THE INTERACTION OF PROPANIL+THIOBENCARB WITH IMAZETHAPYR AND IMAZAMOX FOR ENHANCED RED RICE (*Oryza* spp.) CONTROL IN IMIDAZOLINONE-TOLERANT RICE (*Oryza sativa* L.)

A Thesis

by

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MASTER OF SCIENCE

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ABSTRACT

Recent observations from field systems suggest that RiceBeaux® may enhance efficacy of imidazolinone herbicides for control of red rice. Therefore, this research was undertaken to evaluate the herbicidal interactions of RiceBeaux® with Newpath® and Beyond®. Field experiments were conducted in 2012 and 2013 at the David R. Wintermann Rice Research Station in Eagle Lake, TX. In both years, imazethapyr alone and imazethapyr+RiceBeaux® treatments, were evaluated for control of XL723, which was used to simulate red rice in the field. In 2012, imazethapyr alone treatments provided 60 to 85% control of XL723 14 DAT and 87 to 100% control 21 DAT. Imazethapyr+RiceBeaux® combinations provided 51 to 91% control of XL723 14 DAT and 87 to 100% control 21 DAT. During both years, all treatments provided greater than 98% control of XL723 28 and 35 DAT.

In 2013, treatments that did not include a tank-mix with RiceBeaux® provided 60 to 77% control of XL723 14 DAT and 80 to 94% control 21 DAT. Imazethapyr+RiceBeaux® combinations provided 60 to 85% control of XL723 14 DAT and 81 to 99% control 21 DAT. These data indicated that for both years, Imazethapyr+RiceBeaux® combinations provided no additional control of XL723 compared to imazethapyr alone.

In 2013, experiments were conducted to evaluate the interaction of RiceBeaux® on imazamox in the field. Imazamox alone provided 62 to 75% and 87 to 94% control of XL723 14 and 21 DAT, respectively. Imazamox+RiceBeaux® treatments provided 57 to

85% control 14 DAT and 86 to 100% control 21 DAT. All treatments provided excellent control 28 and 35 DAT. Based on these data, imazamox+RiceBeaux® combinations provided no additional control of XL723 compared to imazamox alone.

Laboratory experiments were also conducted to characterize the interaction of RiceBeaux® on translocation and absorption of imazamox using ^{14}C-imazamox. TX-4 red rice plants were treated with ^{14}C-imazamox, with plants subsequently harvested at 8 separate timings. At each harvest timing, six samples were harvested from each plant and analyzed using Liquid Scintillation Spectrometry to quantify radioactivity.

Significantly more ^{14}C-imazamox was recovered from the cuticle when imazamox was applied alone, resulting in lower amounts of imazamox absorption. In contrast, imazamox+RiceBeaux® resulted in significantly higher absorption of ^{14}C-imazamox at 24, 48, and 96 hr after treatment. Results indicated RiceBeaux® may allow more imazamox to cross the lipophilic cuticle to reach the sites of action, which may result in enhanced red rice control. This interaction may explain the enhanced red rice control observed in field studies when RiceBeaux® tank-mixes were applied.

DEDICATION

I would like to dedicate this thesis to my wife, Whitney, for her love and support that she has given me throughout our marriage. I would also like to dedicate this to my parents, Mark and Gail, who brought me up to put God first in my life and to be a man of character.

ACKNOWLEDGEMENTS

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I would like to thank Texas A&M University for allowing me the educational opportunities that enabled me to pursue this degree.

I also would like to thank my wife, Whitney for her love, support, understanding, and sacrifice during my graduate program.

I would like to thank my dad, Mark, who has always been a perfect example of the man that I aspire to be, and my mom, Gail, who has been a pillar of love and support throughout my life.

I would like to thank my father-in-law, Brad Minton, who first sparked my interest in agriculture and my mother-in-law, Monique Minton, who has always loved and supported me as her own.

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CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.) is an important cereal grain and major staple for over 50% of the world's population (Snyder and Slaton, 2002). According to the USDA Economic Research Service, rice was cultivated as early as 5000 B.C. in the Yangzi Valley of China and has played an integral role in the development of civilization (USDA ERS, 2012; Burgos et al. 2008). Rice has been cultivated in the United States since the middle of the 19th century, beginning on the east coast in Georgia and the Carolinas. By the early 20th century, rice production had spread west to Arkansas, Missouri, Louisiana, Mississippi, California, and Texas (Snyder and Slaton, 2002). These states continue to produce rice while rice production on the east coast of the United States has mostly disappeared.

Currently, the geographic regions in which U.S. rice production is concentrated are the Arkansas Grand Prairie, the Mississippi Delta, the Texas Gulf Coast, the California Sacramento Valley, and Western Louisiana (USDA ERS, 2012). In 2011, there were 1.1 million ha of rice planted in the United States. Currently, Arkansas produces almost half of the rice grown in the United States with 484,004 ha planted in 2011. In 2011, Texas produced 73,652 ha of rice, almost all of which were long grain varieties (USDA NASS, 2012).

Weeds are an agronomic and economic issue in rice fields across the United States, competing with cultivated rice for space, nutrients, and sunlight (Zhang et al.

2006a; Webster and Levy, 2012). Currently, there are numerous weed control programs in use in United States rice production. Depending on the planting method, irrigation practices, and weed pressure, these programs can vary widely (Webster and Levy, 2012). The majority of U.S. producers integrate flooding into these programs to suppress weeds and to achieve optimum yields (Webster and Levy, 2012; Avila et al. 2005b). Red rice (*Oryza sativa* L.), barnyardgrass (*Echinochloa crus-galli* L.), broadleaf signalgrass (*Brachiaria platyphylla* L.), ducksalad (*Heteranthera limosa* L.), junglerice (*Echinochloa colonum* L), alligatorweed (*Alternanthera philoxeroides* L.), yellow nutsedge (*Cyperus esculentus* L.), hemp sesbania (*Sesbania exaltata* L.), and sprangletop species (*Leptochloa* spp.) are some of the most common weeds found in U.S. rice fields. Red rice is currently recognized as one of the most troublesome weeds to control in cultivated rice (Webster and Levy, 2012).

Red rice has been a problematic weed in rice production since the 19th century (Steele et al. 2002; Burgos et al. 2008). Present in most rice-producing countries, red rice, can be found throughout the rice-growing region of the United States (Zhang et al. 2006a). Originating in Asia, it has been in the United States as early as the 1840's (Burgos et al. 2008). The spread of red rice has mirrored the expansion of rice production in the United States (Steele et al. 2002). Red rice and cultivated are both from the genus, *Oryza*. Ecotypes of red rice prevalent in the United States include *Oryza sativa* spp. Indica, *O. sativa* spp. Japonica, *O. nivara*, and *O. rufipogon* (Avila et al. 2005b; Vaughan et al. 2001); although, taxonomically, red rice is most commonly referred to as *Oryza sativa* (Steele et al. 2002). Red rice has historically been difficult to control in rice fields because of the morphological and physiological similarities to cultivated rice (Zhang et al. 2006a; Avila et al. 2005b).

Red rice exhibits faster growth, is taller, and develops a more extensive root system than cultivated rice. Red rice also produces more tillers, which are more slender than that of cultivated rice. When in a non-competitive environment, red rice has the ability to yield twice the amount of grain than cultivated rice. Furthermore, it is more nitrogen-efficient than cultivated rice; therefore an environment with low nitrogen availability is a scenario in which red rice outcompetes other plants (Sales et al. 2011). The seed that it produces can remain dormant for up to 5 years and contains variable amounts of anthocyanins, cathekins, and cathekolic tannins, which result in a red pericarp. Additionally, red rice escapes of less than 5% are sufficient to restore original seed bank population levels, which contributes to the difficulty in maintaining satisfactory red rice control (Ferrero, 2003).

Red rice infestations also result in a significant reduction of yield and milling quality (Ottis et al. 2005). The amount of yield reduction is directly related to the density of the red rice infestation (Estorninos et al. 2005; Sales et al. 2011). Research has shown that one red rice seedhead per square meter can result in a rice yield reduction of 16 kg ha^{-1} (Avila et al. 2005a; Montealegre and Vargas, 1989). Other factors include seeding rate, nutrient availability, and rice varieties. Some rice varieties are more susceptible to yield reductions because of their growth characteristics, with rice varieties that are less competitive being subject to greater reductions in yield (Ottis et al. 2005; Shivrain et al. 2009b). In 2006, red rice contributed to an economic loss of \$275 ha^{-1} in

Arkansas alone (Burgos et al. 2008). Historically, rice producers have utilized crop rotation, especially with soybeans, in order to control red rice. This rotation enables growers to utilize different herbicides to suppress problematic weed populations (Pellerin et al. 2004; Webster and Levy, 2012). However, current red rice management practices rely heavily on the Clearfield[1] rice production system, a program that includes several imidazolinone herbicides used in combination with imidazolinone-tolerant crops.

In 1993, imidazolinone-tolerant rice was developed at Louisiana State University (Pellerin et al. 2004; Zhang et al. 2006b). Imidazolinone-tolerant rice was discovered after a mutated rice seed survived an imidazolinone herbicide application. The resulting rice line, '93-AS-3510' was used as the male parent line to develop several imidazolinone-tolerant rice cultivars (Levy et al. 2006). In approximately 2002, this rice was available for commercial use (Burgos et al. 2008). Cultivating rice that is resistant to the imidazolinone family of herbicides has enabled U.S. rice producers to utilize herbicides previously unavailable to control troublesome weeds. This system gained widespread popularity because of the effective control of red rice that the imidazolinone class of herbicides provides (Carlson et al. 2012).

Newpath[2] (ammonium salt of imazethapyr: (+)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid), Clearpath[2] (imazethapyr: (+)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-

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[1] Clearfield Production System, a weed management program that includes several imidazolinone herbicides used on imidazolinone-tolerant crops. BASF Corporation. 26

[2] Newpath, Clearpath, Beyond. Imidazolinone herbicides utilized in Clearfield Production Systems. BASF Corporation. 26 Davis Drive, Research Triangle Park, NC 27709.

5-ethyl-3-pyridinecarboxylic acid; quinclorac: 3,7-dichloro-8-quinolinecarboxylic acid), and Beyond (ammonium salt of imazamox: 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid) are imidazolinone herbicides that are a part of BASF's Clearfield production system. The imidazolinone family's mode of action is acetolactate synthase inhibition (ALS) (Senseman, 2007). Newpath provides excellent control of many grasses and is therefore an effective tool in the control of red rice (Way and McCauley, 2012). According to the label, sequential applications at a rate of 70 g ai ha^{-1} are required for adequate control of weeds. Sequential applications may involve either a pre-emergence application followed by a post-emergence application, a pre-plant incorporated application followed by a post-emergence application, or a post-emergence application followed by another post-emergence application. Depending on the weed spectrum targeted, Clearpath or Beyond may be substituted for one of the Newpath applications. Beyond is also labeled for a third application after two treatments of Newpath have been applied in order to control red rice escapes.

However, because of the widespread use of Clearfield technologies in mono-cropping operations, imidazolinone-tolerant red rice has developed in some rice-producing areas of the United States (Avila et al. 2005b; Burgos et al. 2008). Research has indicated that this is a result of outcrossing between Clearfield rice and red rice, which emphasizes the importance of minimizing red rice escapes (Zhang et al. 2006a). Hybrid rice has been shown to have higher outcrossing rates than inbred rice (Shivrain et al. 2009a). This is of particular concern because of the risk of spreading imidazolinone-tolerance to red rice and other weeds. There are more resistant weeds attributed to herbicides that inhibit acetolactate synthase (ALS) in plants than any other mode of action (Zhou et al. 2007). Although rice producers are encouraged to utilize multiple modes of action and crop rotation, the superior control the Clearfield system has resulted in an increase in mono-cropping operations reliant on the Clearfield system, and therefore the ALS mode of action, which greatly increases the probability of resistant weeds. Recent studies with a RiceCo herbicide, RiceBeaux[3] (propanil (3,4-dichloropropionanilide; thiobencarb (*S*-[(4-chlorophenyl)methyl] diethylcarbamothiate), may have revealed an answer to this growing problem (Senseman, personal communication March 19, 2013).

RiceBeaux[3] is a mixture of two common rice herbicides, propanil and thiobencarb. Propanil is in the amide chemical family and was labeled for U.S. rice in 1961 (Senseman, 2007). First introduced by Rohm and Haas Company, the mode of action is photosystem II inhibition. It is an emulsifiable concentrate that provides excellent post-emergence control of many common grasses present in rice fields. However, it has shown to have no activity on red rice (Way and McCauley, 2012). Introduced in the U.S. by Chevron, thiobencarb is a member of the thiocarbamate family and has been in use in rice fields since the early 1970's. The mode of action is the inhibition of fatty acid and lipid biosynthesis (Senseman, 2007). It provides pre-

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[3] RiceBeaux®, a herbicide that contains 6.87 kg L^{-1} propanil and 6.87 kg L^{-1} thiobencarb. RiceCo LLC; 5100 Poplar Avenue, Suite 2482 Memphis, Tennessee 38137.

emergence and early post-emergence activity on certain grasses, sedges, and broadleaves. It also provides no control of red rice (Way and McCauley, 2012).

However, a study conducted in 2010 has indicated that when imazethapyr and RiceBeaux are utilized together in a weed control program, imazethapyr's control of red rice was enhanced (Senseman, personal communication March 19, 2013). The enhanced red rice control that was observed from the imazethapyr+RiceBeaux combination could be due to a synergistic interaction between imazethapyr and RiceBeaux. One hypothesis is that the emulsifiable concentrate formulation of RiceBeaux may increase the absorption and translocation of imazethapyr within the rice plant, which in turn could lead to an increase in the overall effectiveness of the herbicide. Carleson et al. (2011) have also reported increased red rice control from imazethapyr+propanil tank-mixes. Furthermore, Camargo et al. (2012) investigated the effect of saflufenacil on imazethapyr translocation and uptake, and reported an increase in the overall uptake (30%) and translocation (35%) of imazethapyr when used with saflufenacil compared to imazethapyr alone. The results from these studies lend support to the hypothesis of a synergistic interaction between RiceBeaux and imazethapyr.

RiceBeaux could significantly impact management of resistant weeds in the Clearfield system. If RiceBeaux enhances the translocation and absorption of imazethapyr in rice, it could decrease red rice escapes and lead to an increase in the effective life span of the Clearfield system. Adding the additional mode of action that RiceBeaux provides will also help in controlling other troublesome weeds in rice. Newpath provides excellent control of most grasses such as barnyardgrass and broadleaf signalgrass. However, RiceBeaux would be able to add to the effectiveness of the Clearfield program in controlling weeds that Newpath does not control effectively, such as hemp sesbania, eclipta (*Eclipta alba* L), and sprangletop species (Way and McCauley, 2012; Zhang et al. 2006b). The importance of utilizing multiple modes of action and limiting escapes will be one of the deciding factors in the continuing effectiveness of the Clearfield system.

The objectives of this research were to evaluate the efficacy of different imazethapyr+RiceBeaux and imazamox+RiceBeaux combinations for increased control of red rice in the field, and to characterize the interaction of RiceBeaux on the translocation and absorption of imazamox within a red rice plant.

CHAPTER II

MATERIALS AND METHODS

Efficacy of imazethapyr and propanil+thiobencarb Timings. Field research was conducted in 2012 and 2013 at the David R. Wintermann Rice Research Station at Eagle Lake, TX. This study focused on the efficacy of propanil+thiobencarb and imazethapyr timings for the control of red rice. The experimental design was a randomized complete block with four replications. The cultural inputs for this experiment are presented in table 1. The plots were drill seeded with CL152[4] at a seeding rate of 78.5 kg ha^{-1} and a planting depth of 2 cm. Field plots were planted with 7 rows at a 19-cm row spacing. Field plots in both years were 2 m wide by 5 m long. To simulate red rice, XL723[5] was cross-drilled into the plots at a seeding rate of 39 kg ha^{-1}. The planting depth, number of rows, and row spacing was the same as the CL152 planting method. The field was fertilized and irrigated in accordance with the 2012 Texas Rice Production Guidelines (Way and McCauley, 2012). Maintenance insecticide applications for insect suppression were administered as needed. The soil at this location was a Nada fine sandy loam (fine-loamy, siliceous, active, hyperthermic Albaquic Hapludalfs) with soil textural fractions of 61% sand, 31% silt, and 8% clay. There were four herbicide applications, pre-plant (PRE), early post emergence (EPOST),

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[4] CL152. An imidazolinone-tolerant rice cultivar. Louisiana State University Agricultural Center, 101 Efferson Hall Baton Rouge, LA 70803.
[5] XL723. A conventional, hybrid rice variety. RiceTec, Inc. 13100 Space Center Boulevard, Suite 300 Houston, TX 77059.

mid post emergence (MPOST), and late post emergence (LPOST). At EPOST applications, the rice plants were at the 1- to 2-leaf stage, at MPOST applications, the rice plants were at the 3- to 4-leaf stage, and at LPOST applications, the rice plants were at the 4- to 6-leaf stage. The treatment list for this study is presented in Table 2. The 2-L mixes were applied with a backpack sprayer powered by CO_2 at 207 kPa. PRE, EPOST, and MPOST applications were made with TeeJet 11002VS[6], flat-fan nozzles. LPOST applications were made with 8002VS[6], flat-fan nozzles. The spray boom was a three-nozzle design with a nozzle spacing of 51-cm. All treatments were applied at a spray volume of 140 L ha^{-1}. All herbicidal rates were determined using the respective herbicide product label recommendations. All treatments were applied with a non-ionic surfactant, Agri-Dex[7], at a rate of 1% v/v. There were four visual ratings with two separate categories, one based on crop response and one on XL723 control. The ratings were conducted using a scale of 0 to 100. Crop response ratings were based on chlorosis, stunting, and general injury. A rating of 0 indicated no phytotoxicity observed and a rating of 100 indicated complete plant death. A rating of 0 for XL723 control indicated no control and a rating of 100 indicated excellent XL723 control with no weeds present in the plot.

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[6] TeeJet 11002VS, XR11002, 8002VS nozzle tips. Spraying Systems Co., North Avenue, Wheaton, IL 60188.
[7] Agri-Dex, a non-ionic surfactant. Helena Chemical Company; 225 Schilling Boulevard, Suite 300 Collierville, Tennessee 38017.

In 2012 and 2013, the middle 4 rows of each plot were harvested using a Mitsubishi Combine[8]. Yield was adjusted to 12% moisture. Rice grain was milled using a Zaccaria[9] milling machine.

Data were analyzed as a randomized complete block. Data were logarithmically transformed in order to achieve reasonable normality. Despite attempting several transformations, data could not be completely normalized according to the Shapiro-Wilke test. Harvest weight were normally distributed; therefore, data were not transformed. All untreated checks were excluded from data analysis. Analysis revealed significant treatment-by-year and yield-by-year interactions; therefore, data were analyzed separately by year. For each year, data were subjected to analysis of variance using the general linear models procedure of the Statistical Analysis System[10]. Means were separated using Duncan's multiple range test at P=0.05. The non-transformed means are presented with the Duncan's alphabet notation based on transformed values.

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[8] Mitsubishi VM221KC Head Threshing Combine. Mitsubishi Motors Corporation; 33-8, Shiba 5-Chome, Minato-Ku, Tokyo, Japan.
[9] Zaccaria PAZ/1DTA small grains milling machine. Zaccaria.; Rua Laranjal, 180 CEP: 13484-016 Cx Post 54 Limeira – SP, Brazil.
[10] Statistical Analysis System, version 9.01, SAS Institute Inc.; Cary, NC.

Table 1. Rice variety, planting, herbicide application, irrigation dates, and harvest dates for 2012 and 2013 at the David R. Wintermann Rice Research Station at Eagle Lake, TX.

Field Culture Data	Years	
	------------2012-----------	-----------2013----------
Rice Variety	CL152	CL152
	XL723	XL723
Planting Date	17-Apr	22-Apr
Herbicide application dates		
PRE[a]	17-Apr	23-Apr
EPOST	1-May	7-May
MPOST	7-May	14-May
LPOST	17-May	21-May
Irrigation		
Flush	24-Apr	21-May
Permanent Flood	22-May	17-Jun
Drained	2-Aug	19-Aug
Harvest date	13-Aug	28-Aug

[a]Abbreviations: PRE = preemergence application, EPOST = early postemergence application-applied when rice was at the 1-to 2-leaf stage, MPOST = mid post emergence application-applied when rice was at the 2-to 3-leaf stage, LPOST = late post emergence application-applied when rice was at the 3-to 4-leaf stage.

Table 2. Treatment list for the field study examining the efficacy of imazethapyr and propanil+thiobencarb timings in 2012 and 2013.

Herbicide treatment[a]	Rate	Application timings[b]
	kg ai ha^{-1}	
untreated		
imazethapyr fb	0.07	EPOST
imazethapyr	0.07	LPOST
imazethapyr fb	0.07	MPOST
imazethapyr	0.07	LPOST
imazethapyr+	0.07	EPOST
propanil+thiobencarb[c] fb	2.24+2.24	EPOST
imazethapyr	0.07	LPOST
imazethapyr+	0.07	MPOST
propanil+thiobencarb fb	2.24+2.24	MPOST
imazethapyr	0.07	LPOST
imazethapyr fb	0.07	EPOST
imazethapyr+	0.07	LPOST
propanil+thiobencarb	2.24+2.24	LPOST
imazethapyr fb	0.07	MPOST
imazethapyr+	0.07	LPOST
propanil+thiobencarb	2.24+2.24	LPOST

Table 2. Continued.

Herbicide treatment	Rate	Application Timings
	kg ai ha^{-1}	
clomazone fb	0.42	PRE
imazethapyr fb	0.07	EPOST
imazethapyr	0.07	LPOST
clomazone fb	0.42	PRE
imazethapyr fb	0.07	MPOST
imazethapyr	0.07	LPOST
clomazone fb	0.42	PRE
imazethapyr+	0.07	EPOST
propanil+thiobencarb fb	2.24+2.24	EPOST
imazethapyr	0.07	LPOST
clomazone fb	0.42	PRE
imazethapyr+	0.07	MPOST
propanil+thiobencarb fb	2.24+2.24	MPOST
imazethapyr	0.07	LPOST
clomazone fb	0.42	PRE
imazethapyr fb	0.07	EPOST
imazethapyr+	0.07	LPOST
propanil+thiobencarb	2.24+2.24	LPOST
clomazone fb	0.42	PRE
imazethapyr fb	0.07	MPOST
imazethapyr+	0.07	LPOST
propanil+thiobencarb	2.24+2.24	LPOST

[a]All treatments were applied with Agri-Dex, a non-ionic surfactant, at 1% v/v.
[b]PRE = pre emergence application, EPOST = early post emergence application-applied when rice was at the 1-to 2-leaf stage, MPOST = mid post emergence application-applied when rice was at the 2-to 3-leaf stage, LPOST = late post emergence application-applied when rice was at the 3-to 4-leaf stage; fb, followed by.
[c]Propanil+thiobencarb treatments were applied as RiceBeaux.

Efficacy of imazamox and propanil+thiobencarb Timings. Field research was conducted in 2013 at the David R. Wintermann Rice Research Station at Eagle Lake, TX. Cultural inputs for this study are presented in Table 3. This study focused on the efficacy of RiceBeaux and imazamox timings for the control of red rice. The experimental design was a randomized complete block with four replications. The plots were drill-seeded with CL152 at a seeding rate of 78.5 kg ha^{-1} and a planting depth of 2 cm. Field plots were planted with 7 rows at a 19-cm row spacing. Field plots were 2 m wide by 5 m long. To simulate red rice, XL723 was cross-drilled into the plots at a seeding rate of 39 kg ha^{-1}. The planting depth, number of rows, and row spacing were the same as the CL152 planting method. The field was fertilized and irrigated in accordance with the 2012 Texas Rice Production Guidelines (Way and McCauley, 2012). Maintenance insecticide applications for insect suppression were administered as needed. The soil at this location was a Nada fine sandy loam (fine-loamy, siliceous, active, hyperthermic Albaquic Hapludalfs) with soil textural fractions of 61% sand, 31% silt, and 8% clay. There were three herbicide applications, EPOST, MPOST, and LPOST. For EPOST applications, the rice was at the 1- to 2-leaf stage, at MPOST applications, the rice was at the 3- to 4-leaf stage, and at LPOST applications, the rice was at the 4- to 6-leaf stage. The 2-L mixes were applied with a backpack sprayer powered by CO_2 at 207 kPa. PRE, EPOST, and MPOST applications were made with TeeJet 11002VS, flat-fan nozzles. LPOST applications were made with 8002VS, flat-fan nozzles. The spray boom was a three-nozzle design with a nozzle spacing of 51-cm. All treatments were applied at a spray volume of 140 L ha^{-1}. All herbicidal rates were determined using the respective herbicide product label recommendations. All treatments were applied with a non-ionic surfactant, Agri-Dex, at a rate of 1% v/v. The treatment list for this study may be found in Table 4. There were four visual ratings with two separate categories, one based on crop response and one on XL723 control. Crop response ratings were based on chlorosis, stunting, and general injury. The ratings were conducted using a scale of 0 to 100. A rating of 0 phytotoxicity indicated no injury observed and a rating of 100 indicated complete plant death. A rating of 0 for XL723 control indicated no control and a rating of 100 indicated excellent XL723 control with no weeds present in the plot.

The middle 4 rows of each plot were harvested using a Mitsubishi Combine. Yield was adjusted to 12% moisture. Rice grain was milled using a Zaccaria milling machine.

Data were analyzed as a randomized complete block. Data were logarithmically transformed in order to achieve normality. Harvest weights were normally distributed therefore, data were not transformed. All untreated checks were excluded from data analysis. Normality was verified using the Shapiro-Wilke test. Data were subjected to analysis of variance using the general linear models procedure of the Statistical Analysis System. Means were separated using Tukey's studentized range test at P=0.05. The non-transformed means are presented with Tukey's alphabet notation based on transformed values.

Table 3. Rice variety, planting, herbicide application, irrigation dates, and harvest dates for 2013 at the David R. Wintermann Rice Research Station at Eagle Lake, TX.

Field Culture Data	Year
	------------2013-----------
Rice Variety	CL152
	XL723
Planting Date	22-Apr
Herbicide application dates	
EPOST[a]	7-May
MPOST	14-May
LPOST	21-May
Irrigation	
Flush	21-May
Permanent Flood	17-Jun
Drained	19-Aug
Harvest date	28-Aug

[a]EPOST = early post emergence application-applied when rice was at the 1-to 2-leaf stage, MPOST = mid post emergence application-applied when rice was at the 2-to 3-leaf stage, LPOST = late post emergence application-applied when rice was at the 3-to 4-leaf stage.

Table 4. Treatment list for the field study examining the efficacy of imazamox and propanil+thiobencarb timings in 2013.

Herbicide treatment[a]	Rate	Application Timings[b]
	kg ai ha^{-1}	
untreated		
imazamox fb	0.07	EPOST
imazamox	0.07	LPOST
imazamox fb	0.07	MPOST
imazamox	0.07	LPOST
imazamox+	0.07	EPOST
propanil+thiobencarb[c] fb	2.24+2.24	EPOST
imazamox	0.07	LPOST
imazamox+	0.07	MPOST
propanil+thiobencarb fb	2.24+2.24	MPOST
imazamox	0.07	LPOST
imazamox fb	0.07	EPOST
imazamox+	0.07	LPOST
propanil+thiobencarb	2.24+2.24	LPOST
imazamox fb	0.07	MPOST
imazamox+	0.07	LPOST
propanil+thiobencarb	2.24+2.24	LPOST

[a]All treatments were applied with Agri-Dex, a non-ionic surfactant, at 1% v/v.
[b]EPOST = early post emergence application-applied when rice was at the 1-to 2-leaf stage, MPOST = mid post emergence application-applied when rice was at the 2-to 3-leaf stage, LPOST = late post emeregence application-applied when rice was at the 3-to 4-leaf stage; fb, followed by.
[c]Propanil+thiobencarb treatments were applied as RiceBeaux.

The Effect of propanil+thiobencarb on the Translocation and Absorption of ^{14}C-imazamox. Research was conducted in 2013 at the Weed Science Laboratory at Texas A&M University. The experiment utilized ^{14}C-imazamox (2-[4,5-dihydro-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)3-pyridinecarboxylic acid-3-pyridinecarboxylic acid) and RiceBeaux to determine the absorption and translocation in TX-4 red rice. The trial consisted of two treatments at 8 timings with three replications of each treatment. An untreated check was included within each replication. The entire experiment was repeated. TX-4 red rice plants were grown in a growth chamber on a 14-hr photoperiod at 35° C until the three-leaf stage. Field rates of imazamox and imazomox+RiceBeaux were applied at 140 L ha^{-1} in an air driven spray chamber, equipped with one XR11002 flat-fan nozzle, to treatments 1 and 2, respectively. Red rice plants were at the three-leaf stage during application. Agri-Dex, a non-ionic surfactant, was applied with all treatments at 1% v/v. Immediately following field rate applications, treatments 1 and 2 were spotted with 1 μL ^{14}C imazamox on the adaxial surface of the middle leaf. There were four tissue and two leaf wash samples collected at each timing. The eight timings were as follows: 0, 1, 4, 8, 12, 24, 48 and 96 hr after treatment (HAT). The following samples were collected at each observation: leaf wash with 3 mL of H_20, leaf wash with 3 mL of 80% methanol, tissue sample above the treated leaf, tissue sample below the treated leaf, tissue sample of the treated leaf, and tissue sample of the roots. Leaf wash samples were combined with 10 mL of liquid scintillation cocktail. Tissue samples were dried at 55°C in an oven for 96 hr. The tissue samples were combusted in a biological sample oxidizer[11] in order to extract the ^{14}C. Combusted samples and leaf wash samples were then analyzed in a liquid scintillation counter[12]. Radioactivity was quantified in each sample.

Data were subjected to analysis of variance using the general linear models procedure of the Statistical Analysis System. Because there were no significant study main effect or interactions, data were pooled over runs and analyzed as a randomized complete block with two factors, treatment and timing. Treatment and timing were the main effects, while treatment by timing was the interaction effect. Data were logarithmically transformed and checked for normality using the Shapiro-Wilke test. Means were compared using contrast analysis at the $P<0.05$ level of significance.

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[11] OX500, biological sample oxidizer, RJ Harvey Instrument Corporation; 11 Jane Street Tappan, New York 10983.
[12] Beckman LS6500 liquid scintillation counter, Beckman Coulter Inc.; 250 South Kraemer Boulevard Brea, California 92821.

CHAPTER III

RESULTS AND DISCUSSION

Efficacy of imazethapyr and propanil+thiobencarb Timings. Analysis of variance revealed treatment-by-year and yield-by-year interactions between 2012 and 2013; therefore, data could not be pooled over years. Data are presented and discussed separately according to year.

In 2012, at the David R. Wintermann Rice Research Station in Eagle Lake, TX, all treatments provided 98% or more control of XL723 at 28 and 35 DAT. XL723 control data are presented in Table 5. Treatments that included a PRE application of clomazone did not provide significantly more control that those without. Treatments that included an EPOST application of imazethapyr or imazethapyr tank-mixed with propanil+thiobencarb provided 74 to 90% control 14 DAT and 92 to 100% control 21 DAT. Treatments that included an MPOST application of imazethapyr or imazethapyr tank-mixed with propanil+thiobencarb provided 52 to 65% control 14 DAT and 87 to 90% control 21 DAT.

At 14, 21, 28, and 35 DAT, there were no significant differences among treatments that included EPOST applications of imazethapyr tank-mixed with propanil+thiobencarb and treatments that included LPOST applications of imazethapyr tank-mixed with propanil+thiobencarb. These data indicate that propanil+thiobencarb may be tank-mixed with imazethapyr at either the EPOST or LPOST applications, with no significant effect on XL723 control. Treatments that did not include a tank-mix with propanil+thiobencarb provided 60 to 85% control of XL723 at 14 DAT and 87 to 100% control 21 DAT. Treatments that included propanil+thiobencarb, regardless of timing, provided 51 to 91% control of XL723 at 14 DAT and 87 to 100% control 21 DAT. These data indicated that propanil+thiobenarb did not significantly enhance control of XL723 when tank-mixed with imazethapyr.

No significant phytotoxicity was observed during visual ratings (Table 6). In 2012, rice yield ranged from 6717 to 10699 kg ha^{-1} (Table 7). The lowest yield (6717 kg ha^{-1}) was recorded in the untreated check, which was significantly lower than all other treatments. Among all other treatments, no significant differences were detected. These data indicate that in 2012, propanil+thiobencarb did not have a significant effect on yield. Milling quality was not recorded for this trial in 2012.

This field experiment was repeated in 2013 at the David R. Wintermann Rice Research Station in Eagle Lake, TX. XL723 control data are presented on Table 8. In 2013, all treatments provided 98% or more control of XL723 at 28 and 35 DAT. Treatments that included a PRE application of clomazone did not provide significantly more control that those without. Treatments that included an EPOST application of imazethapyr or imazethapyr tank-mixed with propanil+thiobencarb provided 67 to 85% control 14 DAT and 90 to 99% control 21 DAT. Treatments that included an MPOST application of imazethapyr or imazethapyr tank-mixed with propanil+thiobencarb provided 60 to 70% control 14 DAT and 80 to 91% control 21 DAT.

At 14, 21, 28, and 35 DAT, there were no significant differences between treatments that included EPOST applications of imazethapyr tank-mixed with propanil+thiobencarb and treatments that included LPOST applications of imazethapyr tank-mixed with propanil+thiobencarb. These data indicate that propanil+thiobencarb may be tank-mixed with imazethapyr at either the EPOST or LPOST applications, with no significant effect on XL723 control. Treatments that did not include a tank-mix with propanil+thiobencarb provided 60 to 77% control of XL723 at 14 DAT and 80 to 94% control 21 DAT. Treatments that included propanil+thiobencarb, regardless of timing, provided 60 to 85% control of XL723 at 14 DAT and 81 to 99% control 21 DAT. These data indicate that propanil+thiobenarb did not significantly enhance control of XL723 when tank-mixed with imazethapyr.

No significant phytotoxicity was observed during visual ratings (Table 9). Rice yield and milling data for 2013 are presented on Table 10. In 2013, rice yield ranged from 6336 to 7045 kg ha^{-1}. It is possible that colder temperatures in the spring of 2013 resulted in lower yields when compared to the yields of 2012. Imazethapyr EPOST fb imazethapyr tank-mixed with propanil+thiobencarb LPOST resulted in the lowest yield (6336 kg ha^{-1}) while clomazone PRE fb imazethapyr MPOST fb imazethapyr LPOST resulted in the highest yield (7045 kg ha^{-1}). Percent whole rice kernels plus broken rice kernels ranged from 72 to 73% while percent whole rice kernels ranged from 63 to 65%. These data suggest that propanil+thiobencarb, when tank-mixed with imazethapyr, does not have a significant effect on yield or milling quality.

Table 5. Effect of weed management systems on XL723 control 14, 21, 28, and 35 DAT[a] at the David R. Wintermann Rice Research Station at Eagle Lake, TX, in 2012.

			XL723 Control			
Herbicide treatment[b]	Rate	Application Timings[c]	14 DAT	21 DAT	28 DAT	35 DAT
	kg ai ha^{-1}		%			
untreated			0 e[d]	0 c	0 c	0 b
imazethapyr fb imazethapyr	0.07 0.07	EPOST LPOST	79.9 ab	92.3 ab	100 a	100 a
imazethapyr fb imazethapyr	0.07 0.07	MPOST LPOST	64.7 bcd	87.6 b	100 a	100 a
imazethapyr+ propanil+thiobencarb[e] fb imazethapyr	0.07 2.24+2.24 0.07	EPOST EPOST LPOST	87.4 a	100 a	100 a	100 a
imazethapyr+ propanil+thiobencarb fb imazethapyr	0.07 2.24+2.24 0.07	MPOST MPOST LPOST	59.8 d	89.9 ab	100 a	100 a
imazethapyr fb imazethapyr+ propanil+thiobencarb	0.07 0.07 2.24+2.24	EPOST LPOST LPOST	73.9 abc	100 a	100 a	100 a
imazethapyr fb imazethapyr+ propanil+thiobencarb	0.07 0.07 2.24+2.24	MPOST LPOST LPOST	51.8 d	89.7 ab	100 a	100 a

Table 5. Continued.

Herbicide treatment	Rate	Application Timings	XL723 Control 14 DAT	21 DAT	28 DAT	35 DAT
	kg ai ha^{-1}		-----------------------	%	-----------------------	
clomazone fb	0.42	PRE				
imazethapyr fb	0.07	EPOST	85 a	100 a	100 a	100 a
imazethapyr	0.07	LPOST				
clomazone fb	0.42	PRE				
imazethapyr fb	0.07	MPOST	60 d	87 b	100 a	100 a
imazethapyr	0.07	LPOST				
clomazone fb	0.42	PRE				
imazethapyr+	0.07	EPOST	91 a	98 a	98 b	100 a
propanil+thiobencarb fb	2.24+2.24	EPOST				
imazethapyr	0.07	LPOST				
clomazone fb	0.42	PRE				
imazethapyr+	0.07	MPOST	65 bcd	87 b	100 a	100 a
propanil+thiobencarb fb	2.24+2.24	MPOST				
imazethapyr	0.07	LPOST				
clomazone fb	0.42	PRE				
imazethapyr fb	0.07	EPOST	86 a	98 ab	100 a	100 a
imazethapyr+	0.07	LPOST				
propanil+thiobencarb	2.24+2.24	LPOST				
clomazone fb	0.42	PRE				
imazethapyr fb	0.07	MPOST	55 d	87 b	100 a	100 a
imazethapyr+	0.07	LPOST				
propanil+thiobencarb	2.24+2.24	LPOST				

[a]DAT = days after treatment.
[b]All treatments were applied with Agri-Dex, a non-ionic surfactant, at 1% v/v.
[c]PRE = pre emergence application, EPOST = early post emergence application-applied when rice was at the 1-to 2-leaf stage, MPOST = mid post emergence application-applied when rice was at the 2-to 3-leaf stage, LPOST = late post emergence application-applied when rice was at the 3-to 4-leaf stage; fb, followed by.
[d]Means within a column followed by one or more letters are not significantly different at 5% according to Duncan's Multiple Range Test.
[e]Propanil+thiobencarb treatments were applied as RiceBeaux.

Table 6. Response of imidazolinone-tolerant rice, variety CL152, 14, 21, 28, and 35 DAT[a] to post emergence herbicide treatments at the David R. Wintermann Rice Research Station at Eagle Lake, TX, in 2012.

			Crop Response[b]			
Herbicide treatment[c]	Rate	Application Timings[d]	14 DAT	21 DAT	28 DAT	35 DAT
	kg ai ha^{-1}		------------------------%------------------------			
untreated			0 a[e]	0 a	0 a	0 a
imazethapyr fb imazethapyr	0.07 0.07	EPOST LPOST	0 a	0 a	0 a	0 a
imazethapyr fb imazethapyr	0.07 0.07	MPOST LPOST	0 a	0 a	0 a	0 a
imazethapyr+ propanil+thiobencarb[f] fb imazethapyr	0.07 2.24+2.24 0.07	EPOST EPOST LPOST	0 a	0 a	0 a	0 a
imazethapyr+ propanil+thiobencarb fb imazethapyr	0.07 2.24+2.24 0.07	MPOST MPOST LPOST	0 a	0 a	0 a	0 a
imazethapyr fb imazethapyr+ propanil+thiobencarb	0.07 0.07 2.24+2.24	EPOST LPOST LPOST	0 a	0 a	0 a	0 a
imazethapyr fb imazethapyr+ propanil+thiobencarb	0.07 0.07 2.24+2.24	MPOST LPOST LPOST	0 a	0 a	0 a	0 a

Table 6. Continued.

Herbicide treatment	Rate	Application Timings	Crop Response 14 DAT	21 DAT	28 DAT	35 DAT
	kg ai ha^{-1}		----------------------%----------------------			
clomazone fb	0.42	PRE				
imazethapyr fb	0.07	EPOST	0 a	0 a	0 a	0 a
imazethapyr	0.07	LPOST				
clomazone fb	0.42	PRE	0 a	0 a	2.4 a	0 a
imazethapyr fb	0.07	MPOST				
imazethapyr	0.07	LPOST				
clomazone fb	0.42	PRE				
imazethapyr+	0.07	EPOST	0 a	0 a	0 a	0 a
propanil+thiobencarb fb	2.24+2.24	EPOST				
imazethapyr	0.07	LPOST				
clomazone fb	0.42	PRE				
imazethapyr+	0.07	MPOST	0 a	0 a	0 a	0 a
propanil+thiobencarb fb	2.24+2.24	MPOST				
imazethapyr	0.07	LPOST				
clomazone fb	0.42	PRE				
imazethapyr fb	0.07	EPOST	2.4 a	0 a	0 a	0 a
imazethapyr+	0.07	LPOST				
propanil+thiobencarb	2.24+2.24	LPOST				
clomazone fb	0.42	PRE				
imazethapyr fb	0.07	MPOST	0 a	0 a	0 a	0 a
imazethapyr+	0.07	LPOST				
propanil+thiobencarb	2.24+2.24	LPOST				

[a]DAT = days after treatment.
[b]Crop response = combination of stunting and interveinal chlorosis.
[c]All treatments were applied with Agri-Dex, a non-ionic surfactant, at 1% v/v.
[d]PRE = pre emergence application, EPOST = early post emergence application-applied when rice was at the 1-to 2-leaf stage, MPOST = mid post emergence application-applied when rice was at the 2-to 3-leaf stage, LPOST = late post emergence application-applied when rice was at the 3-to 4-leaf stage; fb, followed by.
[e]Means within a column followed by one or more letters are not significantly different at 5% according to Duncan's Multiple Range Test.
[f]Propanil+thiobencarb treatments were applied as RiceBeaux.

Table 7. Influence of post emergence herbicide treatments on average rice yield of imidazolinone-tolerant rice, variety CL152, at the David R. Wintermann Rice Research Station at Eagle Lake, TX, in 2012.

Herbicide treatment[a]	Rate	Application Timings[b]	Rice yield[c]
	kg ai ha^{-1}		kg ha^{-1}
untreated			6717 b[d]
imazethapyr fb imazethapyr	0.07 0.07	EPOST LPOST	10240 a
imazethapyr fb imazethapyr	0.07 0.07	MPOST LPOST	10654 a
imazethapyr+ propanil+thiobencarb[e] fb imazethapyr	0.07 2.24+2.24 0.07	EPOST EPOST LPOST	10127 a
imazethapyr+ propanil+thiobencarb fb imazethapyr	0.07 2.24+2.24 0.07	MPOST MPOST LPOST	10229 a
imazethapyr fb imazethapyr+ propanil+thiobencarb	0.07 0.07 2.24+2.24	EPOST LPOST LPOST	10080 a
imazethapyr fb imazethapyr+ propanil+thiobencarb	0.07 0.07 2.24+2.24	MPOST LPOST LPOST	10453 a

Table 7. Continued.

Herbicide treatment	Rate	Application Timings	Rice yield
	kg ai ha^{-1}		kg ha^{-1}
clomazone fb	0.42	PRE	
imazethapyr fb	0.07	EPOST	10420 a
imazethapyr	0.07	LPOST	
clomazone fb	0.42	PRE	
imazethapyr fb	0.07	MPOST	10513 a
imazethapyr	0.07	LPOST	
clomazone fb	0.42	PRE	
imazethapyr+	0.07	EPOST	10524 a
propanil+thiobencarb fb	2.24+2.24	EPOST	
imazethapyr	0.07	LPOST	
clomazone fb	0.42	PRE	
imazethapyr+	0.07	MPOST	10699 a
propanil+thiobencarb fb	2.24+2.24	MPOST	
imazethapyr	0.07	LPOST	
clomazone fb	0.42	PRE	
imazethapyr fb	0.07	EPOST	10340 a
imazethapyr+	0.07	LPOST	
propanil+thiobencarb	2.24+2.24	LPOST	
clomazone fb	0.42	PRE	
imazethapyr fb	0.07	MPOST	10376 a
imazethapyr+	0.07	LPOST	
propanil+thiobencarb	2.24+2.24	LPOST	

[a]All treatments were applied with Agri-Dex, a non-ionic surfactant, at 1% v/v.
[b]PRE = pre emergence application, EPOST = early post emergence application-applied when rice was at the 1-to 2-leaf stage, MPOST = mid post emergence application-applied when rice was at the 2-to 3- leaf stage, LPOST = late post emergence application-applied when rice was at the 3-to 4-leaf stage; fb, followed by.
[c]Yield was adjusted to 12% moisture.
[d]Means within a column followed by one or more letters are not significantly different at 5% according to Duncan's Multiple Range Test.
[e]Propanil+thiobencarb treatments were applied as RiceBeaux.

Table 8. Effect of weed management systems on XL723 control 14, 21, 28, and 35 DAT[a] at the David R. Wintermann Rice Research Station at Eagle Lake, TX, in 2013.

Herbicide treatment[b]	Rate	Application Timings[c]	XL723 Control			
			14 DAT	21 DAT	28 DAT	35 DAT
	kg ai ha^{-1}		------------------------	%	------------------------	
untreated			0 d[d]	0 d	0 b	0 b
imazethapyr fb imazethapyr	0.07 0.07	EPOST LPOST	67 bc	90 b	100 a	100 a
imazethapyr fb imazethapyr	0.07 0.07	MPOST LPOST	60 c	80 c	98 a	99 a
imazethapyr+ propanil+thiobencarb[e] fb imazethapyr	0.07 2.24+2.24 0.07	EPOST EPOST LPOST	85 a	99 a	100 a	100 a
imazethapyr+ propanil+thiobencarb fb imazethapyr	0.07 2.24+2.24 0.07	MPOST MPOST LPOST	62 c	84 c	98 a	100 a
imazethapyr fb imazethapyr+ propanil+thiobencarb	0.07 0.07 2.24+2.24	EPOST LPOST LPOST	77 ab	95 ab	100 a	100 a
imazethapyr fb imazethapyr+ propanil+thiobencarb	0.07 0.07 2.24+2.24	MPOST LPOST LPOST	60 c	84 c	99 a	100 a

Table 8. Continued.

Herbicide treatment	Rate	Application Timings	XL723 Control 14 DAT	21 DAT	28 DAT	35 DAT
	kg ai ha^{-1}		----------------------------%----------------------------			
clomazone fb	0.42	PRE				
imazethapyr fb	0.07	EPOST	77 ab	94 ab	100 a	100 a
imazethapyr	0.07	LPOST				
clomazone fb	0.42	PRE				
imazethapyr fb	0.07	MPOST	60 c	83 c	99 a	100 a
imazethapyr	0.07	LPOST				
clomazone fb	0.42	PRE				
imazethapyr+	0.07	EPOST	82 ab	94 ab	100 a	100 a
propanil+thiobencarb fb	2.24+2.24	EPOST				
imazethapyr	0.07	LPOST				
clomazone fb	0.42	PRE				
imazethapyr+	0.07	MPOST	70 abc	91 b	100 a	100 a
propanil+thiobencarb fb	2.24+2.24	MPOST				
imazethapyr	0.07	LPOST				
clomazone fb	0.42	PRE				
imazethapyr fb	0.07	EPOST	80 ab	95 ab	100 a	100 a
imazethapyr+	0.07	LPOST				
propanil+thiobencarb	2.24+2.24	LPOST				
clomazone fb	0.42	PRE				
imazethapyr fb	0.07	MPOST	60 c	81 c	99 a	99 a
imazethapyr+	0.07	LPOST				
propanil+thiobencarb	2.24+2.24	LPOST				

[a]DAT = days after treatment.
[b]All treatments were applied with Agri-Dex, a non-ionic surfactant, at 1% v/v.
[c]PRE = pre emergence application, EPOST = early post emergence application-applied when rice was at the 1-to 2-leaf stage, MPOST = mid post emergence application-applied when rice was at the 2-to 3-leaf stage, LPOST = late post emergence application-applied when rice was at the 3-to 4 leaf stage; fb, followed by.
[d]Means within a column followed by one or more letters are not significantly different at 5% according to Duncan's Multiple Range Test.
[e]Propanil+thiobencarb treatments were applied as RiceBeaux.

Table 9. Response of imidazolinone-tolerant rice, variety CL152, 14, 21, 28, and 35 DAT[a] to post emergence herbicide treatments at the David R. Wintermann Rice Research Station at Eagle Lake, TX, in 2013.

Herbicide treatment[c]	Rate	Application Timings[d]	Crop Response[b]			
			14 DAT	21 DAT	28 DAT	35 DAT
	kg ai ha^{-1}		------------------------%------------------------			
untreated			0 a[e]	0 a	0 a	0 a
imazethapyr fb imazethapyr	0.07 0.07	EPOST LPOST	0 a	1 a	0 a	0 a
imazethapyr fb imazethapyr	0.07 0.07	MPOST LPOST	0 a	0 a	0 a	0 a
imazethapyr+ propanil+thiobencarb[f] fb imazethapyr	0.07 2.24+2.24 0.07	EPOST EPOST LPOST	0 a	0 a	0 a	0 a
imazethapyr+ propanil+thiobencarb fb imazethapyr	0.07 2.24+2.24 0.07	MPOST MPOST LPOST	0 a	0 a	0 a	0 a
imazethapyr fb imazethapyr+ propanil+thiobencarb	0.07 0.07 2.24+2.24	EPOST LPOST LPOST	0 a	0 a	1 a	0 a
imazethapyr fb imazethapyr+ propanil+thiobencarb	0.07 0.07 2.24+2.24	MPOST LPOST LPOST	0 a	1 a	0 a	0 a

Table 9. Continued.

Herbicide treatment	Rate	Application Timings	Crop Response 14 DAT	21 DAT	28 DAT	35 DAT
	kg ai ha^{-1}		------------------------%----------------------			
clomazone fb imazethapyr fb imazethapyr	0.42 0.07 0.07	PRE EPOST LPOST	0 a	1 a	3 a	0 a
clomazone fb imazethapyr fb imazethapyr	0.42 0.07 0.07	PRE MPOST LPOST	0 a	1 a	0 a	0 a
clomazone fb imazethapyr+ propanil+thiobencarb fb imazethapyr	0.42 0.07 2.24+2.24 0.07	PRE EPOST EPOST LPOST	0 a	2 a	1 a	0 a
clomazone fb imazethapyr+ propanil+thiobencarb fb imazethapyr	0.42 0.07 2.24+2.24 0.07	PRE MPOST MPOST LPOST	0 a	0 a	1 a	0 a
clomazone fb imazethapyr fb imazethapyr+ propanil+thiobencarb	0.42 0.07 0.07 2.24+2.24	PRE EPOST LPOST LPOST	0 a	1 a	0 a	0 a
clomazone fb imazethapyr fb imazethapyr+ propanil+thiobencarb	0.42 0.07 0.07 2.24+2.24	PRE MPOST LPOST LPOST	0 a	1 a	1 a	0 a

[a]DAT = days after treatment.
[b]Crop response = combination of stunting and interveinal chlorosis.
[c]All treatments were applied with Agri-Dex, a non-ionic surfactant, at 1% v/v.
[d]PRE = pre emergence application, EPOST = early post emergence application-applied when rice was at the 1-to 2-leaf stage, MPOST = mid post emergence application-applied when rice was at the 2-to 3-leaf stage, LPOST = late post emergence application-applied when rice was at the 3-to 4-leaf stage; fb, followed by.
[e]Means within a column followed by one or more letters are not significantly different at 5% according to Duncan's Multiple Range Test.
[f]Propanil+thiobencarb treatments were applied as RiceBeaux.

Table 10. Influence of post emergence herbicide treatments on average rice yield of imidazolinone-tolerant rice, variety CL152, at the David R. Wintermann Rice Research Station at Eagle Lake, TX, in 2013.

Herbicide treatment[a]	Rate	Application Timings[b]	Rice yield[c]	Milling Total[d]	Milling Whole[e]
	kg ai ha^{-1}		kg ha^{-1}	------------%-----------	
untreated			6549 ab[f]	72.5 a	63.4 bcd
imazethapyr fb imazethapyr	0.07 0.07	EPOST LPOST	6643 ab	72.1 a	63.8 abcd
imazethapyr fb imazethapyr	0.07 0.07	MPOST LPOST	6440 ab	72.1 a	63.4 cd
imazethapyr+ propanil+thiobencarb[g] fb imazethapyr	0.07 2.24+2.24 0.07	EPOST EPOST LPOST	6549 ab	72.3 a	64.3 abc
imazethapyr+ propanil+thiobencarb fb imazethapyr	0.07 2.24+2.24 0.07	MPOST MPOST LPOST	6696 ab	72.4 a	64.4 abc
imazethapyr fb imazethapyr+ propanil+thiobencarb	0.07 0.07 2.24+2.24	EPOST LPOST LPOST	6336 b	71.8 a	63 d
imazethapyr fb imazethapyr+ propanil+thiobencarb	0.07 0.07 2.24+2.24	MPOST LPOST LPOST	6648 ab	72.1 a	63.6 abcd

Table 10. Continued.

Herbicide treatment	Rate	Application Timings	Rice yield	Milling Total	Milling Whole
	kg ai ha^{-1}		kg ha^{-1}	----------%----------	
clomazone fb imazethapyr fb imazethapyr	0.42 0.07 0.07	PRE EPOST LPOST	6794 ab	72.2 a	64.1 abcd
clomazone fb imazethapyr fb imazethapyr	0.42 0.07 0.07	PRE MPOST LPOST	7045 a	72.3 a	64.7 ab
clomazone fb imazethapyr+ propanil+thiobencarb fb imazethapyr	0.42 0.07 2.24+2.24 0.07	PRE EPOST EPOST LPOST	6816 ab	72 a	64.3 abc
clomazone fb imazethapyr+ propanil+thiobencarb fb imazethapyr	0.42 0.07 2.24+2.24 0.07	PRE MPOST MPOST LPOST	6774 ab	72.1 a	64.4 abc
clomazone fb imazethapyr fb imazethapyr+ propanil+thiobencarb	0.42 0.07 0.07 2.24+2.24	PRE EPOST LPOST LPOST	6957 ab	72.1 a	64.6 abc
clomazone fb imazethapyr fb imazethapyr+ propanil+thiobencarb	0.42 0.07 0.07 2.24+2.24	PRE MPOST LPOST LPOST	6609 ab	72.3 a	64.9 a

[a]All treatments were applied with Agri-Dex, a non-ionic surfactant, at 1% v/v.
[b] PRE = pre emergence application, EPOST = early post emergence application-applied when rice was at the 1-to 2-leaf stage, MPOST = mid post emergence application-applied when rice was at the 2-to 3-leaf stage, LPOST = late post emergence application-applied when rice was at the 3-to 4-leaf stage; fb, followed by.

[c]Yield was adjusted to 12% moisture.

[d]Milling total = % Milled Whole Rice Kernels + % Broken Rice Kernels of 100 g of milled rice.

[e]Milling whole = % Milled Whole Rice Kernels of 100 g of milled rice.
[f]Means within a column followed by one or more letters are not significantly different at 5% according to Duncan's Multiple Range Test.
[g]Propanil+thiobencarb treatments were applied as RiceBeaux.

Efficacy of imazamox and propanil+thiobencarb Timings. This field study was conducted in 2013, at the David R. Wintermann Rice Research Station in Eagle Lake, TX. Treatments that did not include a propanil+thiobencarb application provided 62 to 75% and 87 to 94% control of XL723 14 and 21 DAT, respectively (Table 11). Treatments that included a propanil+thiobencarb application, regardless of timing, provided 57 to 85% control 14 DAT and 86 to 100% control 21 DAT. Treatments that did not include an EPOST application resulted in control ranging from 57 to 62% and 86 to 87% 14 and 21 DAT, respectively. When propanil+thiobencarb was included EPOST, control was significantly increased at 14 and 21 DAT when compared to treatments with MPOST or LPOST propanil+thiobencarb applications. At 28 and 35 DAT, all treatments provided excellent control of XL723, with the exception of the untreated check. These data suggest that propanil+thiobencarb does not enhance control of XL723 when tank-mixed with imazamox.

Crop response data is given on Table 12. No phytoxicity was observed during visual ratings. Rice yield and milling data are presented on Table 13. In 2013, rice yield ranged from 6182 to 6649 kg ha $^{-1}$. Percent whole rice kernels plus broken rice kernels ranged from 72.5 to 73.1% while percent whole rice kernels ranged from 64 to 65%. There were no significant differences detected among treatments in yield or milling quality. These data suggest that propanil+thiobencarb did not have a significant effect on milling quality, crop injury, or yield.

Table 11. Effect of weed management systems on XL723 control 14, 21, 28, and 35 DAT[a] at the David R. Wintermann Rice Research Station at Eagle Lake, TX, in 2013.

			XL723 Control			
Herbicide treatment[b]	Rate	Application Timings[c]	14 DAT	21 DAT	28 DAT	35 DAT
	kg ai ha^{-1}		--------------------------%------------------------			
untreated			0 d[d]	0 d	0 b	0 b
imazamox fb imazamox	0.07 0.07	EPOST LPOST	75 ab	94 ab	100 a	100 a
imazamox fb imazamox	0.07 0.07	MPOST LPOST	62 bc	87 b	100 a	100 a
imazamox+ propanil+thiobencarb[e] fb imazamox	0.07 2.24+2.24 0.07	EPOST EPOST LPOST	85 a	100 a	100 a	100 a
imazamox+ propanil+thiobencarb fb imazamox	0.07 2.24+2.24 0.07	MPOST MPOST LPOST	57 c	87 b	100 a	100 a
imazamox fb imazamox+ propanil+thiobencarb	0.07 0.07 2.24+2.24	EPOST LPOST LPOST	70 abc	95 ab	100 a	100 a
imazamox fb imazamox+ propanil+thiobencarb	0.07 0.07 2.24+2.24	MPOST LPOST LPOST	57 c	86 b	100 a	100 a

[a]DAT = days after treatment.
[b]All treatments were applied with Agri-Dex, a non-ionic surfactant, at 1% v/v.
[c]EPOST = early post emergence application-applied when rice was at the 1-to 2-leaf stage, MPOST = mid post emergence application-applied when rice was at the 2-to 3-leaf stage, LPOST = late post emergence application-applied when rice was at the 3-to 4-leaf stage; fb, followed by.
[d]Means within a column followed by one or more letters are not significantly different at 5% according to Tukey's Studentized Range Test.
[e]Propanil+thiobencarb treatments were applied as RiceBeaux.

Table 12. Response of imidazolinone-tolerant rice, variety CL152, 14, 21, 28, and 35 DAT[a] to post emergence herbicide treatments at the David R. Wintermann Rice Research Station at Eagle Lake, TX, in 2013.

Herbicide treatment[c]	Rate	Application Timings[d]	Crop Response[b] 14 DAT	21 DAT	28 DAT	35 DAT
	kg ai ha^{-1}		------------------------%	------------------------		
untreated			0 a[e]	0 a	0 a	0 a
imazamox fb imazamox	0.07 0.07	EPOST LPOST	0 a	0 a	0 a	0 a
imazamox fb imazamox	0.07 0.07	MPOST LPOST	0 a	0 a	0 a	0 a
imazamox+ propanil+thiobencarb[f] fb imazamox	0.07 2.24+2.24 0.07	EPOST EPOST LPOST	0 a	0 a	0 a	0 a
imazamox+ propanil+thiobencarb fb imazamox	0.07 2.24+2.24 0.07	MPOST MPOST LPOST	0 a	0 a	0 a	0 a
imazamox fb imazamox+ propanil+thiobencarb	0.07 0.07 2.24+2.24	EPOST LPOST LPOST	0 a	0 a	0 a	0 a
imazamox fb imazamox+ propanil+thiobencarb	0.07 0.07 2.24+2.24	MPOST LPOST LPOST	0 a	0 a	0 a	0 a

[a]DAT = days after treatment

[b]Crop response = combination of stunting and interveinal chlorosis.

[c]All treatments were applied with Agri-Dex, a non-ionic surfactant, at 1% v/v.

[d]EPOST = early post emergence application-applied when rice was at the 1-to 2-leaf stage, MPOST = mid post emergence application-applied when rice was at the 2-to 3-leaf stage, LPOST = late post emergence application-applied when rice was at the 3-to 4-leaf stage; fb, followed by.

[e]Means within a column followed by one or more letters are not significantly different at 5% according to Duncan's Multiple Range Test.

[f]Propanil+thiobencarb treatments were applied as RiceBeaux.

Table 13. Influence of post emergence herbicide treatments on average rice yield and milling quality of imidazolinone-tolerant rice, variety CL152, at the David R. Wintermann Rice Research Station at Eagle Lake, TX, in 2013.

Herbicide treatment[a]	Rate	Application Timings[b]	Rice yield[c]	Milling Total[d]	Milling Whole[e]
	kg ai ha^{-1}		kg ha^{-1}	------------%------------	
untreated			6649 a[f]	72.5 a	64.1 a
imazamox fb imazamox	0.07 0.07	EPOST LPOST	6182 a	73.1 a	65.3 a
imazamox fb imazamox	0.07 0.07	MPOST LPOST	6227 a	72.8 a	64.5 a
imazamox+ propanil+thiobencarb[g] fb imazamox	0.07 2.24+2.24 0.07	EPOST EPOST LPOST	6228 a	72.7 a	64.7 a
imazamox+ propanil+thiobencarb fb imazamox	0.07 2.24+2.24 0.07	MPOST MPOST LPOST	6217 a	72.7 a	64.0 a
imazamox fb imazamox+ propanil+thiobencarb	0.07 0.07 2.24+2.24	EPOST LPOST LPOST	6212 a	72.8 a	65.1 a
imazamox fb imazamox+ propanil+thiobencarb	0.07 0.07 2.24+2.24	MPOST LPOST LPOST	6268 a	72.7 a	64.8 a

[a]EPOST = early post emergence application-applied when rice was at the 1-to 2-leaf stage, MPOST = mid post emergence application-applied when rice was at the 2-to 3-leaf stage, LPOST = late post emergence application-applied when rice was at the 3-to 4-leaf stage; fb, followed by.

[b]All treatments were applied with Agri-Dex, a non-ionic surfactant, at 1% v/v.

[c]Yield was adjusted to 12% moisture.

[d]Milling total = % Milled Whole Rice Kernels + %Broken Rice Kernels of a 100 g of milled rice.

[e]Milling whole = % Milled Whole Rice Kernels of a 100 g of milled rice.

[f]Means within a column followed by one or more letters are not significantly different at 5% according to Tukey's Studentized Range Test.

[g]Propanil+thiobencarb treatments were applied as RiceBeaux.

The Effect of propanil+thiobencarb on the Translocation and Absorption of ^{14}C-imazamox. In 2013, at the Weed Science Laboratory at Texas A&M University, ^{14}C-imazamox recovery rates for both treatments were > 93%. Translocation and absorption data are presented on Table 14. Significantly more ^{14}C-imazamox was recovered in the water wash when a tank-mix of imazamox and propanil+thiobencarb was applied when compared to imazamox alone at 0, 1, 4, 12, and 48 HAT. This suggests that propanil+thiobencarb may have slowed ^{14}C-imazamox absorption into the cuticle. However, imazamox alone had significantly higher radioactivity recovered in the methanol wash at all sample timings. At 24 HAT, imazamox alone resulted in higher ^{14}C-imazamox recovery (10.2%) in the methanol wash compared to imazamox+propanil+thiobencarb (3.2%). These data suggest that imazamox, being a hydrophilic compound, was less suited to crossing the cuticle than propanil+thiobencarb, a lipophilic compound. Even though significantly more ^{14}C-imazamox was crossing into the cuticle at earlier timings when imazamox was applied alone, it was unable to move out of the cuticle to travel to the site of action.

Radioactivity recovered in the treated leaf ranged from 2.5 to 8.2% when propanil+thiobencarb was applied and from 2.5 to 5.2% when imazamox alone was applied. Significantly more ^{14}C-imazamox was recovered (5.2%) in the treated leaf at 0 HAT when imazamox was applied alone. However, more radioactivity was recovered in the treated leaf at 8, 24, 48, and 96 HAT when imazamox was applied with propanil+thiobencarb. Significantly greater translocation of ^{14}C-imazamox to the plant tissue above the treated leaf occurred in the presence of propanil+thiobencarb at 24

HAT. When imazamox was applied alone, significantly greater radioactivity was recovered below the treated leaf at 0 and 4 HAT. However, at 96 HAT, significantly more ^{14}C-imazamox was recovered (3.8%) below the treated leaf when propanil+thiobencarb was applied. At 4 and 12 HAT, there was more radioactivity translocated to the roots when imazamox was applied alone. However, at 96 HAT, significantly more ^{14}C-imazamox was recovered from the roots (1.9%).

Among imazamox+propanil+thiobencarb treatments, regardless of timing, absorption recovery ranged from 3.3% at 0 HAT to 14.8% at 96 HAT. Among imazamox alone treatments, ^{14}C-imazamox absorption ranged from 5.7% at 4 HAT to 8.1% at 48 HAT. Imazamox alone had a significantly higher amount of absorption at 0 HAT (7%). However, the majority of absorbed radioactivity was recovered in the methanol wash, and therefore was located in the cuticle. As time progressed, imazamox+propanil+thiobencarb had significantly higher ^{14}C-imazamox absorption at 8, 24, 48, and 96 HAT. These data suggest that although it took longer for the radioactivity to move from the leaf surface to the cuticle when imazamox+propanil+thiobencarb was applied, it was able to traverse the cuticle in order to move to the site of action. Among imazamox+propanil+thiobencarb treatments, ^{14}C-imazamox translocation ranged from 0.5% at 0 HAT to 7.5% at 48 HAT. Among imazamox alone treatments, translocation ranged from 0.9% at 0 HAT to 6.2% at 48 HAT. The highest amount of translocation for both treatments occurred at 48 HAT. There were no significant differences in translocation between treatments at all timings.

Table 14. Distribution of ^{14}C-imazamox plus propanil+thiobencarb at different time intervals following application to red rice plants.

	^{14}C-imazamox activity							
Treatment[b]	Water Wash	Methanol Wash	TL	Above TL	Below TL	Roots	Absorbed	Translocated
	0 hours							
	---% of applied---							
Imaz[c]	76.2***[a]	16.1***	5.2**	0.6	0.2*	0.1	7.0**	0.9
Imaz+RB	99.5***	1.0***	2.5**	0.3	0.1*	0.1	3.3**	0.5
	1 hours							
	---% of applied---							
Imaz	81.3***	10.1***	5.0	0.9	0.4	0.2	6.9	1.6
Imaz+RB	96.8***	1.8***	4.5	0.9	0.4	0.2	6.4	1.5
	4 hours							
	---% of applied---							
Imaz	81.0**	13.2***	3.1	0.8	1.0**	0.4*	5.7	2.5
Imaz+RB	92.2**	2.6***	2.5	0.6	0.5**	0.2*	4.0	1.4
	8 hours							
	---% of applied---							
Imaz	84.7	8.0***	3.2**	1.5	1.3	0.8	6.9*	3.6
Imaz+RB	89.4	2.0***	6.7**	3.0	1.2	0.6	11.6*	4.9
	12 hours							
	---% of applied---							
Imaz	78.7*	10.0***	3.1	0.9	1.8	1.3**	6.5	4.3
Imaz+RB	88.1*	2.9***	4.6	1.7	1.3	0.5**	8.5	3.8
	24 hours							
	---% of applied---							
Imaz	75.2	10.2***	2.8***	1.3*	2.4	1.5	8.0**	5.2
Imaz+RB	80.0	3.2***	8.2***	3.4*	2.1	1.0	14.8**	6.5
	48 hours							
	---% of applied---							
Imaz	69.0**	17.7***	2.5**	1.6	2.5	1.8	8.1*	6.2
Imaz+RB	78.9**	3.7***	6.2**	1.7	3.7	1.8	13.8*	7.5
	96 hours							
	---% of applied---							
Imaz	79.8	15.1**	2.8**	1.2	1.4**	0.8**	6.2**	3.6
Imaz+RB	72.4	5.7**	7.2**	1.6	3.8**	1.9**	14.8**	7.1

[a]Means followed by *,**, or *** are significantly different at the 0.05, 0.01, and 0.001 levels of significance, respectively.
[b]All treatments included Agri-Dex, a non-ionic surfactant, at 1% v/v.
[c]Imaz = imazamox-applied as Beyond, RB = propanil+thiobencarb-applied as RiceBeaux.

CHAPTER IV

CONCLUSION

Field experiments were conducted in 2012 and 2013 at the David R. Wintermann Rice Research Station in Eagle Lake, TX. In both years, imazethapyr alone and imazethapyr+propanil+thiobencarb treatments, were evaluated for control of XL723, which was used to simulate red rice in the field. In 2012, imazethapyr alone treatments provided 60 to 85% control of XL723 14 DAT and 87 to 100% control 21 DAT. Imazethapyr+propanil+thiobencarb combinations provided 51 to 91% control of XL723 14 DAT and 87 to 100% control 21 DAT. During both years, all treatments provided greater than 98% control of XL723 28 and 35 DAT.

In 2013, treatments that did not include a tank-mix with propanil+thiobencarb provided 60 to 77% control of XL723 14 DAT and 80 to 94% control 21 DAT. Imazethapyr+propanil+thiobencarb combinations provided 60 to 85% control of XL723 14 DAT and 81 to 99% control 21 DAT. These data indicated that for both years, Imazethapyr+propanil+thiobencarb combinations provided no additional control of XL723 compared to imazethapyr alone.

In 2013, experiments were conducted to evaluate the interaction of propanil+thiobencarb on imazamox in the field. Imazamox alone provided 62 to 75% and 87 to 94% control of XL723 14 and 21 DAT, respectively. Imazamox+propanil+thiobencarb treatments provided 57 to 85% control 14 DAT and 86 to 100% control 21 DAT. All treatments provided excellent control 28 and 35 DAT.

Based on these data, imazamox+propanil+thiobencarb combinations provided no additional control of XL723 compared to imazamox alone.

In the laboratory experiments, significantly more ^{14}C-imazamox was recovered from the cuticle when imazamox was applied alone, resulting in lower amounts of imazamox absorption. In contrast, imazamox+propanil+thiobencarb resulted in significantly higher absorption of ^{14}C-imazamox at 24, 48, and 96 hr after treatment. Results indicated propanil+thiobencarb may allow more imazamox to cross the lipophilic cuticle to reach the sites of action, which may result in enhanced red rice control.

The data for field experiments conducted in 2012 and 2013 indicated propanil+thiobencarb did not significantly improve XL723 control. However, results may have differed if red rice was utilized, as opposed to XL723. Data for the laboratory study conducted in 2013 indicated that propanil+thiobencarb significantly improved imazamox absorption in red rice plants. In the presence of red rice, the increased herbicide absorption that propanil+thiobencarb tank-mixes provide may result in the enhanced red rice control needed to slow the development of resistance in a Clearfield program.

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