BL	A	**30**	**BL**	**A**
				384	BL	A	3	BL	A

Table 16 continued.

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn
3.2				425	BL	A	390	BL	A
				414	BL	A	384	BL	A
				409	BL	A	414	BL	A
				390	BL	A	**425**	**BL**	**A**
				172	BL	A	**409**	**BL**	**A**
				166	BL	A	**428**	**BL**	**A**
				161	BL	A	136	BL	A
				136	BL	A	**172**	**BL**	**A**
				140	BL	A	**166**	**BL**	**A**
				728	BL	A	**140**	**BL**	**A**
				493	BL	A	**161**	**BL**	**A**

Table 16 continued.

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn
3.2				971	BL	A	**142**	**BL**	**A**
							971	**BL**	**A**
							728	**BL**	**A**
							493	**BL**	**A**
3.1	223	BL	A	297	S	A	297	S	A
	205	BL	A	2265	BL	A	296	BL	A
	623	BL	A	18	BL	A	**311**	**BL**	**A**
				223	BL	A	2251	BL	A
				205	**BL**	**A**	223	BL	A
				28-2	BL	A	18	BL	A
				58	BL	A	28-1	BL	A

Table 16 continued.

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn
3.1				5	BL	A	**28-2**	**BL**	**A**
				4	BL	A	58	BL	A
				429	BL	A	5	BL	A
				23	BL	A	429	BL	A
				623	BL	A	405	BR	A

Table 16 continued.

Group	Imazethapyr			Imazamox			Glufosinate		
	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn	Ecotype	Hull color	Awn
				811	BL	A	**623**	**BL**	**A**
				815	BL	A	813	BL	A
				813	BL	A			

[a] WAA = weeks after application; Group TX4 = red rice ecotypes known to be TX4; Strawhulled = red rice ecotypes genetically similar to *Oryza sativa* ssp. *indica*; Intermediate = red rice ecotypes genetically similar to *Oryza rufipogon* and TX4; 3.2 = red rice ecotypes genetically similar to TX4; 3.1 = red rice ecotypes genetically similar to *Oryza rufipogon*.

[b] Glufosinate 1x = 0.4 kg/ha; glyphosate 1x = 0.8 kg/ha; imazethapyr 1x = 0.07 kg/ha; and imazamox 1x = 0.04 kg/ha, first treatment applied to 3- to 4- leaf red rice, second treatment applied to 6- to8- leaf red rice, BL = black, BR = brown, S = straw, A = awned, N = not awned.

[c] Ecotypes in bold are ≤ 50% control.

CHAPTER V

SUMMARY AND CONCLUSIONS

Winter weed control programs for Texas rice production

A single application of any herbicide or combination of herbicides was not adequate for weed control throughout the fall, winter, and spring. The best herbicide programs contained a burndown application prior to planting cultivated rice for adequate weed control. Fall applications of clomazone plus flumioxazin provided acceptible weed control. Clomazone plus prosulfuron, however, was inadequate to control volunteer rice (ORYSA) under high weed pressure. Glyphosate plus flumioxazin provided control of all weed species in 2004 – 2005 at both locations. In 2005-2006 glyphosate plus flumioxazin was inadequate for controlling all weed species at both locations. Differences in control were due to different weeds present at each location. Clomazone plus flumioxazin at Eagle Lake and clomazone plus prosulfuron at Beaumont provided the best control of all species present during the spring. The broad spectrum control of flumioxazin or prosulfuron combined with residual control of clomazone is very effective for total weed control at this timing. The data showed that proper selection of the postemergence herbicide is required to adequately control existing vegetation. Single applications of herbicides without residual soil activity provided failed to provide control for one or more weed species at each location. In the first year after spring applications weed control was marginal using clomazone plus flumioxazin near Beaumont and glyphosate in the winter fb glyphosate plus flumioxazin in the spring near Eagle Lake. In the second year no treatment adequately controlled all weed species present at either location. Residual herbicides controlled many weeds through early spring, but by late spring summer annual grasses and sedges emerged. This occurred at both locations in both years but was more pronounced in the second year. Combining a burndown herbicide with a residual herbicide may be viable for controlling winter annual weeds throughout the off-season, although emerging summer annuals must be controlled prior to planting. Selecting a burndown herbicide to match weed species is essential for adequate control.

Combinations of tillage and herbicide intensity for weed control in Texas rice

By eight WAA in 2006 all treatments in all studies provided ≥ 90% control of all weed species present. In 2005 near Beaumont, 8 WAA significant reductions in weed control were found in FSS (fall stale seedbed tillage) and SSS (spring stale seedbed tillage) treatments receiving low herbicide input for barnyardgrass (ECHCG) and hemp sesbania (SEBEX). Differences in weed control provided by the same treatments could be due to differences in weed pressure between the two years. Weeds may be effectively controlled under light weed pressure with conservation tillage practices using lower herbicide rates. Under heavy weed pressure higher herbicide rates may be needed to inhibit weed growth that would usually be provided by tillage in a conventional system. The reduced weed control in 2005 resulted in reduced rice grain yield. However, the CT (conventional tillage) treatment receiving the lowest herbicide input provided the highest yield. Although the weed control was much improved in all locations in 2006, FSS treatments tended to be among the lowest in yield. Since the weed control was excellent in 2006 rice yield differences may be due to lack of proper seedbed tillage. This particular effect may have been masked in 2005 by the higher weed pressure. Near Ganado, CT treatments tended toward low rice yields. Increased tillage in the CT treatments may have provided very loose soil for planting causing differences in planting depth as well as seed placement. A stale seedbed program may be beneficial and useful for early planting or for red rice suppression, but under increased weed pressure, increasing herbicide intensity may be necessary to offset the lack of tillage. With the exception of Ganado, highest yields were found in CT treatments with low herbicide input, although yields were not significantly different from SSS programs with medium or high herbicide input level. Comparable yields can be achieved through pairing a stale seedbed program with an appropriate herbicide program. With this in mind producers must decide whether the savings gained from the reduction in tillage will outweigh increased herbicide program cost.

Red rice ecotype response to rates of herbicides

Ecotypes from every region of the Texas rice belt showed possible tolerance to the 1x rate of glufosinate or were not adequately controlled by the 1x rate of imazamox. Ecotypes from the east and west regions only, were not adequately controlled by imazethapyr.

Only one red rice ecotype was found tolerant to 2x rates of imazethapyr or imazamox. No ecotype was found tolerant to 2x rates of more than two of the four herbicides including imazethapyr, imazamox, glufosinate, and glyphosate. Ecotypes from the 3.2 group as defined by Vaughan (2005) through genetic clustering appeared the most likely to exhibit tolerance to a given herbicide with the exception of glyphosate. The 3.2 group consists of ecotypes genetically similar to the ecotype TX4 identified in Katy, TX, this ecotype has low susceptibility to glufosinate. Therefore, 70% of the group 3.2 ecotypes were tolerant to glufosinate. Additionally, 60% of the group 3.1 ecotypes were not adequately controlled by the 1x rate of glufosinate. Subgroup 3.1 as defined by Vaughan (2005) through genetic clustering included all ecotypes that genetically resemble *Oryza rufipogon* accession IRGC 105491. These results suggest that most red rice ecotypes genetically similar to the awned and black hulled *Oryza rufipogon* may prove tolerant to glufosinate. With very few exceptions red rice ecotypes genetically similar to *Oryza rufipogon* are also awned and have black hulls. The distinct difference in proportion of ecotype tolerance to glufosinate suggests that glufosinate would not be a viable option for red rice control in Texas. All ecotypes were adequately controlled by glyphosate and continued rotation to glyphosate tolerant crops or use in fallow years for red rice control is an option. With 57% more ecotypes poorly controlled with imazamox than imazethapyr, it is clear that imazamox may be best for late season treatment. Imazamox and glufosinate lack adequate control among red rice ecotypes throughout all regions of the rice belt. Data indicated that the use of full labeled rates of imazethapyr and imazamox are essential to prevent increased occurrence of tolerance to the imidizolinone herbicide family. The rotation of herbicides for red rice control is essential for existing herbicide technologies to continue to provide effective red rice control in cultivated rice crops or in rotational cropping systems.

ENDNOTES: SOURCES OF MATERIALS

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[2] SAS institute. 2002. SAS User's Guide: Statistics. Version 9.1. SAS Institute. SAS Campus Drive, Cary, NC 27513.

[3] Great Plains model 1020 minimum-till drill. Great Plains Manufacturing, Inc. P.O. Box 5060, Salina, KS 67402-5060.

[4] Kubota Skyrod RX1450, Kubota Manufacturing of America Corporation, 2715 Ramsey Road, Gainesville, GA 30501.

[5] Sun Grow Metro-mix 200 series growing medium, Sun Grow Horticulture Distribution Inc., Bellevue, WA

[6] Hege Model 90 light weight plot drill. Wintersteiger Ag. Niedelassung, Deutshlsnd, Kollmering 10, D-94535 Eging am See.

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APPENDIX A

Appendix A. Phenotypic data for 72 red rice ecotypes found in Texas.

Red Rice Data 2005

Ecotype Number	County	Tillers/plant	Seed/panicle	Panicles/plant	Plant height	100 seed weight	Germination
		------#------	------#-------	--------#-------	-----cm-----	--------g---------	------%-----
429	Wharton	30	59.5	44	139.7	2.135	90
6	Waller	34	80.5	47	160.02	2.165	100
815	Liberty	25	81	23.5	165.1	2.128	100
28-1	Fort Bend	24	60	39.5	144.78	2.229	100
56	Matagorda	21.5	102.5	23.5	140.97	1.777	85
471	Wharton	27.5	115	29	187.96	1.921	85
24	Wharton	31	76	36	170.18	2.236	100
1249	Liberty	20.5	103.5	20	139.7	2.028	100
348	Fort Bend	26	68.5	38.5	146.05	2.435	100
136	Jefferson	41.5	61.5	53	162.56	2.52	100
384	Chambers	30.5	70	28.5	132.08	2.644	95

Appendix A continued.

Red Rice Data 2005

Ecotype Number	County	Tillers/plant	Seed/panicle	Panicles/plant	Plant height	100 seed weight	Germination
		------#------	------#-------	--------#-------	-----cm-----	--------g---------	------%-----
161	Jefferson	25.5	60.5	30.5	142.24	2.551	100
356	Fort Bend	29	95	25	142.24	2.607	70
25-1	Matagorda	27	98.5	42	160.02	2.421	95
493	Liberty	22.5	102.5	21.5	167.64	2.438	95
TX4-3	Waller	35	57	35	157.48	2.573	95
2254	Brazoria	23.5	86.5	40	91.44	1.64	100
596	Liberty	36	71	56.5	144.78	2.196	90
205	Colorado	25	157.5	23	149.86	2.422	85
405	Chambers	28.5	105.5	35	170.18	2.183	100
297	Bowie	25.5	127.5	26.5	160.02	2.026	95
811	Liberty	27.5	100.5	30.5	160.02	2.248	90

Appendix A continued.

Red Rice Data 2005

Ecotype Number	County	Tillers/plant	Seed/panicle	Panicles/plant	Plant height	100 seed weight	Germination
		------#------	------#-------	--------#-------	-----cm-----	--------g---------	------%-----
2251	Brazoria	23	58.5	41	152.4	2.145	85
28-2	Fort Bend	25.5	100	40	160.02	2.425	[a]
279	Bowie	36	62.5	59	142.24	2.031	95
1309	Liberty	28.5	92.5	29.5	142.24	2.283	70
183	Colorado	39.5	56	44.5	166.37	2.722	95
140	Jefferson	31.5	52.5	40.5	154.94	2.623	95
428	Chambers	36	62	31.5	165.1	2.531	90
425	Chambers	34	56.5	41.5	142.24	2.484	90
11	Fort Bend	29.5	81.5	30.5	165.1	2.681	95
25-2	Matagorda	26	59	38	160.02	2.294	75
728	Liberty	29	70	30.5	157.48	2.559	100

Appendix A continued.

Red Rice Data 2005

Ecotype Number	County	Tillers/plant	Seed/panicle	Panicles/plant	Plant height	100 seed weight	Germination
		------#------	------#-------	--------#-------	-----cm-----	--------g---------	------%-----
TX4-2	Waller	19.5	47	27	147.32	2.34	85
325	Bowie	33.5	48.5	49	134.62	2.586	95
521	Liberty	15	68.5	23	127	2.04	90
55	Matagorda	22.5	82	25.5	157.48	1.705	90
623	Jefferson	39	84.5	50.5	157.48	2.491	80
4	Waller	28.5	81.5	32	157.48	2.041	85
23	Wharton	34	138	44.5	157.48	2.175	85
223	Colorado	25	80.5	26	170.18	1.902	75
2265	Brazoria	27	48	45	162.56	2.087	100
154	Jefferson	30.5	60	31	142.24	2.207	100
430	Wharton	23	170	28	200.66	1.936	100

Appendix A continued.

Red Rice Data 2005

Ecotype Number	County	Tillers/plant	Seed/panicle	Panicles/plant	Plant height	100 seed weight	Germination
		------#------	------#-------	--------#-------	-----cm-----	--------g---------	------%-----
414	Chambers	28.5	87.5	29.5	167.64	2.497	95
142	Jefferson	47.5	54.5	48	167.64	2.67	70
361	Fort Bend	32	56.5	32	167.64	2.549	95
30	Matagorda	28	69	25.5	162.56	2.738	100
409	Chambers	28	54	30.5	172.72	2.616	75
27-2	Fort Bend	31	49.5	30.5	160.02	2.562	95
27-1	Fort Bend	24.5	42	25	162.56	2.475	75
TX4-5	Waller	29.5	60.5	29	139.7	2.464	80
585	Liberty	24.5	73	34.5	139.7	2.261	85
2	Waller	35	74	54.5	114.3	2.068	70
311	Bowie	40.5	79	40	152.4	2.1	85

Appendix A continued.

Red Rice Data 2005							
Ecotype Number	County	Tillers/plant	Seed/panicle	Panicles/plant	Plant height	100 seed weight	Germination
		------#------	------#-------	--------#-------	-----cm-----	--------g---------	------%-----
58	Matagorda	30	89.5	30	172.72	1.959	100
296	Bowie	45	58.5	44	137.16	2.479	90
18	Colorado	32.5	61.5	32.5	162.56	2.029	75
5	Waller	28	60.5	23.5	162.56	2.161	90
813	Liberty	26.5	85.5	25.5	157.48	2.197	75
304	Bowie	30	194.5	30.5	160.02	2.547	95
2261	Brazoria	24.5	148.5	22.5	152.4	2.674	100
374	Fort Bend	26.5	106	25.5	140.97	2.17	100
390	Chambers	33	98.5	33	166.37	2.681	100
179	Colorado	32	69	29	167.64	2.426	85
166	Jefferson	30.5	59.5	29.5	156.21	2.617	90

Appendix A continued.

Ecotype Number	County	Tillers/plant	Seed/panicle	Panicles/plant	Plant height	100 seed weight	Germination
		Red Rice Data 2005					
		------#------	------#-------	--------#-------	-----cm-----	--------g---------	------%-----
971	Liberty	34.5	62	33.5	160.02	2.502	85
3	Waller	35.5	65	33	160.02	2.452	75
172	Jefferson	19.5	65	22.5	142.24	2.439	90
TX4-4	Waller	35	88	26	152.4	2.544	100
539	Liberty	40	112.5	44.5	165.1	2.197	90
600	Liberty	33.5	54	34.5	134.62	2.321	90

[a] Data not taken on germination for ecotype 28-2.

APPENDIX B

Appendix B. Red rice control with herbicides at time one in 2006 at Beaumont, TX.[abc]

	County	Group	0.5x Glufosinate		0.5x Glyphosate		0.5x Imazethapyr		0.5x Imazamox	
Ecotype			Two	Four	Two	Four	Two	Four	Two	Four
			---%							---
6	Waller	3.1	55 BCD	40 BCD	88 A-D	85 AB	58 C-F	50 D-G	53 BCD	20 ABC
815	Liberty	3.1	63 ABC	40 BCD	90 ABC	95 A	55 DEF	53 D-G	53 BCD	43 AB
28-1	Fort Bend	3.1	53 CD	40 BCD	88 A-D	98 A	58 C-F	55 C-G	60 AB	48 A
405	Chambers	3.1	53 CD	38 BCD	78 D	78 B	58 C-F	53 D-G	43 DE	18 BC
2265	Brazoria	3.1	53 CD	35 CD	90 ABC	95 A	55 DEF	55 C-G	45 CDE	18 BC
58	Matagorda	3.1	55 BCD	38 BCD	85 A-D	90 AB	63 B-E	73 ABC	53 BCD	20 ABC
297	Bowie	3.1	53 CD	38 BCD	93 AB	93 A	63 B-E	63 B-E	60 AB	28 ABC
429	Wharton	3.1	53 CD	43 BCD	80 CD	90 AB	63 B-E	75 AB	53 BCD	33 ABC
811	Liberty	3.1	60 A-D	43 BCD	90 ABC	95 A	63 B-E	50 D-G	48 CDE	28 ABC
55	Matagorda	3.1	68 ABC	58 A	93 AB	98 A	73 AB	73 ABC	70 A	43 AB
296	Bowie	3.1	58 BCD	48 AB	90 ABC	93 A	65 A-E	68 BCD	53 BCD	23 ABC

Appendix B continued.

Ecotype	County	Group	0.5x Glufosinate Two	0.5x Glufosinate Four	0.5x Glyphosate Two	0.5x Glyphosate Four	0.5x Imazethapyr Two	0.5x Imazethapyr Four	0.5x Imazamox Two	0.5x Imazamox Four
			-------------------	-------------------	-------------------	-----------%-----------	-------------------	-------------------	-------------------	-------------------
5	Waller	3.1	68 ABC	45 BC	88 A-D	93 A	63 B-E	48 EFG	50 BCD	20 ABC
56	Matagorda	3.1	63 ABC	38 BCD	88 A-D	95 A	78 A	90 A	55 BC	20 ABC
205	Colorado	3.1	75 A	45 BC	83 BCD	93 A	45 F	38 G	38 E	23 ABC
2251	Brazoria	3.1	53 CD	40 BCD	83 BCD	93 A	65 A-E	68 BCD	50 BCD	28 ABC
4	Waller	3.1	55 BCD	43 BCD	88 A-D	88 AB	70 ABC	58 B-F	45 CDE	20 ABC
23	Wharton	3.1	70 AB	40 BCD	95 A	95 A	68 A-D	65 B-E	60 AB	28 ABC
311	Bowie	3.1	55 BCD	43 BCD	90 ABC	95 A	68 A-D	68 BCD	55 BC	30 ABC
623	Jefferson	3.1	45 D	38 BCD	78 D	85 AB	53 EF	53 D-G	48 CDE	10 C
223	Colorado	3.1	55 BCD	43 BCD	88 A-D	90 AB	60 B-E	55C-G	48 CDE	18 BC
18	Colorado	3.1	55 BCD	35 CD	88 A-D	85 AB	55 DEF	53 D-G	53 BCD	58 ABC
813	Liberty	3.1	55 BCD	35 CD	85 A-D	88 AB	58 C-F	55 C-G	48 CDE	25 ABC

Appendix B continued.

Ecotype	County	Group	0.5x Glufosinate		0.5x Glyphosate		0.5x Imazethapyr		0.5x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			---%							---
28-2	Fort Bend	3.1	45 D	33 D	88 A-D	93 A	55 DEF	43 FG	48 CDE	15 BC

Appendix B continued.

Ecotype	County	Group	0.5x Glufosinate		0.5x Glyphosate		0.5x Imazethapyr		0.5x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			--------------------	--------------------	--------------------	--------------------	%	--------------------	--------------------	--------------------
348	Fort Bend	3.2	43 BCD	33 ABC	70 DE	75 BC	48 D	48 B	53 A	28 A
136	Jefferson	3.2	45 A-D	33 ABC	73 CDE	70 C	53 BCD	53 B	43 BC	18 A
161	Jefferson	3.2	45 A-D	33 ABC	78 A-E	78 ABC	50 CD	53 B	43 BC	20 A
728	Liberty	3.2	58 AB	38 A	75 B-E	73 BC	53 BCD	48 B	43 BC	18 A
30	Matagorda	3.2	43 BCD	28 C	73 CDE	80 ABC	60 AB	50 B	50 AB	23 A
390	Chambers	3.2	53 A	38 A	73 CDE	95 A	53 BCD	50 B	45 ABC	20 A
414	Chambers	3.2	40 CD	33 ABC	75 B-E	85 ABC	55 A-D	48 B	43 BC	20 A
361	Fort Bend	3.2	38 D	33 ABC	78 A-E	85 ABC	58 ABC	48 B	50 AB	20 A
27	Fort Bend	3.2	40 CD	30 BC	75 B-E	85 ABC	58 ABC	43 B	45 ABC	20 A
384	Chambers	3.2	45 A-D	35 AB	78 A-E	80 ABC	53 BCD	43 B	40 C	10 A
25-1	Matagorda	3.2	45 A-D	35 AB	83 ABC	90 AB	55 A-D	73 A	48 ABC	18 A

Appendix B continued.

Ecotype	County	Group	0.5x Glufosinate Two	0.5x Glufosinate Four	0.5x Glyphosate Two	0.5x Glyphosate Four	0.5x Imazethapyr Two	0.5x Imazethapyr Four	0.5x Imazamox Two	0.5x Imazamox Four
			%							
493	Liberty	3.2	43 BCD	30 BC	75 B-E	80 ABC	50 CD	50 B	43 BC	8 A
183	Colorado	3.2	45 A-D	38 A	83 ABC	80 ABC	55 A-D	60 AB	45 ABC	25 A
140	Jefferson	3.2	40 CD	35 AB	68 E	85 ABC	50 CD	48 B	48 ABC	18 A
11	Fort Bend	3.2	40 CD	35 A	73 CDE	88 ABC	53 BCD	50 B	45 ABC	8 A
428	Chambers	3.2	43 BCD	33 ABC	75 B-E	80 ABC	63 A	53 B	50 AB	20 A
425	Chambers	3.2	43 BCD	30 BC	73 CDE	80 ABC	55 A-D	48 B	48 ABC	20 A
166	Jefferson	3.2	43 BCD	35 AB	75 B-E	80 ABC	55 A-D	48 B	48 ABC	18 A
172	Jefferson	3.2	45 A-D	33 ABC	80 A-D	85 ABC	58 ABC	50 B	45 ABC	10 A
971	Liberty	3.2	45 A-D	35 AB	80 A-D	80 ABC	53 BCD	50 B	43 BC	18 A
179	Colorado	3.2	43 BCD	35 AB	85 AB	78 ABC	53 BCD	48 B	50 AB	20 A
25-2	Matagorda	3.2	48 ABC	33 ABC	85 AB	85 ABC	58 ABC	73 A	53 A	20 A

Appendix B continued.

Ecotype	County	Group	0.5x Glufosinate Two	0.5x Glufosinate Four	0.5x Glyphosate Two	0.5x Glyphosate Four	0.5x Imazethapyr Two	0.5x Imazethapyr Four	0.5x Imazamox Two	0.5x Imazamox Four
			-----------	-----------	-----------	-----------	%	-----------	-----------	-----------
409	Chambers	3.2	43 BCD	33 ABC	73 CDE	75 BC	53 BCD	43 B	43 BC	18 A
27-1	Fort Bend	3.2	43 BCD	33 ABC	88 A	80 ABC	53 BCD	43 B	48 ABC	18 A
3	Waller	3.2	43 BCD	30 BC	83 ABC	80 ABC	50 CD	43 B	45 ABC	25 A
356	Fort Bend	3.2	40 CD	30 BC	83 ABC	78 ABC	48 D	43 B	40 C	8 A
142	Jefferson	3.2	40 CD	30 BC	75 B-E	75 BC	58 ABC	45 B	48 ABC	25 A

Appendix B continued.

Ecotype	County	Group	0.5x Glufosinate		0.5x Glyphosate		0.5x Imazethapyr		0.5x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			---%							
2254	Brazoria	Int	58 A	43 A	75 B	93 A	70 A	85 A	63 A	55 A
325	Bowie	Int	45 AB	35 BC	73 B	95 A	55 C	43 BC	43 C	8 C
539	Liberty	Int	40 B	35 BC	70 B	78 B	63 B	53 B	43 C	8 C
600	Liberty	Int	43 B	35 BC	70 B	75 B	63 B	58 B	43 C	10 C
596	Liberty	Int	48 AB	33 C	73 B	78 B	53 C	30 C	43 C	10 C
521	Liberty	Int	58 A	40 AB	75 B	70 B	58 BC	43 BC	43 C	10 C
585	Liberty	Int	58 A	43 A	90 A	93 A	55 C	50 BC	48 BC	25 BC
2	Waller	Int	53 AB	38 ABC	95 A	95 A	63 B	53 B	50 B	33 B

Appendix B continued.

Ecotype	County	Group	0.5x Glufosinate Two	0.5x Glufosinate Four	0.5x Glyphosate Two	0.5x Glyphosate Four	0.5x Imazethapyr Two	0.5x Imazethapyr Four	0.5x Imazamox Two	0.5x Imazamox Four
			----------	----------	----------	----------	%	----------	----------	----------
24	Wharton	Straw	63 AB	40 A	83 AB	95 A	58 B	75 A	60 A	45 AB
1249	Liberty	Straw	45 C	35 A	73 B	73 B	55 BC	50 A	55 ABC	50 A
154	Jefferson	Straw	60 ABC	40 A	83 AB	90 A	63 AB	60 A	58 AB	35 ABC
430	Wharton	Straw	58 ABC	35 A	80 AB	90 A	70 A	73 A	53 ABC	18 C
2261	Brazoria	Straw	60 ABC	33 A	85 A	95 A	65 AB	53 A	50 ABC	10 C
374	Fort Bend	Straw	73 A	35 A	83 AB	95 A	65 AB	65 A	53 ABC	18 C
304	Bowie	Straw	60 ABC	35 A	85 A	93 A	45 C	50 A	48 BC	20 BC
279	Bowie	Straw	53 BC	38 A	85 A	90 A	60 AB	60 A	50 ABC	28 ABC
471	Wharton	Straw	63 AB	38 A	83 A	98 A	65 AB	60 A	45 C	18 C
1309	Liberty	Straw	48 BC	38 A	88 A	93 A	63 AB	53 A	45 C	18 C

Appendix B continued.

Ecotype	County	Group	0.5x Glufosinate		0.5x Glyphosate		0.5x Imazethapyr		0.5x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			---%---							
tx4-4	Waller	TX4	40 A	30 C	73 A	80 A	50 B	48 A	45 A	20 A
tx4-3	Waller	TX4	40 A	30 C	83 A	88 A	50 B	48 A	48 A	18 A
tx4-2	Waller	TX4	48 A	40 A	78 A	78 A	68 A	53 A	50 A	23 A
tx4-5	Waller	TX4	48 A	35 B	80 A	78 A	60 B	50 A	45 A	15 A

Appendix B continued.

Ecotype	County	Group	1x Glufosinate Two	1x Glufosinate Four	1x Glyphosate Two	1x Glyphosate Four	1x Imazethapyr Two	1x Imazethapyr Four	1x Imazamox Two	1x Imazamox Four
			----------	----------	----------	----------	%	----------	----------	----------
6	Waller	3.1	90 ABC	60 A-E	100 A	100 A	83 AB	93 A-D	68 ABC	88 A
815	Liberty	3.1	78 C-G	50 CDE	100 A	100 A	63 EF	78 D-I	55 BC	63 BCD
28-1	Fort Bend	3.1	63 HI	40 DE	100 A	100 A	65 DEF	75 E-I	70 AB	70 A-D
405	Chambers	3.1	88 A-D	58 B-E	100 A	100 A	65 DEF	80 C-I	68 ABC	80 ABC
2265	Brazoria	3.1	73 E-I	45 CDE	98 A	100 A	70 B-F	83 B-H	68 ABC	78 A-D
58	Matagorda	3.1	80 B-F	48 CDE	100 A	100 A	63 EF	85 A-G	65 ABC	78 A-D
297	Bowie	3.1	80 B-F	48 CDE	98 A	100 A	68 C-F	85 A-G	63 ABC	78 A-D
429	Wharton	3.1	65 GHI	38 E	100 A	100 A	78 A-D	98 AB	68 ABC	78 A-D
811	Liberty	3.1	80 B-F	50 CDE	100 A	100 A	63 EF	65 I	73 A	73 A-D
55	Matagorda	3.1	95 A	83 AB	100 A	100 A	80 ABC	100 A	78 A	88 A
296	Bowie	3.1	75 D-H	48 CDE	100 A	100 A	75 A-E	95 ABC	65 ABC	85 AB

Appendix B continued.

Ecotype	County	Group	1x Glufosinate Two	1x Glufosinate Four	1x Glyphosate Two	1x Glyphosate Four	1x Imazethapyr Two	1x Imazethapyr Four	1x Imazamox Two	1x Imazamox Four
			-----%							-----%
5	Waller	3.1	80 B-F	55 CDE	98 A	100 A	65 DEF	88 A-F	68 ABC	73 A-D
56	Matagorda	3.1	93 AB	85 A	98 A	100 A	85 A	88 A-F	78 A	80 ABC
205	Colorado	3.1	88 A-D	68 ABC	100 A	100 A	40 G	35 J	55 BC	38 E
2251	Brazoria	3.1	73 E-I	45 CDE	100 A	100 A	60 F	90 A-E	63 ABC	85 AB
4	Waller	3.1	88 A-D	68 ABC	100 A	100 A	78 A-D	83 B-H	63 ABC	55 DE
23	Wharton	3.1	85 A-E	48 CDE	100 A	100 A	75 A-E	85 A-G	63 ABC	68 A-D
311	Bowie	3.1	70 F-I	45 CDE	100 A	98 B	70 B-F	88 A-F	73 A	83 AB
623	Jefferson	3.1	68 F-I	40 DE	100 A	98 B	60 F	70 GHI	63 ABC	58 CDE
223	Colorado	3.1	90 ABC	65 A-D	100 A	100 A	65 DEF	78 D-I	63 ABC	55 DE
18	Colorado	3.1	78 C-G	58 B-E	100 A	100 A	65 DEF	85 A-G	55 BC	75 A-D
813	Liberty	3.1	85 A-E	68 ABC	100 A	100 A	63 EF	73 F-I	53 C	58 CDE

Appendix B continued.

	County	Group	1x Glufosinate		1x Glyphosate		1x Imazethapyr		1x Imazamox	
Ecotype			Two	Four	Two	Four	Two	Four	Two	Four
			---%---							
28-2	Fort Bend	3.1	60 I	40 DE	100 A	100 A	60 F	68 HI	55 BC	58 CDE

Appendix B continued.

Ecotype	County	Group	1x Glufosinate Two	1x Glufosinate Four	1x Glyphosate Two	1x Glyphosate Four	1x Imazethapyr Two	1x Imazethapyr Four	1x Imazamox Two	1x Imazamox Four
			--------	--------	--------	--------	%	--------	--------	--------
348	Fort Bend	3.2	60 AB	40 AB	98 AB	100 A	60 BCD	73 BCD	58 ABC	70 ABC
136	Jefferson	3.2	63 AB	48 AB	95 AB	100 A	63 BCD	78 BCD	60 ABC	68 ABC
161	Jefferson	3.2	58 AB	35 AB	93 B	98 AB	58 CD	65 D	63 ABC	65 ABC
728	Liberty	3.2	60 AB	38 AB	98 AB	100 A	63 BCD	70 CD	63 ABC	65 ABC
30	Matagorda	3.2	68 AB	35 AB	95 AB	100 A	58 CD	65 D	68 A	73 ABC
390	Chambers	3.2	68 AB	35 AB	98 AB	100 A	78 A	93 A	58 ABC	60 BC
414	Chambers	3.2	60 AB	53 A	95 AB	100 A	55 D	75 BCD	65 AB	58 C
361	Fort Bend	3.2	60 AB	35 AB	95 AB	95 B	58 CD	70 CD	65 AB	73 ABC
27-2	Fort Bend	3.2	55 B	35 AB	98 AB	100 A	60 BCD	73 BCD	55 BC	65 ABC
384	Chambers	3.2	63 AB	38 AB	98 AB	100 A	60 BCD	85 AB	58 ABC	73 ABC
25-1	Matagorda	3.2	63 AB	38 AB	98 AB	100 A	60 BCD	85 AB	58 ABC	80 AB

Appendix B continued.

Ecotype	County	Group	1x Glufosinate		1x Glyphosate		1x Imazethapyr		1x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			%							
493	Liberty	3.2	58 AB	35 AB	95 AB	100 A	58 CD	73 BCD	60 ABC	73 ABC
183	Colorado	3.2	63 AB	50 AB	100 A	100 A	63 BCD	73 BCD	68 A	60 BC
140	Jefferson	3.2	60 AB	35 AB	95 AB	98 AB	60 BCD	75 BCD	68 A	53 C
11	Fort Bend	3.2	58 AB	33 B	98 AB	100 A	58 CD	68 D	68 A	55 C
428	Chambers	3.2	55 B	38 AB	95 AB	100 A	60 BCD	70 CD	63 ABC	85 A
425	Chambers	3.2	60 AB	38 AB	98 AB	100 A	58 CD	65 D	60 ABC	63 BC
166	Jefferson	3.2	65 AB	38 AB	98 AB	100 A	58 CD	83 ABC	58 ABC	68 ABC
172	Jefferson	3.2	65 AB	40 AB	100 A	100 A	65 BC	73 BCD	58 ABC	73 ABC
971	Liberty	3.2	68 AB	40 AB	100 A	100 A	60 BCD	75 BCD	53 C	65 ABC
179	Colorado	3.2	55 B	35 AB	100 A	100 A	60 BCD	65 D	58 ABC	73 ABC
25-2	Matagorda	3.2	73 A	53 A	98 AB	100 A	65 BC	95 A	55 BC	70 ABC

Appendix B continued.

Ecotype	County	Group	1x Glufosinate Two	1x Glufosinate Four	1x Glyphosate Two	1x Glyphosate Four	1x Imazethapyr Two	1x Imazethapyr Four	1x Imazamox Two	1x Imazamox Four
			--------------	--------------	--------------	--------------	%	--------------	--------------	--------------
409	Chambers	3.2	58 AB	38 AB	100 A	95 B	60 BCD	70 CD	55 BC	63 BC
27-1	Fort Bend	3.2	63 AB	45 AB	100 A	100 A	58 CD	73 BCD	55 BC	70 ABC
3	Waller	3.2	60 AB	40 AB	98 AB	100 A	68 B	78 BCD	55 BC	63 BC
356	Fort Bend	3.2	63 AB	38 AB	93 B	100 A	63 BCD	68 D	53 C	60 BC
142	Jefferson	3.2	63 AB	38 AB	95 AB	98 AB	63 BCD	68 D	58 ABC	68 ABC

Appendix B continued.

Ecotype	County	Group	1x Glufosinate		1x Glyphosate		1x Imazethapyr		1x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			--%--							
2254	Brazoria	Int	80 A	60 A	98 AB	100 A	75 A	90 AB	83 A	100 A
325	Bowie	Int	73 A	40 B	98 AB	100 A	70 AB	70 BC	70 AB	55 BC
539	Liberty	Int	73 A	48 AB	100 A	100 A	70 AB	63 C	60 B	43 BC
600	Liberty	Int	70 A	45 AB	93 B	100 A	58 C	73 BC	58 B	35 C
596	Liberty	Int	70 A	38 B	100 A	100 A	58 C	53 C	60 B	38 C
521	Liberty	Int	63 A	40 B	98 AB	100 A	60 BC	58 C	55 B	48 BC
585	Liberty	Int	80 A	43 AB	98 AB	100 A	65 ABC	65 C	70 AB	60 BC
2	Waller	Int	73 A	55 AB	100 A	100 A	73 A	98 A	60 B	68 B

Appendix B continued.

Ecotype	County	Group	1x Glufosinate Two	Four	1x Glyphosate Two	Four	1x Imazethapyr Two	Four	1x Imazamox Two	Four
			-----	-----	-----	-----	%	-----	-----	-----
24	Wharton	Straw	73 BC	50 BC	100 A	100 A	68 BC	95 A	73 A	95 A
1249	Liberty	Straw	68 C	48 BC	98 A	100 A	70 ABC	88 AB	58 A	73 AB
154	Jefferson	Straw	80 ABC	65 B	100 A	100 A	73 ABC	88 AB	73 A	70 AB
430	Wharton	Straw	80 ABC	43 C	100 A	100 A	65 C	73 BC	65 A	65 B
2261	Brazoria	Straw	80 ABC	65 B	100 A	100 A	78 A	83 AB	65 A	73 AB
374	Fort Bend	Straw	93 A	95 A	100 A	100 A	75 AB	80 ABC	70 A	70 AB
304	Bowie	Straw	80 ABC	55 BC	100 A	98 B	65 C	73 BC	58 A	58 B
279	Bowie	Straw	83 AB	55 BC	98 A	100 A	65 C	70 BC	73 A	78 AB
471	Wharton	Straw	83 AB	53 BC	100 A	100 A	70 ABC	63 C	70 A	55 B
1309	Liberty	Straw	80 ABC	45 C	98 A	100 A	70 ABC	78 ABC	63 A	63 B

Appendix B continued.

Ecotype	County	Group	1x Glufosinate		1x Glyphosate		1x Imazethapyr		1x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			-----------------------------%	-----------------------------						
tx4-4	Waller	TX4	58 A	38 A	98 A	100 A	65 A	75 A	65 A	60 A
tx4-3	Waller	TX4	53 A	33 A	95 A	98 A	60 A	68 A	55 A	70 A
tx4-2	Waller	TX4	60 A	40 A	100 A	100 A	68 A	83 A	65 A	68 A
tx4-5	Waller	TX4	58 A	35 A	98 A	100 A	60 A	63 A	63 A	55 A

Appendix B continued.

Ecotype	County	Group	2x Glufosinate		2x Glyphosate		2x Imazethapyr		2x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			---%							
6	Waller	3.1	98 AB	85 A-E	100 A	100 A	78 A-D	100 A	75 AB	95 AB
815	Liberty	3.1	95 ABC	83 A-E	100 A	100 A	70 CDE	100 A	70 AB	95 AB
28-1	Fort Bend	3.1	85 D	65 E	100 A	100 A	68 CDE	98 A	75 AB	95 AB
405	Chambers	3.1	95 ABC	90 A-D	100 A	98 B	70 CDE	98 A	75 AB	93 AB
2265	Brazoria	3.1	95 ABC	88 A-D	100 A	100 A	63 E	100 A	78 AB	93 AB
58	Matagorda	3.1	98 AB	98 AB	100 A	100 A	78 A-D	100 A	75 AB	93 AB
297	Bowie	3.1	100 A	100 A	100 A	100 A	88 A	100 A	78 AB	93 AB
429	Wharton	3.1	93 A-D	75 CDE	100 A	100 A	73 B-E	100 A	75 AB	95 AB
811	Liberty	3.1	95 ABC	95 ABC	100 A	100 A	78 A-D	95 A	68 AB	90 AB
55	Matagorda	3.1	98 AB	100 A	100 A	100 A	80 ABC	100 A	83 A	95 AB
296	Bowie	3.1	85 D	80 A-E	100 A	100 A	78 A-D	98 A	65 AB	95 AB

Appendix B continued.

Ecotype	County	Group	2x Glufosinate Two	2x Glufosinate Four	2x Glyphosate Two	2x Glyphosate Four	2x Imazethapyr Two	2x Imazethapyr Four	2x Imazamox Two	2x Imazamox Four
			%							
5	Waller	3.1	100 A	100 A	100 A	100 A	85 AB	100 A	68 AB	95 AB
56	Matagorda	3.1	88 CD	78 B-E	100 A	100 A	80 ABC	95 A	68 AB	93 AB
205	Colorado	3.1	98 AB	100 A	100 A	100 A	40 F	25 B	38 C	23 D
2251	Brazoria	3.1	95 ABC	100 A	100 A	100 A	73 B-E	100 A	70 AB	98 A
4	Waller	3.1	93 A-D	88 A-D	100 A	100 A	75 A-E	100 A	70 AB	85 AB
23	Wharton	3.1	95 ABC	90 A-D	100 A	100 A	75 A-E	98 A	70 AB	95 AB
311	Bowie	3.1	90 BCD	85 A-E	100 A	100 A	73 B-E	100 A	75 AB	98 A
623	Jefferson	3.1	88 CD	73 DE	100 A	100 A	70 CDE	100 A	65 AB	85 AB
223	Colorado	3.1	100 A	98 AB	100 A	100 A	68 CDE	100 A	65 AB	83 B
18	Colorado	3.1	93 A-D	93 A-D	100 A	100 A	68 CDE	100 A	73 AB	95 AB
813	Liberty	3.1	98 AB	98 AB	100 A	100 A	73 B-E	98 A	68 AB	68 C

Appendix B continued.

Ecotype	County	Group	2x Glufosinate		2x Glyphosate		2x Imazethapyr		2x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			-----------%							-----------
28-2	Fort Bend	3.1	88 CD	65 E	98 B	100 A	65 DE	100 A	63 B	85 AB

Appendix B continued.

Ecotype	County	Group	2x Glufosinate Two	2x Glufosinate Four	2x Glyphosate Two	2x Glyphosate Four	2x Imazethapyr Two	2x Imazethapyr Four	2x Imazamox Two	2x Imazamox Four
			------	------	------	------	------%	------	------	------
348	Fort Bend	3.2	78 B-E	63 A-D	100 A	100 A	60 C	93 AB	63 BC	90 AB
136	Jefferson	3.2	78 B-E	65 A-D	100 A	100 A	65 ABC	98 AB	60 BC	85 AB
161	Jefferson	3.2	80 A-E	63 A-D	100 A	100 A	60 C	95 AB	60 BC	83 B
728	Liberty	3.2	88 ABC	70 A-D	100 A	100 A	63 BC	98 AB	70 AB	93 AB
30	Matagorda	3.2	70 E	50 D	100 A	100 A	63 BC	98 AB	68 ABC	88 AB
390	Chambers	3.2	83 A-E	65 A-D	98 A	98 B	70 ABC	93 AB	68 ABC	88 AB
414	Chambers	3.2	80 A-E	70 A-D	100 A	100 A	68 ABC	98 AB	78 A	85 AB
361	Fort Bend	3.2	90 AB	68 A-D	98 A	100 A	70 ABC	93 AB	68 ABC	90 AB
27-2	Fort Bend	3.2	80 A-E	70 A-D	100 A	100 A	70 ABC	93 AB	65 BC	88 AB
384	Chambers	3.2	78 B-E	65 A-D	100 A	100 A	65 ABC	93 AB	63 BC	90 AB
25-1	Matagorda	3.2	85 A-D	68 A-D	100 A	100 A	68 ABC	100 A	70 AB	93 AB

Appendix B continued.

Ecotype	County	Group	2x Glufosinate		2x Glyphosate		2x Imazethapyr		2x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			----------	----------	----------	----------	%----------	----------	----------	----------
493	Liberty	3.2	85 A-D	80 AB	100 A	100 A	68 ABC	100 A	68 ABC	93 AB
183	Colorado	3.2	93 A	85 A	100 A	100 A	63 BC	95 AB	60 BC	83 B
140	Jefferson	3.2	88 ABC	75 ABC	100 A	100 A	63 BC	90 B	60 BC	83 B
11	Fort Bend	3.2	80 A-E	58 BCD	98 A	100 A	68 ABC	95 AB	58 C	83 B
428	Chambers	3.2	73 DE	48 D	100 A	100 A	73 AB	100 A	65 BC	88 AB
425	Chambers	3.2	75 CDE	55 CD	100 A	100 A	68 ABC	100 A	63 BC	85 AB
166	Jefferson	3.2	85 A-D	68 A-D	100 A	100 A	68 ABC	98 AB	63 BC	90 AB
172	Jefferson	3.2	83 A-E	75 ABC	100 A	100 A	75 A	98 AB	63 BC	90 AB
971	Liberty	3.2	83 A-E	60 BCD	100 A	100 A	70 ABC	98 AB	60 BC	85 AB
179	Colorado	3.2	75 CDE	60 BCD	100 A	100 A	70 ABC	95 AB	68 ABC	85 AB
25-2	Matagorda	3.2	88 ABC	70 A-D	100 A	100 A	65 ABC	100 A	65 BC	95 A

Appendix B continued.

Ecotype	County	Group	2x Glufosinate		2x Glyphosate		2x Imazethapyr		2x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			---%---							
409	Chambers	3.2	78 B-E	60 BCD	98 A	98 B	73 AB	95 AB	65 BC	88 AB
27-1	Fort Bend	3.2	70 E	50 D	100 A	100 A	73 AB	98 AB	65 BC	83 B
3	Waller	3.2	83 A-E	60 BCD	98 A	100 A	60 C	95 AB	65 BC	88 AB
356	Fort Bend	3.2	85 A-D	55 CD	100 A	100 A	60 C	98 AB	65 BC	88 AB
142	Jefferson	3.2	85 A-D	58 BCD	98 A	98 B	68 ABC	100 A	65 BC	83 B

Appendix B continued.

Ecotype	County	Group	2x Glufosinate Two	2x Glufosinate Four	2x Glyphosate Two	2x Glyphosate Four	2x Imazethapyr Two	2x Imazethapyr Four	2x Imazamox Two	2x Imazamox Four
			--------	--------	--------	--------	%	--------	--------	--------
2254	Brazoria	Int	93 A	85 A	100 A	100 A	83 A	100 A	80 A	100 A
325	Bowie	Int	98 A	95 A	100 A	100 A	73 BC	95 AB	60 BC	65 BC
539	Liberty	Int	98 A	93 A	100 A	100 A	68 C	90 AB	58 C	65 BC
600	Liberty	Int	95 A	93 A	100 A	100 A	73 BC	88 BC	55 C	65 BC
596	Liberty	Int	95 A	90 A	100 A	100 A	65 C	78 C	58 C	55 C
521	Liberty	Int	90 A	80 A	100 A	100 A	65 C	85 BC	65 BC	68 BC
585	Liberty	Int	93 A	80 A	100 A	100 A	68 C	95 AB	65 BC	83 AB
2	Waller	Int	95 A	88 A	98 A	100 A	78 AB	100 A	70 AB	90 A

Appendix B continued.

Ecotype	County	Group	2x Glufosinate Two	2x Glufosinate Four	2x Glyphosate Two	2x Glyphosate Four	2x Imazethapyr Two	2x Imazethapyr Four	2x Imazamox Two	2x Imazamox Four
			%							
24	Wharton	Straw	93 B	93 A	100 A	100 A	78 AB	100 A	73 A	100 A
1249	Liberty	Straw	85 C	70 B	98 A	100 A	73 AB	100 A	75 A	93 AB
154	Jefferson	Straw	93 B	98 A	100 A	98 B	70 AB	98 A	75 A	90 AB
430	Wharton	Straw	93 B	88 A	100 A	100 A	65 B	98 A	68 A	83 BC
2261	Brazoria	Straw	98 AB	93 A	100 A	100 A	73 AB	95 A	70 A	88 AB
374	Fort Bend	Straw	98 AB	93 A	100 A	100 A	80 A	100 A	75 A	93 AB
304	Bowie	Straw	100 A	100 A	98 A	100 A	68 AB	100 A	75 A	93 AB
279	Bowie	Straw	95 AB	90 A	100 A	100 A	70 AB	98 A	73 A	88 AB
471	Wharton	Straw	95 AB	95 A	100 A	100 A	73 AB	90 A	65 A	68 C
1309	Liberty	Straw	100 A	100 A	100 A	100 A	78 AB	100 A	75 A	95 AB

Appendix B continued.

Ecotype	County	Group	2x Glufosinate		2x Glyphosate		2x Imazethapyr		2x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			--------------------------------------%--------------------------------------							
tx4-4	Waller	TX4	88 A	70 A	100 A	98 A	65 A	95 A	63 A	88 A
tx4-3	Waller	TX4	73 B	58 A	100 A	100 A	63 A	95 A	68 A	85 A
tx4-2	Waller	TX4	90 A	60 A	100 A	100 A	70 A	100 A	73 A	93 A
tx4-5	Waller	TX4	75 B	60 A	100 A	100 A	68 A	93 A	63 A	85 A

[a] Group 3.1 = red rice ecotypes genetically similar to *Oryza rufipogon*, 3.2 = red rice ecotypes genetically similar to TX4, Intermediate = red rice ecotypes genetically similar to *Oryza rufipogon* and TX4, Strawhulled = red rice ecotypes genetically similar to *Oryza sativa* ssp. *indica*, and TX4 = red rice ecotypes known to be TX4, two = two weeks after the second application, four = four weeks after the second application.

[b] Glufosinate 0.5x = 0.2 kg ai/ha, 1x = 0.4 kg/ha, 2x = 0.8 kg/ha; glyphosate 0.5x = 0.4 kg/ha, 1x = 0.8 kg/ha, 2x = 1.7 kg/ha; imazethapyr 0.5x = 0.04 kg/ha, 1x = 0.07 kg/ha, 2x = 0.14 kg/ha; and imazamox 0.5x = 0.02 kg/ha, 1x = 0.04 kg/ha, 2x = 0.07 kg/ha, first treatment applied to 3- to 4- leaf red rice, second treatment applied to 6- to 8- leaf red rice.

[c] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.05.

APPENDIX C

Appendix C. Red rice control with herbicides at site two in 2006 at Beaumont, TX.[abc]

Ecotype	County	Group	0.5x Glufosinate Two	0.5x Glufosinate Four	0.5x Glyphosate Two	0.5x Glyphosate Four	0.5x Imazethapyr Two	0.5x Imazethapyr Four	0.5x Imazamox Two	0.5x Imazamox Four
			--------------------	--------------------	--------------------	--------%	--------------------	--------------------	--------------------	--------------------
6	Waller	3.1	58 B-F	53 B-E	100 A	100 A	70 AB	73 ABC	60 A-E	53 C-G
815	Liberty	3.1	45 DEF	43 CDE	100 A	100 A	63 A-E	60 ABC	60 A-E	73 A-D
28-1	Fort Bend	3.1	53 B-F	48 B-E	100 A	100 A	63 A-E	83 A	58 B-F	68 A-F
405	Chambers	3.1	53 B-F	43 CDE	100 A	100 A	73 A	78 AB	63 A-E	58 B-G
2265	Brazoria	3.1	55 B-F	53 B-E	100 A	100 A	58 A-E	55 BC	60 A-E	60 A-G
58	Matagorda	3.1	48 C-F	48 B-E	100 A	98 B	58 A-E	50CD	68 A-D	70 A-E
297	Bowie	3.1	43 EF	53 B-E	100 A	100 A	65 A-D	63 ABC	65 A-D	58 B-G
2429	Wharton	3.1	48 C-F	53 B-E	100 A	100 A	68 ABC	63 ABC	68 A-D	78 ABC
811	Liberty	3.1	48 C-F	43 CDE	100 A	100 A	60 A-E	65 ABC	80 A	88 A
55	Matagorda	3.1	85 A	80 A	100 A	100 A	73 A	65 ABC	78 AB	68 A-F
296	Bowie	3.1	55 B-F	55 A-E	100 AB	100 A	65 A-D	73 ABC	75 ABC	68 A-F

Appendix C continued.

Ecotype	County	Group	0.5x Glufosinate Two	0.5x Glufosinate Four	0.5x Glyphosate Two	0.5x Glyphosate Four	0.5x Imazethapyr Two	0.5x Imazethapyr Four	0.5x Imazamox Two	0.5x Imazamox Four
			------	------	------	------	%------	------	------	------
5	Waller	3.1	68 ABC	60 A-E	98 AB	98 B	53 CDE	58 BC	48 DEF	45 D-G
56	Matagorda	3.1	73 AB	73 AB	100 A	100 A	63 A-E	70 ABC	65 A-D	85 AB
205	Colorado	3.1	65 A-D	67 ABC	100 A	100 A	33 F	30 D	38 F	35 G
2251	Brazoria	3.1	38 F	40 DE	100 A	100 A	50 DE	55 BC	55 C-F	40 FG
4	Waller	3.1	55 B-F	68 ABC	100 A	100 A	60 A-E	63 ABC	65 A-D	58 B-G
23	Wharton	3.1	65 A-D	65 A-D	98 AB	100 A	63 A-E	68 ABC	60 A-E	55 C-G
311	Bowie	3.1	43 EF	40 DE	98 AB	100 A	63 A-E	63 ABC	48 DEF	50 C-G
623	Jefferson	3.1	40 EF	40 DE	95 B	100 A	58 A-E	55 BC	43 EF	40 FG
223	Colorado	3.1	55 B-F	38 E	98 AB	100 A	53 CDE	53 CD	50 DEF	43 EFG
18	Colorado	3.1	60 B-E	50 B-E	100 A	100 A	48 EF	70 ABC	48 DEF	43 EFG
813	Liberty	3.1	58 B-F	53 B-E	95 B	100 A	48 EF	53 CD	50 DEF	43 EFG

Appendix C continued.

Ecotype	County	Group	0.5x Glufosinate		0.5x Glyphosate		0.5x Imazethapyr		0.5x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			---%--							
28-2	Fort Bend	3.1	50 C-F	50 B-E	100 A	100 A	55 B-E	60 ABC	55 C-F	53 C-G

Appendix C continued.

Ecotype	County	Group	0.5x Glufosinate		0.5x Glyphosate		0.5x Imazethapyr		0.5x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			----------------------	--------------------	--------------------	---------%	--------------------	--------------------	--------------------	--------------------
348	Fort Bend	3.2	50 A-E	45 ABC	100 A	100 A	63 AB	60 BCD	55 ABC	50 AB
136	Jefferson	3.2	55 A-D	60 AB	95 AB	100 A	60 AB	63 A-D	53 ABC	65 AB
161	Jefferson	3.2	50 A-E	48 ABC	98 AB	100 A	55 AB	53 BCD	50 ABC	48 AB
728	Liberty	3.2	38 DE	43 ABC	100 A	100 A	55 AB	68 AB	70 A	73 A
30	Matagorda	3.2	38 DE	38 ABC	93 AB	93 B	65 A	63 A-D	53 ABC	58 AB
390	Chambers	3.2	60 AB	60 AB	95 AB	98 AB	48 AB	48 BCD	55 ABC	60 AB
414	Chambers	3.2	38 DE	35 BC	100 A	100 A	58 AB	65 ABC	40 C	43 AB
361	Fort Bend	3.2	35 E	35 BC	95 AB	100 A	53 AB	60 BCD	43 C	58 AB
27-2	Fort Bend	3.2	43 B-E	48 ABC	90 B	95 AB	60 AB	55 BCD	43 C	43 AB
384	Chambers	3.2	58 ABC	63 A	95 AB	98 AB	55 AB	58 BCD	45 C	55 AB
25-1	Matagorda	3.2	53 A-E	55 ABC	95 AB	98 AB	63 AB	83 A	45 C	40 B

Appendix C continued.

Ecotype	County	Group	0.5x Glufosinate Two	0.5x Glufosinate Four	0.5x Glyphosate Two	0.5x Glyphosate Four	0.5x Imazethapyr Two	0.5x Imazethapyr Four	0.5x Imazamox Two	0.5x Imazamox Four
			---	---	---	---	%	---	---	---
493	Liberty	3.2	40 CDE	40 ABC	95 AB	95 AB	50 AB	55 BCD	50 ABC	38 B
183	Colorado	3.2	65 A	60 AB	93 AB	98 AB	55 AB	58 BCD	68 AB	65 AB
140	Jefferson	3.2	50 A-E	58 ABC	93 AB	98 AB	60 AB	53 BCD	45 C	45 AB
11	Fort Bend	3.2	38 DE	50 ABC	98 AB	98 AB	55 AB	50 BCD	45 C	45 AB
428	Chambers	3.2	35 E	33 C	95 AB	98 AB	58 AB	63 A-D	45 C	58 AB
425	Chambers	3.2	43 B-E	43 ABC	98 AB	100 A	50 AB	68 AB	50 ABC	55 AB
166	Jefferson	3.2	38 DE	33 C	93 AB	95 AB	50 AB	43 D	45 C	40 B
172	Jefferson	3.2	48 A-E	50 ABC	100 A	100 A	45 AB	48 BCD	53 ABC	43 AB
971	Liberty	3.2	53 A-E	50 ABC	95 AB	98 AB	48 AB	45 CD	43 C	38 B
179	Colorado	3.2	38 DE	35 BC	98 AB	98 AB	45 AB	43 D	43 C	35 B
25-2	Matagorda	3.2	53 A-E	50 ABC	98 AB	100 A	55 AB	55 BCD	50 ABC	53 AB

Appendix C continued.

Ecotype	County	Group	0.5x Glufosinate Two	0.5x Glufosinate Four	0.5x Glyphosate Two	0.5x Glyphosate Four	0.5x Imazethapyr Two	0.5x Imazethapyr Four	0.5x Imazamox Two	0.5x Imazamox Four
			-------------------	-------------------	-------------------	-------------------	%	-------------------	-------------------	-------------------
409	Chambers	3.2	40 CDE	38 ABC	95 AB	100 A	43 B	50 BCD	50 ABC	40 B
27-1	Fort Bend	3.2	40 CDE	35 BC	95 AB	98 AB	45 AB	50 BCD	60 ABC	53 AB
3	Waller	3.2	50 A-E	50 ABC	98 AB	100 A	53 AB	53 BCD	48 BC	55 AB
356	Fort Bend	3.2	48 A-E	40 ABC	95 AB	100 A	50 AB	43 D	53 ABC	45 AB
142	Jefferson	3.2	40 CDE	35 BC	98 AB	100 A	58 AB	60 BCD	55 ABC	48 AB

Appendix C continued.

Ecotype	County	Group	0.5x Glufosinate Two	0.5x Glufosinate Four	0.5x Glyphosate Two	0.5x Glyphosate Four	0.5x Imazethapyr Two	0.5x Imazethapyr Four	0.5x Imazamox Two	0.5x Imazamox Four
			---	---	---	---	%	---	---	---
2254	Brazoria	Int	53 A	58 A	98 A	100 A	75 A	83 A	83 A	73 A
325	Bowie	Int	43 A	35 B	100 A	100 A	58 BC	55 B	50 B	45 B
539	Liberty	Int	48 A	38 B	93 A	95 A	53 BC	50 B	48 B	38 B
600	Liberty	Int	48 A	35 B	93 A	100 A	63 AB	65 AB	50 B	38 B
596	Liberty	Int	48 A	45 AB	98 A	100 A	45 C	48 B	48 B	43 B
521	Liberty	Int	45 A	43 AB	98 A	100 A	45 C	58 B	53 B	45 B
585	Liberty	Int	48 A	43 AB	98 A	100 A	63 AB	63 B	50 B	48 B
2	Waller	Int	45 A	48 AB	100 A	100 A	63 AB	65 AB	58 B	53 AB

Appendix C continued.

Ecotype	County	Group	0.5x Glufosinate Two	0.5x Glufosinate Four	0.5x Glyphosate Two	0.5x Glyphosate Four	0.5x Imazethapyr Two	0.5x Imazethapyr Four	0.5x Imazamox Two	0.5x Imazamox Four
			----------------	----------------	----------------	----------------	--------%--------	----------------	----------------	----------------
4	Wharton	Straw	50 AB	38 B	100 A	100 A	70 A	73 A	65 AB	63 AB
1249	Liberty	Straw	43 B	38 B	100 A	100 A	75 A	75 A	70 A	65 AB
154	Jefferson	Straw	50 AB	45 AB	95 B	98 A	73 A	73 A	68 A	63 AB
430	Wharton	Straw	60 A	60 A	100 A	100 A	68 A	63 A	65 AB	68 A
2261	Brazoria	Straw	53 AB	53 AB	100 A	100 A	70 A	65 A	68 A	53 AB
374	Fort Bend	Straw	53 AB	50 AB	98 AB	98 A	70 A	68 A	60 AB	50 AB
304	Bowie	Straw	60 A	58 AB	98 AB	100 A	63 A	60 A	48 B	40 AB
279	Bowie	Straw	50 AB	55 AB	100 A	100 A	70 A	65 A	60 AB	55 AB
471	Wharton	Straw	60 A	50 AB	100 A	100 A	63 A	60 A	48 B	38 B
1309	Liberty	Straw	43 B	38 B	98 AB	98 A	68 A	73 A	55 AB	55 AB

Appendix C continued.

Ecotype	County	Group	0.5x Glufosinate		0.5x Glyphosate		0.5x Imazethapyr		0.5x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			---%							
tx4-4	Waller	TX4	43 A	40 A	95 A	98 A	50 A	43 A	48 A	35 A
tx4-3	Waller	TX4	43 A	48 A	95 A	100 A	60 A	63 A	60 A	50 A
tx4-2	Waller	TX4	35 A	43 A	100 A	100 A	58 A	58 A	60 A	35 A
tx4-5	Waller	TX4	43 A	45 A	100 A	100 A	55 A	55 A	43 A	40 A

Appendix C continued.

Ecotype	County	Group	1x Glufosinate		1x Glyphosate		1x Imazethapyr		1x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			-----%	-----	-----	-----	-----	-----	-----	-----
6	Waller	3.1	90 AB	85 AB	100 A	100 A	90 AB	88 AB	53 BCD	60 B-E
815	Liberty	3.1	90 AB	83 AB	100 A	100 A	85 ABC	90 AB	65 ABC	63 A-E
28-1	Fort Bend	3.1	73 B-F	78 A-D	98 A	100 A	83 A-D	90 AB	58 A-D	80 A
405	Chambers	3.1	70 C-F	68 B-E	100 A	100 A	68 DE	85 AB	70 ABC	73 ABC
2265	Brazoria	3.1	85 ABC	85 AB	100 A	100 A	78 A-E	88 AB	65 ABC	63 A-E
58	Matagorda	3.1	75 A-E	68 B-E	100 A	100 A	75 B-E	85 AB	73 ABC	55 C-F
297	Bowie	3.1	75 A-E	65 B-F	100 A	100 A	83 A-D	90 AB	78 A	68 A-D
429	Wharton	3.1	70 C-F	65 B-F	98 A	100 A	93 A	98 A	78 A	63 A-E
811	Liberty	3.1	83 A-D	80 ABC	100 A	100 A	75 B-E	88 AB	75 AB	73 ABC
55	Matagorda	3.1	90 AB	85 AB	100 A	100 A	90 AB	100 A	73 ABC	75 AB
296	Bowie	3.1	70 C-F	60 C-F	100 A	100 A	78 A-E	90 AB	60 A-D	63 A-E

Appendix C continued.

Ecotype	County	Group	1x Glufosinate		1x Glyphosate		1x Imazethapyr		1x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			------------------------------------	------------------------------------	------------------------------------	---%---	------------------------------------	------------------------------------	------------------------------------	------------------------------------
5	Waller	3.1	70 C-F	65 B-F	98 A	100 A	73 CDE	90 AB	65 ABC	60 B-E
56	Matagorda	3.1	85 ABC	85 AB	100 A	100 A	90 AB	85 AB	63 A-D	65 A-D
205	Colorado	3.1	90 AB	97 A	98 A	100 A	48 F	38 C	40 D	40 F
2251	Brazoria	3.1	68 C-F	68 B-E	100 A	100 A	65 E	80 B	70 ABC	68 A-D
4	Waller	3.1	90 AB	95 A	100 A	100 A	73 CDE	88 AB	60 A-D	53 DEF
23	Wharton	3.1	93 A	93 A	100 A	100 A	83 A-D	98 A	73 ABC	65 A-D
311	Bowie	3.1	55 F	45 F	100 A	100 A	73 CDE	90 AB	63 A-D	70 A-D
623	Jefferson	3.1	63 EF	53 EF	93 B	100 A	63 EF	75 B	65 ABC	70 A-D
223	Colorado	3.1	73 B-F	68 B-E	100 A	100 A	65 E	75 B	55 A-D	53 DEF
18	Colorado	3.1	73 B-F	65 B-F	100 A	100 A	75 B-E	90 AB	68 ABC	70 A-D
813	Liberty	3.1	78 A-E	78 A-D	100 A	100 A	75 B-E	85 AB	50 CD	45 EF

Appendix C continued.

Ecotype	County	Group	1x Glufosinate		1x Glyphosate		1x Imazethapyr		1x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			----------%----------							
28-2	Fort Bend	3.1	65 DEF	58 DEF	100 A	100 A	73 CDE	88 AB	53 BCD	53 DEF

Appendix C continued.

Ecotype	County	Group	1x Glufosinate Two	1x Glufosinate Four	1x Glyphosate Two	1x Glyphosate Four	1x Imazethapyr Two	1x Imazethapyr Four	1x Imazamox Two	1x Imazamox Four
			--------------------	----------	----------	----------	%	----------	----------	--------------------
348	Fort Bend	3.2	58 CDE	55 A-E	100 A	100 A	73 B-F	88 ABC	50 CDE	53 ABC
136	Jefferson	3.2	63 BCD	60 A-E	100 A	100 A	75 A-F	80 B-F	48 DE	45 C
161	Jefferson	3.2	60 CDE	53 B-E	98 AB	100 A	68 C-F	78 B-F	43 E	48 BC
728	Liberty	3.2	63 BCD	53 B-E	100 A	100 A	73 B-F	85 A-D	78 A	68 AB
30	Matagorda	3.2	55 DE	48 CDE	100 A	100 A	70 C-F	85 A-D	50 CDE	53 ABC
390	Chambers	3.2	73 ABC	73 AB	100 A	100 A	90 AB	93 AB	50 CDE	48 BC
414	Chambers	3.2	65 BCD	50 B-E	100 A	100 A	70 C-F	80 B-F	63 A-E	68 AB
361	Fort Bend	3.2	55 DE	43 DE	100 A	100 A	65 C-F	70 DEF	60 A-E	53 ABC
27-2	Fort Bend	3.2	55 DE	45 DE	98 AB	100 A	65 C-F	78 B-F	65 A-E	65 ABC
384	Chambers	3.2	73 ABC	65 A-D	100 A	100 A	83 ABC	88 ABC	63 A-E	58 ABC
25-1	Matagorda	3.2	73 ABC	65 A-D	100 A	100 A	83 ABC	93 AB	63 A-E	58 ABC

Appendix C continued.

Ecotype	County	Group	1x Glufosinate		1x Glyphosate		1x Imazethapyr		1x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			-----	-----	-----	-----	%	-----	-----	-----
493	Liberty	3.2	63 BCD	53 B-E	98 AB	100 A	73 B-F	83 A-E	63 A-E	58 ABC
183	Colorado	3.2	88 A	78 A	100 A	100 A	83 ABC	88 ABC	75 AB	70 A
140	Jefferson	3.2	50 DE	45 DE	98 AB	100 A	78 A-E	85 A-D	53 B-E	53 ABC
11	Fort Bend	3.2	45 E	38 E	95 B	100 A	70 C-F	83 A-E	53 B-E	55 ABC
428	Chambers	3.2	55 DE	45 DE	100 A	100 A	70 C-F	85 A-D	48 DE	53 ABC
425	Chambers	3.2	53 DE	50 B-E	100 A	100 A	63 DEF	83 A-E	60 A-E	65 ABC
166	Jefferson	3.2	55 DE	45 DE	100 A	100 A	63 DEF	78 B-F	53 B-E	55 ABC
172	Jefferson	3.2	63 BCD	53 B-E	100 A	100 A	80 A-D	93 AB	73 ABC	65 ABC
971	Liberty	3.2	55 DE	53 B-E	100 A	100 A	75 A-F	85 A-D	58 A-E	55 ABC
179	Colorado	3.2	45 E	38 E	95 B	100 A	60 EF	65 F	53 B-E	53 ABC
25-2	Matagorda	3.2	78 AB	70 ABC	100 A	100 A	93 A	98 A	68 A-D	55 ABC

Appendix C continued.

Ecotype	County	Group	1x Glufosinate		1x Glyphosate		1x Imazethapyr		1x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			----------------------	----------------------	----------------------	---------------------- %-------	----------------------	----------------------	----------------------	----------------------
409	Chambers	3.2	50 DE	48 CDE	98 AB	100 A	58 F	68 EF	60 A-E	60 ABC
27-1	Fort Bend	3.2	45 E	45 DE	98 AB	100 A	63 DEF	70 DEF	63 A-E	55 ABC
3	Waller	3.2	73 ABC	73 AB	100 A	100 A	80 A-D	85 A-D	63 A-E	65 ABC
356	Fort Bend	3.2	55 DE	40 E	100 A	100 A	60 EF	70 DEF	43 E	48 BC
142	Jefferson	3.2	50 DE	40 E	100 A	100 A	63 DEF	75 C-F	58 A-E	53 ABC

Appendix C continued.

Ecotype	County	Group	1x Glufosinate		1x Glyphosate		1x Imazethapyr		1x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			--------------------	--------------------	--------------------	--------------------	%	--------------------	--------------------	--------------------
2254	Brazoria	Int	83 A	80 A	100 A	100 A	83 A	100 A	88 A	88 A
325	Bowie	Int	60 CD	55 B	98 A	100 A	75 AB	83 B	60 B	63 B
539	Liberty	Int	70 BC	68 AB	100 A	100 A	70 BC	75 BCD	58 B	50 B
600	Liberty	Int	73 AB	75 AB	100 A	100 A	78 AB	85 B	55 B	48 B
596	Liberty	Int	68 BC	68 AB	100 A	100 A	63 C	70 CD	55 B	55 B
521	Liberty	Int	55 D	58 B	100 A	100 A	60 C	68 D	60 B	63 B
585	Liberty	Int	65 BCD	65 AB	100 A	100 A	70 BC	78 BCD	60 B	63 B
2	Waller	Int	70 BC	68 AB	100 A	100 A	68 BC	80 BC	68 B	60 B

Appendix C continued.

Ecotype	County	Group	1x Glufosinate		1x Glyphosate		1x Imazethapyr		1x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			---%	---	---	---	---	---	---	---
24	Wharton	Straw	80 A	73 AB	100 A	100 A	75 ABC	98 A	75 A	73 A
1249	Liberty	Straw	75 A	70 B	100 A	100 A	78 AB	93 AB	58 A	68 AB
154	Jefferson	Straw	88 A	88 A	98 A	100 A	83 A	93 AB	65 A	60 AB
430	Wharton	Straw	90 A	85 AB	100 A	100 A	75 ABC	93 AB	63 A	58 AB
2261	Brazoria	Straw	80 A	78 AB	100 A	100 A	73 ABC	90 AB	73 A	70 AB
374	Fort Bend	Straw	83 A	83 AB	100 A	100 A	75 ABC	88 AB	70 A	55 AB
304	Bowie	Straw	83 A	85 AB	98 A	100 A	80 AB	85 B	60 A	48 B
279	Bowie	Straw	78 A	85 AB	100 A	100 A	78 AB	90 AB	70 A	63 AB
471	Wharton	Straw	88 A	87 A	100 A	100 A	65 C	85 B	65 A	63 AB
1309	Liberty	Straw	83 A	70 B	100 A	100 A	70 BC	88 AB	65 A	68 AB

Appendix C continued.

Ecotype	County	Group	1x Glufosinate		1x Glyphosate		1x Imazethapyr		1x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			----------------------	----------------------	----------------------	----------%	-----------------------	----------------------	----------------------	----------------------
tx4-4	Waller	TX4	63 A	60 A	98 A	100 A	68 A	75 A	45 C	43 B
tx4-3	Waller	TX4	55 A	50 A	98 A	100 A	65 A	75 A	68 A	58 A
tx4-2	Waller	TX4	58 A	53 A	98 A	100 A	63 A	75 A	63 AB	55 A
tx4-5	Waller	TX4	58 A	58 A	100 A	100 A	70 A	75 A	50 BC	55 A

Appendix C continued.

Ecotype	County	Group	2x Glufosinate Two	2x Glufosinate Four	2x Glyphosate Two	2x Glyphosate Four	2x Imazethapyr Two	2x Imazethapyr Four	2x Imazamox Two	2x Imazamox Four
			------	------	------	------	%	------	------	------
6	Waller	3.1	100 A	100 A	100 A	100 A	78 AB	93 A	88 A-D	98 AB
815	Liberty	3.1	100 A	100 A	100 A	100 A	88 A	98 A	85 A-E	95 ABC
28-1	Fort Bend	3.1	90 A	90 A	100 A	100 A	90 A	98 A	80 A-F	98 AB
405	Chambers	3.1	100 A	100 A	100 A	100 A	83 AB	93 A	83 A-E	93 ABC
2265	Brazoria	3.1	98 A	98 A	100 A	100 A	88 A	95 A	90 ABC	98 AB
58	Matagorda	3.1	93 A	95 A	100 A	100 A	73 AB	90 A	80 A-F	85 BC
297	Bowie	3.1	95 A	98 A	100 A	100 A	80 AB	95 A	90 ABC	100 A
429	Wharton	3.1	93 A	90 A	100 A	100 A	83 AB	95 A	88 A-D	98 AB
811	Liberty	3.1	100 A	100 A	100 A	100 A	78 AB	93 A	78 B-F	83 C
55	Matagorda	3.1	100 A	100 A	100 A	100 A	85 A	98 A	95 A	98 AB
296	Bowie	3.1	90 A	90 A	98 B	100 A	83 AB	93 A	78 B-F	93 ABC

Appendix C continued.

Ecotype	County	Group	2x Glufosinate Two	2x Glufosinate Four	2x Glyphosate Two	2x Glyphosate Four	2x Imazethapyr Two	2x Imazethapyr Four	2x Imazamox Two	2x Imazamox Four
			-----	-----	-----	-----	%	-----	-----	-----
5	Waller	3.1	100 A	100 A	100 A	100 A	78 AB	88 A	80 A-F	93 ABC
56	Matagorda	3.1	95 A	95 A	100 A	95 B	83 AB	85 A	93 AB	98 AB
205	Colorado	3.1	100 A	100 A	100 A	100 A	63 B	33 B	73 DEF	65 D
2251	Brazoria	3.1	95 A	98 A	100 A	100 A	70 AB	93 A	73 DEF	85 BC
4	Waller	3.1	100 A	100 A	100 A	100 A	80 AB	90 A	83 A-E	93 ABC
23	Wharton	3.1	100 A	100 A	100 A	100 A	78 AB	95 A	90 ABC	98 AB
311	Bowie	3.1	95 A	93 A	100 A	100 A	85 A	90 A	75 C-F	95 ABC
623	Jefferson	3.1	95 A	95 A	98 B	100 A	73 AB	90 A	70 EF	95 ABC
223	Colorado	3.1	95 A	95 A	100 A	100 A	70 AB	90 A	65 F	85 BC
18	Colorado	3.1	100 A	100 A	100 A	100 A	83 AB	95 A	85 A-E	90 ABC
813	Liberty	3.1	98 A	98 A	100 A	100 A	83 AB	93 A	73 DEF	85 BC

Appendix C continued.

	County	Group	2x Glufosinate		2x Glyphosate		2x Imazethapyr		2x Imazamox	
Ecotype			Two	Four	Two	Four	Two	Four	Two	Four
			------------------	------------------	------------------	---% ---	------------------	------------------	------------------	------------------
28-2	Fort Bend	3.1	90 A	90 A	100 A	100 A	70 AB	88 A	75 C-F	93 ABC

Appendix C continued.

Ecotype	County	Group	2x Glufosinate		2x Glyphosate		2x Imazethapyr		2x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			---%---							
348	Fort Bend	3.2	80 B	88 ABC	100 A	100 A	78 A-D	93 ABC	80 ABC	93 AB
136	Jefferson	3.2	90 AB	95 AB	100 A	100 A	73 A-D	98 A	80 ABC	90 ABC
161	Jefferson	3.2	90 AB	95 AB	100 A	100 A	78 A-D	95 AB	73 A-E	90 ABC
728	Liberty	3.2	90 AB	90 AB	100 A	100 A	83 AB	95 AB	88 A	95 A
30	Matagorda	3.2	88 AB	85 ABC	100 A	100 A	80 ABC	88 ABC	75 A-E	83 A-F
390	Chambers	3.2	90 AB	90 AB	100 A	100 A	73 A-D	93 ABC	70 A-E	80 B-F
414	Chambers	3.2	90 AB	88 ABC	98 B	100 A	68 BCD	88 ABC	73 A-E	85 A-E
361	Fort Bend	3.2	85 AB	78 BC	100 A	100 A	80 ABC	88 ABC	65 CDE	75 DEF
27-2	Fort Bend	3.2	90 AB	95 AB	100 A	100 A	75 A-D	90 ABC	75 A-E	78 C-F
384	Chambers	3.2	90 AB	90 AB	100 A	100 A	78 A-D	95 AB	75 A-E	85 A-E
25-1	Matagorda	3.2	83 B	85 ABC	100 A	100 A	75 A-D	95 AB	75 A-E	95 A

Appendix C continued.

Ecotype	County	Group	2x Glufosinate Two	2x Glufosinate Four	2x Glyphosate Two	2x Glyphosate Four	2x Imazethapyr Two	2x Imazethapyr Four	2x Imazamox Two	2x Imazamox Four
			--------	--------	--------	--------	%	--------	--------	--------
493	Liberty	3.2	100 A	95 AB	100 A	100 A	80 ABC	90 ABC	80 ABC	90 ABC
183	Colorado	3.2	100 A	100 A	100 A	100 A	73 A-D	83 C	73 A-E	88 A-D
140	Jefferson	3.2	88 AB	88 ABC	100 A	100 A	73 A-D	88 ABC	68 B-E	80 B-F
11	Fort Bend	3.2	90 AB	90 AB	100 A	100 A	75 A-D	88 ABC	85 AB	88 A-D
428	Chambers	3.2	75 B	70 C	100 A	100 A	80 ABC	88 ABC	73 A-E	88 A-D
425	Chambers	3.2	80 B	78 BC	100 A	98 B	73 A-D	85 BC	83 ABC	93 AB
166	Jefferson	3.2	90 AB	90 AB	100 A	100 A	85 A	88 ABC	73 A-E	83 A-F
172	Jefferson	3.2	83 B	90 AB	100 A	100 A	80 ABC	93 ABC	78 ABC	95 A
971	Liberty	3.2	88 AB	83 ABC	100 A	100 A	68 BCD	90 ABC	75 A-E	88 A-D
179	Colorado	3.2	88 AB	90 AB	100 A	100 A	70 A-D	88 ABC	68 B-E	78 C-F
25-2	Matagorda	3.2	88 AB	88 ABC	100 A	100 A	75 A-D	95 AB	85 AB	95 A

Appendix C continued.

Ecotype	County	Group	2x Glufosinate		2x Glyphosate		2x Imazethapyr		2x Imazamox	
			Two	Four	Two	Four	Two	Four	Two	Four
			---%	---	---	---	---	---	---	---
409	Chambers	3.2	88 AB	85 ABC	98 B	100 A	73 A-D	90 ABC	68 B-E	78 C-F
27-1	Fort Bend	3.2	85 AB	83 ABC	100 A	100 A	70 A-D	88 ABC	68 B-E	83 A-F
3	Waller	3.2	90 AB	83 ABC	100 A	100 A	63 D	85 BC	60 DE	73 EF
356	Fort Bend	3.2	90 AB	88 ABC	100 A	100 A	65 CD	88 ABC	58 E	73 EF
142	Jefferson	3.2	83 B	83 ABC	100 A	98 B	73 A-D	88 ABC	65 CDE	70 F

Appendix C continued.

Ecotype	County	Group	2x Glufosinate Two	2x Glufosinate Four	2x Glyphosate Two	2x Glyphosate Four	2x Imazethapyr Two	2x Imazethapyr Four	2x Imazamox Two	2x Imazamox Four
			---%							---
2254	Brazoria	Int	100 A	100 A	100 A	100 A	90 A	100 A	93 A	95 AB
325	Bowie	Int	98 A	98 A	100 A	100 A	75 BC	93 AB	78 ABC	85 AB
539	Liberty	Int	93 A	93 A	100 A	100 A	85 AB	98 AB	88 AB	95 AB
600	Liberty	Int	95 A	98 A	100 A	100 A	78 ABC	95 AB	83 ABC	90 AB
596	Liberty	Int	95 A	95 A	100 A	100 A	73 BC	93 AB	73 BC	80 B
521	Liberty	Int	93 A	95 A	100 A	100 A	70 C	88 B	83 ABC	98 A
585	Liberty	Int	93 A	95 A	100 A	100 A	73 BC	93 AB	68 C	80 B
2	Waller	Int	95 A	95 A	100 A	100 A	68 C	90 AB	85 AB	93 AB

Appendix C continued.

Ecotype	County	Group	2x Glufosinate Two	2x Glufosinate Four	2x Glyphosate Two	2x Glyphosate Four	2x Imazethapyr Two	2x Imazethapyr Four	2x Imazamox Two	2x Imazamox Four
			-----	-----	-----	-----	%	-----	-----	-----
24	Wharton	Straw	98 A	98 AB	100 A	100 A	88 A	90 A	83 AB	90 A
1249	Liberty	Straw	93 A	88 B	100 A	100 A	78 AB	93 A	85 AB	95 A
154	Jefferson	Straw	98 A	100 A	100 A	100 A	73 B	95 A	85 AB	95 A
430	Wharton	Straw	100 A	100 A	100 A	98 B	70 B	95 A	80 B	90 A
2261	Brazoria	Straw	100 A	100 A	100 A	100 A	73 B	93 A	80 B	93 A
374	Fort Bend	Straw	98 A	100 A	100 A	100 A	78 AB	98 A	85 AB	98 A
304	Bowie	Straw	100 A	100 A	100 A	100 A	70 B	93 A	85 AB	95 A
279	Bowie	Straw	93 A	93 AB	100 A	100 A	80 AB	98 A	93 A	98 A
471	Wharton	Straw	98 A	100 A	100 A	100 A	68 B	93 A	88 AB	95 A
1309	Liberty	Straw	98 A	98 AB	100 A	100 A	73 B	90 A	80 B	88 A

Appendix C continued.

Ecotype	County	Group	2x Glufosinate Two	2x Glufosinate Four	2x Glyphosate Two	2x Glyphosate Four	2x Imazethapyr Two	2x Imazethapyr Four	2x Imazamox Two	2x Imazamox Four
			----------	----------	----------	----------	%	----------	----------	----------
tx4-4	Waller	TX4	93 A	93 A	100 A	100 A	68 A	88 A	65 A	73 B
tx4-3	Waller	TX4	93 A	93 A	100 A	100 A	78 A	90 A	78 A	93 A
tx4-2	Waller	TX4	90 A	90 A	100 A	100 A	73 A	88 A	78 A	85 AB
tx4-5	Waller	TX4	78 B	70 B	100 A	100 A	65 A	85 A	75 A	83 AB

[a] Group 3.1 = red rice ecotypes genetically similar to *Oryza rufipogon*, 3.2 = red rice ecotypes genetically similar to TX4, Intermediate = red rice ecotypes genetically similar to *Oryza rufipogon* and TX4, Strawhulled = red rice ecotypes genetically similar to *Oryza sativa* ssp. *indica*,, and TX4 = red rice ecotypes known to be TX4, two = two weeks after the second application, four = four weeks after the second application.

[b] Glufosinate 0.5x = 0.2 kg ai/ha, 1x = 0.4 kg/ha, 2x = 0.8 kg/ha; glyphosate 0.5x = 0.4 kg/ha, 1x = 0.8 kg/ha, 2x = 1.7 kg/ha; imazethapyr 0.5x = 0.04 kg/ha, 1x = 0.07 kg/ha, 2x = 0.14 kg/ha; and imazamox 0.5x = 0.02 kg/ha, 1x = 0.04 kg/ha, 2x = 0.07 kg/ha, first treatment applied to 3- to 4- leaf red rice, second treatment applied to 6- to 8- leaf red rice.

[c] Means within columns followed by a different letter are significantly different at a p-value ≤ 0.05.

VITA

Weldon Duane Nanson graduated from Angleton High School, Angleton, Texas, in May of 2000. He was a member of the Corps of Cadets and received a Bachelor of Science degree in agronomy from Texas A&M University, College Station, Texas, in December of 2004. In the early spring of 2005 he began to pursue a Master of Science degree in Agronomy with an emphsis in weed science. He completed his masters degree in August of 2007. He is currently working as an agronomist for Bayer Crop Science.

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