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Interactions of Herbicide Mixtures in Imidazolinone-resistant Rice

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INTERACTIONS OF HERBICIDE MIXTURES IN IMIDAZOLINONE-RESISTANT RICE

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TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

Propanil has long been a staple of weed management in rice production. The introduction of IR rice allowed for the use of imidazolinone herbicides in crop for the control of red rice. Six studies were conducted in 2011 and 2012 to evaluate the weed control interactions, synergistic, antagonistic, or additive, of imazethapyr or imazamox when mixed in a single application with propanil, thiobencarb, or a pre-packaged mixture of propanil plus thiobencarb. Blouin's modified Colby's was used to determine if a synergistic, antagonistic, or additive response occurred.

Two studies were established to evaluate imazethapyr at 0 and 70 g ha^{-1}, or imazamox at 0 and 44 g ha^{-1}, when mixed with propanil at 1680 or 3360 g ha^{-1}, thiobencarb at 1680 or 3360 g ha^{-1}, a pre-packaged mix of propanil plus thiobencarb at 840 or 1680 g ha^{-1}, and no mixture herbicide. A synergistic response occurred for red rice control at 7, 14, 21, and 49 DAT when imazethapyr was mixed with propanil plus thiobencarb at 840 and 1680 g ha^{-1}; and at 7, 14, 21, and 49 DAT when imazamox was mixed with propanil plus thiobencarb at 1680 g ha^{-1}.

Two other studies were established to evaluate imazethapyr at 0 and 70 g ha^{-1}, or imazamox at 0 and 44 g ha^{-1}, was mixed with propanil at 0, 1.12, 2.24, 3.36, or 4.48 kg ha^{-1}.A synergistic response occurred for red rice control at 7 and 14 DAT when imazethapyr was mixed with propanil at 2.24, 3.36, and 4.48 kg ha^{-1}; and at 7, 14, 21, 28, 35, and 49 DAT when imazamox was mixed with propanil at 3.31 and 4.48 kg ha^{-1}.

The addition of propanil, thiobencarb, or a pre-packaged mixture of propanil plus thiobencarb in a mixture with imazethapyr or imazamox can increase the overall weed spectrum from the herbicides applied alone. The addition of multiple herbicide modes of action in a single application can help prevent or slow the development of herbicide resistant weeds as well as red rice outcrossing with IR rice.

Chapter 1
Introduction

Red rice (*Oryza sativa* L.) has been recognized as a weed in U.S. rice (*Oryza sativa* L.) fields for over 150 years and has become increasingly troublesome in cultivated rice fields throughout the southern U.S. (Craigmiles 1978; Khodayari et al. 1987; Smith 1974; Smith 1981; Webster 2004). In the United States red rice generally produces more tillers and panicles per plant than production rice (Noldin et al. 1999), and this is why it is highly competitive with production rice.

Red rice belongs to the same genus and species as cultivated rice and shares many of its morphological, biochemical, and physiological characteristics; therefore, inherently making red rice difficult to control in cultivated rice (Cohn and Hughes 1981; Smith et al. 1977). The presence of red rice as a weed in rice can lower grain quality due to seed contamination, whereas removal of the red pericarp from the red rice grain during milling increases the proportion of broken grains with consequent grade reduction (Smith, 1981; Webster 2014). Physiological similarities between red rice and domestic rice limit available herbicide control options in conventional rice (Baldwin 1978; Webster et al. 2012b); however, this changed with the development of imidazolinone resistant (IR) rice (Croughan 1994).

In 1993, rice was identified and exhibited tolerance to the imidazolinone class of herbicides, which provided control of red rice with no effect on the crop (Croughan 1994; Pellerin et al. 2004; Steele et al. 2002; Webster and Masson 2001). The imidazolinone herbicides provide broad-spectrum weed control with both soil and foliar activity by inhibiting the acetohydroxy acid synthase enzyme (AHAS, EC 2.2.1.6), also known as acetolactate synthase enzyme (Stidham and Singh 1991; Stougaard et al. 1990).

Pellerin et al. (2004) reported barnyardgrass [Echinochloa crus-galli (L.) P. Beauv.] control was 66% with a preemergence application of imazethapyr at 70 g ha^{-1} with no postemergence application; however, control increased to 81% at 35 days after treatment with the addition of imazethapyr at 70 g ha^{-1} applied postemergence. Research conducted in Texas reported similar findings (Steele et al. 2002). Red rice control was 82 to 95% with imazethapyr applied postemergence at 70 to 140 g ha^{-1} (Carlson et al. 2012; Webster et al. 2012b; Webster and Masson 2001).

Imazethapyr is labeled for use at 70 to 105 g ha^{-1}; however, imazethapyr has reduced activity on many broadleaf weeds infesting rice (Ottis et al. 2002; Webster et al. 2012b; Zhang et al. 2001). Richburg et al. (1995) reported inconsistent control of yellow nutsedge (*Cyperus esculentus* L.) with imazethapyr at 18, 36, 54, and 72 g ha^{-1} when applied postemergence. Researchers have also demonstrated the lack of activity of imazethapyr on weeds in the Fabaceae family (Judd et al. 1999). Rice production provides favorable growing conditions for both hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh] and Indian jointvetch (*Aeschynomene indica* L.) (Lorenzi and Jeffery 1987), and the use of imazethapyr in IR rice provides minimal control of these two weeds (Webster and Masson 2001; Zhang et al. 2001).

Imazamox is another imidazolinone herbicide labeled for use in IR rice. Imazamox is labeled at rates of 44 to 53 g ha^{-1}, and it is normally applied at a late season application on rice in the panicle initiation (PI) stage of growth to 14 days after PI (Anonymous 2009; Webster 2014). This is a useful tool for late season application due to its lack of residual activity (Senseman 2007). However, it is weak on many of the same weeds as imazethapyr (Webster et al. 2012b).

In addition to red rice, a number of grass and broadleaf weeds exist in rice culture (Braverman 1995). The most common weeds in Louisiana include broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster], ducksalad [*Heteranthera limosa* (Sw.) Willd.], hemp sesbania, spreading dayflower (*Commelina diffusa* Burm. f.), barnyardgrass, alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.], and Indian jointvetch.

As previous research has shown applying two or more herbicides sequentially or in mixture is commonly used to improve the spectrum of weed control, reduce production costs, and slow the development of weed resistance (Bruff and Shaw 1992; Carlson et al. 2011; Hydrick and Shaw 1994; Webster et al. 2012b; Zhang et al. 1995). Herbicide mixtures have proven to be beneficial in improving weed control and broadening the weed control spectrum in imidazolinone resistant rice (Carlson et al. 2011; Carlson et al. 2012; Pellerin et al. 2003). Herbicide mixtures having foliar and soil residual activity can enhance initial weed control, provide residual activity, and reduce the number of herbicide applications (Bruce and Kells 1990; Carlson et al. 2012; Minton et al. 1989). Researchers have demonstrated the importance of incorporating herbicide mixtures to the standard imazethapyr program in IR rice production to maximize weed control (Carlson et al. 2011; Fish et al. 2012; Fish et al. 2013; Webster et al. 2012a).

The selectivity of postemergence herbicides often requires applying two or more herbicides to increase the spectrum of weeds controlled. These herbicide mixtures are preferred because of reduced number of applications and reduced cost (Minton et al. 1989). Synergistic and antagonistic effects for herbicide mixtures do not have a single definition (Drury 1980; Morse 1978; Streibig et al. 1998). Synergistic effects imply that the level of weed infestation is lower when herbicides are applied in mixture than when they are applied alone, whereas antagonistic effects imply levels of infestation that are higher (Blouin et al. 2010). A generalized expression for expected responses was described by Colby (1967), which when applied to means, yields the defining contrast for synergism and antagonism.

In soybean, antagonism was observed in mixtures including sethoxydim or quizalofop combined with imazaquin, chlorimuron, or lactofen for control of barnyardgrass, red rice, johnsongrass (*Sorghum halepense* L.), and large crabgrass (*Digitaria sanguinalis* L.) (Wesley and Shaw 1992). In rice production, control of barnyardgrass decreased to the level of antagonism when fenoxaprop was mixed with carfentrazone or halosulfuron compared with a single application of fenoxaprop (Zhang et al. 2005).

Blouin et al. (2010) displayed a flexible and efficient method of analysis for synergistic and antagonistic effects, and this method can be offered as an alternative method of Flint et al. (1988) and the standard LSD method. The methodology augmented standard mixed-model methods with the Delta Method for nonlinear functions of the means. Nonlinear mixed-model estimates and tests of synergistic and antagonistic effects were more sensitive in detecting significance, and PROC NLMIXED was a versatile tool for implementation (Blouin 2004). This analysis provides researchers a useful set of statistical tools for developing weed control recommendations and evaluating pre-packaged herbicide mixtures (Blouin et al. 2010).

Propanil has been the standard of weed control programs in rice since the 1960s (Smith 1961; Smith 1965; Smith 1974; Smith 1981; Smith and Hill 1990). Propanil is widely used to control annual grass and broadleaf weeds in rice (Crawford and Jordan 1995), and propanil use in the mid-south is between 40 to 60% of hectares and 80 to 85% of hectares in California rice production (J. Wells, personal communication, Former Technical Service Rep. Rice Co., Memphis, TN, 2013). However, mixtures with other herbicides such as pendimethalin and thiobencarb with propanil are common, and are often used for both POST and residual control of broadleaf and grass species (Richard and Street 1984).

Thiobencarb, sold under the tradename Bolero, is used to control grass and broadleaf weeds, and is in the thiocarbamate herbicide family (Senseman 2007). Mixtures of propanil plus thiobencarb have been used for increased control of broadleaf and grass weeds by employing multiple modes of action and residual performance for the control of barnyardgrass and propanil-resistant barnyardgrass (Baltazar and Smith 1994; Jordan and Kendig 1998; Smith and Khodayari 1985; Stauber et al. 1991). Rice yields and economic returns were improved when propanil was mixed with thiobencarb or molinate, compared with propanil applied alone (Crawford and Jordan 1995).

The objective of this research was to evaluate the weed control interactions, synergistic and antagonistic, of imazethapyr or imazamox when mixed with propanil, thiobencarb, or a pre-packaged mixture of propanil plus thiobencarb.

LITERATURE CITED

Anonymous. 2009. Beyond herbicide label. BASF Corporation. http://agproducts.basf.us/products/label-and-msds/beyond-herbicide-label.pdf. Verified September 25, 2014.

Baldwin, F.L. 1978. Red rice control in alternate crops. Pages 16-18 *in* Red rice research and control. Texas Agric. Exp. Stn. Bul. 1270. 46 pp.

Baltazar, A.M., and R.J. Smith. 1994. Propanil-resistant barnyardgrass (*Echinochloa crus-galli*) control in rice (*Oryza sativa*). Weed Technol. 8:576-581.

Blouin, D.C., E.P. Webster, and J.A. Bond. 2010. On a method for synergistic and antagonistic joint-action effects with fenoxaprop mixtures in rice. Weed Technol. 24:583-589.

Blouin, D.C., E.P. Webster, and W. Zhang. 2004. Analysis of synergistic and antagonistic effects of using nonlinear mixed-model methodology. Weed Technol. 18:464-472.

Braverman, M.P. 1995. Weed control in rice (*Oryza sativa*) with quinclorac and bensulfuron coating of granular herbicides and fertilizer. Weed Technol. 9:494–498.

Bruce, J.A., and J.J. Kells. 1990. Horseweed (*Conyza canadensis*) control in no-tillage soybeans (*Glycine max*) with preplant and preemergence herbicides. Weed Technol. 4:642-647.

Bruff, S.A. and D.R. Shaw. 1992. Tank-mix combinations for weed control in stale seedbed soybean (*Glycine max*). Weed Technol. 6:45-51.

Carlson, T.P., E.P. Webster, M.E. Salassi, J.B. Hensley, and D.C. Blouin. 2011. Imazethapyr plus propanil programs in imidazolinone-resistant rice. Weed Technol. 25:204-211.

Carlson, T.P., E.P. Webster, M.E. Salassi, J.A. Bond, J.B. Hensley, and D.C. Blouin. 2012. Economic evaluations of imazethapyr rates and timings on rice. Weed Technol. 26:24-28.

Cohn, M.A. and J.A. Hughes. 1981. Seed dormancy in red rice (*Oryza sativa*). Effective of temperature on dry-after ripening. Weed Sci. 29:402-404.

Colby, S.R. 1967. Calculating synergistic and antagonistic responses of herbicide combinations. Weeds. 20-22.

Craigmiles, J.P. 1978. Introduction. Pages 5-6 *in* E.F. Eastin, ed. Red rice research and control. Texas Agricultural Experiment Station Bull. 1270.

Crawford, S.H., and D.L. Jordan. 1995. Comparison of single and multiple applications of propanil and residual herbicides in dry-seeded rice (*Oryza sativa*). Weed Technol. 9:153-157.

Croughan, T.P. 1994. Application of tissue culture techniques to development of herbicide resistant rice. Louis. Agric. 37:25–26.

Drury, R.E. 1980. Physiological interaction, its mathematical expression. Weed Sci. 28:573-576.

Fish, J.C., E.P. Webster, B.M. McKnight, N.D. Fickett, and J. Bond. 2013. Newpath + propanil interactions influence weed control in Clearfield rice. Weed Sci. Soc. Am. 53: http://wssaabstracts.com/public/17/abstract-13.html. Accessed September 19, 2014.

Fish, J.C., E.P. Webster, J.A. Bond, E.L. Thevis, and N.D. Fickett. 2012. Herbicide mixture may increase activity of Newpath and red rice. Proc. South. Weed Sci. Soc. 65:73.

Flint, J.L., P.L. Cornelius, and M. Barrett. 1988. Analyzing herbicide interactions: a statistical treatment of Colby's method. Weed Technol. 2:304-309.

Hydrick, D.E. and D.R. Shaw. 1994. Effects of tank-mix combination of non-selective foliar herbicides on three weed species. Weed Technol. 8:129-133.

Jordan D.L. and J.A. Kendig. 1998. Barnyardgrass (*Echninochloa crus-galli*) control with postemergence applications of propanil and clomazone in dry-seeded rice. Weed Technol. 12:537-541.

Judd, W.S., C.S. Campbell, E.A. Kellogg, and P.F. Stevens. 1999. Plant systematics: a phylogenic approach. Sunderland, MA: Sinauer Associates. Pp. 283-288.

Khodayari, K.R., R.J. Smith, Jr., and H.L. Black. 1987. Red rice (*Oryza sativa*) control with herbicide treatments in soybeans (*Glycine max*). Weed Sci. 35:127-129.

Minton, B.W., D.R. Shaw, and M.E. Kurtz. 1989. Postemergence grass and broadleaf herbicide interactions for red rice (*Oryza sativa*) control in soybean (*Glycine max*). Weed Technol. 3:329-334.

Morse, P.M. 1978. Some comments on the assessment of joint action herbicide mixtures. Weed Sci. 26:58-71.

Noldin, J.A., J.M. Chandler, and G.N. McCauley. 1999. Red rice (*Oryza sativa*) biology. I. Characterization of red rice ecotypes: Weed Technol. 13:12-18.

Ottis, B.V., J.M. Chandler, and G.N. McCauley. 2002. Imazethapyr application methods and sequences for imidazolinone-tolerant rice (*Oryza sativa*). Weed Technol. 17:526-533.

Pellerin, K.J., E.P. Webster, W. Zhang, and D.C. Blouin. 2003. Herbicide mixtures in water-seeded imidazolinone-resistant rice. Weed Technol. 17:836-841.

Pellerin, K.J., E.P. Webster, W. Zhang, and D.C. Blouin. 2004. Potential use of imazethapyr mixtures in drill-seeded imidazolinone resistant rice. Weed Technol. 18:1037-1042.

Richard, E.P., Jr. and J.E. Street. 1984. Herbicide performance in rice (*Oryza sativa*) under three flooding conditions. Weed Sci. 32:157-162.

Richburg, J.S., III, J.W. Wilcut, and G.L. Wiley. 1995. AC 263,222 and imazethapyr rates and mixtures for weed management in peanut (*Arachis hypogaea*). Weed Technol. 9:801-806.

Senseman, S.A., ed. 2007. Herbicide Handbook 9th ed. Lawrence, KS: Weed Science Society of America. Pp. 81-82; 89-91; 169-171; 316-317.

Smith, R.J., Jr. 1961. 3,4-Dichloropropionanilide for control of barnyardgrass in rice. Weeds 9:318-322.

Smith, R.J., Jr. 1965. Propanil and mixtures with propanil for weed control in rice. Weeds 13:236-238.

Smith, R.J., Jr. 1974. Response of rice to postemergence treatments of propanil. Weed Sci.22:563-568.

Smith, R.J., Jr. 1981. Control of red rice (*Oryza sativa*) in water seeded rice (*O. sativa*). Weed Sci. 29:663-666.

Smith, R.J., W.T. Flinchum, and D.E. Seaman. 1977. Weed control in US rice production. USDA Handb. 497:78.

Smith, R.J., Jr. and J.E. Hill. 1990. Weed control technology in U.S. rice. Pages 314-327 *in* B.T. Grayson, M.B. Green, and L.G. Copping, eds. Pest Management in Rice. United Kingdom: Elsevier Science.

Smith, R.J., Jr. and K. Khodayari. 1985. Herbicide treatments for control of weeds in dry-seeded rice (*Oryza sativa*). Weed Sci. 33:686-692.

Stauber, L.G., P. Nastasi, R.J. Smith, Jr., A.M. Baltazar, and R.E Talbert. 1991. Barnyardgrass (*Echinochloa crus-galli*) and bearded sprangletop (*Leptochloa fascicularis*) control in rice (*Oryza sativa*). Weed Technol. 5:337-344.

Steele, G.L., J.M. Chandler, and G.N. McCauley. 2002. Control of red rice (*Oryza sativa*) in imidazolinone-tolerant rice (*O. sativa*). Weed Technol. 16:627-630.

Stidham, M.A. and B.K. Singh. 1991. Imidazolinone-acetohydroxyacid synthase interactions. *In* Shaner, D.L. and S.L. O'Conner. eds. The Imidazolinone Herbicides. Boca Raton, FL: CRC. Pages 71–90.

Stougaard, R.N., P.J. Shea, and A.R. Martin. 1990. Effect of soil type and pH on adsorption, mobility, and efficacy of imazaquin and imazethapyr. Weed Sci. 38:67–73.

Streibig, J.C., P. Kudsk, and J.E. Jensen. 1998. A general joint action for herbicide mixture. Pestic. Sci. 53:21-28.

Webster, E.P. and J.A. Masson. 2001. Acetolactate synthase-inhibiting herbicides on imidazolinone-tolerant rice. Weed Sci. 49:652-657.

Webster, E.P. 2014. Weed Management. Pages 54-81. *in* J. Saichuk, ed. Louisiana Rice Production Handbook. Baton Rouge, LA: Louisiana State University Agricultural Center Pub. 2321-5/14 rev.

Webster, E.P., J.C. Fish, N.D. Fickett, and B.M. McKnight. 2012a. Rice Weed Science 2012 Annual Research Report. Baton Rouge, LA: Louisiana State University Agricultural Center Pub. http://www.lsuagcenter.com/MCMS/RelatedFiles/%7B9CF8B5B7-6472-4816-A2E6-B5F272939C94%7D/2012-Annual-Report-%28Eric-Webster%29.pdf. Verified September 25, 2014.

Webster, E.P., T.P. Carlson, M.E. Salassi, J.B. Hensley, and D.C. Blouin. 2012b. Imazethapyr plus residual herbicide programs for imidazolinone-resistant rice. Weed Technol. 26:410-416.

Webster, T.M. 2004. Weed survey - southern states. Proc. South. Weed Sci. Soc. 57:404-426.

Wesley, M.T. and D.R. Shaw. 1992. Interactions of diphenylether herbicides with chlorimuron and imazaquin. Weed Technol. 6:345-351.

Zhang, J., A.S. Hamill, and S.E. Weaver. 1995. Antagonism and synergism between herbicides: Trends from previous studies. Weed Technol. 9:86-90.

Zhang, W., E.P. Webster, D.C. Blouin, and C.T. Leon. 2005. Fenoxaprop interactions for barnyardgrass (*Echinochloa crus-galli*) control in rice. Weed Technol. 19:293-297.

Zhang, W., E.P. Webster, and H.M. Selim. 2001. Effect of soil moisture on efficacy of imazethapyr in greenhouse. Weed Technol. 15:355-359.

Chapter 2
Interactions of Herbicide Mixtures with Imidazolinone Herbicides for Weed Control

Introduction

Advances in weed management technology have played an essential role in the development of the rice (*Oryza sativa* L.) industry (Ashton and Monaco 1991; Carlson et al. 2011). Weed management decisions often drive the overall production system in rice and numerous herbicides are available for preemergence and postemergence weed control in rice (Norsworthy et al. 2007; Webster 2014).

Imidazolinone-resistance (IR) rice allows for the use of imidazolinone herbicides for control of red rice (*Oryza sativa* L.) and other troublesome weeds while producing a rice crop (Croughan 1994; Masson and Webster 2001; Pellerin et al. 2004; Webster and Masson 2001). Imazethapyr is labeled for use in IR rice with both residual and postemergence activity at rates of 70 to 105 g ha^{-1} (Avila et al. 2005; Masson and Webster 2001). Imazamox is another imidazolinone herbicide labeled for use in IR rice. Imazamox is labeled at rates of 44 to 53 g ha^{-1}, and it is usually applied at a late season application on rice in the panicle initiation (PI) stage of growth to 14 days after PI (Anonymous 2009; Webster 2014). This is a useful tool for late season application due to its lack of residual activity (Senseman 2007). However, it has little to no effect on many of the same weeds as imazethapyr (J. Saichuk, personal communication, Rice Specialist. Louisiana State University Agricultural Center's Rice Research Station, Crowley, LA).

The use of propanil in a mixture with herbicides with residual activity has been commonly used to broaden weed spectrum (Carlson et al. 2011; Crawford and Jordan 1995; Jordan 1997; Jordan et al. 1998; Norsworthy et al. 2010; Smith and Hill 1990). Propanil is a broad-spectrum postemergence herbicide labeled for use in rice in 1961 (Senseman 2007), and is selective between grass weeds and rice on the basis of physiological processes

(Baltazar and Smith 1994; Smith 1961; Smith 1965). For many years, the weed control program for rice in the southern United States has centered around propanil, and propanil has long been used to control annual grass and broadleaf weeds in southern U.S. rice production (Smith 1961; Smith 1965; Smith and Hill 1990).

Mixing two or more herbicides into one spray solution can afford producers multiple benefits, such as a broader weed spectrum and reduced costs (Hydrick and Shaw 1994). This can be accomplished by mixing a herbicide that controls only grasses with a herbicide that is predominantly active on broadleaf weeds (Blouin et al. 2010; Rhodes and Coble 1984). Another practice is to mix a herbicide having nonselective postemergence activity on a stale seedbed production system with a herbicide possessing soil-residual activity (Hydrick and Shaw 1994; Lanclos et al. 2002; Webster and Shaw 1997). For both practices, the modes of action of the herbicides are often different.

Synergism is a term that can describe an agrichemical's ability to interact with another agrichemical in such a way that overall weed control is improved compared with the effect of each product applied independently (Hatzios and Penner 1985). Synergistic effects imply that the level of weed infestation is lower after herbicides are applied in mixture than when they are applied alone, and antagonistic effects imply levels of infestation are higher after herbicides are applied (Akobundu et al. 1975; Blouin et al. 2010; Colby 1967; Hatzios and Penner 1985; Morse 1978). Herbicide interactions are not significant in either a synergistic or antagonistic way an additive response can be said to occur. A generalized expression for expected responses was given by Colby (1967), which when applied to means, yields the defining contrast for synergism and antagonism (Colby 1967; Flint et al. 1988). Blouin et al. (2004) offered a third strategy employing nonlinear mixed-model methodology (NLMIXED) of SAS to perform tests of hypotheses (SAS Institute 2010), but its implementation became considerably more difficult and inefficient as the experimental design and analysis became more complex. This modified Colby's procedure can be used to separate the means of herbicide mixtures to determine if a synergistic, antagonistic, or additive response occurs when mixing herbicides together in a single application for weed control.

Synergistic responses with co-applications or mixtures of herbicides with 2,4-D have been observed (Waltz et al. 2003); however, antagonistic responses have been observed with co-applications of 2,4-D mixed with fenoxaprop, haloxyfop, and sethoxydim on johnsongrass [*Sorghum halepense* (L.) Pers.] (Mueller et al. 1989). Lanclos et al. (2002) reported both synergism and antagonism interactions with herbicides mixed with glufosinate. In a stale seedbed study, Webster and Shaw (1997) reported synergistic and antagonistic interactions when paraquat was mixed with herbicides with residual activity.

Red rice is one of the most troublesome weeds of cultivated rice in the southern United States (Webster 2004). Red rice has been recognized as a weed in U.S. rice fields for over 150 years and has become increasingly troublesome in cultivated rice fields throughout the southern United States (Craigmiles 1978; Khodayari et al. 1987; Smith 1981). Since the development and widespread adoption of IR rice across the southern rice belt, red rice control can vary (J. Saichuk, personal communication, Rice Specialist. Louisiana State University Agricultural Center's Rice Research Station, Crowley, LA). In addition to red rice, a number of grass and broadleaf weeds exist in rice culture (Braverman 1995). The most common weeds in Louisiana include broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R. D. Webster], ducksalad [*Heteranthera limosa* (Sw.) Willd.], hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh], spreading dayflower (*Commelina diffusa* Burm. f.), barnyardgrass [*Echinochloa crus galli* (L.) P. Beauv], alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.], and Indian jointvetch (*Aeschynomene indica* L.), and many of these are not controlled with imidazolinone herbicides (Ottis et al. 2002; Richburg et al. 1995; Webster and Masson 2001; Webster et al. 2012; Zhang et al. 2001).

The objectives of this research were to evaluate the interaction of an imazethapyr or imazamox mixture with propanil, thiobencarb, or a pre-packaged mixture of propanil plus thiobencarb on several weeds in rice production. Blouin's modified Colby's will be used to determine if a synergistic, antagonistic, or additive response occurred with each mixture (Blouin et al 2004; Blouin et al. 2010). An additive response will be reported as a neutral response from this point forward.

Materials and Methods

Two studies were conducted at four locations: 1) the Louisiana State University Agricultural Center's Rice Research Station (RRS) near Crowley, Louisiana, in 2011 and 2012 on a Crowley silt loam soil (fine montmorillinitic, thermic Typic Albaqualf), with pH 6.4 and 1.4% OM; 2) the Louisiana State University Agricultural Center's Northeast Research Station (NERS) near St. Joseph, Louisiana, in 2012 on Sharkey clay (very fine, montmorillonitic, nonacid, Vertic Haplaquept) with pH 6.1 and 2.2% OM; 3) the Louisiana State University Agricultural Center's Macon Ridge Research Station (MRRS) near Winnsboro, Louisiana, in 2012 on a Gigger silt loam (fine-silty, mixed, thermic Typic Fragiudalf) with pH 5.8 and 1.3% OM; 4) the Mississippi State University Delta Research and Extension Center (DREC) near Stoneville, Mississippi, in 2012 on a Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) with a pH of 8.2 and 2.2% OM.

The experimental design was a two-factor factorial in a randomized complete block with four replications. 'CL161' IR rice was planted in 2011 and 'CL111' IR rice was planted in 2012 at the RRS, NERS, and MRRS, and 'CL151' IR rice was planted in 2012 at DREC. The cultivars were long grain lines. Factor A was imazethapyr, sold under the tradename Newpath (Table

2.1), at 0 and 70 g ai ha^{-1}, Factor B was propanil, sold under the tradename RiceShot, at 840 and 1680 g ai ha^{-1}, thiobencarb, sold under the tradename Bolero, at 840 and 1680 g ai ha^{-1}, a pre-packaged mix of propanil plus thiobencarb, sold under the tradename RiceBeaux, at 1680 and 3360 g ai ha^{-1}, and no mixture herbicide. Propanil and thiobencarb rates used are equal to the rates found in the pre-packaged mix of propanil plus thiobencarb rates evaluated.

At the RRS, seedbed preparation consisted of fall disking and a spring disking followed by two passes with a two-way bed conditioner equipped with S-tine harrows set at a 7.5 operating depth in opposite direction. Rice was drilled at 84 kg/ha on April 29, 2011 and April 23, 2012 with eight 19-cm rows, 5.2-m long. The experimental area was surface irrigated three to four times after planting at 7 day intervals to maintain adequate soil moisture and rice growth in 2011 and 2012. Fertility management consisted of 280 kg ha^{-1} of 8-24-24 fertilizer applied preplant and 280 kg ha^{-1} of 46-0-0 urea nitrogen 1 day prior to permanent flood establishment. A permanent 6-cm flood was established on May 26, 2011 and June 4, 2012, and maintained until two weeks prior to harvest.

At the NERS, field preparation during each year consisted of a fall disking followed by a spring disking and two passes in opposite directions with a field cultivator equipped with S-tine harrows set to operate 6 cm deep. Rice was drilled at 84 kg/ha on April 23, 2012 with eight 19-cm rows, 5.2-m long. The experimental area was surface irrigated four times after planting at 7 day intervals to maintain adequate soil moisture and rice growth. Fertility management consisted of 280 kg ha^{-1} of 8-24-24 fertilizer applied preplant and 280 kg ha^{-1} of 46-0-0 urea nitrogen 1 day prior to permanent flood establishment. A permanent 6-cm flood was established on June 4, 2012, and maintained until two weeks prior to harvest.

Table 2.1. Source of materials.

Herbicide	Trade name	Form	Rate g ha^{-1}	Manufacturer	Address	Website
Imazethapyr	Newpath	AS	70	BASF Corporation	Fordam, NJ	www.agro.basf.us
Imazamox	Beyond	AS	44	BASF Corporation	Fordam, NJ	www.agro.basf.us
Propanil	RiceShot	EC	1680/ 3360	Rice Co.	Memphis, TN	www.ricecousa.com
Thiobencarb	Bolero	EC	1680/ 3360	Valent BioSciences Corporation	Walnut Creek, CA	www.valent.com
Propanil + thiobencarb	RiceBeaux	EC	840/ 1680	Rice Co.	Memphis, TN	www.ricecousa.com

At the MRRS, seedbed preparation consisted of fall and spring disking followed by two passes with a field cultivator equipped with S-tine harrows set at a 7.5 operating depth. Rice was drilled at 84 kg/ha on May 2, 2012 with eight 19-cm rows, 5.2-m long. The experimental area was surface irrigated seven times after planting at 7 day intervals to maintain adequate soil moisture and rice growth. Fertility management consisted of 280 kg ha^{-1} of 8-24-24 fertilizer preplant and 280 kg ha^{-1} of 46-0-0 urea nitrogen 1 day prior to permanent flood establishment. A permanent 6-cm flood was established on June 23, 2012, and maintained until two weeks prior to harvest.

At the DREC, seedbed preparation consisted of fall and spring disking followed by two passes with a two-way bed conditioner equipped with S-tine harrows set at a 7.5 operating depth. CL151 was drill seeded on May 10, 2012 with eight 19-cm rows, 5.2-m long. The experimental area was surface irrigated six times after planting at 7 day intervals to maintain adequate soil moisture and rice growth. Fertility management consisted of 280 kg ha^{-1} of 8-24-24 fertilizer preplant and 280 kg ha^{-1} of 46-0-0 urea nitrogen 1 day prior to permanent flood establishment. A permanent 6-cm flood was established on June 6, 2012 and maintained until two weeks prior to harvest.

Herbicide applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L/ha solution at 190 kPa. Treatments were applied on one- to three-leaf rice, with a second application 14 days later of imazethapyr applied at four- to five-leaf rice.

Data obtained from the studies included visual weed control and injury on a scale of 0 to 100, with 0 being no weed control or crop injury and 100 being complete weed control or crop death (Data not shown). Rice plant height was recorded from the ground to tip of the extended panicle immediately prior to harvest (Data not shown), and rough rice yield was obtained for the primary crop with a small plot combine harvesting the center 4 rows of each plot. Grain yield was adjusted to 12% moisture.

Treatments were applied at the RRS in 2011 on red rice in the one- to three-leaf stage with a height of 2 to 8 cm tall, 1 to 8 cm barnyardgrass with one- to four-leaf, 1 to 8 cm broadleaf signalgrass with one- to four-leaf, and in 2012 on 5 to 10 cm red rice with two- to three-leaf, and 5 to 10 cm barnyardgrass with two- to three-leaf. In 2012 at the NERS applications were made on 1 to 8 cm barnyardgrass with two- to six-leaf. In 2012 at the MRRS application were made on 3 to 5 cm barnyardgrass with 2- to 4-leaf. In 2012, at the DREC on 5 to 8 cm red rice with one- to four-leaf, 3 to 5 cm barnyardgrass with one-to three-leaf, 1 to 2 cm browntop millet one- to three-leaf, and 1 to 5 cm Amazon sprangletop one- to four-leaf.

Visual observations of red rice and broadleaf signalgrass control were evaluated in 2011 and 2012 at the RRS at 14, 21, 35, and 49 DAT and in 2012 at the DREC at 7 and 14 DAT. Barnyardgrass visual observations were made in 2011 and 2012 at the RRS at 14, 21, 35, and 49 DAT, in 2012 at the NERS at 14, 28, and 49 DAT, in 2012 at the MRES at 28, 42, 49 DAT, and at the DREC at 7 and 14 DAT. Browntop millet and Amazon sprangletop visual observations were made at the DREC at 7 and 14 DAT.

Control data were analyzed under the guidelines described in detail by Blouin et al. (2010), and rough rice yield were analyzed using PROC MIXED. The fixed effects used in the analysis were rates of imidazolinone herbicides, the companion herbicides including none, DAT, and all interactions, the random effects were location, blocks within location, and the treatment-by-block. The dependent variables are red rice, barnyardgrass, browntop millet, Amazon sprangletop, broadleaf signalgrass, and rough rice yield.

A similar but separate study was conducted at all locations using imazamox, sold under the tradename Beyond, at 0 and 44 g ha^{-1} for Factor A (Table 2.1). Factor B remained the same as previously described.

Results and Discussion

Imazethapyr Mixed with Propanil and Thiobencarb Combinations. At 7 days after treatment (DAT), synergism occurred for red rice when treated with imazethapyr at 70 g ha^{-1} mixed with propanil plus thiobencarb at 1680 and 3360 g ha^{-1}, observed control increased over an expected control of 59 and 61% to 66 and 71% control, respectively (Table 2.2). At 14 DAT, red rice when treated with imazethapyr mixed with propanil plus thiobencarb at 1680 and 3360 g ha^{-1}, or with propanil at 1680 g ha^{-1} was synergistic by increasing control from an expected 78% to an observed 87, 91, and 85% control, respectively. At 21 and 49 DAT, the same synergistic response occurred with the pre-packaged mixture plus imazethapyr co-application as occurred at 7 and 14 DAT. This indicates that the propanil and thiobencarb pre-packaged mixture consistently provides synergism when mixed with imazethapyr for red rice control. A neutral response occurred for all other mixtures at all other rating dates. No antagonism for red rice control was observed for any herbicide mixtures evaluated. These data indicate that the addition of the pre-packaged mixture can be beneficial for red rice control and help broaden

Table 2.2. Red rice control with imazethapyr mixed with propanil and/or thiobencarb, in 2011 and 2012 at the RRS[a] and DREC.

Mixture Herbicide[b]	Rate	Imazethapyr (g ha^{-1}) 0 OBSERVED[c]	70 EXPECTED	70 OBSERVED	P VALUE
	g ha^{-1}	% of Control			
7 DAT					
None	-	0	-	58	-
Propanil + thiobencarb[d]	1680	3	59	66+	0.0069
Propanil + thiobencarb	3360	8	61	71+	0.0003
Propanil	840	1	58	63	0.1071
Propanil	1680	4	59	64	0.0897
Thiobencarb	840	0	58	58	1.0000
Thiobencarb	1680	0	58	61	0.1768
14 DAT					
None	-	0	-	78	-
Propanil + thiobencarb	1680	0	78	87+	0.0001
Propanil + thiobencarb	3360	0	78	91+	0.0000
Propanil	840	0	78	80	0.3050
Propanil	1680	0	78	85+	0.0033
Thiobencarb	840	0	78	79	0.5378
Thiobencarb	1680	0	78	82	0.0949
21 DAT					
None	-	0	-	82	-
Propanil + thiobencarb	1680	0	82	94+	0.0000
Propanil + thiobencarb	3360	2	82	96+	0.0000
Propanil	840	2	82	83	0.6641
Propanil	1680	1	81	83	0.5900
Thiobencarb	840	0	82	83	0.7676
Thiobencarb	1680	0	82	83	0.5548

continued

Table 2.2. Continued

Mixture Herbicide[b]	Rate	Imazethapyr (g ha^{-1}) 0 OBSERVED[c]	70 EXPECTED	70 OBSERVED	P VALUE
	g ha^{-1}	% of Control			
49 DAT					
None	-	0	-	81	-
Propanil + thiobencarb	1680	0	81	89+	0.0168
Propanil + thiobencarb	3360	3	81	91+	0.0026
Propanil	840	2	81	79	0.4867
Propanil	1680	2	81	80	0.7293
Thiobencarb	840	2	81	79	0.4867
Thiobencarb	1680	1	81	79	0.5373

[a] RRS – Louisiana State University AgCenter's Rice Research Station near Crowley, LA; DREC – Mississippi State University's Delta Research and Extension Center near Stoneville, MS.

[b] Evaluation date and respective herbicide mixture.

[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

[d] The products applied alone are equivalent to rates found in pre-packaged mixtures.

the weed spectrum. Carlson et al. (2011) reported increased red rice control with propanil mixed with imazethapyr.

At 7 DAT, antagonism was observed for barnyardgrass with imazethapyr mixed with propanil plus thiobencarb at 840 g ha^{-1}, propanil at 1680 g ha^{-1}, or thiobencarb at 840 and 1680 g ha^{-1} by decreasing control from an expected control of 93, 92, 89, and 90% to an observed control of 86, 88, 77, and 79%, respectively (Table 2.3). These data indicate a 7 DAT rating may be too early to evaluate the potential benefits of the co-application. A neutral response was observed on barnyardgrass with the high rate of the pre-packaged mixture

Table 2.3. Barnyardgrass control with imazethapyr mixed with propanil and/or thiobencarb, in 2011 at the RRS[a] and 2012 at the RRS, NERS, MRRS, and DREC.

Mixture Herbicide[b]	Rate	Imazethapyr ($g\ ha^{-1}$) 0 OBSERVED[c]	70 EXPECTED	70 OBSERVED	P VALUE
	$g\ ha^{-1}$	% of Control			
7 DAT					
None	-	0	-	71	-
Propanil + thiobencarb[d]	1680	76	93	86-	0.0376
Propanil + thiobencarb	3360	83	95	90	0.1425
Propanil	840	69	91	85	0.1636
Propanil	1680	74	92	88-	0.0475
Thiobencarb	840	63	89	77-	0.0000
Thiobencarb	1680	67	90	79-	0.0004
14 DAT					
None	-	0	-	71	-
Propanil + thiobencarb	1680	47	84	88	0.4088
Propanil + thiobencarb	3360	56	87	95	0.0636
Propanil	840	34	81	81	0.8262
Propanil	1680	44	84	87	0.3933
Thiobencarb	840	31	80	81	0.7863
Thiobencarb	1680	45	85	83	0.7803
21 DAT					
None	-	0	-	72	-
Propanil + thiobencarb	1680	32	81	91+	0.0220
Propanil + thiobencarb	3360	52	87	96+	0.0259
Propanil	840	40	83	77	0.1430
Propanil	1680	43	84	81	0.4588
Thiobencarb	840	25	79	78	0.8078
Thiobencarb	1680	37	83	80	0.4581

Continued

Table 2.3. Continued

Mixture Herbicide[b]	Rate	Imazethapyr (g ha^{-1}) 0 OBSERVED[c]	70 EXPECTED	70 OBSERVED	P VALUE
	g ha^{-1}	% of Control			
49 DAT					
None	-	0	-	61	-
Propanil + thiobencarb	1680	28	71	78	0.2486
Propanil + thiobencarb	3360	40	76	92+	0.0024
Propanil	840	24	70	68	0.6416
Propanil	1680	29	72	78	0.2967
Thiobencarb	840	30	73	69	0.5380
Thiobencarb	1680	30	72	71	0.7263

[a] RRS - Louisiana State University AgCenter's Rice Research Station near Crowley, LA; NERS - Louisiana State University AgCenter's Northeast Research Station near St. Joseph, LA; MERS - Louisiana State University AgCenter's Macon Ridge Research Station near Winnsboro, LA; and DREC - Mississippi State University's Delta Research and Extension Center near Stoneville, MS.

[b] Evaluation date and respective herbicide mixture.

[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

[d] The products applied alone are equivalent to rates found in pre-packaged mixtures.

plus imazethapyr at 7 and 14 DAT. The high rate of the pre-package mixture resulted in a synergistic response for barnyardgrass control at 21 and 49 DAT. As observed for red rice control, the pre-packaged mixture plus imazethapyr can consistently increase barnyardgrass control over the products applied alone.

At 7 DAT, antagonism was observed when browntop millet was treated with imazethapyr mixed with propanil at 840 and 1680 g ha^{-1}, and thiobencarb at 840 and 1680 g ha^{-1} by decreasing control from an expected value of 95, 96, 90, and 91% to an observed value of 85, 86, 79, and 74%, respectively (Table 2.4). The same mixture resulted in antagonism for browntop millet control at

Table 2.4. Browntop millet control with imazethapyr mixed with propanil and/or thiobencarb, at 7 and 14 DAT in 2012 at the DREC[a].

		Imazethapyr (g ha^{-1})			
		0	70		
Mixture Herbicide[b]	Rate	OBSERVED[c]	EXPECTED	OBSERVED	P VALUE
	g ha^{-1}	% of Control			
7 DAT					
None	-	0	-	66	-
Propanil + thiobencarb[d]	1680	81	94	90	0.2163
Propanil + thiobencarb	3360	90	97	94	0.3286
Propanil	840	84	95	85-	0.0023
Propanil	1680	88	96	86-	0.0022
Thiobencarb	840	71	90	79-	0.0004
Thiobencarb	1680	74	91	74-	0.0000
14 DAT					
None	-	0	-	65	-
Propanil + thiobencarb	1680	83	94	93	0.6394
Propanil + thiobencarb	3360	89	96	95	0.7150
Propanil	840	88	96	89-	0.0225
Propanil	1680	88	96	92	0.1385
Thiobencarb	840	61	86	74-	0.0002
Thiobencarb	1680	60	86	76-	0.0030

[a] DREC- Mississippi State University's Delta Research and Extension Center near Stoneville, MS.

[b] Evaluation date and respective herbicide mixture.

[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

[d] The products applied alone are equivalent to rates found in pre-packaged mixtures.

14 DAT except browntop millet treated with the high rate of propanil plus imazethapyr which resulted in a neutral response. At both 7 and 14 DAT, browntop millet treated with imazethapyr mixed with the pre-packaged mix of propanil plus thiobencarb at 1680 and 3360 g ha^{-1} resulted in a neutral response. Although no synergism occurred with the pre-package mixture across

both evaluation dates, these data indicate that a mixture with imazethapyr would be beneficial and increase control of other weeds not controlled by imazethapyr.

Amazon sprangletop control was similar to observation with browntop millet (Table 2.5). Although no synergism was observed, there was also no antagonism observed for a mixture of imazethapyr plus a pre-package mixture of propanil plus thiobencarb; however, antagonism did occur with thiobencarb at 840 and 1680 g ha^{-1} when mixed with imazethapyr. The neutral response observed for the pre-packaged mixture of propanil plus thiobencarb indicates the potential for mixing the herbicides when trying to manage a broad spectrum of weeds, including Amazon sprangletop.

At 14 DAT, synergism was observed for broadleaf signalgrass control treated with imazethapyr mixed with propanil plus thiobencarb at 1680 and 3360 g ha^{-1}, propanil at 840 g ha^{-1}, and thiobencarb at 840 and 1680 g ha^{-1} by increasing control from an expected control of 89, 89, 89, 90, and 90% to an observed control of 97, 96, 94, 95, and 96% control, respectively (Table 2.6). However, by 21 DAT, broadleaf signalgrass observed control decreased from the expected control, indicating antagonism occurred with a mixture of imazethapyr plus propanil at 1680 g ha^{-1} or thiobencarb at 840 g ha^{-1}. At 49 DAT, all co-application resulted in 98% control of broadleaf signalgrass resulting in a neutral response of the weed to the mixtures. Crop injury was less than 10% across all locations, treatments, and ratings (Data not shown). Rice treated with mixtures containing imazethapyr resulted in a higher yield than those without imazethapyr (Table 2.7). Although no yield increase was observed for co-application of imazethapyr plus propanil, thiobencarb, or the pre-package mixture, yield increases and increased profits have been reported when other herbicides, such as propanil, are mixed with imazethapyr (Carlson 2011; Pellerin 2003; Pellerin 2004; Webster et al. 2012).

Table 2.5. Amazon sprangletop control with imazethapyr mixed with propanil and/or thiobencarb, at 7 and 14 DAT in 2012 at the DREC[a].

		Imazethapyr (g ha^{-1})			
		0	70		
Mixture Herbicide[b]	Rate	OBSERVED[c]	EXPECTED	OBSERVED	P VALUE
	g ha^{-1}	% of Control			
7 DAT					
None	-	0	-	25	-
Propanil + thiobencarb[d]	1680	89	92	95	0.2475
Propanil + thiobencarb	3360	97	98	97	0.8147
Propanil	840	91	93	88	0.4900
Propanil	1680	94	95	94	0.5953
Thiobencarb	840	70	78	71-	0.0459
Thiobencarb	1680	76	82	74-	0.0074
14 DAT					
None	-	0	-	18	-
Propanil + thiobencarb	1680	86	89	90	0.6875
Propanil + thiobencarb	3360	96	96	95	0.6523
Propanil	840	86	89	85	0.2770
Propanil	1680	90	92	91	0.8804
Thiobencarb	840	65	71	68	0.3037
Thiobencarb	1680	66	72	71	0.7950

[a] DREC- Mississippi State University's Delta Research and Extension Center near Stoneville, MS.

[b] Evaluation date and respective herbicide mixture.

[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

[d] The products applied alone are equivalent to rates found in pre-packaged mixtures.

Table 2.6. Broadleaf Signalgrass Control with Imazethapyr mixed with propanil and thiobencarb, in 2011 and 2012 at the RRS[a].

		Imazethapyr (g ha^{-1})			
		— 0 —	— 70 —		
Mixture Herbicide[b]	Rate	OBSERVED[c]	EXPECTED	OBSERVED	P VALUE
	g ha^{-1}	— % of Control —			
14 DAT					
None	-	0	-	84	-
Propanil + thiobencarb[d]	1680	33	89	97+	0.0004
Propanil + thiobencarb	3360	35	89	96+	0.0047
Propanil	840	31	89	94+	0.0269
Propanil	1680	38	90	94	0.0527
Thiobencarb	840	40	90	95+	0.0263
Thiobencarb	1680	41	90	96+	0.0135
21 DAT					
None	-	0	-	31	-
Propanil + thiobencarb	1680	11	92	97	0.1652
Propanil + thiobencarb	3360	24	93	97	0.2470
Propanil	840	28	94	91	0.4674
Propanil	1680	31	94	87-	0.0364
Thiobencarb	840	28	94	85-	0.0119
Thiobencarb	1680	45	95	95	0.9837
49 DAT					
None	-	0	-	98	-
Propanil + thiobencarb	1680	13	98	98	0.8979
Propanil + thiobencarb	3360	17	98	98	0.9548
Propanil	840	18	98	98	0.9162
Propanil	1680	31	99	98	0.9068
Thiobencarb	840	15	98	98	0.9241
Thiobencarb	1680	44	99	98	0.7854

[a] RRS- Louisiana State University AgCenter's Rice Research Station near Crowley, LA.
[b] Evaluation date and respective herbicide mixture.
[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.
[d] The products applied alone are equivalent to rates found in pre-packaged mixtures.

Table 2.7. Rough rice yields of rice treated with imazethapyr mixed with propanil and/or thiobencarb at the RRS[a] in 2011 and 2012.

		Imazethapyr (g ha^{-1})			
Mixture Herbicide[b]	Rate	0		70	
	kg ha^{-1}	kg ha^{-1}		kg ha^{-1}	
None	-	1220	C[d]	4030	A
Propanil + thiobencarb[c]	1680	2480	B	4360	A
Propanil + thiobencarb	3360	3300	B	5210	A
Propanil	840	2050	BC	4310	A
Propanil	1680	1920	BC	4460	A
Thiobencarb	840	1460	C	3820	A
Thiobencarb	1680	2110	C	4360	A

Standard Error: 3290
[a] RRS- Louisiana State University AgCenter's Rice Research Station near Crowley, LA.
[b] Evaluation date and respective herbicide mixture.
[c] The products applied alone are equivalent to rates found in pre-packaged mixtures.
[d] Means followed by a common letter are not significantly different at P=0.05 using PROC MIXED.

Imazamox Mixed with Propanil and Thiobencarb Combinations. At 7 DAT, red rice treated with imazamox at 44 g ha^{-1} mixed with propanil plus thiobencarb at 3360 g ha^{-1} or propanil at 840 and 1680 g ha^{-1} resulted in an increase in control, or synergistic response, from the expected values of 63, 61, and 61% to the observed control of 75, 68, and 70%, respectively (Table 2.8). At 14 DAT, the same treatments applied to red rice and the propanil plus thiobencarb at 1680 g ha^{-1} and thiobencarb at 1680 g ha^{-1} mixed with imazamox resulted in an increased control, or synergistic response, over the expected 78, 79, 79, 79, and 79% control to the observed 89, 93, 83, 87, and 83% control, respectively. At 21 and 49 DAT, synergism was only observed on red rice when treated with imazamox plus both rates of the propanil plus thiobencarb pre-packaged mix. This indicates that the addition of the pre-

Table 2.8. Red rice control with imazamox mixed with propanil and/or thiobencarb, in 2011 and 2012 at the RRS[a] and DREC.

		Imazamox (g ha^{-1})			
Mixture		— 0 —	— 44 —		
Herbicide[b]	Rate	OBSERVED[c]	EXPECTED	OBSERVED	P VALUE
	g ha^{-1}	— % of Control —			
7 DAT					
None	-	0	-	61	-
Propanil + thiobencarb[d]	1680	1	62	64	0.3376
Propanil + thiobencarb	3360	4	63	75+	0.0000
Propanil	840	0	61	68+	0.0048
Propanil	1680	0	61	70+	0.0002
Thiobencarb	840	0	61	65	0.0804
Thiobencarb	1680	0	61	61	1.0000
14 DAT					
None	-	0	-	79	-
Propanil + thiobencarb	1680	0	79	89+	0.0000
Propanil + thiobencarb	3360	2	79	93+	0.0000
Propanil	840	0	79	83+	0.0244
Propanil	1680	0	79	87+	0.0001
Thiobencarb	840	0	79	81	0.3029
Thiobencarb	1680	0	79	83+	0.0490
21 DAT					
None	-	0	-	86	-
Propanil + thiobencarb	1680	3	86	93+	0.0045
Propanil + thiobencarb	3360	3	86	97+	0.0000
Propanil	840	5	86	84	0.3980
Propanil	1680	3	86	86	0.9205
Thiobencarb	840	4	86	85	0.5453
Thiobencarb	1680	8	87	84	0.3141

Continued

Table 2.8. Continued

Mixture Herbicide[b]	Rate	Imazamox (g ha^{-1}) 0 OBSERVED[c]	44 EXPECTED	44 OBSERVED	P VALUE
	g ha^{-1}	% of Control			
49 DAT					
None	-	0	-	76	-
Propanil + thiobencarb	1680	0	76	89+	0.0025
Propanil + thiobencarb	3360	0	76	96+	0.0000
Propanil	840	0	76	78	0.6519
Propanil	1680	0	76	79	0.5476
Thiobencarb	840	0	76	80	0.4003
Thiobencarb	1680	0	76	77	0.8804

[a] RRS – Louisiana State University AgCenter's Rice Research Station near Crowley, LA; DREC – Mississippi State University's Delta Research and Extension Center near Stoneville, MS.

[b] Evaluation date and respective herbicide mixture.

[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

[d] The products applied alone are equivalent to rates found in pre-packaged mixtures.

package mixture can be beneficial when mixed with imazamox to increase red rice control, and this is similar to results observed with imazethapyr (Table 2.2).

Antagonism was observed for barnyardgrass control when barnyardgrass was treated with imazamox mixed with all herbicide mixtures evaluated at 7 DAT (Table 2.9). This was similar to the interactions observed with imazethapyr co-application on browntop millet (Table 2.4), and this may be due to the short time after application and before the benefits of imazamox are observed. However, at 14 and 21 DAT all combinations applied to barnyardgrass resulted in a neutral response indicating no negative impacts of the mixture, and a synergistic response occurred with barnyardgrass treated with imazamox mixed with propanil plus thiobencarb at 3360 g ha^{-1} at 49 DAT.

As with imazethapyr, imazamox mixed with propanil and/or thiobencarb can struggle to control, or manage, browntop millet at 7 DAT (Table 2.10). However, by 14 DAT, propanil or the pre-package mixture of propanil plus thiobencarb resulted in a neutral response with 94 to 95% control of browntop millet. As with the results observed with barnyardgrass applying a mixture of imazamox plus propanil combinations may not be synergistic, but no negative response was observed indicating potential mixtures in Clearfield rice to broaden the spectrum of weed control and help manage herbicide resistance.

Amazon sprangletop response to the applications of the imazamox combinations (Table 2.11) was similar to those observed with browntop millet (Table 2.10) and imazethapyr co-applications (Table 2.5). All combinations applied to Amazon sprangletop were neutral at 7 DAT except the low rate of thiobencarb mixed with imazamox which resulted in an antagonistic response. By 14 DAT, no synergism was observed, but all propanil containing mixtures resulted in a neutral response with 93 to 95% control. Once again this indicates the potential of these combinations of herbicides in a Clearfield rice production system.

Rice injury was less than 10% over all locations, applications, and evaluations (Data not shown). Rough rice yield was determined at the RRS in 2011 and 2012 and indicated an increase in yield when rice was treated with an application of imazamox regardless of co-application product (Table 2.12).

In conclusion, the addition of a pre-packaged mixture of propanil plus thiobencarb in mixture with imazethapyr or imazamox can increase the overall weed spectrum when compared with the herbicides applied alone. These results are similar to other research reported from Louisiana (Carlson et al. 2012; Pellerin et al. 2003; Pellerin et al. 2004; Webster et al. 2012). The

Table 2.9. Barnyardgrass control with imazamox mixed with propanil and/or thiobencarb, in 2011 at the RRS[a] and 2012 at the RRS, NERS, MRRS, and DREC.

		Imazamox ($g\ ha^{-1}$)			
Mixture		0	44		
Herbicide[b]	Rate	OBSERVED[c]	EXPECTED	OBSERVED	P VALUE
	$g\ ha^{-1}$	% of Control			
7 DAT					
None	-	0	-	75	-
Propanil + thiobencarb[d]	1680	74	93	85-	0.0000
Propanil + thiobencarb	3360	84	96	89-	0.0000
Propanil	840	69	92	80-	0.0025
Propanil	1680	79	95	89-	0.0000
Thiobencarb	840	57	89	78-	0.0090
Thiobencarb	1680	63	91	79-	0.0013
14 DAT					
None	-	0	-	80	-
Propanil + thiobencarb	1680	49	90	88	0.5922
Propanil + thiobencarb	3360	62	92	92	0.8550
Propanil	840	44	89	85	0.3529
Propanil	1680	52	90	88	0.5366
Thiobencarb	840	33	87	79	0.0540
Thiobencarb	1680	42	88	84	0.2283
21 DAT					
None	-	0	-	79	-
Propanil + thiobencarb	1680	50	89	94	0.4340
Propanil + thiobencarb	3360	55	90	97	0.2529
Propanil	840	36	86	88	0.8168
Propanil	1680	51	90	89	0.9025
Thiobencarb	840	27	84	86	0.8742
Thiobencarb	1680	35	86	82	0.4091

Continued

Table 2.9. Continued

Mixture Herbicide[b]	Rate	Imazamox (g ha^{-1}) 0 OBSERVED[c]	44 EXPECTED	44 OBSERVED	P VALUE
	g ha^{-1}	% of Control			
49 DAT					
None	-	0	-	72	-
Propanil + thiobencarb	1680	36	82	90	0.1670
Propanil + thiobencarb	3360	47	85	97+	0.0320
Propanil	840	33	81	74	0.2053
Propanil	1680	31	80	73	0.1491
Thiobencarb	840	25	79	75	0.5155
Thiobencarb	1680	35	82	76	0.2845

[a] RRS - Louisiana State University AgCenter's Rice Research Station near Crowley, LA; NERS - Louisiana State university AgCenter's Northeast Research Station near St. Joseph, LA; MERS - Louisiana State University AgCenter's Macon Ridge Research Station near Winnsboro, LA; and DREC - Mississippi State University's Delta Research and Extension Center near Stoneville, MS.

[b] Evaluation date and respective herbicide mixture.

[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

[d] The products applied alone are equivalent to rates found in pre-packaged mixtures.

Table 2.10. Browntop millet control with imazamox mixed with propanil and/or thiobencarb, at 7 and 14 DAT in 2012 at the DREC[a].

		Imazamox (g ha^{-1})			
Mixture		0	44		
Herbicide[b]	Rate	OBSERVED[c]	EXPECTED	OBSERVED	P VALUE
	g ha^{-1}	% of Control			
7 DAT					
None	-	0	-	69	-
Propanil + thiobencarb[d]	1680	88	96	90-	0.0034
Propanil + thiobencarb	3360	93	98	91-	0.0021
Propanil	840	88	96	88-	0.0001
Propanil	1680	90	97	90-	0.0011
Thiobencarb	840	61	88	80-	0.0005
Thiobencarb	1680	70	90	81-	0.0000
14 DAT					
None	-	0	-	69	-
Propanil + thiobencarb	1680	89	96	94	0.1338
Propanil + thiobencarb	3360	90	97	95	0.2998
Propanil	840	86	96	94	0.2820
Propanil	1680	91	97	95	0.2113
Thiobencarb	840	50	84	76-	0.0002
Thiobencarb	1680	56	86	80-	0.0021

[a] DREC - Mississippi State University's Delta Research and Extension Center near Stoneville, MS.

[b] Evaluation date and respective herbicide mixture.

[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

[d] The products applied alone are equivalent to rates found in pre-packaged mixtures.

Table 2.11. Amazon sprangletop control with imazamox mixed with propanil and/or thiobencarb, at 7 and 14 DAT in 2012 at the DREC[a].

Mixture Herbicide[b]	Rate	Imazamox ($g\ ha^{-1}$) 0: OBSERVED[c]	44: EXPECTED	44: OBSERVED	P VALUE
	$g\ ha^{-1}$	% of Control			
7 DAT					
None	-	0.00	-	38	-
Propanil + thiobencarb[d]	1680	93	95	93	0.1962
Propanil + thiobencarb	3360	97	98	96	0.3399
Propanil	840	89	93	93	0.7178
Propanil	1680	94	96	95	0.6117
Thiobencarb	840	68	80	71-	0.0005
Thiobencarb	1680	69	80	84	0.1496
14 DAT					
None	-	0	-	46	-
Propanil + thiobencarb	1680	93	96	93	0.0768
Propanil + thiobencarb	3360	95	97	95	0.2325
Propanil	840	86	93	93	0.9548
Propanil	1680	94	97	95	0.3950
Thiobencarb	840	62	81	70-	0.0000
Thiobencarb	1680	66	82	73-	0.0000

[a] DREC - Mississippi State University's Delta Research and Extension Center near Stoneville, MS.

[b] Evaluation date and respective herbicide mixture.

[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

[d] The products applied alone are equivalent to rates found in pre-packaged mixtures.

Table 2.12. Rough Rice Yields of rice treated with imazamox mixed with propanil and thiobencarb at the RRS[a] in 2011 and 2012.

		Imazamox (g ha^{-1})			
Mixture Herbicide[b]	Rate	0		44	
	kg ha^{-1}	kg ha^{-1}		kg ha^{-1}	
None	-	2660	C[d]	7090	A
Propanil + thiobencarb[c]	1680	4180	B	8410	A
Propanil + thiobencarb	3360	5310	B	8430	A
Propanil	840	4980	B	7320	A
Propanil	1680	3620	B	7270	A
thiobencarb	840	4502	B	7810	A
thiobencarb	1680	3890	B	7720	A

Standard Error: 1720
[a] RRS - Louisiana State University AgCenter's Rice Research Station near Crowley, LA.
[b] Evaluation date and respective herbicide mixture.
[c] The products applied alone are equivalent to rates found in pre-packaged mixtures.
[d] Means followed by a common letter are not significantly different at P=0.05 using PROC MIXED.

addition of multiple herbicide modes of action per individual application can help prevent or reduce the development of herbicide resistant weeds. Herbicide programs containing co-applications resulted in higher rough rice yields and higher profits than programs including only single herbicide applications (Carlson et al 2011; Webster et al. 2012). Increased weed pressure, even over a short period of time, decreases rough rice yield (Webster et al. 2012). There are multiple weed species that infest rice fields and rarely is there a single weed monoculture in rice production (Braverman 1995; Webster 2004). In an IR rice production system weeds such as Indian jointvetch, hemp sesbania, and alligatorweed can be difficult to consistently control, or a resistant management control program may be needed, when barnyardgrass and red rice infest rice fields. The combinations of imazethapyr plus propanil plus thiobencarb provides a mixture with three different modes of action, and provides an excellent opportunity to broaden the weed control spectrum and offers growers with an excellent resistant management strategy (Carlson et al. 2011; Carlson et al. 2012; Masson and Webster 2001; Norsworthy et al. 2007; Pellerin et al. 2004; Webster et al. 2012).

Literature Cited

Akobundu, I.O., R.D. Sweet, and W.B. Duke. 1975. A method of evaluating herbicide combinations and determining herbicide synergism. Weed Sci. 23:20–25.

Anonymous. 2009. Beyond herbicide label. BASF Corporation. http://agproducts.basf.us/products/label-and-msds/beyond-herbicide-label.pdf. Verified September 25, 2014.

Ashton, F.M. and T.J. Monaco. 1991. Weed Science: Principles and Practices. 3rd ed. New York J. Wiley. 466 p.

Avila, L.A., S.A. Senseman, G.N. McCauley, J.M. Chandler, and J.H. O'Barr. 2005. Effect of flood timing on red rice (*Oryza* spp.) control with imazethapyr applied at different dry-seeded rice growth stages. Weed Technol. 19:476–480.

Baltazar, A.M. and R.J. Smith, Jr. 1994. Propanil-resistant barnyardgrass (*Echinochloa crus-galli*) control in rice (*Oryza sativa*). Weed Technol. 8:575–581.

Blouin, D.C., E.P. Webster, and J.A. Bond. 2010. On a method of analysis for synergistic and antagonistic joint-action effects with fenoxaprop mixtures in rice (*Oryza sativa*). Weed Technol. 24:583-589.

Blouin, D.C., E.P. Webster, and W. Zhang. 2004. Analysis of synergistic and antagonistic effects of herbicides using nonlinear mixed-model methodology. Weed Technol. 18:464–472.

Braverman, M.P. 1995. Weed control in rice (*Oryza sativa*) with quinclorac and bensulfuron coating of granular herbicides and fertilizer. Weed Technol. 9:494–498.

Carlson, T.P., E.P. Webster, M.E. Salassi, J.B. Hensley, and D.C. Blouin. 2011. Imazethapyr plus propanil programs in imidazolinone-resistant rice. Weed Technol. 25:204-211.

Carlson, T.P., E.P. Webster, M.E. Salassi, J.A. Bond, J.B. Hensley, and D.C. Blouin. 2012. Economic evaluations of imazethapyr rates and timings on rice. Weed Technol. 26:24-28.

Colby, S.R. 1967. Calculating synergistic and antagonistic response of herbicide combinations. Weeds 15:20-22.

Craigmiles, J.P. 1978. Introduction. Pages 5–6. *in* Eastin, E.F. ed. Red Rice Research and Control Tx. Agri. Exp. Stat. Bull. 1270.

Crawford, S.H. and D.L. Jordan. 1995. Comparison of single and multiple applications of propanil and residual herbicides in dry-seeded rice (*Oryza sativa*). Weed Technol. 9:153–157.

Croughan, T.P. 1994. Application of tissue culture techniques to the development of herbicide resistant rice. Louisi. Agric. 37:25-26.

Flint, J.L., P.L. Cornelius, and M. Barrett. 1988. Analyzing herbicide interactions: a statistical treatment of Colby's method. Weed Technol. 2:304-309.

Hatzios, K.K. and D. Penner. 1985. Interactions of herbicides with other agrochemicals in higher plants. Rev. Weed Sci. 1:1–52.

Hydrick, D.E. and D.R. Shaw. 1994. Effects of tank-mix combinations of non-selective foliar and selective soil-applied herbicides on three weed species. Weed Technol. 8:129–133.

Jordan, D.L. 1997. Efficacy of reduced rates of quinclorac applied with propanil or propanil plus molinate in dry-seeded rice (*Oryza sativa*). Weed Sci. 45:824–828.

Jordan, D.L., D.K. Miller, and S.H. Crawford. 1998. Barnyardgrass (*Echinochloa crus-galli*) control in dry-seeded rice (*Oryza sativa*) with soil applied and postemergence herbicide programs. Weed Technol. 12:69–73.

Khodayari, K., R.J. Smith Jr., and H.L. Black. 1987. Red rice (*Oryza sativa*) control with herbicide treatments in soybeans (*Glycine max*). Weed Sci. 35:127–129.

Lanclos, D.Y., E.P. Webster, and W. Zhang. 2002. Glufosinate tank-mix combinations in glufosinate-resistant rice (*Oryza sativa*). Weed Technol. 16:659-663.

Masson, J.A. and E.P. Webster. 2001. Use of imazethapyr in water-seeded imidazolinone-tolerant rice (*Oryza sativa*). Weed Technol. 15:103–106.

Morse, P.M. 1978. Some comments on the assessment of joint action in herbicide mixtures. Weed Sci. 26:58-71.

Mueller, T.C., W.W. Witt, and M. Barrett. 1989. Antagonism of johnsongrass (*Sorghum halepense*) control with fenoxaprop, haloxyfop, and sethoxydim by 2,4–D. Weed Technol. 3:86–89.

Norsworthy, J.K., S.K. Bangarwa, R.C. Scott, J. Still, and G.M. Griffith. 2010. Use of propanil and quinclorac tank mixtures for broadleaf weed control on rice (*Oryza sativa*) levees. Crop Protect. 29:255–259.

Norsworthy, J.K., N.R. Burgos, R.C. Scott, and K.L. Smith. 2007. Consultant perspectives on weed management needs in Arkansas rice. Weed Technol. 21:832–839.

Ottis, B.V., J.M. Chandler, and G.N. McCauley. 2002. Imazethapyr application methods and sequences for imidazolinone-tolerant rice (*Oryza sativa*). Weed Technol. 17:526-533.

Pellerin, K.J., E.P. Webster, W. Zhang, and D.C. Blouin. 2003. Herbicide mixtures in water-seeded imidazolinone-resistant rice. Weed Technol. 17:836-841.

Pellerin, K.J., E.P. Webster, W. Zhang, and D.C. Blouin. 2004. Potential use of imazethapyr mixtures in drill-seeded imidazolinone-resistant rice. Weed Technol. 18:1037-1042.

Rhodes, G.N., Jr. and H.D. Coble. 1984. Influence of bentazon on absorption and translocation of sethoxydim in goosegrass. Weed Sci. 32:595–597.

Richburg, J.S., III., J.W. Wilcut. And G.L. Wiley. 1995. AC 263,222 and imazethapyr rates and mixtures for weed management in peanut (*Arachis hypogaea*). Weed Technol. 9:801-806.

SAS Institute Inc. 2010. SAS/STAT User's Guide, release 9.3 ed. Cary, NC SAS Institute.

Senseman, S.A. ed. 2007. Herbicide Handbook. 9th ed. Lawrence, KS: Weed Science Society of America. Pp. 169–171.

Smith, R.J., Jr., 1961. 3,4-Dichloropropionanilide for control of barnyardgrass in rice. Weeds 9:318–322.

Smith, R.J., Jr., 1965. Propanil and mixtures with propanil for weed control in rice. Weeds 13:236–238.

Smith, R.J., Jr., 1981. Control of red rice (*Oryza sativa*) in water-seeded rice (*O. sativa*). Weed Sci. 29:663–666.

Smith, R.J., Jr., and J.E. Hill. 1990. Weed control technology in U.S. rice. Pages 314–327. *in* Grayson, B.T., M.B. Green, and L.G. Copping. eds. Pest Management in Rice. United Kingdom: Elsevier Science.

Waltz, A.L., A.R. Martin, and K.T. Horky. 2003. Weed control in grain sorghum. N. Cent. Weed Sci. Res. Rep. 60:45–46.

Webster, E.P. and J.A. Masson. 2001. Acetolactate synthase-inhibiting herbicides on imidazolinone-tolerant rice. Weed Sci. 49:652-657.

Webster, E.P. 2014. Weed Management. Pages 54-81. *in* J. Saichuk, ed. Louisiana Rice Production Handbook. Baton Rouge, LA: Louisiana State University Agricultural Center Pub. 2321-5/14 rev.

Webster, E.P. and D.R. Shaw. 1997. Potential stale seedbed herbicide combinations for cotton. Miss. Agri. and For. Exp. Stat. Techni. Bull. 216.p. 6.

Webster, E.P., T.P. Carlson, M.E. Salassi, J.B. Hensley, and D.C. Blouin. 2012. Imazethapyr plus residual herbicide programs for imidazolinone-resistant rice. Weed Technol. 26:410-416.

Webster, T.M. 2004. Weed survey — southern states. Proc. South. Weed Sci. Soc. 57:404–426.

Zhang, W., E.P. Webster, and H.M. Selim. 2001. Effect of soil moisture on efficacy of imazethapyr in greenhouse. Weed Technol. 15:355-359.

Chapter 3
Interactions of Herbicide Mixtures of Various Propanil Rates with Imidazolinone Herbicides for Weed Control

Introduction

Red rice (*Oryza sativa* L.) has been recognized as a weed in U.S. rice (*Oryza sativa* L.) fields for over 150 years and has become increasingly troublesome in cultivated rice fields throughout the southern United States (Craigmiles 1978; Dowler 1997; Khodayari et al. 1987; Smith 1981; Webster 2004). Barnyardgrass is another troublesome weed problem in rice production in temperate and tropical areas (Dowler 1997; Holm et al. 1977) and is capable of reducing rice yields by as much as 80% (Smith 1965). In the southern U.S. rice production initial weed management decisions are often based on the control of barnyardgrass, because of the lack of herbicides available for red rice control. However, this changed with the development of imidazolinone-resistant (IR) rice (Croughan 1994).

The introduction of IR rice in the early 2000s exhibited tolerance to the imidazolinone class of herbicides, which inhibit acetohydroxy acid synthase (EC 2.2.1.6), also known as acetolactate synthase (Stidham and Singh 1991; Stougaard et al. 1990). IR rice was developed in 1993 through seed mutagenesis, allowing IR rice lines to be considered nontransgenic (Croughan 1994). For the first time red rice could be controlled while producing a crop of rice with the use of imidazolinone herbicides. Imazethapyr was designated as the target herbicide for use in IR rice in the U.S. (Anonymous 2011).

Research has demonstrated the efficacy of imazethapyr on grass weed species, particularly red rice and barnyardgrass. Webster and Masson (2001) reported red rice control above 95% with imazethapyr applied at 70 and 140 g ha^{-1} to rice in the two- to three-leaf stage. Soil applications of imazethapyr at 70, 105, or 140 g ha^{-1} followed by 70 g ha^{-1} POST controlled barnyardgrass 88 to 96% (Pellerin and Webster 2004). Rice production provides favorable growing conditions for both hemp sesbania [*Sesbania herbaccea* (Mill.)

McVaugh] and Indian jointvetch (*Aeschynomene indica* L.)(Lorenzi and Jeffery 1987), and the use of imazethapyr in IR rice provides minimal control of hemp sesbania and Indian jointvetch (Masson et al. 2001; Webster and Masson 2001; Zhang et al. 2001).

Imazamox is another imidazolinone herbicide labeled for use in IR rice (Anonymous 2009). Imazamox is labeled at rates of 44 to 53 g ha^{-1}, and it is usually applied at a late season application on rice in the panicle initiation (PI) stage of growth to 14 days after PI (Webster 2014). This is a useful tool for late season application due to its lack of residual activity (Senseman 2007). However, it has reduced activity on many of the same weeds as imazethapyr.

For many years, the weed control program for rice in the southern United States centered around propanil, and propanil has long been used to control annual grass and broadleaf weeds in southern U.S. rice production (Smith 1961; Smith 1965; Smith and Hill 1990). Propanil was commercialized in the early 1960s and became the primary herbicide for controlling barnyardgrass. By the early 1990s, 98% of the rice acreage was treated with at least one application of propanil each year (Carey et al. 1995). The first propanil-resistant barnyardgrass biotype was reported in Poinsett County, AR in 1989. Numerous cases of propanil resistance have been confirmed since then; those resistant barnyardgrass biotypes may require 2.5 to 20 times the commercial use rate of propanil for control (Baltazar and Smith 1994; Carey et al. 1995).

Herbicide mixtures have proven to be beneficial in improving efficacy and broadening the weed control spectrum in IR rice (Carlson et al. 2011; Pellerin et al. 2003; Pellerin et al. 2004; Webster et al. 2012), and the use of herbicide mixtures is favorable to producers because of increased weed control and reduced application cost (Hydrick and Shaw 1994). Researchers have demonstrated the importance of incorporating herbicide mixtures to the standard imazethapyr program in IR rice production to maximize weed control (Carlson et al. 2011; Fish et al. 2013, Fish et al. 2012; Pellerin et al. 2003; Pellerin et al. 2014; Webster et al. 2012). With this in mind, the objective of this research was to evaluate the interaction of an imazethapyr or imazamox mixture with various rates of propanil on several weeds in rice production. Blouin's modified Colby's will be used to determine if a synergistic, antagonistic, or additive response occurred with each mixture (Blouin et al 2004; Blouin et al. 2010). An additive response will be reported as a neutral response from this point forward.

Materials and Methods

Two studies were conducted at four locations: 1) the Louisiana State University Agricultural Center's Rice Research Station (RRS) near Crowley, Louisiana, in 2011 and 2012 on a Crowley silt loam soil (fine montmorillinitic, thermic Typic Albaqualf) with pH 6.4 and 1.4% organic matter (OM); 2) the Louisiana State University Agricultural Center's Northeast Research Station (NERS) near St. Joseph, Louisiana, in 2012 on a Sharky clay (very fine, montmorillonitic, nonacid, Vertic Haplaquept) with pH 6.1 and 2.1% OM; 3) the Louisiana State University Agricultural Center's Macon Ridge Research Station (MRRS) near Winnsboro, Louisiana, in 2012 on a Gigger silt loam (fine-silty, mixed, thermic Typic Fragiudalf) with pH 5.8 and 1.3% OM; and 4) the Mississippi State University Delta Research and Extension Station (DREC) near Stoneville, Mississippi in 2012 on a Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) with a pH of 8.2 and 2.1% OM.

The experimental design was a two-factor factorial in a randomized complete block with four replications. 'CL161' IR rice was planted in 2011 and 'CL111' IR rice was planted in 2012 at the RRS, NERS, and the MRRS, and 'CL151' IR rice was planted in 2012 at the DREC. The cultivars were long grain lines. Factor A was imazethapyr, sold under the tradename Newpath, at 0 and 70 g ha^{-1}, Factor B was propanil, sold under the tradename RiceShot, at 0, 1.12, 2.24, 3.36, and 4.5 kg ha^{-1} (Table 3.1). Treatments were applied to one- to three-leaf rice.

At the RRS, seedbed preparation consisted of fall disking and a spring disking followed by two passes with a two-way bed conditioner equipped with S-tine harrows set at a 7.5 operating depth in opposite direction. Rice was drilled at 84 kg/ha on April 29, 2011 and April 23, 2012 with eight 19-cm rows, 5.2-m long. The experimental area was surface irrigated three to four times after planting at 7 day intervals to maintain adequate soil moisture and rice growth in 2011 and 2012. Fertility management consisted of 280 kg ha^{-1} of 8-24-24 fertilizer preplant and 280 kg ha^{-1} of 46-0-0 urea nitrogen 1 day prior to permanent flood establishment. A permanent 6-cm flood was established on May 26, 2011 and June 4, 2012, and maintained two weeks prior to harvest.

At the NERS, field preparation during each year consisted of a fall disking followed by a spring disking and two passes in opposite directions with a field cultivator equipped with S-tine harrows set to operate 6 cm deep. Rice was drilled at 84 kg/ha on April 23, 2012 with eight 19-cm rows, 5.2-m long. The experimental area was surface irrigated four times after planting at 7 day intervals to maintain adequate soil moisture and rice growth. Fertility management consisted of 280 kg ha^{-1} of 8-24-24 fertilizer preplant and 336 kg ha^{-1} of 46-0-0 urea nitrogen 1 day prior to permanent flood establishment. A permanent 6-cm flood was established on June 4, 2012, and maintained two weeks prior to harvest.

At the MRRS, seedbed preparation consisted of fall and spring disking followed by two passes with a field cultivator equipped with S-tine harrows set at a 7.5 operating depth. Rice was drilled at 84 kg/ha on May 2, 2012 with eight 19-cm rows, 5.2-m long. The experimental area was surface

Table 3.1. Source of materials.

Herbicide	Trade name	Form	Rate g ha^{-1}	Manufacturer	Address	Website
Imazethapyr	Newpath	AS	70	BASF Corporation	Fordam, NJ	www.agro.basf.us
Imazamox	Beyond	AS	44	BASF Corporation	Fordam, NJ	www.agro.basf.us
Propanil	RiceShot	EC	1120/ 2240/ 3360/ 4480	Rice Co.	Memphis, TN	www.ricecousa.com

irrigated seven times after planting to maintain adequate soil moisture and rice growth. Fertility management consisted of 280 kg ha^{-1} of 8-24-24 fertilizer preplant and 280 kg ha^{-1} of 46-0-0 urea nitrogen 1 day prior to permanent flood establishment. A permanent 6-cm flood was established on June 23, 2012, and maintained two weeks prior to harvest.

At the DREC, seedbed preparation consisted of fall and spring disking followed by two passes with a two-way bed conditioner equipped with S-tine harrows set at a 7.5 operating depth. Rice was drill seeded on May 10, 2012 with eight 19-cm rows, 5.2-m long. The experimental area was surface irrigated six times after planting to maintain adequate soil moisture and rice growth. Fertility management consisted of 280 kg ha^{-1} of 8-24-24 fertilizer preplant and 336 kg ha^{-1} of 46-0-0 urea nitrogen 1 day prior to permanent flood establishment. A permanent 6-cm flood was established on June 6, 2012, and maintained two weeks prior to harvest.

Herbicide applications at all locations were made using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L/ha solution at 190 kPa. Treatments were applied on one- to three-leaf rice, with a second application 14 days later of imazethapyr applied at four- to five-leaf rice.

Data obtained from the studies include visual weed control and injury on a scale of 0 to 100 with 0 being no weed control or crop injury and 100 being complete weed control or crop death. Rice plant height was recorded from the ground to the tip of the extended panicle immediately prior to harvest (Data not shown), and rough rice yield was obtained for the primary crop with a small plot combine harvesting the center 4 rows of each plot. Grain yield was adjusted to 12% moisture.

Treatments were applied at the RRS in 2011 on red rice in the one- to three-leaf stage with a height of 2 to 8 cm tall, 1 to 8 cm barnyardgrass with one- to four-leaf, 1 to 8 cm broadleaf signalgrass with one- to four-leaf, and in 2012 on 5 to 10 cm red rice with two- to three-leaf, and 5 to 10 cm barnyardgrass with two- to three-leaf. In 2012 at the NERS applications were made on 1 to 8 cm barnyardgrass with two- to six-leaf. In 2012 at the MRRS application were made on 3 to 5 cm barnyardgrass with 2- to 4-leaf. In 2012, at the DREC on 5 to 8 cm red rice with one- to four-leaf, 3 to 5 cm barnyardgrass with one-to three-leaf, 1 to 2 cm browntop millet one- to three-leaf, and 1 to 5 cm Amazon sprangletop one- to four-leaf.

Visual observations of red rice and broadleaf signalgrass control were taken in 2011 and 2012 at the RRS at 14, 21, 35, and 49 DAT and in 2012 at DREC at 7 and 14 DAT. Barnyardgrass visual observations were made in 2011 and 2012 at the RRS at 14, 21, 35, and 49 DAT, in 2012 at the NERS at 14, 28, and 49 DAT, in 2012 at the MRRS at 28, 42, 49 DAT, and at DREC at 7 and 14 DAT. Browntop millet and Amazon sprangletop visual observations were made at DREC at 7 and 14 DAT.

Control data were analyzed under the guidelines described in detail by Blouin et al. (2010), and rough rice yield data were analyzed using PROC MIXED. The fixed effects used in the analysis were the rates of rates of imidazolinone herbicides, the companion herbicides including none, DAT, and all interactions. The random effects were location, blocks within location, and the treatment-by-block. The dependent variables are red rice, barnyardgrass, browntop millet, Amazon sprangletop, broadleaf signalgrass, and rough rice yield.

A similar but separate study was conducted at all locations using imazamox, sold under the tradename Beyond, at 0 and 44 g ha^{-1} for Factor A. Factor B remained the same as previously described (Table 3.1).

Results and Discussion

Imazethapyr Mixed with Different Propanil Rates Study. At 7 days after treatment (DAT), synergism occurred for red rice when treated with imazethapyr at 70 g ha^{-1} mixed with all rates of propanil by increasing control from an expected control of 53% to an observed control of 59, 61, 66, and 71% control, respectively (Table 3.2). At 14 DAT, red rice treated with imazethapyr mixed with propanil at 2.24, 3.36, and 4.48 kg ha^{-1} indicated a synergistic response by increasing control from an expected control of 76% to an observed control of 81, 85, and 87%, respectively. The only mixture that provided synergism for red rice control at every evaluation was imazethapyr plus the high rate of propanil at 4.48 kg ha^{-1}. Every other mixture resulted in a neutral interaction. However, the 3.36 kg ha^{-1} propanil rate plus imazethapyr was synergistic at 35 DAT, but resulted in a neutral interaction at 49 DAT. No antagonism was observed for red rice treated with any mixture at any evaluation. These neutral and synergistic responses observed indicate the increase in red rice control, similar to Carlson et al. (2011), can help reduce the potential for outcrossing and help manage herbicide resistance.

At 7 DAT, antagonism was observed for barnyardgrass control when barnyardgrass was treated with a mixture of imazethapyr at 70 g ha^{-1} plus propanil at 2.24, 3.36, and 4.48 kg ha^{-1} by decreasing control from an expected control of 96, 97, and 98% to an observed control of 91, 94, and 95%, respectively (Table 3.3). This indicates that imazethapyr plus propanil may not result in a neutral or synergistic response; however, control was 85 to 95% for all mixtures compared with 74 to 93% control with imazethapyr or

Table 3.2. Red rice control with imazethapyr and propanil mixtures in 2011 and 2012 at the RRS[a] and DREC.

Mixture Herbicide[b]	Rate	Imazethapyr (g ha^{-1}) 0 OBSERVED[c]	70 EXPECTED	70 OBSERVED	P VALUE
	kg ha^{-1}	% of Control			
7 DAT					
none	-	0	-	53	-
propanil	1.12	0	53	59+	0.0181
propanil	2.24	0	53	61+	0.0015
propanil	3.36	2	53	66+	0.0000
propanil	4.48	5	55	71+	0.0000
14 DAT					
none	-	0	-	75	-
propanil	1.12	0	75	79	0.1220
propanil	2.24	0	75	81+	0.0314
propanil	3.36	0	76	85+	0.0001
propanil	4.48	0	76	87+	0.0000
21 DAT					
none	-	0	-	87	-
propanil	1.12	0	87	86	0.7303
propanil	2.24	0	87	89	0.2771
propanil	3.36	1	87	90	0.1928
propanil	4.48	5	87	93+	0.0152
35 DAT					
none	-	0	-	80	-
propanil	1.12	5	91	85	0.0983
propanil	2.24	5	81	86	0.0596
propanil	3.36	5	81	90+	0.0008
propanil	4.48	6	81	95+	0.0000
49 DAT					
none	-	0	-	82	-
propanil	1.12	0	82	79	0.2395
propanil	2.24	0	82	84	0.3458
propanil	3.36	0	82	84	0.4758
propanil	4.48	0	82	93+	0.0001

[a] RRS – Louisiana State University AgCenter’s Rice Research Station near Crowley, LA; DREC – Mississippi State University’s Delta Research and Extension Center near Stoneville, MS.

[b] Evaluation date and respective herbicide mixture.

[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin’s Modified Colby’s expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

Table 3.3. Barnyardgrass control with imazethapyr and propanil mixtures in 2011 at the RRS[a] and 2012 at the RRS, NERS, MRRS, and DREC.

Mixture Herbicide[b]	Rate	Imazethapyr (g ha^{-1}) 0 OBSERVED[c]	70 EXPECTED	70 OBSERVED	P VALUE
	kg ha^{-1}	% of Control			
7 DAT					
None	-	0	-	74	-
Propanil	1.12	74	93	85	0.0724
Propanil	2.24	86	96	91-	0.0498
Propanil	3.36	89	97	94-	0.0013
Propanil	4.48	93	98	95-	0.0724
14 DAT					
None	-	0	-	80	-
Propanil	1.12	49	90	85	0.2612
Propanil	2.24	61	92	88	0.3137
Propanil	3.36	72	94	91	0.4591
Propanil	4.48	80	97	94	0.5574
21 DAT					
None	-	0	-	83	-
Propanil	1.12	49	91	85	0.3362
Propanil	2.24	53	92	88	0.5948
Propanil	3.36	63	94	89	0.5101
Propanil	4.48	61	91	92	0.8866
28 DAT					
None	-	0	-	80	-
Propanil	1.12	73	95	87-	0.0016
Propanil	2.24	71	94	88-	0.0100
Propanil	3.36	79	96	91-	0.0400
Propanil	4.48	82	96	95	0.5658
35 DAT					
None	-	0	-	86	-
Propanil	1.12	27	89	75	0.0503
Propanil	2.24	36	91	84	0.3177
Propanil	3.36	51	93	88	0.4570
Propanil	4.48	52	93	93	0.9483
42 DAT					
None	-	0	-	76	-
Propanil	1.12	57	89	76-	0.0423
Propanil	2.24	51	87	87	0.9798
Propanil	3.36	57	89	91	0.6846
Propanil	4.48	68	92	91	0.9261

Continued

Table 3.3. Continued

Mixture Herbicide[b]	Rate	Imazethapyr (g ha^{-1}) 0 OBSERVED[c]	70 EXPECTED	70 OBSERVED	P VALUE
	kg ha^{-1}	% of Control			
49 DAT					
None	-	0	-	69	-
Propanil	1.12	29	78	64-	0.0089
Propanil	2.24	35	81	72	0.1392
Propanil	3.36	41	82	75	0.2176
Propanil	4.48	50	85	87	0.7234

[a] RRS - Louisiana State University AgCenter's Rice Research Station near Crowley, LA; NERS - Louisiana State University AgCenter's Northeast Research Station near St. Joseph, LA; MERS - Louisiana State University AgCenter's Macon Ridge Research Station near Winnsboro, LA; and DREC - Mississippi State University's Delta Research and Extension Center near Stoneville, MS.

[b] Evaluation date and respective herbicide mixture.

[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

any rate of propanil applied alone. However, by 14 and 21 DAT all mixtures were neutral. Slight antagonism occurred when propanil at 1.12 kg ha^{-1} was mixed with imazethapyr at 28, 42, and 49 DAT. Indicating this lower rate may need to be avoided in a co-application with imazethapyr. Although no synergistic response occurred for barnyardgrass control across all ratings a neutral response occurred for the propanil at 4.48 kg ha^{-1} plus imazethapyr mixture across all evaluations, except 7 DAT. The addition of another mode of action with imazethapyr can be beneficial in a resistance management program for barnyardgrass.

At 7 DAT, an antagonistic response was shown for browntop millet that was treated with imazethapyr at 70 g ha^{-1} mixed with propanil at 1.12, 2.24, 3.36, and 4.48 kg ha^{-1} by decreasing control from an expected control of 97, 98, 98, and 99% to the observed control of 93, 94, 95, and 94%, respectively (Table 3.4). At 14 DAT, an antagonistic response was also observed for

Table 3.4. Browntop millet control with imazethapyr and propanil mixtures at 7 and 14 DAT in 2012 at the DREC[a].

Mixture Herbicide[b]	Rate	Imazethapyr (g ha^{-1}): 0 OBSERVED[c]	70 EXPECTED	70 OBSERVED	P VALUE
	kg ha^{-1}	% of Control			
7 DAT					
None	-	0	-	75	-
Propanil	1.12	88	97	93-	0.0097
Propanil	2.24	93	98	94-	0.0058
Propanil	3.36	93	98	95-	0.0367
Propanil	4.48	95	99	94-	0.0035
14 DAT					
None	-	0	-	73	-
Propanil	1.12	88	97	94	0.0617
Propanil	2.24	93	98	95	0.0556
Propanil	3.36	95	98	95-	0.0351
Propanil	4.48	95	99	95-	0.0216

[a] DREC - Mississippi State University's Delta Research and Extension Center near Stoneville, MS.

[b] Evaluation date and respective herbicide mixture.

[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

browntop millet treated with imazethapyr mixed with propanil at 3.36 and 4.48 kg ha^{-1}. These results indicate a mixture of propanil plus imazethapyr when browntop millet is a problem weed may need to be avoided. However, even though antagonism occurred, control was above 90% and higher than imazethapyr applied alone with 73% control. In this case, the antagonism was caused by the imazethapyr not providing any activity on browntop millet when mixed with propanil at 14 DAT. Further evaluation may be needed at 21 to 49 DAT.

Crop injury was less than 10% across all evaluations (Data not shown). No difference occurred in yield with any propanil plus imazethapyr mixes or the two higher rates of propanil applied alone (Table 3.5); however, based on weed management and the neutral and synergistic responses observed for red

Table 3.5. Rough rice yields of rice treated with imazethapyr mixed with propanil at the RRS[a] in 2011 and 2012.

		Imazethapyr (g ha^{-1})			
Mixture Herbicide[b]	Rate	0		70	
	kg ha^{-1}	kg ha^{-1}		kg ha^{-1}	
None	-	3180	D[c]	6090	AB
Propanil	1.12	4090	CD	5820	AB
Propanil	2.24	5160	BC	6660	A
Propanil	3.36	5710	AB	6700	A
Propanil	4.48	5910	AB	6970	A

Standard Error: 1380
[a] RRS - Louisiana State University AgCenter's Rice Research Station near Crowley, LA.
[b] Evaluation date and respective herbicide mixture.
[c] Means followed by a common letter are not significantly different at P=0.05 using PROC MIXED.

rice and barnyardgrass control with the high rate of propanil plus imazethapyr this mixture would help prevent or delay red rice outcrossing with IR rice and help manage resistance development in barnyardgrass and browntop millet.

Imazamox Mixed with Different Propanil Rates Study. At 7 DAT, a synergistic response was observed for red rice treated with imazamox at 44 g ha^{-1} mixed with propanil at 3.36 and 4.48 kg ha^{-1} by increasing control from an expected control of 63% to an observed control of 68 and 75%, respectively (Table 3.6). This synergistic response continued across all evaluations through 49 DAT. The positive aspect of this mixture was that no antagonism occurred for any mixture regardless of propanil rate. Similar results were observed with imazethapyr plus propanil mixtures (Table 3.2), indicating the addition of propanil to imazamox can aid in the control of red rice when propanil is applied at 3.36 and 4.48 kg ha^{-1}. The lower rates of propanil mixed with

Table 3.6. Red rice control with imazamox and propanil mixtures in 2011 and 2012 at the RRS[a] and DREC.

Mixture Herbicide[b]	Rate	Imazamox (g ha^{-1}) — 0 — OBSERVED[c]	— 44 — EXPECTED	OBSERVED	P VALUE
	kg ha^{-1}	% of Control			
7 DAT					
None	-	0	-	63	-
Propanil	1.12	0	63	64	0.4473
Propanil	2.24	0	63	66	0.0285
Propanil	3.36	0	63	68+	0.0047
Propanil	4.48	4	63	75+	0.0000
14 DAT					
None	-	0	-	85	-
Propanil	1.12	0	83	84	0.6261
Propanil	2.24	0	83	86	0.3312
Propanil	3.36	0	83	88+	0.0247
Propanil	4.48	1	83	91+	0.0038
21 DAT					
None	-	0	-	81	-
Propanil	1.12	0	81	81	NS
Propanil	2.24	0	81	84	0.2174
Propanil	3.36	4	81	90+	0.0009
Propanil	4.48	0	81	89+	0.0009
28 DAT					
None	-	0	-	84	-
Propanil	1.12	0	74	90+	0.0031
Propanil	2.24	0	74	92+	0.0006
Propanil	3.36	0	74	94+	0.0000
Propanil	4.48	0	74	90+	0.0000
35 DAT					
None	-	0	-	77	-
Propanil	1.12	3	79	84	0.0508
Propanil	2.24	5	78	85+	0.0173
Propanil	3.36	6	78	90+	0.0001
Propanil	4.48	8	78	95+	0.0000

Continued

Table 3.6. Continued

Mixture Herbicide[b]	Rate	Imazamox (g ha^{-1}) 0 OBSERVED[c]	44 EXPECTED	44 OBSERVED	P VALUE
	kg ha^{-1}	% of Control			
49 DAT					
None	-	0	-	73	-
Propanil	1.12	0	73	80+	0.0201
Propanil	2.24	0	73	84+	0.0005
Propanil	3.36	0	73	83+	0.0018
Propanil	4.48	0	73	84+	0.0005

[a] RRS – Louisiana State University AgCenter's Rice Research Station near Crowley, LA; DREC – Mississippi State University's Delta Research and Extension Center near Stoneville, MS.
[b] Evaluation date and respective herbicide mixture.
[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

imazamox may aid in a resistance management strategy based on a neutral interaction.

At 7 DAT, an antagonistic response was shown for barnyardgrass control when imazamox at 44 g ha^{-1} plus propanil at 1.12, 2.24, 3.36, and 4.48 kg ha^{-1} by decreasing control from an expected control of 96, 96, 98, and 98% to an observed control of 87, 92, 93, and 94%, respectively (Table 3.7). Propanil has long been used for control of barnyardgrass, and the antagonistic responses observed at 7, 14, 28, and 42 DAT were probably due to the addition of imazamox by not adding additional activity to the mix for barnyardgrass control. However, the high rate of propanil plus imazamox resulted in a neutral response across all evaluation except 7 DAT. This neutral response indicates the addition of another mode of action from propanil may be an option in a resistance management strategy.

At 7 and 14 DAT, an antagonistic response occurred for the control of browntop millet treated with imazamox at 44 g ha^{-1} mixed with propanil at

Table 3.7. Barnyardgrass control with imazamox and propanil mixtures in 2011 at the RRS[a] and 2012 at the RRS, NERS, MRRS, and DREC.

Mixture Herbicide[b]	Rate	Imazamox ($g\ ha^{-1}$) 0 OBSERVED[c]	44 EXPECTED	44 OBSERVED	P VALUE
	$kg\ ha^{-1}$	% of Control			
7 DAT					
None	-	0	-	82	-
Propanil	1.12	76	96	87-	0.0349
Propanil	2.24	79	96	92-	0.0150
Propanil	3.36	87	98	93-	0.0129
Propanil	4.48	88	98	94-	0.0000
14 DAT					
None	-	0	-	79	-
Propanil	1.12	57	91	82-	0.0088
Propanil	2.24	64	93	87	0.1512
Propanil	3.36	72	94	90	0.2239
Propanil	4.48	76	95	92	0.4555
21 DAT					
None	-	0	-	77	-
Propanil	1.12	41	86	83	0.5629
Propanil	2.24	51	88	88	0.8907
Propanil	3.36	66	92	92	0.9926
Propanil	4.48	78	95	94	0.9601
28 DAT					
None	-	0	-	80	-
Propanil	1.12	67	92	78-	0.0001
Propanil	2.24	71	93	84-	0.0053
Propanil	3.36	76	90	84-	0.0015
Propanil	4.48	80	95	92	0.4143
35 DAT					
None	-	0	-	74	-
Propanil	1.12	16	79	74	0.3928
Propanil	2.24	28	81	79	0.6590
Propanil	3.36	35	83	84	0.8600
Propanil	4.48	46	86	91	0.3928
42 DAT					
None	-	0	-	63	-
Propanil	1.12	70	89	78-	0.0252
Propanil	2.24	73	90	79-	0.0282
Propanil	3.36	78	92	84	0.1053
Propanil	4.48	88	95	90	0.2155

Continued

Table 3.7. Continued

Mixture Herbicide[b]	Rate	Imazamox (g ha^{-1}): 0 — OBSERVED[c]	44 — EXPECTED	44 — OBSERVED	P VALUE
	kg ha^{-1}	% of Control			
49 DAT					
None	-	0	-	46	-
Propanil	1.12	32	76	69	0.3166
Propanil	2.24	37	78	74	0.6335
Propanil	3.36	42	79	83	0.6150
Propanil	4.48	47	81	89	0.2461

[a] RRS - Louisiana State University AgCenter's Rice Research Station near Crowley, LA; NERS - Louisiana State university AgCenter's Northeast Research Station near St. Joseph, LA; MERS - Louisiana State University AgCenter's Macon Ridge Research Station near Winnsboro, LA; and DREC - Mississippi State University's Delta Research and Extension Center near Stoneville, MS.

[b] Evaluation date and respective herbicide mixture.

[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

1.12, 2.24, 3.36, and 4.48 kg ha^{-1}, except the 3.36 kg ha^{-1} at 14 DAT (Table 3.8). Even though antagonism was shown for almost all herbicide mixtures for control of browntop millet, the visual control was 93 to 95%. If browntop millet existed in a monoculture with IR rice it may be beneficial to avoid the use of imazamox on this weed. However, browntop millet is not a major weed problem in rice production across the southern rice belt, and it is rarely observed as a single weed infestation in rice production (J. Saichuk, personal communication, Rice Specialist. Louisiana State University AgCenter's Rice Research Station, Crowley, LA).

Crop injury was less than 10% across all evaluations (data not shown). Rice treated with propanil at 4.48 kg ha^{-1} plus imazamox resulted in a yield of 6200 kg/ha (Table 3.9). This yield was higher than rice treated with propanil alone or propanil at 1.12 or 2.24 kg ha^{-1} mixed with imazamox. Yield

Table 3.8. Browntop millet control with imazamox and propanil mixtures at 7 and 14 DAT in 2012 at DREC[a].

		Imazamox (g ha^{-1})			
		0	44		
Mixture Herbicide[b]	Rate	OBSERVED[c]	EXPECTED	OBSERVED	P VALUE
	kg ha^{-1}	% of Control			
7 DAT					
None	-	0	-	68	-
Propanil	1.12	89	96	94-	0.0157
Propanil	2.24	90	97	94-	0.0015
Propanil	3.36	95	98	95-	0.0005
Propanil	4.48	95	98	95-	0.0005
14 DAT					
None	-	0	-	69	-
Propanil	1.12	85	95	93-	0.0275
Propanil	2.24	89	96	95	0.2276
Propanil	3.36	95	98	95-	0.0079
Propanil	4.48	95	98	95-	0.0079

[a] DREC - Mississippi State University's Delta Research and Extension Center near Stoneville, MS.

[b] Evaluation date and respective herbicide mixture.

[c] Observed means followed by a plus (+) or a minus (-) are significantly different from Blouin's Modified Colby's expected responses at the 5% level indicating a synergistic or an antagonistic response. No (+) or (-) indicates a neutral response.

Table 3.9. Rough Rice Yields of rice treated with imazamox mixed with propanil at the RRS[a] in 2011 and 2012.

		Imazamox (g ha^{-1})			
Mixture Herbicide[b]	Rate	0		44	
	kg ha^{-1}	kg ha^{-1}		kg ha^{-1}	
None	-	0	G[c]	4520	C
Propanil	1.12	1440	F	5120	BC
Propanil	2.24	1830	E	4850	BC
Propanil	3.36	2830	DE	5890	AB
Propanil	4.48	3140	D	6200	A

Standard Error: 1240

[a] RRS - Louisiana State University AgCenter's Rice Research Station near Crowley, LA.

[b] Evaluation date and respective herbicide mixture.

[c] Means followed by a common letter are not significantly different at P=0.05 using PROC MIXED.

data indicate a yield increase with propanil at 3.36 and 4.48 kg ha^{-1} plus imazamox, and as a resistance management tool a propanil plus imazamox co-application can be employed. Carlson (2011) reported increased yields and increased profits with propanil at 3.4 kg ha^{-1} plus imazethapyr at 70 g ha^{-1}.

In conclusion, the addition of propanil in a mixture with imazethapyr or imazamox can increase the overall weed spectrum when compared with the herbicides applied alone (Carlson et al. 2011; Pellerin et al. 2003; Pellerin et al. 2004). Research has shown that the addition of propanil to an application of imazethapyr can increase hemp sesbania and Indian jointvetch control (Carlson et al. 2011; Pellerin et al. 2003; Webster et al. 2012). The addition of multiple herbicide modes of action in a single application can help prevent or slow the development of herbicide resistant weeds as well as red rice outcrossing with IR rice (Carlson et al. 2011; Carlson et al. 2012; Norsworthy et al. 2007). Herbicide programs containing co-applications resulted in higher rough rice yields than programs including only one herbicide application (Carlson et al.2011; Webster et al. 2012). Increased weed pressure, even over a short period of time, decreases rough rice yield. Therefore, it is recommended that producers be aggressive early in the growing season with herbicide programs and apply imazethapyr plus additional herbicides on one- to three-leaf rice (Anonymous 2009; Anonymous 2011; Webster 2014).

Literature Cited

Anonymous. 2009. Beyond herbicide label. BASF Corporation. http://agproducts.basf.us/products/label-and-msds/beyond-herbicide-label.pdf. Verified October 1, 2014.

Anonymous. 2011. Newpath herbicide label. BASF Corporation. http://www.cdms.net/LDat/ld4FL012.pdf. Verified October 1, 2014.

Baltazar, A.M. and R.J. Smith, Jr. 1994. Propanil-resistant barnyardgrass (*Echinochloa crus-galli*) control in rice (*Oryza sativa*). Weed Technol. 8:575-581.

Blouin, D.C., E.P. Webster, and J.A. Bond. 2010. On a method for synergistic and antagonistic joint-action effects with fenoxaprop mixtures in rice. Weed Technol. 24:583-589.

Carey, III, V.F., R.E. Hoagland, and R.E. Talbert. 1995. Verification and distribution of propanil-resistant barnyardgrass (*Echinochloa crus-galli*) in Arkansas. Weed Technol. 9:366-372.

Carlson, T.P., E.P. Webster, M.E. Salassi, J.B. Hensley, and D.C. Blouin. 2011. Imazethapyr plus propanil programs in imidazolinone-resistant rice. Weed Technol. 25:205-211.

Carlson, T.P., E.P. Webster, M.E. Salassi, J.A. Bond, J.B. Hensley, and D.C. Blouin. 2012. Economic evaluations of imazethapyr rates and timings on rice. Weed Technol. 26:24-28.

Craigmiles, J.P. 1978. Introduction. Pages 5-6. E.F. Eastin, Ed. Red rice research and control. College Station, TX: Tx. Agri. Exp. Stat. Bull. B-1270.

Croughan, T.P. 1994. Application of tissue culture techniques to development of herbicide resistant rice. Louisi. Agric. 37:25-26.

Dowler, C.C. 1997. Weed survey — southern states. Proc. South. Weed Sci. Soc. 50:237.

Fish, J.C., E.P. Webster, B.M. McKnight, N.D. Fickett, and J. Bond. 2013. Newpath + propanil interactions influence weed control in Clearfield rice. Weed Sci. Soc. Am. 53: http://wssaabstracts.com/public/17/abstract-13.html. Accessed September 19, 2014.

Fish, J.C., E.P. Webster, J.A. Bond, E.L. Thevis, and N.D. Fickett. 2012. Herbicide mixture may increase activity of Newpath and red rice. Proc. South. Weed Sci. Soc. 65:73.

Holm, L.G., D.L. Plucknett, J.V. Pancho, and J.P. Herberger. 1977. The World's Worst Weeds: Distribution and Biology. Honolulu, HI University Press of Hawaii. 1129.

Hydrick, D.E. and D.R. Shaw. 1994. Effects of tank-mix combinations of non-selective foliar and selective soil-applied herbicides on three weed species. Weed Technol. 8:129–133.

Khodayari, K., R.J. Smith, Jr., and H.L. Black. 1987. Red rice (*Oryza sativa*) control with herbicide treatments in soybeans (*Glycine max*). Weed Sci. 35:127–129.

Lorenzi, H.J. and L.S. Jeffery. 1987. Weeds of the United States and their control. New York: Van Norstrand Reinhold. 355 p.

Masson, J.A., E.P. Webster, and S.N. Morris. 2001. Evaluation of imazethapyr on imidazolinone-resistant rice. Proc. South. Weed Sci. Soc. 52:18.

Norsworthy, J.K., N.R. Burgos, R.C. Scott, and K.L. Smith. 2007. Consultant perspectives on weed management needs in Arkansas rice. Weed Technol. 21:832–839.

Pellerin, K.J. and E.P. Webster. 2004. Imazethapyr at different rates and timings in drill- and water-seeded imidazolinone-tolerant rice. Weed Technol. 18:223-227

Pellerin, K.J., E.P. Webster, W. Zhang, and D.C. Blouin. 2003. Herbicide mixtures in water-seeded imidazolinone-resistant rice (*Oryza sativa*). Weed Technol. 17:836–841.

Pellerin, K.J., E.P. Webster, W. Zhang, and D.C. Blouin. 2004. Potential use of imazethapyr mixtures in drill-seeded imidazolinone-resistant rice. Weed Technol. 18:1037-1042.

Senseman, S.A. ed. 2007. Herbicide Handbook. 9th ed. Lawrence, KS: Weed Science Society of America. Pp. 169–171.

Smith, R.J., Jr. 1961. 3,4-Dichloropropionanilide for control of barnyardgrass in rice. Weeds 9:318–322.

Smith, R.J., Jr. 1965. Propanil and mixtures with propanil for weed control in rice. Weeds 13:236–238.

Smith, R.J., Jr. 1981. Control of red rice (*Oryza sativa*) in water-seeded rice (*O. sativa*). Weed Sci. 29:663–666.

Smith, R.J., Jr., and J.E. Hill. 1990. Weed control technology in U.S. rice. Pages 314–327. in Grayson, B.T., M.B. Green, and L.G. Copping. eds. Pest Management in Rice. United Kingdom Elsevier Science.

Stidham, M.A. 1991. Herbicides that inhibit acetohydroxyacid synthase. Weed Sci. 428-434.

Stougaard, R.N., P.J. Shea, and A.R. Martin. 1990. Effect of soil type and pH on adsorption, mobility, and efficacy of imazaquin and imazethapyr. Weed Sci. 38:67–73.

Webster, E.P. and J.A. Masson. 2001. Acetolactate synthase-inhibiting herbicides on imidazolinone-tolerant rice. Weed Sci. 49:652–657.

Webster, E.P., T.P. Carlson, M.E. Salassi, J.B. Hensley, and D.C. Blouin. 2012. Imazethapyr plus residual herbicide programs for imidazolinone-resistant rice. Weed Technol. 26:410-416.

Webster, E.P. 2014. Weed Management. Pages 54-81. *in* J. Saichuk, ed. Louisiana Rice Production Handbook. Baton Rouge, LA: Louisiana State University Agricultural Center Pub. 2321-5/14 rev.

Webster, T.M. 2004. Weed survey—southern states. Proc. South. Weed Sci. Soc. 57:404–426.

Zhang, W., E.P. Webster, and H.M. Selim. 2001. Effect of soil moisture on efficacy of imazethapyr in greenhouse. Weed Technol. 15:355–359.

Chapter 4
Summary

Two field studies were established in 2011 and in 2012 to evaluate the interactions of imazethapyr, or imazamox, when mixed in a single application with propanil, thiobencarb, or a pre-packaged mix of propanil plus thiobencarb for the control of red rice, barnyardgrass, browntop millet, broadleaf signalgrass, and Amazon sprangletop. All treatments were applied to imidazolinone-resistant (IR) rice (*Oryza sativa* L.). Blouin’s modified Colby’s was used to determine if a synergistic, antagonistic, or neutral response occurred.

A study was conducted in 2011 near Crowley, LA and in 2012 at Crowley, LA, St. Joseph, LA, Winnsboro, LA, and near Stoneville, MS, to evaluate the interactions of imazethapyr at 0 and 70 g ha^{-1} mixed with propanil at 1680 and 3360 g ha^{-1}, thiobencarb at 1680 and 3360 g ha^{-1}, and with a pre-packaged mixture of propanil plus thiobencarb at 840 and 1680 g ha^{-1}, and no herbicide mixture. Red rice, barnyardgrass, browntop millet, broadleaf signalgrass, and Amazon sprangletop control, rice injury, and yield data from Crowley, was obtained.

At 7 days after treatment (DAT), a synergistic response occurred for red rice control when imazethapyr was mixed with propanil plus thiobencarb at 840 and 1680 g ha^{-1}, and an antagonistic response occurred for barnyardgrass control when imazethapyr was mixed with propanil plus thiobencarb at 840 g ha^{-1}, propanil at 3360 g ha^{-1}, or thiobencarb at 1680 and 3360 g ha^{-1}. At 7 and 14 DAT, an antagonistic response occurred for browntop millet control when imazethapyr was mixed with propanil at 1680 g ha^{-1} or thiobencarb at 1680 and 3360 g ha^{-1}, and at 7 DAT Amazon sprangletop control when treated with imazethapyr was mixed with thiobencarb at 1680 and 3360 g ha^{-1}. This antagonism may be due to the short time after application and before the benefits of imazethapyr are observed. By 49 DAT, a synergistic response occurred for red rice and barnyardgrass when imazethapyr was mixed with propanil plus thiobencarb at 1680 g ha^{-1}. No antagonism occurred for any weed evaluated with any herbicide mixed with imazethapyr at 49 DAT.

Rice injury was less than 10% over all locations, all treatments and all evaluations. Rice treated with mixtures containing imazethapyr resulted in a higher yield than those without imazethapyr. Although no yield increase was observed for co-application of imazethapyr plus propanil, thiobencarb, or the pre-package mixture the weed management and the neutral and synergistic responses observed for red rice and barnyardgrass control with the high rate of propanil plus imazethapyr this mixture would help prevent or delay red rice outcrossing with IR rice and help manage resistance development in barnyardgrass and browntop millet.

A similar but separate study was conducted to evaluate the interactions of imazamox at 0 and 44 g ha^{-1} mixed with same the rates of propanil, thiobencarb, and propanil plus thiobencarb as previously mentioned before. Red rice, barnyardgrass, browntop millet, broadleaf signalgrass, and Amazon sprangletop control, rice injury, and yield data from Crowley, was obtained.

At 7 days after treatment (DAT), a synergistic response occurred for red rice control when imazamox was mixed with all herbicide mixtures except thiobencarb at 1680 and 3360 g ha^{-1}, and an antagonistic response occurred for barnyardgrass control when imazamox was mixed with any mixture herbicide. At 7 and 14 DAT, an antagonistic response occurred for browntop millet and Amazon sprangletop control when imazamox was mixed with thiobencarb at 1680 and 3360 g ha^{-1}. This antagonism may be due to the short time after application and before the benefits of imazamox are observed. By 49 DAT, a synergistic response occurred for red rice control when treated with imazamox was mixed with propanil plus thiobencarb at 840 and 1680 g ha^{-1}, and barnyardgrass control when imazamox was mixed with propanil plus thiobencarb at 1680 g ha^{-1}. No antagonism occurred for any weed evaluated with any herbicide mixed with imazamox at 49 DAT.

Rice injury was less than 10% over all locations, all application and all evaluations. Rough rice yield was determined at the RRS in 2011 and 2012 and indicated an increase in yield when rice was treated with an application of imazamox regardless of co-application product.

The addition of a pre-packaged mixture of propanil plus thiobencarb in mixture with imazethapyr or imazamox can increase the overall weed spectrum when compared with herbicides applied alone. The addition of multiple herbicide modes of action per individual application can help prevent or reduce the development of herbicide resistant weeds. Herbicide programs containing co-applications resulted in higher rough rice yields than programs including single herbicide applications. In an IR rice production system weeds such as Indian jointvetch, hemp sesbania, and alligatorweed can be difficult to consistently control or may need a resistant management control program, when barnyardgrass and red rice infest the field. The combinations of imazethapyr plus propanil plus thiobencarb provides a mixture with three different modes of action, and provides an excellent opportunity to broaden the weed control spectrum and offers growers with an excellent resistant management strategy.

Two field studies were established in 2011 and in 2012 to evaluate the interactions of imazethapyr, or imazamox, when mixed in a single application with various rates of propanil for the control of red rice, barnyardgrass, browntop millet, broadleaf signalgrass, and Amazon sprangletop. All treatments were applied to imidazolinone-resistant (IR) rice (*Oryza sativa* L.). Blouin's modified Colby's was used to determine if a synergistic, antagonistic, or additive response occurred.

A study was conducted in 2011 near Crowley, La and in 2012 at Crowley, LA, St. Joseph, LA, Winnsboro, LA, and near Stoneville, MS, to evaluate the interactions of imazethapyr at 0 and 70 g ha^{-1} mixed with propanil at 1.12, 2.24, 3.36, and 4.48 kg ha^{-1}. Red rice, barnyardgrass, and browntop millet control, rice injury, and yield data from Crowley, was obtained. At 7 days after treatment (DAT), a synergistic response occurred for red rice control when imazethapyr was mixed with propanil at 1.12, 2.24, 3.36, and 4.48 kg ha^{-1}, and an antagonistic response occurred for barnyardgrass control when imazethapyr was mixed with propanil at 2.24, 3.36, and 4.48 kg ha^{-1}.

At 7 and 14 DAT, an antagonistic response occurred for browntop millet control when imazethapyr was mixed with propanil at all rates. This antagonism may be due to the short time after application and before the benefits of imazethapyr are observed. By 49 DAT, a synergistic response occurred for red rice control when imazethapyr was mixed with propanil at 4.48 kg ha^{-1}, and barnyardgrass control when treated with imazethapyr mixed with propanil at 1.12 kg ha^{-1}. No antagonism occurred for any weed evaluated with any herbicide mixed with imazethapyr at 49 DAT.

Rice injury was less than 10% over all locations, all application and all evaluations. No difference occurred in rough rice yield with any mixture or the two high rates of propanil; however, based on weed management and the synergistic and additive response for red rice and barnyardgrass control with the high rate of propanil mixed with imazethapyr could help prevent or delay red rice outcrossing with IR rice and help manage herbicide management resistance development in barnyardgrass and browntop millet.

A similar but separate study was conducted to evaluate the interactions of imazamox at 0 and 44 g ha^{-1} mixed with propanil at 1.12, 2.24, 3.36, and 4.48 kg ha^{-1}. Red rice, barnyardgrass, and browntop millet control, rice injury, and yield data from Crowley, were obtained.

At 7 DAT, a synergistic response occurred for red rice control when imazamox was mixed with propanil at 3.36 and 4.48 kg ha^{-1}, and an antagonistic response occurred for barnyardgrass control when imazethapyr was mixed with all rates of propanil. At 7 and 14 DAT, an antagonistic response occurred for browntop millet control when imazamox was mixed with propanil at all rates, except the 2.24 kg ha^{-1} rate of propanil at 14 DAT. This antagonism may be due to the short time after application and before the benefits of imazamox are observed. By 49 DAT, a synergistic response occurred for red rice control when imazamox was mixed with all rates of propanil. No antagonism occurred for any weed evaluated with any herbicide mixed with imazamox at 49 DAT.

Rice injury was less than 10% over all locations, applications, and evaluations. Yield data indicates a yield increase with propanil at 3.36 and 4.48 kg ha^{-1} plus imazamox; and as a resistance management tool a propanil plus imazamox co-application can be employed. The addition of propanil in a mixture with imazethapyr or imazamox can increase the overall weed spectrum when compared with the herbicides applied alone. The addition of multiple herbicide modes of action in a single application can help prevent or slow the development of herbicide resistant weeds as well as red rice outcrossing with IR rice. Herbicide programs containing co-applications resulted in higher rough rice yields than programs including only one herbicide application. Therefore, it is recommended that producers be aggressive early in the growing season with herbicide programs, and apply imazethapyr plus additional herbicides on one- to three-leaf rice.

VITA

John Caleb Fish was born on June 22, 1987, the eldest of three children to Tim and Danette Fish in Bartlett, Tennessee. He attended high school at Bolton High School in Arlington, Tennessee, where he was a member of both the football team and the soccer team, he was also a member of the FFA where he served as President his junior and senior years. After graduation in 2005, he received a four year athletic scholarship from Bethel College, in which he was a member of the football team. As an undergraduate he was a member of the Zeta Delta Tau fraternity and served as Vice President his senior year. He graduated in May of 2009 with a Bachelor’s of Science in Biology. In May 2009 he began his graduate career under the supervision of Dr. Eric Webster. During his graduate years he was a member of numerous professional organizations, including the Weed Science Society of America, the Southern Weed Science Society, and the Rice Technical Working Group. He is currently a candidate for the degree of Masters of Science in Weed Science and plans on finishing this degree in December of 2014. Upon graduation, Caleb plans on pursuing his career in Weed Science.