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VALUE OF CLEARFIELD RICE: AN AGRONOMIC AND ECONOMIC APPROACH

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

In

The Department of Agricultural Economics & Agribusiness

By
Tyler P. Carlson
B.S., McNeese State University 2007
May 2010

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Abstract

Field studies were conducted in Crowley, Louisiana and Stoneville, Mississippi in drill seeded rice to evaluate weed control, yield, and economical returns with imazethapyr programs. Red rice (*Oryza sativa*) and barnyardgrass (*Echinochloa crus-galli*) was evaluated with imazethapyr applied alone at various rates and application timings. Imazethapyr, averaged across rate, controlled red rice 89% and barnyardgrass 90% when the initial application of imazethapyr was applied at emergence followed by (fb) a second application of imazethapyr two weeks after the initial application. While imazethapyr, averaged across timing, showed no differences for red rice and barnyardgrass control. Yield and economical returns were maximized when the initial application of imazethapyr was applied at rice emergence fb a second application of imazethapyr two weeks later.

Research was conducted in Crowley, Louisiana in 2008 and 2009 to evaluate the addition of different propanil formulations in mixture with a standard imazethapyr program of 70 g/ha early postemergence fb 70 g/ha late postemergence. Weeds evaluated included red rice, barnyardgrass, Texasweed (*Caperonia palustris*), and alligatorweed (*Althernanthera philoxeroides*). Weed control of all weeds evaluated with treatments consisting of a propanil formulation in mixture with imazethapyr was equivalent to, or higher, than the standard imazethapyr program. Yield and economical returns were maximized when the propanil formulation of RiceShot® or Stam M4® was in mixture with imazethapyr in the initial application. The addition of propanil in mixture with imazethapyr increased rough rice yield and economical returns due to the increased weed control

Research was conducted in Crowley, Louisiana in 2008 and 2009 to evaluate the addition of a herbicide with soil residual activity in mixture with imazethapyr applied very-early postemergence fb an application of imazethapyr or imazamox two weeks after the initial application. Weeds evaluated included red rice, barnyardgrass, Texasweed, and alligatorweed. Weed control with treatments including a herbicide with soil residual activity was equivalent to or higher than imazethapyr applied alone fb imazethapyr or imazamox. Yield and economical returns were maximized with quinclorac or penoxsulam mixed with imazethapyr fb imazethapyr or imazamox. The addition of quinclorac or penoxsulam proved to be beneficial in a total weed management program.

Chapter 1

Introduction

Rice (*Oryza sativa* L.) is a staple food for a large part of the world's human population [CWHF 2010]. For the 2008/09 marketing year, world milled rice production was estimated at approximately 434 million metric tons (USDA FAS 2009). For the United States, the top five rice producing states are Arkansas, California, Louisiana, Mississippi, and Missouri (NASS 2009). In 2008, over 1.1 million hectares of rice was grown in the United States and of that total over 188,000 hectares were harvested in Louisiana.

In order to maximize rice yields and achieve the best economical return, producers use integrated weed management programs that are best accomplished through the use of cultural, mechanical, and chemical practices (Webster and Levy 2009). Weeds are found on every hectare of U.S. crop land (Ashton and Monaco 1991). In the United States, the estimated annual yield loss caused by weeds in 64 crops is $7.5 billion with field crops accounting for 85% of this loss.

Herbicides are critical to obtaining optimum yield and maximum profit. In 1997, approximately 74 million of 128 million total hectares of farm land received at least one herbicide application (USBC 1998). The cost of controlling weeds in crops is significant. It has been estimated that U.S. producers spend $3.6 billion annually for chemical weed control and $2.6 billion for cultural and other methods of weed control (Ashton and Monaco 1991).

Advances in weed management technology have played an essential role in the development of the rice industry (Ashton and Monaco 1991). Weed management decisions often drive the overall production system in rice (Eric P. Webster, personal communication). Currently, producers have a choice of numerous effective herbicides for almost all weed problems (Gianessi 2005). Economic considerations determine the specific herbicides a producer will include in a weed management program. Adoption of a new weed control program is dependent upon its ability to displace previously used programs on the basis of economic considerations, such as saving the producer money, improving yield, or reducing inputs. Other factors that are important in weed management decisions are perceived simplicity, manufacturer incentive programs, and the potential for crop injury.

Red rice (*Oryza sativa L.*) is one of the most troublesome weeds of cultivated rice in the southern United States (Webster 2004; Dowler 1994). 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). Because of genetic similarities, controlling red rice with traditional rice herbicides has been unsuccessful. Red rice competition with rice reduces grain yield and causes reduction in milling yields and grade (Webster and Levy 2009). However, in 1993, imidazolinone-resistant (IR) rice was developed and exhibited tolerance to the imidazolinone class of herbicides, which offered an opportunity to effectively control red rice with no effect on the crop (Croughan 1994; Pellerin et al. 2004; Webster and Masson 2001).

The target herbicide for use in IR rice is the imidazolinone herbicide imazethapyr (Croughan 1994). Compounds in the imidazolinone family of 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). Imazethapyr is readily absorbed through roots and foliage making it ideal for preplant incorporated (PPI), preemergence (PRE), or postemergence (POST) applications (Cantwell et al. 1989). Imazethapyr POST controls existing susceptible weeds while enhancing the control of weeds germinating later in the season (Hart et al. 1991). Imazethapyr is, also, registered for use in soybean [*Glycine max* (L.) Merr.] and peanut (*Arachis* *hypoaea L.*) to control grass and broadleaf weed species (Cantwell et al. 1989; Grichar 1994; Richburg et al. 1993).

Studies evaluating the efficacy of imazethapyr on red rice resulted in 93% control with a single postemergence (POST) application and up to 99% control with a sequential application (Klingaman et al. 1992; Steele et al. 2002). These results were similar to red rice control data from soybean field experiments with 92 and 94% control of red rice in the five-leaf stage with imazethapyr at 70 g/ha (Askew et al. 1998). Steele et al. (2002) reported red rice control with imazethapyr at 70 g/ha applied PPI was significantly improved when followed by imazethapyr POST regardless of rate.

In addition to red rice, a number of grass and broadleaf weeds exist in the rice culture in Louisiana (Braverman 1995). The most common weeds 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.) Beauv], alligatorweed [*Althernanthera philoxeroides* (Mart.) Griseb.], and Indian jointvetch (*Aeschynomene indica* L.).

Studies have indicated that imazethapyr effectively controlled many key grass weeds in rice, including red rice, barnyardgrass, and broadleaf signalgrass (Klingaman et al. 1992; Webster and Masson 2001; Masson et al. 2001). However, researchers have demonstrated the weakness of imazethapyr on some broadleaf weeds and sedges. Inconsistent control has been documented for yellow nutsedge (*Cyperus esculentus* L.) with imazethapyr POST at 18, 36, 54, and 72 g/ha (Richburg et al. 1995). Researchers have also demonstrated the lack of activity of imazethapyr on weeds in the Fabaceae family (Judd et al. 1999). The use of imazethapyr in IR rice provides minimal control of hemp sesbania and Indian jointvetch (Webster and Masson 2001; Zhang et al. 2001). In a water-seeded study conducted in Louisiana, soil applications of imazethapyr at 105 and 140 g/ha fb 70 g/ha POST resulted in 74% control of Indian jointvetch (Masson and Webster 2001). Rice production promotes the establishment and growth of hemp sesbania and Indian jointvetch because both weeds favor wet, saturated soils (Lorenzi and Jeffery 1987).

Herbicide mixtures have proved to be beneficial in improving efficacy and broadening the weed control spectrum in IR rice (Pellerin et al. 2003). The use of herbicide mixtures is favorable to producers because of the increased weed control and reduced application cost (Hydrick and Shaw 1994).

For many years, the weed control program for rice in the southern United States has centered around propanil (Smith 1961; Smith 1965; Smith and Hill 1990). Propanil has long been used to control annual grass and broadleaf weeds in southern U.S. rice production. It is a broad spectrum POST herbicide labeled for use in rice in 1961 (Senseman 2007), and selects between grasses and rice based on physiological processes (Baltazar and Smith 1994). At least 3.4 kg/ha of propanil has been applied each year to about 70% of rice growing acreage (Smith 1974; Smith and Hill 1990).

Propanil has historically controlled barnyardgrass effectively; however, repeated use of propanil has resulted in development of propanil-resistant barnyardgrass biotypes (Smith and Baltazar 1992). The confirmation of propanil-resistant barnyardgrass in Louisiana, Mississippi, Texas, and Arkansas, coupled with the difficulty of controlling red rice, has producers searching for effective herbicide programs (Baltazar and Smith 1994; Carey et al. 1995). Applying herbicides with multiple sites of action that provide residual weed control may provide more effective season-long barnyardgrass control and delay resistance.

Several herbicides are labeled for use as PRE or delayed PRE applications in rice (LSU AgCenter 2009). These herbicides are applied at planting or within seven days after planting to allow establishment of the crop with minimum weed competition. The registration of clomazone for weed control in southern dry-seeded rice provides rice growers in the region with an alternative herbicide to manage existing and emerging weed problems (Mudge et al. 2005a; Mudge et al. 2005b; Webster et al. 1999; Zhang et al. 2004). Webster et al. (1999) reported that a delayed PRE application of clomazone at 0.67 kg/ha controlled barnyardgrass 98%. Applications of quinclorac at 560 or 751 g ai/ha PRE to dry or moist soil can control barnyardgrass at least 80% without injuring rice (Street and Mueller 1993). The addition of pendimethalin to quinclorac broadens weed control and barnyardgrass control will increase with a delayed PRE application of a quinclorac pendimethalin mixture (Webster et al. 1999). Daou and Talbert (1999) reported that propanil plus quinclorac or propanil plus pendimethalin controlled resistant barnyardgrass at least 98% with one application at the two-leaf stage. Webster et al. (2007) reported that a single mid POST application of penoxsulam at 50 g/ha controlled barnyardgrass 78% and when penoxsulam followed a PRE application of clomazone at 448 g ai/ha barnyardgrass control was 89%.

Given this, the objectives of this research were to 1) evaluate the economic impact of imazethapyr application timings and rates on Clearfield rice production; 2) evaluate the economic impacts of various propanil formulations in mixture with imazethapyr on Clearfield rice production; 3) evaluate the cost effectiveness of herbicides with soil residual activity when used in an overall Clearfield production system.

Applicable economic theory relevant to this research project involves three basic economic principles. The first principle is related to the theory of the firm and the assumption that firms in a purely competitive market are profit maximizers (Pindyck and Rubinfeld 2001). This profit relationship can be expressed in general form as

$$Max\ \pi = p\ q(x_1, x_2, \ldots x_n) - r_1x_1 - r_2x_2\ .\ .\ .\ -r_nx_n$$

where π is a measure of profit, *p* is the commodity market price, *q* is production, x_i is quantity of a variable input used in production and r_i is the price of that variable input.

The second basic economic principle relevant to this research involves the determination of the optimal level of input quantity used in the production process. Comparison of economically optimal herbicide applications, both in terms of herbicide combination and timing of application, will be evaluated using the economic decision rule of determining the profit maximizing level of production. This decision rule can be expressed in terms of either output values or input values. The profit maximizing level of production is determined in ouput units at the point where marginal revenue equals marginal cost (Pindyck and Rubinfeld 2001). This is expessed in general form as

$$\Delta\pi/\Delta q = \Delta Revenue/\Delta q - \Delta Cost/\Delta q = 0$$

From this relationship, the profit maximizing level of output (*q*) can be determined as the production level where marginal revenue ($\Delta Revenue/\Delta q$) equals marginal cost ($\Delta Cost/\Delta q$).

Profit maximizing levels of input use may also be expressed in terms of input units. This decision rule states that the profit maximizing level of a single variable input occurs at the point where marginal value product (MVP) equals marginal factor cost (MFC) (Wetzstein 2005; Kay et al. 2004). This relationship can be expressed in general form as

$$\Delta \textit{ total value product } / \Delta \textit{ input use} = \Delta \textit{ total input cost}/\Delta \textit{ input use}$$

where total value product equals output price multiplied by output level (*pq*), *total input cost equals input price multiplied by total quantity of input used* ($r_i x_i$), *marginal* value product equals *Δ total value product / Δ input use* and marginal factor cost equals *Δ total input cost/Δ input use*. In this research project, output price, in terms of the market price of rough rice, will not be constant across all herbicide applications, but rather will be adjusted to reflect changes in rice grain quality and grade. This output price adjustment will impact estimates of both total and marginal value product.

The third basic economic principle utilized in this study involves the relevant costs and returns to include in the profit maximization analysis. Herbicide application decisions within a single rice production season represent a specific case of short-run profit maximization by a competitive firm. In the short-run, some production costs are fixed and do not vary with the level of output production. As a result, the relevant costs to include in short-run profit maximization are the variable costs, those costs which vary directly with the level of output production. A firm would remain in production as long as the price of the output is greater than its average variable cost of production at the profit maximizing output level (Pindyck and Rubinfeld 2001). Therefore, in this research project, evaluation of optimal rice herbicide applications will be based on net returns above variable herbicide costs.

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Chapter 2

Economic Evaluations of Imazethapyr Rates and Timings

Introduction

Red rice (*Oryza sativa L.*) is one of the most troublesome weeds of cultivated rice in the southern United States (Webster 2004; Dowler 1994). 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). Because of genetic similarities, controlling red rice with traditional rice herbicides has been unsuccessful. Red rice competition with rice reduces grain yield and causes reduction in milling yields and grade (Webster and Levy 2009). However, in 1993, imidazolinone-resistant (IR) rice was developed and exhibited tolerance to the imidazolinone class of herbicides, which offered an opportunity to effectively control red rice with no effect on the crop (Croughan 1994; Pellerin et al. 2004; Webster and Masson 2001).

The target herbicide for use in IR rice is the imidazolinone herbicide imazethapyr (Croughan 1994). Compounds in the imidazolinone family of 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). Imazethapyr is readily absorbed through roots and foliage making it ideal for preplant incorporated (PPI), preemergence (PRE), or postemergence (POST) applications (Cantwell et al. 1989). Imazethapyr POST controls existing susceptible weeds while enhancing the control of weeds germinating later in the season (Hart et al. 1991). Imazethapyr is, also, registered for use in soybean [*Glycine max* (L.) Merr.] and peanut (*Arachis hypoaea L.*) to control grass and broadleaf weed species (Cantwell et al. 1989; Grichar 1994; Richburg et al. 1993).

In Arkansas, season long competition from red rice and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv] reduced rice grain yields more than other rice weeds including broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R. D. Webster], ducksalad [*Heteranthera limosa* (Sw.) Willd], hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh], and spreading dayflower (*Commelina diffusa* Burm. f.) (Smith 1988). Stauber et al. (1991) reported barnyardgrass competition reduced 'Lemont' and 'Newbonnet' rice grain yields by 301 and 257 kg/ha, respectively.

Imazethapyr has been reported to control red rice 93% with a single POST application and up to 99% with sequential applications (Klingaman et al. 1992; Steele et al. 2002). These results were similar to red rice control from soybean field experiments with 92 and 94% control of five-leaf red rice with imazethapyr at 70 g/ha (Askew et al. 1998). Steele et al. (2002) reported red rice control with imazethapyr at 70 g/ha applied PPI was significantly improved when followed by imazethapyr POST regardless of rate.

Imazethapyr applied at rates lower than 70 g/ha controlled barnyardgrass and seedling johnsongrass [*Sorghum halepense (L.) Pers.*] 90% or better, but only when weeds were treated at the one-leaf stage (Klingaman et al. 1992). Masson et al. (2001) reported 90 to 93% barnyardgrass control with PPI and PRE applications of imazethapyr at 140 g/ha.

Webster and Masson (2001) reported imazethapyr applied at 70 and 140 g/ha controlled two to three leaf barnyardgrass 24 and 31%, respectively. A second study resulted in 93% control with imazethapyr applied at 140 g/ha on two to four leaf barnyardgrass, but a reduction in control was observed with applications made to four to five leaf barnyardgrass (Masson et al. 2001). Sequential POST applicatioins of imazethapyr at a reduced rate of 35 g/ha resulted in red rice control below 80%, but a single soil application of imazethapyr at 70, 105, or 140 g/ha fb 70 g/ha POST on two- to three-leaf rice controlled barnyardgrass 88 to 96% in water-seeded rice (Masson and

Webster 2001). Preliminary studies reported that sequential applications of imazethapyr would be required for effective control of red rice and barnyardgrass, especially with high weed populations (Webster and Masson 2001). Zhang et al. (2001), also, reported saturated soils at 50% moisture following imazethapyr PPI reduced control of red rice and barnyardgrass compared with 13 to 25% soil moisture. However, control with imazethapyr POST was not influenced by soil moisture.

Because of economical costs and total weed management concerns surrounding the most effective imazethapyr rate and timing, this research was conducted to evaluate the weed control, crop response, cost, yield, and overall economical return of imazethapyr at various application timings and rates throughout the growing season. Results from a previous study examining imazethapyr at different rates and timings indicated that delaying the POST application of imazethapyr until late POST (LPOST), four- to five-leaf rice stage, reduced rice yields (Pellerin and Webster 2004). However, no studies evaluating the economical costs associated with varied imazethapyr application timings and rates have been published.

Materials and Methods

A study was conducted in 2009 at the Louisiana State University AgCenter Rice Research Station near Crowley, Louisiana and the Mississippi State University Delta Research and Extension Center in Stoneville, Mississippi. The study was conducted on a Crowley silt loam (fine montmorillonitic, thermic Typic Albaqualf) with pH 6.9 and 1.2% organic matter near Crowley; and a Sharkey silty clay (very-fine, smectitic, thermic Chromic Epiaquerts) soil with pH 8.2 and 2.1% organic matter near Stoneville.

Seed bed preparation, at both locations, consisted of a fall and spring disking followed by two passes in opposite directions with a two-way bed conditioner equipped with rolling baskets and S-tine harrows 7.5 cm deep. At Crowley, a preplant application of 280 kg/ha of 8-24-24 (N-P_2O_5-K_2O) fertilizer and a preflood application of 365 kg/ha 46-0-0 urea fertilizer was applied to the study area. At Stoneville, soil fertility management consisted of 450 kg/ha of 46-0-0 (N-P_2O_5-K_2O) urea immediately before permanent flood establishment. A final pass of the bed conditioner was made before planting for incorporation of fertilizer.

The long grain rice cultivar 'CL 131' was drill-seeded in 18-cm rows at a planting rate of 84 kg/ha near Crowley on April 16, 2009 and 92 kg/ha near Stoneville on June 8, 2009. Immediately after rice planting, the area was surface irrigated to a level of 2.5 cm, and drained immediately. A 10-cm permanent flood was established when rice reached the five-leaf to one-tiller growth stage and was maintained until 2 wk prior to harvest.

The experimental design was a randomized complete block with four replications. The initial application of imazethapyr was applied at emergence, 1 wk after emergence (WAE), 2 WAE, 3 WAE, or 4 WAE followed by an application of imazethapyr 14 d after the initial application of each treatment. Imazethapyr was applied at either 70 g/ha for both applications, 105 g/ha for both applications, 105 fb 70 g/ha, or 70 fb 105 g/ha. A crop oil concentrate (COC) was added in each application at 1% v/v. Each application of herbicide was applied at 140 L/ha with a CO_2-pressurized backpack sprayer at a pressure of 145 kPa.

Weed control ratings were collected 2 to 3 weeks after the final application. Weed control ratings were visually estimated on a scale of 0 to 100%, where 0 = no control and 100 = complete plant death. Rice height was recorded at harvest in Crowley. Plant height was taken immediately prior to harvest from two plants per plot from the ground to the tip of the extended panicle. Plots were harvested on August 24, 2009 at Crowley, and October 19, 2009 at Stoneville. Yield was collected from the center 0.75 by 6-m^2 area of the plot using a mechanical plot harvester. Rough rice yield was adjusted to 12% moisture.

Economic applications were based on the average long grain rice price for 2009 (WASDE 2009). Base rice price was $285/MT with price deductions based on rice grade. Actual rough rice market prices are adjusted by grade and these grade price discounts can vary across rice mills. In this study, rough rice price deductions for grades 1, 2, 3, 4, 5, 6 and sample grade were $0.00, $0.00, $5.50, $12.00, $27.50, $33.00 and $44.00/MT, respectively. These price reductions are representative of actual market price discounts based upon the grade of rice for sale. Imazethapyr was applied as Newpath®[1], which was priced at $140/L and COC was applied as Agri-Dex®[2], which was priced at $4.00/L. Profitability of the herbicide programs were determined by evaluating the total value product, which was calculated by multiplying the rough rice yield by the price. Net returns above herbicide cost were also evaluated, where the net returns equals the total value product minus the herbicide program cost.

Data were subjected to the Mixed Procedure of SAS (SAS 2003). Location, replications (nested within location), and all interactions containing either of these effects were considered random effects. Application timing and rate were considered fixed effects. Considering location or combination of locations as random effects permits inferences about treatments over a range of environments (Carmer et al. 1989; Hager et al. 2003). Type III statistics were used to test all possible effects of fixed factors (application timing and rate) and least square means were used for mean separation at the 5% probability level ($p \leq 0.05$).

Results and Discussion

Data analysis of this study indicated a timing interaction for weed control and rough rice yield and a rate interaction was, also, observed for

[1] Newpath® herbicide label. BASF Corporation, 26 Davis Drive, Research Triangle Park, NC, 27709.

[2] Agri-Dex® label. Helena Chemical Company, 225 Schilling Blvd., Suite 300, Collierville, Tennessee 38017.

rice yield. However, there was no timing by rate interactions. Therefore, data will be presented separately for timing and rate effects.

Timing Interaction. The initial application of imazethapyr applied at rice emergence resulted in 89% red rice and 90% barnyardgrass control (Table 2.1). By delaying the initial application of imazethapyr to 1 to 4 WAE control decreased below 60%. This decrease in control indicates the importance of applying imazethapyr on small actively growing weeds to maximize control, and is similar to results reported by Pellerin and Webster (2004).

A rice plant height at harvest response was observed with imazethapyr applied at various timings (Table 2.2). The initial application of imazethapyr applied to rice at 1 WAE or later resulted in reduced rice plant height at harvest, 61 to 66 cm, compared to the initial application of imazethapyr applied at emergence, 82 cm. These data indicate that increased weed competition due to lack of control by herbicide program can effect rice plant growth.

Initial applications of imazethapyr applied at rice emergence resulted in a rough rice yield of 4800 kg/ha (Table 2.2). By delaying the initial application 1 to 3 WAE yield was reduced an average of 1525 kg/ha and by delaying to 4 WAE overall yield was reduced 2420 kg/ha. This is similar to findings reported by Pellerin and Webster (2004). Rice samples were obtained at the Crowley, Louisiana location and milling yield and rice grade were evaluated.

Percent whole rice kernels over percent whole plus broken rice kernels indicated that imazethapyr applied at rice emergence resulted in a milling yield of 61/69 with a rice grade of 3 (Table 2.2). Delaying the initial application of imazethapyr to 1, 2, and 3 WAE resulted in a 28, 37, and 30% decrease in rough rice yield, respectively. Milling yield and rice grade for these timings were 59/69 with a grade of 5, 58/66 with a grade of 6, and 61/70 with a grade of 5, respectively. Furthermore, by delaying the initial

Table 2.1. Effects of imazethapyr application timing on red rice and barnyardgrass control 2 to 3 weeks after final imazethapyr application, 2009, averaged over location and imazethapyr rate.[abcde]

Herbicide program	Timing	Red rice	Barnyardgrass
		%	
imazethapyr fb imazethapyr	Emergence 2 WAE	89 a	90 a
imazethapyr fb imazethapyr	1 WAE 3 WAE	49 b	58 b
imazethapyr fb imazethapyr	2 WAE 4 WAE	48 b	40 c
imazethapyr fb imazethapyr	3 WAE 5 WAE	50 b	18 d
imazethapyr fb imazethapyr	4 WAE 6 WAE	59 b	57 b

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] Locations: Crowley, Louisiana and Stoneville, Mississippi.

[c] Data averaged across application rates of 70 fb 70, 105 fb 105, 105 fb 70, and 70 fb 105 g ai/ha imazethapyr.

[d] A crop oil concentrate (COC) was added in each application at 1% v/v.

[e] Abbreviations: fb, followed by; WAE, weeks after emergence.

Table 2.2. Effects of imazethapyr application timing on rice plant heigh at harvest, yield, milling, and grade, 2009, averaged over location and imazethapyr rate.[abcdefg]

Herbicide program	Timing	Harvest height	Rough rice yield	Milling yield	Grade
		— cm —	— kg/ha —	— % —	
imazethapyr fb imazethapyr	Emergence 2 WAE	82 a	4800 a	61/69	3
imazethapyr fb imazethapyr	1 WAE 3 WAE	63 bc	3440 b	59/69	5
imazethapyr fb imazethapyr	2 WAE 4 WAE	61 c	3030 b	58/66	6
imazethapyr fb imazethapyr	3 WAE 5 WAE	66 b	3350 b	61/70	5
imazethapyr fb imazethapyr	4 WAE 6 WAE	65 bc	2380 c	60/69	6

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] Locations: Crowley, Louisiana and Stoneville, Mississippi.

[c] Data averaged across application rates of 70 fb 70, 105 fb 105, 105 fb 70, and 70 fb 105 g/ha imazethapyr.

[d] A crop oil concentrate (COC) was added in each application at 1% v/v.

[e] Milling yield: % whole kernels / % whole plus broken kernels.

[f] Milling and grades were only obtained on rice harvested in Crowley, Louisiana.

[g] Abbreviations: fb, followed by; WAE, weeks after emergence.

application of imazethapyr to 4 WAE, rough rice yield was decreased by 50%, compared with the initial emergence application, with a milling yield of 60/69 and a rice grade of 6. These data indicate that delaying the initial application of imazethapyr decreases rough rice yield due to the increase weed competition. Results also indicate that weed control played a direct relationship with rice quality, when weed control was reduced rice quality decreased. Rough rice yield and quality were maximized when the initial application of imazethapyr was applied within the first week of rice emergence.

Profitability of imazethapyr treatment programs can be determined by evaluating the total value product, which was calculated by multiplying the rough rice yield by the price. Therefore, the impact of imazethapyr applied at different timings on rough rice yield and quality will directly impact total value product. The initial application of imazethapyr applied at rice emergence resulted in a total value product of $1350/ha (Table 2.3). Delaying the initial imazethapyr application to 1, 2, or 3 WAE decreased total value product 34, 43, and 36%, respectively, compared with the program of imazethapyr applied at emergence followed by imazethapyr at 2 WAE. Delaying the initial imazethapyr application to 4 WAE decreased total value product 55% compared with the initial imazethapyr application applied at rice emergence. Net returns above herbicide cost were also evaluated, where the net returns above herbicide cost equals the total value product minus the imazethapyr program cost. However, since all imazethapyr rates were averaged across application timing, cost of the treatment was constant for all timings. Imazethapyr programs of 70 fb 70 g/ha resulted in herbicide cost of $90/ha, 105 fb 105 g/ha cost $130/ha, and programs containing a combination of the 70 and 105 g/ha cost $110/ha; since all rates were averaged over timing the imazethapyr program cost averaged $110/ha.

Table 2.3. Economical returns from imazethapyr applied at various application timings, 2009, averaged over location and imazethapyr rate.[abcdefg]

Herbicide program	Timing	Total value product	Net returns above herbicide cost	Decrease in total value product
		$/ha		
imazethapyr fb imazethapyr	Emergence 2 WAE	1350 a	1240 a	0
imazethapyr fb imazethapyr	1 WAE 3 WAE	890 b	780 b	460 (34%)
imazethapyr fb imazethapyr	2 WAE 4 WAE	770 b	660 b	580 (43%)
imazethapyr fb imazethapyr	3 WAE 5 WAE	860 b	750 b	490 (36%)
imazethapyr fb imazethapyr	4 WAE 6 WAE	600 c	490 c	750 (55%)

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] Locations: Crowley, Louisiana and Stoneville, Mississippi.

[c] Data averaged across application rates of 70 fb 70, 105 fb 105, 105 fb 70, and 70 fb 105 g/ha imazethapyr.

[d] A crop oil concentrate (COC) was added in each application at 1% v/v.

[e] Calculed as the total value product minus the average herbicide cost.

[f] Equals the dollars per hectare decrease in total value product compared with initial application at emergence.

[g] Abbreviations: fb, followed by; WAE, weeks after emergence.

Rate Interaction. Averaged across application timings, an imazethapyr program application rate affect on red rice and barnyardgrass control was not observed at 2 to 3 wk after final imazethapyr application (Tables 2.4). Red rice control was 59 to 60% and barnyardgrass control was 51 to 56% for all imazethapyr applications with no difference observed across rates.

No difference occurred for rice plant height; however, a difference was observed for rough rice yield (Table 2.5). The standard imazethapyr program of 70 fb 70 g/ha resulted in a rough rice yield of 3260 kg/ha with a milling yield of 59/69 and a rice of grade 5. Imazethapyr programs evaluated in this study that included at least one 70 g/ha imazethapyr application resulted in a rough rice yield similar to the base imazethapyr program. However, when both applications of imazethapyr applied at 105 g/ha resulted in a rough rice yield of 3790 kg/ha with a milling yield of 62/69 and a rice grade of 4. These data indicate that increasing both applications of imazethapyr to 105 g/ha increases rice yield and quality, which will directly benefit total value product.

Given that application rates were varied, cost of the treatment will play a bigger role in over all profit, compared to the timing interaction evaluations. The standard imazethapyr program resulted in a total value product of $840/ha (Table 2.6). The cost for the standard imazethapyr program was $90/ha resulting in net returns above herbicide cost of $750/ha. When imazethapyr was applied at 105 fb 70 g/ha and 70 fb 105 g/ha total value product was $840 and $850, respectively. However, the cost of the 105 fb 70 g/ha and 70 fb 105 g/ha treatments were increased to $110/ha and the net returns above herbicide cost decreased by 3 and 1%, respectively, compared with the standard program. Imazethapyr applied at 105 fb 105 g/ha resulted in a total value of $1040/ha. This program resulted in the highest herbicide cost at $130/ha; however, the net returns from the 105 fb 105 g/ha imazethapyr program increased by 21%, compared with the standard program.

Table 2.4. Effects of imazethapyr program application rates on red rice and barnyardgrass control 2 to 3 weeks after final imazethapyr application, 2009, averaged over location and application timing.[abcde]

Herbicide program	Rates	Red rice	Barnyardgrass
	g ai/ha	%	
imazethapyr fb imazethapyr	70 70	60 a	50 a
imazethapyr fb imazethapyr	105 105	59 a	56 a
imazethapyr fb imazethapyr	105 70	59 a	51 a
imazethapyr fb imazethapyr	70 105	59 a	54 a

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] Locations: Crowley, Louisiana and Stoneville, Mississippi.

[c] Data averaged across emergence, 1 week after emergence (WAE), 2 WAE, 3 WAE, and 4 WAE application timings.

[d] A crop oil concentrate (COC) was added in each application at 1% v/v.

[e] Abbreviation: fb, followed by.

Table 2.5. Effects of imazethapyr program application rates on rice plant height at harvest, yield, milling, and grade, 2009, averaged over location and application timing.[abcdefg]

Herbicide program	Rates	Harvest height	Rough rice yield	Milling	Grade
	g ai/ha	—— cm ——	— kg/ha —	——— % ———	
imazethapyr fb imazethapyr	70 70	68 a	3260 b	59/69	5
imazethapyr fb imazethapyr	105 105	68 a	3790 a	62/69	4
imazethapyr fb imazethapyr	105 70	66 a	3250 b	62/70	5
imazethapyr fb imazethapyr	70 105	68 a	3280 b	60/69	5

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] Locations: Crowley, Louisiana and Stoneville, Mississippi.

[c] Data averaged across emergence, 1 week after emergence (WAE), 2 WAE, 3 WAE, and 4 WAE application timings.

[d] A crop oil concentrate (COC) was added in each application at 1% v/v.

[e] Milling: % whole kernels / % whole plus broken kernels.

[f] Milling and grades were only obtained on rice harvested in Crowley, Louisiana.

[g] Abbreviations: fb, followed by.

Table 2.6. Economical returns from imazethapyr applied at various application rates, 2009, averaged over location and application timing.[abcdefg]

Herbicide program	Rates	Total value product	Net returns above herbicide cost	Change in net returns
	g ai/ha	$/ha		
imazethapyr fb imazethapyr	70 70	840 b	750 b	0
imazethapyr fb imazethapyr	105 105	1040 a	910 a	160 (21%)
imazethapyr fb imazethapyr	105 70	840 b	730 b	-20 (-3%)
imazethapyr fb imazethapyr	70 105	850 b	740 b	-10 (-1%)

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] Locations: Crowley, Louisiana and Stoneville, Mississippi.

[c] Data averaged across emergence, 1 week after emergence (WAE), 2 WAE, 3 WAE, and 4 WAE application timings.

[d] A crop oil concentrate (COC) was added in each application at 1% v/v.

[e] Calculed as the total value product minus the average herbicide cost.

[f] Equals the dollar per hectare difference in net returns above herbicide cost, when compared with the standard imazethapyr program of 70 fb 70 g/ha.

[g] Abbreviations: fb, followed by.

These data indicate that the higher rates of imazethapyr, applied at both locations, resulted in increased profits, even though cost of treatment increased. This increase in profit was due to higher rice yield and higher rice quality increasing total value product, which overcome the additive cost of herbicide.

In conclusion, the effectiveness of imazethapyr will depend on weed spectrum and densities. The use of herbicide tank mixtures would be beneficial in a total weed management program. However, earlier imazethapyr applications were observed to be more advantageous in controlling red rice and barnyardgrass. Imazethapyr programs evaluated in this study resulted in higher rough rice yields, rice quality, and returns when the initial application of imazethapyr was applied within one week of rice emergence. Also, an imazethapyr program of 105 fb 105 g/ha increased rough rice yield and quality. Data concludes that imazethapyr application timing, averaged across rate, increases weed control, rice yield, and overall economical returns when applied early. Also, data indicated that imazethapyr applied at the higher rate for both applications, averaged across timing, was more beneficial. Therefore, it may be concluded that imazethapyr applied at rice emergence at 105 g/ha fb 105 g/ha would maximize overall rice production. Increased weed pressure, even over a short period of time, decreased rice yield. Therefore, it’s recommended that producers be aggressive up front and treat weed problems early. Data concludes that when weeds are controlled early and there is minimum weed competition rice plants produce higher yields, which in turn will produce higher profits. In this study, economic returns were nearly doubled when the initial application of imazethapyr was applied at rice emergence.

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Chapter 3

Effects of Imazethapyr and Propanil Program on Rice

Introduction

Advances in weed management technology have played an essential role in the development of the rice industry (Ashton and Monaco 1991). Weed management decisions often drive the overall production system in rice (Eric P. Webster, personal communication). Currently, producers have a choice of numerous herbicides for almost all weed problems (Gianessi 2005). Economic considerations determine the specific herbicides a producer will include in a weed management program. Adoption of a new weed control program is dependent upon its ability to displace previously used programs on the basis of economic considerations, such as saving the producer money, improving yield, or reducing inputs. Other factors that are important in weed management decisions are perceived simplicity, manufacturer incentive programs, and the potential for crop injury.

Red rice (*Oryza sativa L.*) is one of the most troublesome weeds of cultivated rice in the southern United States (Webster 2004; Dowler 1994). 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). Because of genetic similarities, controlling red rice with traditional rice herbicides has been unsuccessful. Red rice competition with rice reduces grain yield and causes reduction in milling yields and grade (Webster and Levy 2009). However, in 1993, imidazolinone-resistant (IR) rice was developed and exhibited tolerance to the imidazolinone class of herbicides, which offered an opportunity to effectively control red rice with no effect on the crop (Croughan 1994; Pellerin et al. 2004; Webster and Masson 2001).

The target herbicide for use in IR rice is the imidazolinone herbicide imazethapyr (Croughan 1994). Compounds in the imidazolinone family of 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).

In addition to red rice, a number of grass and broadleaf weeds exist in the rice culture in Louisiana (Braverman 1995). The most common weeds 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.) Beauv], alligatorweed [*Althernanthera philoxeroides* (Mart.) Griseb.], and Indian jointvetch (*Aeschynomene indica* L.).

Studies have indicated that imazethapyr effectively controlled many key grass weeds in rice, including red rice, barnyardgrass, and broadleaf signalgrass (Klingaman et al. 1992; Webster and Masson 2001; Masson et al. 2001). However, researchers have demonstrated the weakness of imazethapyr on some broadleaf weeds and sedges. Inconsistent control has been documented for yellow nutsedge (*Cyperus esculentus*) with imazethapyr postemergence (POST) at 18, 36, 54, and 72 g/ha (Richburg et al. 1995). Researchers have also demonstrated the lack of activity of imazethapyr on weeds in the Fabaceae family (Judd et al. 1999). In peanuts, imazethapyr applied at various rates from 18 to 72 g/ha controlled sicklepod [*Senna obtusifolia (L.) Irwin and Barneby*] and Flordia beggarweed [*Desmodium tortuosm (Sw.) DC.*] 0 to 33% (Richburg et al. 1995). The use of imazethapyr in IR rice provides minimal control of hemp sesbania and Indian jointvetch (Webster and Masson 2001; Zhang et al. 2001). In a water seeded study conducted in Louisiana, soil applications of imazethapyr at 105 and 140 g/ha fb 70 g/ha POST resulted in 74% control of Indian jointvetch (Masson and Webster 2001). Rice production promotes the establishment and growth of hemp sesbania and Indian jointvetch because both weeds favor wet, saturated soils (Lorenzi and Jeffery 1987).

Herbicide mixtures have proved to be beneficial in improving efficacy and broadening the weed control spectrum in IR rice (Pellerin et al. 2003). The use of herbicide mixtures is favorable to producers because of the increased weed control and reduced application cost (Hydrick and Shaw 1994).

For many years, the weed control program for rice in the southern United States has centered around propanil (Smith 1961; Smith 1965; Smith and Hill 1990). Propanil has long been used to control annual grass and broadleaf weeds in southern U.S. rice production. It is a broad spectrum POST herbicide labeled for use in rice in 1961 (Senseman 2007), and selects between grasses and rice based on physiological processes (Baltazar and Smith 1994). At least 3.4 kg/ha of propanil has been applied each year to about 70% of rice growing acreage (Smith 1974; Smith and Hill 1990). In southern U.S. rice production, barnyardgrass was controlled by a standard treatment of propanil applied at 3.4 kg/ha POST (Smith 1974). However, combinations of propanil plus pendimethalin POST were used for residual control of broadleaf and grass weeds (Richard and Street 1984). Propanil plus thiobencarb or butachlor controlled barnyardgrass greater than standard treatment of propanil alone at 4.5 kg/ha (Smith and Khodayari 1985).

However, there are several formulations of propanil which include Stam M4®[3], Stam SC®[1], Stam EDF®[1], RiceShot®[4], and SuperWham®[2]. With this in mind, the objective of this study was to evaluate the economical effects of these various propanil formulations with imazethapyr applied at early postemergence (EPOST) or late postemergence (LPOST) on IR rice production. Data from this

[3] Stam M4®, Stam SC®, and Stam EDF® herbicide label. United Phosphorus, Inc., 630 Freedom Business Center, Suite 402, King of Prussia, PA 19406.
[4] RiceShot® and SuperWham® herbicide label. RiceCo LLC., 5100 Poplar Avenue, Suite 2428, Memphis, TN 38137.

study could prove to be essential when considering a propanil formulation in a herbicide program.

Materials and Methods

A study was conducted in 2008 and 2009 at the Louisiana State University AgCenter Rice Research Station near Crowley, Louisiana on a Crowley silt loam (fine montmorillonitic, thermic Typic Albaqualf) with pH 6.9 and 1.2% organic matter. Seed bed preparation consisted of a fall and spring disking followed by two passes in opposite directions with a two-way bed conditioner equipped with rolling baskets and S-tine harrows 7.5 cm deep. A preplant application of 280 kg/ha of 8-24-24 ($N-P_2O_5-K_2O$) fertilizer and a preflood application of 365 kg/ha 46-0-0 urea fertilizer was applied to the study area. A final pass of the bed conditioner was made before planting for incorporation of fertilizer.

The long grain rice cultivar 'CL 161' was drill-seeded in 18-cm rows at a planting rate of 84 kg/ha on April 24, 2008 and 'CL 131' on April 16, 2009. Immediately after rice planting, the area was surface irrigated to a level of 2.5 cm, and drained immediately. A 10-cm permanent flood was established when rice reached the five-leaf to one-tiller growth stage and was maintained until 2 wk prior to harvest.

The experimental design was a randomized complete block with four replications. The herbicide programs of a propanil formulation in mixture with imazethapyr applied EPOST, two- to three-leaf rice stage, followed by a LPOST, four- to five-leaf rice stage, application of imazethapyr or imazethapyr applied alone EPOST followed by imazethapyr plus a propanil formulation applied LPOST were evaluated. Propanil was applied as Stam M4®, Stam SC®, Stam EDF®, RiceShot®, or SuperWham® at 3.4 kg ai/ha and imazethapyr was applied as Newpath®[5] at 70 g ai/ha. A crop oil concentrate (COC), Agri-Dex®[6], was added in each application, except for applications including Stam M4 and Riceshot, at 1% v/v. Each application of herbicide was applied at 140 L/ha with a CO_2-pressurized backpack sprayer at a pressure of 145 kPa.

Weed control ratings were collected 14, 28, and 35 days after the final application (DAFA). Weed control ratings were visually estimated on a scale of 0 to 100%, where 0 = no control and 100 = complete plant death. Rice height was recorded at harvest. Height measurements were taken from two plants per plot from the ground to the tip of the extended panicle. The center 0.75 by 6 m area of each plot was harvested on August 22, 2008 and August 24, 2009 using a mechanical plot harvester. Rough rice yield was adjusted to 12% moisture.

Economic applications were based on the average long grain rice price for 2009 (WASDE 2009). Base rice price was $285/MT with price deductions based on rice grade. Actual rough rice market prices are adjusted by grade and these grade price discounts can vary across rice mills. In this study, rough rice price deductions for grades 1, 2, 3, 4, 5, 6 and sample grade were $0.00, $0.00, $5.50, $12.00, $27.50, $33.00 and $44.00/MT, respectively. These price reductions are representative of actual market price discounts based upon the grade of rice for sale. Newpath® was priced at $140/L, Agri-Dex® at $4.00/L, Stam M4® at $6.70/L, Stam SC® at $9.80/L, Stam EDF® at $33.10/kg, RiceShot® at $8.10/L, and SuperWham® at $8.90/L. Profitability of the herbicide programs were determined by evaluating the total value product, which was calculated by multiplying the rough rice yield by the price. Net returns above herbicide cost were also evaluated, where the net returns equals the total value product minus the herbicide program cost.

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[5] Newpath® herbicide label. BASF Corporation, 26 Davis Drive, Research Triangle Park, NC, 27709.

[6] Agri-Dex® label. Helena Chemical Company, 225 Schilling Blvd., Suite 300, Collierville, Tennessee 38017.

Data were subjected to the Mixed Procedure of SAS (SAS 2003). Year, replications (nested within year), and all interactions containing either of these effects were considered random effects. Application timing and rate were considered fixed effects. Considering year or combination of year as random effects permits inferences about treatments over a range of environments (Carmer et al. 1989; Hager et al. 2003). Type III statistics were used to test all possible effects of fixed factors (application timing and rate) and least square means were used for mean separation at the 5% probability level ($p \leq 0.05$).

Results and Discussion

A treatment interaction occurred for red rice, barnyardgrass, Texasweed (*Caperonia palustris*), and alligatorweed control, and data were averaged over year; therefore, tables for these interactions were developed. The standard program included two applications of imazethapyr at 70 g/ha applied EPOST fb LPOST. When propanil was added at 3400 g/ha in either the first or second application of imazethapyr red rice control increased at 14 DAFA, compared with the standard program (Table 3.1). At 28 DAFA, red rice control increased compared with the standard program except when Stam M4® was applied in the second application. Also, herbicide programs evaluated at the 35 DAFA that included any propanil formulation in the initial application or SuperWham® or RiceShot® in the second application resulted in increased red rice control compared with the standard program.

Barnyardgrass control is similar to results observed for red rice control in this study (Table 3.1). An imazethapyr program that included an application of propanil resulted in an increase in barnyardgrass control at 14 DAFA, compared with the standard program. At 28 DAFA, all treatments increased barnyardgrass control compared with the standard imazethapyr program except with Stam M4® applied in the second application. The addition of any propanil product in the initial imazethapyr application, or the

Table 3.1. Effects of imazethapyr and propanil programs on red rice and barnyardgrass control 14, 28, and 35 days after final application (DAFA), averaged over 2008 and 2009, near Crowley, Louisiana.[a]

Herbicide program[bc]	Form.	Rate	Timing	Red rice control			Barnyardgrass control		
				14 DAFA	28 DAFA	35 DAFA	14 DAFA	28 DAFA	35 DAFA
		— g ai/ha —		%					
imazethapyr fb[d]	AS[d]	70	EPOST[d]	63 d	57 d	58 d	59 e	55 e	47 e
imazethapyr	AS	70	LPOST[d]						
imazethapyr +	AS	70		94 a	95 a	94 a	95 a	94 a	90 a
Stam M4® fb	EC[d]	3400	EPOST						
imazethapyr	AS	70	LPOST						
imazethapyr +	AS	70		84 abc	83 abc	82 abc	84 abcd	75 bcd	72 bcd
Stam SC® fb	F[d]	3400	EPOST						
imazethapyr	AS	70	LPOST						
imazethapyr +	AS	70		96 a	94 a	95 a	95 a	95 a	92 a
RiceShot® fb	EC	3400	EPOST						
imazethapyr	AS	70	LPOST						
imazethapyr +	AS	70		94 a	95 a	96 a	94 a	95 a	91 a
SuperWham® fb	F	3400	EPOST						
imazethapyr	AS	70	LPOST						
imazethapyr +	AS	70		91 ab	93 a	95 a	91 ab	90 ab	86 ab
Stam EDF® fb	WG[d]	3400	EPOST						
imazethapyr	AS	70	LPOST						
imazethapyr fb	AS	70	EPOST	76 c	71 cd	67 cd	79 cd	64 de	55 de
imazethapyr +	AS	70	LPOST						
Stam M4®	EC	3400							
imazethapyr fb	AS	70	EPOST	80 bc	77 bc	68 cd	78 d	72 cd	61 cde
imazethapyr +	AS	70	LPOST						
Stam SC®	F	3400							
imazethapyr fb	AS	70	EPOST	87 abc	78 bc	75 bc	86 abcd	76 bcd	71 bcd
imazethapyr +	AS	70	LPOST						
RiceShot®	EC	3400							

continued

Table 3.1. Continued.

Herbicide program[bc]	Form.	Rate	Timing	Red rice control 14 DAFA	Red rice control 28 DAFA	Red rice control 35 DAFA	Barnyardgrass control 14 DAFA	Barnyardgrass control 28 DAFA	Barnyardgrass control 35 DAFA
		g ai/ha		%					
imazethapyr fb	AS	70	EPOST	90 ab	89 ab	87 ab	90 abc	84 abc	76 abc
imazethapyr +	AS	70	LPOST						
SuperWham®	F	3400							
imazethapyr fb	AS	70	EPOST	81 bc	74 c	71 cd	80 bcd	71 cd	59 cde
imazethapyr +	AS	70	LPOST						
Stam EDF®	WG	3400							

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] A crop oil concentrate (COC) was added at a rate of 1% v/v, except for treatments that included an application of Stam M4® or Riceshot®.

[c] Stam M4®, Stam SC®, and Stam EDF® herbicide label; United Phosphorus, Inc., 630 Freedom Business Center, Suite 402, King of Prussia, PA 19406. Riceshot® and Superwham® herbicide label; RiceCo LLC., 5100 Poplar Avenue, Suite 2428, Memphis, TN 38137.

[d] Abbreviations: Form., Formulation ; fb, followed by; AS, aqueous solution; EC, emulsifiable concentrate; F, flowable; WG, wettable granules; EPOST, early postemergence; LPOST, late postemergence.

addition of SuperWham® or RiceShot® in the second application of imazethapy resulted in increased barnyardgrass control at 35 DAFA, compared with the standard program.

An imazethapyr program that included an application of any propanil formulation evaluated in the initial application or when SuperWham® or RiceShot® was applied in the second application resulted in an increase in Texasweed control at 14 DAFA, compared with the standard program (Table 3.2). All programs evaluating propanil applied EPOST, except for Stam SC®, and only the LPOST application of SuperWham® and Stam EDF® resulted in increased Texasweed control, compared with the standard program at 28 DAFA.

With the exception of Stam SC® evaluated at 35 DAFA, imazethapyr programs that included an application of propanil applied EPOST increased alligatorweed control, compared with the standard program at all rating dates (Table 3.2). Delaying propanil applications to LPOST only resulted in increased alligatorweed control with the addition of RiceShot® and Stam EDF® at 28 DAFA and SuperWham® at all rating dates.

These data indicate that weed control with propanil, regardless of timing, was equivalent to or higher than imazethapyr applied alone. The addition of propanil was also observed to be more beneficial for weed control when propanil was applied in the initial application of imazethapyr compared with delaying the propanil application to LPOST. This increase in control indicates the importance of incorporating other herbicides in mixture with imazethapyr to maximize weed control across multiple weed species.

A rice plant height at harvest response was observed when rice was treated with imazethapyr applied in mixture with propanil (Table 3.3). Imazethapyr plus any propanil formulation evaluated in the initial application resulted in increased rice plant height at harvest, 88 to 91 cm, compared with rice treated with the standard program, 81 cm. The differences

Table 3.2. Effects of imazethapyr and propanil programs on Texasweed control 14 and 28 days after final application (DAFA) and alligatorweed control 14, 28, and 35 DAFA, averaged over 2008 and 2009, near Crowley, Louisiana.[a]

Herbicide program[bc]	Form.	Rate	Timing	Texasweed control 14 DAFA	Texasweed control 28 DAFA	Alligatorweed control 14 DAFA	Alligatorweed control 28 DAFA	Alligatorweed control 35 DAFA
		— g ai/ha —		%				
imazethapyr fb[d]	AS[d]	70	EPOST[d]	64 e	89 c	55 e	55 d	53 d
imazethapyr	AS	70	LPOST[d]					
imazethapyr +	AS	70		90 ab	95 ab	71 ab	85 ab	86 ab
Stam M4® fb	EC[d]	3400	EPOST					
imazethapyr	AS	70	LPOST					
imazethapyr +	AS	70		80 abcd	93 abc	66 abcd	76 abc	68 bcd
Stam SC® fb	F[d]	3400	EPOST					
imazethapyr	AS	70	LPOST					
imazethapyr +	AS	70		92 a	97 a	69 abc	87 ab	89 a
RiceShot® fb	EC	3400	EPOST					
imazethapyr	AS	70	LPOST					
imazethapyr +	AS	70		89 ab	97 a	73 a	90 a	88 a
SuperWham® fb	F	3400	EPOST					
imazethapyr	AS	70	LPOST					
imazethapyr +	AS	70		90 ab	97 a	65 abcd	83 ab	88 a
Stam EDF® fb	WG[d]	3400	EPOST					
imazethapyr	AS	70	LPOST					
imazethapyr fb	AS	70	EPOST	72 de	93 abc	56 de	66 cd	53 d
imazethapyr +	AS	70	LPOST					
Stam M4®	EC	3400						
imazethapyr fb	AS	70	EPOST	73 de	92 bc	61 cde	65 cd	60 cd
imazethapyr +	AS	70	LPOST					
Stam SC®	F	3400						
imazethapyr fb	AS	70	EPOST	79 bcd	93 abc	63 bcde	79 abc	71 abcd
imazethapyr +	AS	70	LPOST					
RiceShot®	EC	3400						

continued

Table 3.2. Continued.

Herbicide program[bc]	Form.	Rate	Timing	Texasweed control		Alligatorweed control		
				14 DAFA	14 DAFA	14 DAFA	14 DAFA	
		— g ai/ha —		%				
imazethapyr fb	AS	70	EPOST	86 abc	96 ab	68 abc	80 abc	78 abc
imazethapyr +	AS	70	LPOST					
SuperWham®	F	3400						
imazethapyr fb	AS	70	EPOST	75 cde	94 ab	61 cde	71 bc	63 cd
imazethapyr +	AS	70	LPOST					
Stam EDF®	WG	3400						

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] A crop oil concentrate (COC) was added at a rate of 1% v/v, except for treatments that included an application of Stam M4® or Riceshot®.

[c] Stam M4®, Stam SC®, and Stam EDF® herbicide label; United Phosphorus, Inc., 630 Freedom Business Center, Suite 402, King of Prussia, PA 19406. Riceshot® and Superwham® herbicide label; RiceCo LLC., 5100 Poplar Avenue, Suite 2428, Memphis, TN 38137.

[d] Abbreviations: Form., Formulation; fb, followed by; AS, aqueous solution; EC, emulsifiable concentrate; F, flowable; WG, wettable granules; EPOST, early postemergence; LPOST, late postemergence.

Table 3.3. Effects of imazethapyr and propanil programs on rice plant height at harvest, yield, milling, and grade, averaged over 2008 and 2009, near Crowley, Louisiana.[a]

Herbicide program[bc]	Formulation	Rate	Timing	Plant height	Rough rice yield	Milling[d]	Grade
		— g ai/ha —		— cm —	— kg/ha —	— % —	
imazethapyr fb[d]	AS[e]	70	EPOST[e]	81 c	4270 e	65/71	3
imazethapyr	AS	70	LPOST[e]				
imazethapyr +	AS	70		91 a	6870 ab	65/71	3
Stam M4® fb	EC[e]	3400	EPOST				
imazethapyr	AS	70	LPOST				
imazethapyr +	AS	70		88 ab	5700 cd	65/71	3
Stam SC® fb	F[e]	3400	EPOST				
imazethapyr	AS	70	LPOST				
imazethapyr +	AS	70		90 ab	7240 a	65/71	3
RiceShot® fb	EC	3400	EPOST				
imazethapyr	AS	70	LPOST				
imazethapyr +	AS	70		90 ab	6640 abc	65/71	3
SuperWham® fb	F	3400	EPOST				
imazethapyr	AS	70	LPOST				
imazethapyr +	AS	70		90 ab	6760 abc	65/71	3
Stam EDF® fb	WG[e]	3400	EPOST				
imazethapyr	AS	70	LPOST				
imazethapyr fb	AS	70	EPOST	81 c	5330 de	66/71	3
imazethapyr +	AS	70	LPOST				
Stam M4®	EC	3400					
imazethapyr fb	AS	70	EPOST	85 bc	5000 de	64/71	3
imazethapyr +	AS	70	LPOST				
Stam SC®	F	3400					
imazethapyr fb	AS	70	EPOST	85 abc	5150 de	64/71	3
imazethapyr +	AS	70	LPOST				
RiceShot®	EC	3400					

continued

Table 3.3. Continued.

Herbicide program[bc]	Formulation	Rate	Timing	Plant height	Rough rice yield	Milling[d]	Grade
		— g ai/ha —		— cm —	— kg/ha —	— % —	
imazethapyr fb	AS	70	EPOST	86 abc	6060 bcd	65/71	2
imazethapyr +	AS	70	LPOST				
SuperWham®	F	3400					
imazethapyr fb	AS	70	EPOST	81 c	5250 de	64/71	3
imazethapyr +	AS	70	LPOST				
Stam EDF®	WG	3400					

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] A crop oil concentrate (COC) was added at a rate of 1% v/v, except for treatments that included an application of Stam M4® or Riceshot®.

[c] Stam M4®, Stam SC®, and Stam EDF® herbicide label; United Phosphorus, Inc., 630 Freedom Business Center, Suite 402, King of Prussia, PA 19406. Riceshot® and Superwham® herbicide label; RiceCo LLC., 5100 Poplar Avenue, Suite 2428, Memphis, TN 38137.

[d] Milling yield: % whole kernels / % whole plus broken kernels.

[e] Abbreviations: fb, followed by; AS, aqueous solution; EC, emulsifiable concentrate; F, flowable; WG, wettable granules; EPOST, early postemergence; LPOST, late postemergence.

in height are probably due to reduced weed control which resulted in increased competition.

Rice yield was recorded for both years and samples were obtained for milling yield and rice grade. Rice treated with the standard imazethapyr program had a rough rice yield of 4270 kg/ha (Table 3.3). Percent whole rice kernels over percent whole plus broken rice kernels indicated that the standard imazethapyr program resulted in a milling yield of 65/71 with a rice grade of 3. Rice treated with propanil, regardless of formulation, in the initial imazethapyr application or SuperWham® in the second imazethapyr application resulted in a yield increase of 1430 to 2970 kg/ha, compared with the standard program. However, no differences in milling yield and rice grade were observed. Rice treated with imazethapyr plus Stam M4®, Stam EDF®, or RiceShot® applied EPOST resulted in an increased rough rice yield, compared with these propanil formulations added to the second imazethapyr application. Rice treated with imazethapyr plus Stam M4® or RiceShot® applied EPOST resulted in an increased rough rice yield compared with rice treated with Stam SC® at the same timing. No differences in rough rice yield were observed when rice was treated with imazethapyr plus any propanil formulation applied LPOST. These data indicate that the addition of propanil in mixture with imazethapyr increased rough rice yield due to increased weed control. Also, rough rice yield can be maximized by including one of these propanil formulations, except for Stam SC, in the initial application of an imazethapyr herbicide program.

Profitability of these herbicide programs can be determined by evaluating the total value product, which was calculated by multiplying the rough rice yield by the price. Therefore, the impact of propanil in mixture with imazethapyr on rough rice yield and quality will directly impact total value product. Also, the net returns above herbicide cost can be calculated by subtracting the cost of the herbicide from total value product. The standard imazethapyr program resulted in a total value product of $1210/ha (Table 3.4). The standard imazethapyr program cost $90/ha resulting in an net returns of $1120/ha. Programs that included propanil in the initial imazethapyr application or SuperWham® applied in the second application resulted in an increase in total value product of $390 to $830/ha, compared with the standard program. Observations were similar for the net returns above herbicide cost. Programs that included propanil in the initial imazethapr application, except for Stam SC®, or SuperWham® applied in the second application increased the net returns above herbicide cost by 40 to 70%, compared with the standard program. Even though total value product was increased with Stam SC®, results showed no differences in net returns; this was due to the increased herbicide cost. Also, directly reflecting rough rice yield, total value product and the net returns above herbicide cost increased when Stam M4®, Stam EDF®, or RiceShot® was applied EPOST compared with these products applied LPOST. Imazethapyr applied EPOST plus Stam M4® or RiceShot® resulted in an increased total value product and net returns compared with adding Stam SC®. These data showed no differences in total value product between propanil formulations applied LPOST. However, due to differences in herbicide cost, imazethapyr applied LPOST plus SuperWham® increased the net returns compared with adding Stam SC®. These data indicate that the addition of propanil in mixture with imazethapyr resulted in increased profits, even though cost of treatment increased. This increase in profit was due to increased weed control and higher rice yield increasing total value product, which made up for the additional herbicide cost. Also, net returns were increased when herbicide programs in this study included propanil in the initial herbicide application.

In conclusion, the addition of propanil in mixture with imazethapyr proved to be beneficial in a total weed management program. However, the addition of propanil in the EPOST timing tended to be more advantageous than

Table 3.4. Economical returns of imazethapyr and propanil programs applied on rice, averaged over 2008 and 2009, near Crowley, Louisiana.[a]

Herbicide program[bc]	Formulation	Rate	Timing	Program herbicide cost	Total value product	Net returns above herbicide cost	Increase in net returns[d]
		— g ai/ha —		$/ha			
imazethapyr fb[d]	AS[e]	70	EPOST[e]	90	1210 d	1120 e	0
imazethapyr	AS	70	LPOST[e]				
imazethapyr +	AS	70		130	1950 a	1820 a	700 (63%)
Stam M4® fb	EC[e]	3400	EPOST				
imazethapyr	AS	70	LPOST				
imazethapyr +	AS	70		160	1600 bc	1440 bcde	320 (29%)
Stam SC® fb	F[e]	3400	EPOST				
imazethapyr	AS	70	LPOST				
imazethapyr +	AS	70		140	2040 a	1900 a	780 (70%)
RiceShot® fb	EC	3400	EPOST				
imazethapyr	AS	70	LPOST				
imazethapyr +	AS	70		150	1880 ab	1730 ab	610 (54%)
SuperWham® fb	F	3400	EPOST				
imazethapyr	AS	70	LPOST				
imazethapyr +	AS	70		230	1890 bc	1660 abc	540 (48%)
Stam EDF® fb	WG[e]	3400	EPOST				
imazethapyr	AS	70	LPOST				
imazethapyr fb	AS	70	EPOST	130	1490 cd	1360 cde	240 (21%)
imazethapyr +	AS	70	LPOST				
Stam M4®	EC	3400					
imazethapyr fb	AS	70	EPOST	160	1400 cd	1240 e	120 (11%)
imazethapyr +	AS	70	LPOST				
Stam SC®	F	3400					
imazethapyr fb	AS	70	EPOST	140	1440 cd	1300 de	180 (16%)
imazethapyr +	AS	70	LPOST				
RiceShot®	EC	3400					

continued

Table 3.4. Continued.

Herbicide program[bc]	Formulation	Rate	Timing	Program herbicide cost	Total value product	Net returns above herbicide cost	Increase in net returns[d]
		— g ai/ha —		———	——— $/ha	———	———
imazethapyr fb	AS	70	EPOST	150	1720 abc	1570 abcd	450 (40%)
imazethapyr +	AS	70	LPOST				
SuperWham®	F	3400					
imazethapyr fb	AS	70	EPOST	230	1490 cd	1260 de	140 (13%)
imazethapyr +	AS	70	LPOST				
Stam EDF®	WG	3400					

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] A crop oil concentrate (COC) was added at a rate of 1% v/v, except for treatments that included an application of Stam M4® or Riceshot®.

[c] Stam M4®, Stam SC®, and Stam EDF® herbicide label; United Phosphorus, Inc., 630 Freedom Business Center, Suite 402, King of Prussia, PA 19406. Riceshot® and Superwham® herbicide label; RiceCo LLC., 5100 Poplar Avenue, Suite 2428, Memphis, TN 38137.

[d] Equals the dollar per hectare increase in net returns above herbicide cost, when compared with the standard imazethapyr program of 70 fb 70 g ai/ha.

[e] Abbreviations: fb, followed by; AS, aqueous solution; EC, emulsifiable concentrate; F, flowable; WG, wettable granules; EPOST, early postemergence; LPOST, late postemergence.

adding to the LPOST timing in managing weeds. Herbicide programs evaluated in this study resulted in higher rough rice yields and net returns when the EPOST application included a propanil formulation. Herbicide programs that included RiceShot® or Stam M4® in the EPOST application maximized overall economic returns. However, when propanil was applied in the LPOST application overall economic returns were maximized with SuperWham®. Increased weed pressure, even over a short period of time, decreases rice yield. Therefore, producers should treat weed problems early. When weeds are controlled early, thus reducing weed competition, rice plants produce higher yields, which in turn will produce higher profits. In this study, economic returns were increased by 29 to 70% when propanil was added to imazethapyr applied EPOST.

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Chapter 4

Effects of Imazethapyr Plus a Herbicide with Soil Residual Activity Program in Rice

Introduction

Imidazolinone-resistant (IR) rice exhibits tolerance to the imidazolinone class of herbicides which 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). IR rice was developed in 1993 through seed mutatgenesis allowing rice lines to be considered nontrasgenic (Croughan 1994). Imazethapyr is labeled for use in IR rice as Newpath®[7] at 70 to 105 g/ha applied to the surface as a preplant incorporated (PPI) or preemergence (PRE) application followed by (fb) 70 to 105 g/ha postemergence (POST).

Red rice (*Oryza* sativa) and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv] competition with rice reduces grain yield and causes reduction in milling yields and grade (Webster and Levy 2009). Red rice (*Oryza sativa L.*) is one of the most troublesome weeds of cultivated rice in the southern United States (Dowler 1994; 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). Because of genetic similarities, before the development of IR rice controlling red rice with traditional rice herbicides has been unsuccessful.

However, previous research has demonstrated the efficacy of imazethapyr on grass weed species particularly red rice and barnyardgrass. Webster and Masson (2001) reported red rice control was above 95% with imazethapyr applied at 70 and 140 g/ha to rice in the two- to three-leaf stage. Soil

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[7] Newpath® herbicide label. BASF Corporation, 26 Davis Drive, Research Triangle Park, NC, 27709.

applications of imazethapyr at 70, 105, or 140 g/ha fb 70 g/ha POST controlled barnyardgrass 88% or better (Masson and Webster 2001). A single applications of imazethapyr at 140 g/ha POST controlled barnyardgrass (Masson et al. 2001).

In addition to red rice and barnyardgrass, a number of other grasses and broadleaf weeds exist in the rice culture in Louisiana (Braverman 1995). The most common weeds 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.), alligatorweed [*Althernanthera philoxeroides* (Mart.) Griseb.], and Indian jointvetch (*Aeschynomene indica* L.).

Studies have indicated that imazethapyr effectively controlled many key grass weeds in rice, including red rice, barnyardgrass, and broadleaf signalgrass (Klingaman et al. 1992; Masson et al. 2001; Webster and Masson 2001). However, the use of imazethapyr in IR rice provides minimal control of hemp sesbania and Indian jointvetch (Webster and Masson 2001; Zhang et al. 2001). Herbicide mixtures have proved to be beneficial in improving efficacy and broadening the weed control spectrum in IR rice (Pellerin et al. 2003). The use of herbicide mixtures is favorable to producers because of the increased weed control and reduced application cost (Hydrick and Shaw 1994).

Barnyardgrass is one of the most common weeds in U.S. rice production (Dowler 1994; Webster 2004). Propanil has historically controlled barnyardgrass effectively; however, repeated use of propanil has resulted in development of propanil-resistant barnyardgrass biotypes (Smith and Baltazar 1992). The confirmation of propanil-resistant barnyardgrass in Louisiana, Mississippi, Texas, and Arkansas, coupled with the difficulty of controlling red rice, has producers searching for effective herbicide programs (Baltazar and Smith 1994; Carey et al. 1995). Applying herbicides with multiple sites of action that provide residual weed control may provide more effective season-long barnyardgrass control and delay resistance.

Several herbicides are labeled for use as PRE or delayed PRE applications in rice (LSU AgCenter 2009). These herbicides are applied at planting or within seven days after planting to allow establishment of the crop with minimum weed competition. There are several herbicides that are applied PRE or delayed PRE in rice, such as pendimethalin[8], clomazone[9], quinclorac[2], and penoxsulam[10].

The registration of clomazone for weed control in southern dry-seeded rice provides rice growers in the region with an alternative herbicide to manage existing and emerging weed problems (Mudge et al. 2005a; Mudge et al. 2005b; Webster et al. 1999; Zang et al. 2004). As a residual herbicide, clomazone can be applied alone PRE or delayed PRE, or it can be applied in a mixture with other herbicides POST. This research has demonstrated that barnyardgrass control with clomazone equals or exceeds that with residual herbicides currently registered for use in rice. Webster et al. (1999) reported that a delayed PRE application of clomazone at 0.67 kg/ha controlled barnyardgrass 98%.

Applications of quinclorac at 560 or 751 g ai/ha PRE to dry or moist soil can control barnyardgrass at least 80% without injuring rice (Street and Mueller 1993). Barnyardgrass control will also increase with a delayed PRE application of quinclorac mixed with pendimethalin (Webster et al. 1999). The addition of pendimethalin to quinclorac broadens weed control. Daou and Talbert (1999) reported that propanil plus quinclorac or propanil plus pendimethalin controlled resistant barnyardgrass at least 98% with one

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[8] Prowl H_2O® and Facet® herbicide label. BASF Corporation, 26 Davis Drive, Research Triangle Park, NC, 27709.

[9] Command® herbicide label. FMC Corporation, 1735 Market Street, Philadelphia, PA 19103.

[10] Grasp® herbicide label. Dow AgroSciences LLC. 9330 Zionsville Road, Indianapolis, IN 46268-1189.

application at the two-leaf stage. Arnold et al. (1993) reported imazethapyr applied PPI or PRE in pinto beans (*Phaseolus vulgaris L.*) at 0.05 and 0.07 kg/ha controlled barnyardgrass less than the mixture of imazethapyr plus pendimethalin.

Penoxsulam is a selective herbicide which has activity on annual grasses and many annual broadleaf weeds in rice (Griffin et al. 2008; Webster et al. 2007). Webster et al. (2007) reported that a single mid POST application of penoxsulam at 50 g/ha controlled barnyardgrass 78% and when penoxsulam followed a PRE application of clomazone at 448 g ai/ha barnyardgrass control was 89%.

The objective of this study was to evaluate the economical effects of pendimethalin, clomazone, quinclorac, or penoxsulam applied with the first application of imazethapyr at VEPOST fb a POST application of imazethapyr or imazamox on IR rice. Data from this study could prove to be essential when considering including a herbicide with PRE activity in a herbicide program.

Materials and Methods

A study was conducted in 2008 and 2009 at the Louisiana State University AgCenter Rice Research Station near Crowley, Louisiana on a Crowley silt loam (fine montmorillonitic, thermic Typic Albaqualf) with pH 6.9 and 1.2% organic matter. Seed bed preparation consisted of a fall and spring disking followed by two passes in opposite directions with a two-way bed conditioner equipped with rolling baskets and S-tine harrows set at 7.5 cm deep. A preplant application of 280 kg/ha of 8-24-24 (N-P_2O_5-K_2O) fertilizer and a preflood application of 365 kg/ha 46-0-0 urea fertilizer was applied to the study area. A final pass of the bed conditioner was made prior to planting for incorporation of fertilizer.

The long grain rice cultivar 'CL 161' was drill-seeded in 18-cm rows at a planting rate of 84 kg/ha on April 24, 2008 and the following year 'CL 131' was planted on April 16, 2009. Immediately after rice planting, the area was surface irrigated to a level of 2.5 cm and drained immediately. A 10 cm permanent flood was established when rice reached the five-leaf to one-tiller growth stage and was maintained until 2 wk prior to harvest.

The experimental design was a randomized complete block with four replications. The herbicide programs evaluated were imazethapyr applied alone or imazethapyr plus a herbicide with soil residual activity applied VEPOST (one- to two-leaf rice stage) followed by (fb) an application of imazethapyr or imazamox two weeks after the VEPOST application. Imazethapyr was applied at 70 g/ha and imazamox at 44 g ai/ha. The soil residual herbicides applied were: pendimethalin at 1,121 g ai/ha, clomazone at 336 g ai/ha, quinclorac at 560 g ai/ha, and penoxsulam at 49 g ai/ha. The imazethapyr fb imazethapyr program was considered the standard program for comparison purpose. A crop oil concentrate (COC) was added in each application at 1% v/v. Each application of herbicide was applied at 140 L/ha with a CO_2-pressurized backpack sprayer at a pressure of 145 kPa.

Weed control ratings were collected 18, 28, and 38 days after the final application (DAFA). Weed control ratings were visually estimated on a scale of 0 to 100%, where 0 = no control and 100 = complete plant death. Rice height was recorded at harvest. Height measurements were taken from two plants per plot from the ground to the tip of the extended panicle. The center 0.75 by 6 m area of each plot was harvested on August 22, 2008 and August 24, 2009 using a mechanical plot harvester. Rough rice yield was adjusted to 12% moisture.

Economic applications were based on the average long grain rice price for 2009 (WASDE 2009). Base rice price was $285/MT with price deductions based on rice grade. Actual rough rice market prices are adjusted by grade and these grade price discounts can vary across rice mills. In this study, rough rice price deductions for grades 1, 2, 3, 4, 5, 6 and sample grade were $0.00, $0.00, $5.50, $12.00, $27.50, $33.00 and $44.00/MT, respectively.

These price reductions are representative of actual market price discounts based upon the grade of rice for sale. Imazethapyr was applied as Newpath® with a price of $140/L. Imazamox was applied as Beyond®[11] priced at $160/L. Pendimethalin was applied as Prowl H_2O® priced at $10.20/L. Clomazone was applied as Command® priced at $36.50/L. Quinclorac was applied as Facet® priced at $125/kg. Penoxsulam was applied as Grasp® priced at $360/L. The COC Agri-Dex®[12] was included with every herbicide application at $4.00/L. Profitability of the herbicide programs were determined by evaluating the total value product, which was calculated by multiplying the rough rice yield by the price. Net returns above herbicide cost were also evaluated, where the net returns equals the total value product minus the herbicide program cost.

Data were subjected to the Mixed Procedure of SAS (SAS 2003). Year, replications (nested within year), and all interactions containing either of these effects were considered random effects. Application timing and rate were considered fixed effects. Considering year or combination of year as random effects permits inferences about treatments over a range of environments (Carmer et al. 1989; Hager et al. 2003). Type III statistics were used to test all possible effects of fixed factors (application timing and rate) and least square means were used for mean separation at the 5% probability level ($p \leq 0.05$).

Results and Discussion

An interaction for red rice control was observed at 18, 28, and 38 DAFA, averaged over two years (Table 4.1). Rice treated with imazethapyr plus quinclorac fb imazethapyr or imazethapyr plus penoxsulam fb imazethapyr or imazamox resulted in an increase in red rice control at 18 DAFA, compared with the standard program. Herbicide programs evaluated that included

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[11] Beyond® herbicide label. BASF Corporation, 26 Davis Drive, Research Triangle Park, NC, 27709.

[12] Agri-Dex® label. Helena Chemical Company, 225 Schilling Blvd., Suite 300, Collierville, Tennessee 38017.

Table 4.1. Effects of imazethapyr plus a soil residual herbicide followed by imazethapyr or imazamox programs on red rice and barnyardgrass control 18, 28, and 39 days after final application (DAFA), 2008 and 2009, Crowley, Louisiana.[a]

Herbicide program[b]	Form.	Rate	Timing	Red rice control 18 DAFA	Red rice control 28 DAFA	Red rice control 38 DAFA	Barnyardgrass control 18 DAFA	Barnyardgrass control 28 DAFA	Barnyardgrass control 38 DAFA
		— g ai/ha —		— % —					
imazethapyr fb[c]	AS[c]	70	VEPOST[c]	92 d	94 b	94 bc	93 b	93 c	92 de
imazethapyr	AS	70	2 WAA[c]						
imazethapyr fb	AS	70	VEPOST	93 bcd	94 b	92 c	93 b	92 c	90 e
imazamox	AS	44	2 WAA						
imazethapyr +	AS	70		93 bcd	95 ab	95 abc	93 b	95 abc	94 bcd
pendimethalin fb	SC[c]	1121	VEPOST						
imazethapyr	AS	70	2 WAA						
imazethapyr +	AS	70		94 abcd	96 ab	94 bc	94 ab	95 abc	93 cde
pendimethalin fb	SC	1121	VEPOST						
imazamox	AS	44	2 WAA						
imazethapyr +	AS	70		93 bcd	95 ab	97 ab	93 b	94 abc	97 ab
clomazone fb	ME[c]	336	VEPOST						
imazethapyr	AS	70	2 WAA						
imazethapyr +	AS	70		94 abcd	95 ab	94 bc	93 b	94 abc	93 cde
clomazone fb	ME	336	VEPOST						
imazamox	AS	44	2 WAA						
imazethapyr +	AS	70		95 abc	98 a	97 ab	95 ab	97 ab	97 ab
quinclorac fb	WDG[c]	560	VEPOST						
imazethapyr	AS	70	2 WAA						
imazethapyr +	AS	70		94 abcd	98 a	97 ab	94 ab	98 a	98 a
quinclorac fb	WDG	560	VEPOST						
imazamox	AS	44	2 WAA						
imazethapyr +	AS	70		97 a	98 a	98 a	97 a	98 a	98 a
penoxsulam fb	EC[c]	49	VEPOST						
imazethapyr	AS	70	2 WAA						

continued

Table 4.1. Continued.

Herbicide program[b]	Form.	Rate	Timing	Red rice control 18 DAFA	28 DAFA	38 DAFA	Barnyardgrass control 18 DAFA	28 DAFA	38 DAFA
		— g ai/ha —		%					
imazethapyr +	AS	70		96 ab	98 a	97 ab	96 ab	98 a	98 ab
penoxsulam fb	EC	49	VEPOST						
imazamox	AS	44	2 WAA						

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] A crop oil concentrate (COC) was added at a rate of 1% v/v.

[c] Abbreviations: Form., Formulation; fb, followed by; AS, aqueous solution; SC, suspension concentrate; ME, micro-encapsulated; WDG, wettable dispersible granules; EC, emulsifiable concentrate; VEPOST, very early postemergence; WAA, weeks after application.

quinclorac or penoxsulam resulted in an increase to 98% red rice control at the 28 DAFA evaluation, compared with 94% red rice control with the standard program. At 38 DAFA, penoxsulam fb imazethapyr resulted in increased red rice control compared with the standard program. Addition of quinclorac or penoxsulam at VEPOST applications increased red rice control at the earliest rating dates; however, only penoxsulam fb imazethapyr increased red rice control, compared to the standard program, at 38 DAFA. This extended period of control can contribute to increased rice yield and quality which increases growers profit and also increases harvest efficiency.

A barnyardgrass control interaction was observed at all rating dates, averaged over years (Table 4.1). Penoxsulam fb imazethapyr resulted in 97% control, compared with 93% control with the standard program at 18 DAFA. Herbicide programs evaluated that included quinclorac or penoxsulam resulted in an increase in barnyardgrass control at 28 and 38 DAFA, compared with the standard program.

A Texasweed control effect was not observed at any rating date, compared with the standard program at 93 to 96% control (Table 4.2). Regardless of program evaluated, Texasweed control was 93 to 97%.

An alligatorweed control interaction was observed (Table 4.2). Pendimethalin or clomazone fb imazamox and programs with quinclorac or penoxsulam increased alligatorweed control at 18 DAFA, compared with the standard program. At 28 DAFA, quinclorac controlled alligatorweed 90 to 92% compared with 83% control with the standard program. At 38 DAFA, herbicide programs that included quinclorac or penoxsulam or pendimethalin fb imazamox increased alligatorweed control to 89 to 93%, compared with 75% control with the standard program.

Compared with the standard program, none of the soil residual herbicides evaluated in this study increased Texasweed control. However, increased red rice, barnyardgrass, and alligatorweed control was observed

Table 4.2. Effects of imazethapyr plus a soil residual herbicide followed by imazethapyr or imazamox programs on Texasweed and alligatorweed control 18, 28, and 39 days after final application (DAFA), 2008 and 2009, Crowley, Louisiana.[a]

Herbicide program[b]	Form.	Rate	Timing	Texasweed control 18 DAFA	Texasweed control 28 DAFA	Texasweed control 38 DAFA	Alligatorweed control 18 DAFA	Alligatorweed control 28 DAFA	Alligatorweed control 38 DAFA
		— g ai/ha —		%					
imazethapyr fb[c]	AS[c]	70	VEPOST[c]	96 a	95 ab	93 a	73 c	83 c	75 de
imazethapyr	AS	70	2 WAA[c]						
imazethapyr fb	AS	70	VEPOST	96 a	96 ab	95 a	80 abc	83 c	76 cde
imazamox	AS	44	2 WAA						
imazethapyr +	AS	70		96 a	97 a	93 a	77 abc	84 bc	78 bcde
pendimethalin fb	SC[c]	1121	VEPOST						
imazethapyr	AS	70	2 WAA						
imazethapyr +	AS	70		97 a	97 a	96 a	84 ab	88 abc	89 abc
pendimethalin fb	SC	1121	VEPOST						
imazamox	AS	44	2 WAA						
imazethapyr +	AS	70		96 a	94 b	97 a	76 bc	83 c	68 e
clomazone fb	ME[c]	336	VEPOST						
imazethapyr	AS	70	2 WAA						
imazethapyr +	AS	70		97 a	97 a	96 a	85 a	89 abc	84 abcd
clomazone fb	ME	336	VEPOST						
imazamox	AS	44	2 WAA						
imazethapyr +	AS	70		97 a	97 a	97 a	83 ab	92 a	90 ab
quinclorac fb	WDG[c]	560	VEPOST						
imazethapyr	AS	70	2 WAA						
imazethapyr +	AS	70		97 a	97 a	97 a	84 ab	90 ab	93 a
quinclorac fb	WDG	560	VEPOST						
imazamox	AS	44	2 WAA						
imazethapyr +	AS	70		96 a	96 ab	97 a	82 ab	87 abc	91 ab
penoxsulam fb	EC[c]	49	VEPOST						
imazethapyr	AS	70	2 WAA						

continued

Table 4.2. Continued.

Herbicide program[b]	Form.	Rate	Timing	Texasweed control 18 DAFA	Texasweed control 28 DAFA	Texasweed control 38 DAFA	Alligatorweed control 18 DAFA	Alligatorweed control 28 DAFA	Alligatorweed control 38 DAFA
		— g ai/ha —		%					
imazethapyr +	AS	70		97a	96 ab	95 a	82 ab	87 abc	92 a
penoxsulam fb	EC	49	VEPOST						
imazamox	AS	44	2 WAA						

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] A crop oil concentrate (COC) was added at a rate of 1% v/v.

[c] Abbreviations: Form., Formulation; fb, followed by; AS, aqueous solution; SC, suspension concentrate; ME, micro-encapsulated; WDG, wettable dispersible granules; EC, emulsifiable concentrate; VEPOST, very early postemergence; WAA, weeks after application.

with programs that included quinclorac or penoxsulam. This increase in control indicates the importance of incorporating herbicide mixtures to the standard imazethapyr program in clearfield rice to maximize weed control. The increase in broad spectrum weed control with the addition of a soil residual herbicide can be beneficial to producers by increasing weed control with little increase in herbicide cost and no increase in application cost.

A rice plant height at harvest response was not observed in the rice crop, regardless of herbicide program (Table 4.3). Slight difference in height occurred within treatments; however plant height was 90 to 95 cm, compared with the standard program, 92 cm.

A rough rice yield response was observed (Table 4.3). Rice treated with the standard program had a rough rice yield of 6200 kg/ha, a milling yield of 65/71, percent whole over percent whole plus broken rice kernels, and a rice grade of 3. Herbicide programs that included quinclorac or penoxsulam or clomazone fb imazamox resulted in an increase in rough rice yield of 1020 to 1680 kg/ha, compared with the standard program. However, no decrease in milling yield or rice grade was observed for all herbicide programs evaluated, compared with the standard program. No differences in yield were observed with imazamox applied following a given soil residual herbicide compared with imazethapyr applied following an application of the same soil residual herbicide. Herbicide programs that included quinclorac or penoxsulam increased rough rice yield, compared with clomazone fb imazethapyr. Also, quinclorac fb imazamox or penoxsulam fb imazethapyr increased rough rice yield, compared with programs that included pendimethalin. These data indicate that the addition of quinclorac or penoxsulam in mixture with imazethapyr fb imazethapyr or imazamox resulted in increased rough rice yield due to the increased broad spectrum weed control observed with these herbicide programs (Table 4.1 and 4.2)

Table 4.3. Effects of imazethapyr plus a soil residual herbicide followed by imazethapyr or imazamox programs on rice plant height at harvest, yield, milling, and grade, 2008 and 2009, Crowley, Louisiana.[a]

Herbicide program[b]	Formulation	Rate	Timing	Plant height	Rough rice yield	Milling[c]	Grade
		— g ai/ha —		— cm —	— kg/ha —	— % —	
imazethapyr fb[d]	AS[d]	70	VEPOST[d]	92 abc	6200 d	65/71	3
imazethapyr	AS	70	2 WAA[d]				
imazethapyr fb	AS	70	VEPOST	93 abc	6760 cd	66/71	2
imazamox	AS	44	2 WAA				
imazethapyr +	AS	70		92 abc	6890 bcd	66/71	3
pendimethalin fb	SC[d]	1121	VEPOST				
imazethapyr	AS	70	2 WAA				
imazethapyr +	AS	70		90 c	6890 bcd	66/71	2
pendimethalin fb	SC	1121	VEPOST				
imazamox	AS	44	2 WAA				
imazethapyr +	AS	70		91 bc	6710 cd	66/71	3
clomazone fb	ME[d]	336	VEPOST				
imazethapyr	AS	70	2 WAA				
imazethapyr +	AS	70		92 abc	7220 abc	66/71	3
clomazone fb	ME	336	VEPOST				
imazamox	AS	44	2 WAA				
imazethapyr +	AS	70		94 ab	7790 ab	66/72	3
quinclorac fb	WDG[d]	560	VEPOST				
imazethapyr	AS	70	2 WAA				
imazethapyr +	AS	70		94 ab	7880 a	67/71	3
quinclorac fb	WDG	560	VEPOST				
imazamox	AS	44	2 WAA				
imazethapyr +	AS	70		95 a	7840 a	66/71	3
penoxsulam fb	EC[d]	49	VEPOST				
imazethapyr	AS	70	2 WAA				

continued

Table 4.3. Continued.

Herbicide program[b]	Formulation	Rate	Timing	Plant height	Rough rice yield	Milling[c]	Grade
		— g ai/ha —		— cm —	— kg/ha —	— % —	
imazethapyr +	AS	70		93 abc	7750 ab	66/71	3
penoxsulam fb	EC	49	VEPOST				
imazamox	AS	44	2 WAA				

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] A crop oil concentrate (COC) was added at a rate of 1% v/v.

[c] Milling yield: % whole kernels / % whole plus broken kernels.

[d] Abbreviations: fb, followed by; AS, aqueous solution; SC, suspension concentrate; ME, micro-encapsulated; WDG, wettable dispersible granules; EC, emulsifiable concentrate; VEPOST, very early postemergence; WAA, weeks after application.

Profitability of these herbicide programs can be determined by evaluating the total value product, which was calculated by multiplying the rough rice yield by the price of rice. Therefore, the impact of the herbicide programs evaluated on rough rice yield and quality will directly impact total value product. Also, the net returns above herbicide cost can be calculated by subtracting the cost of the herbicide program from total value product. The standard program resulted in a total value product of $1760/ha (Table 4.4). The cost for the standard program was $90/ha resulting in net returns above herbicide cost of $1670/ha. Herbicide programs with quinclorac or penoxsulam or clomazone fb imazamox resulted in an increase in total value product of $270 to $450/ha, compared with the standard program. A similar trend was observed when evaluating the net returns above herbicide cost. Herbicide programs of quinclorac or penoxsulam increased the net returns by 20 to 22%, compared with the standard program. However, the additive herbicide cost for clomazone fb imazamox resulted in an net returns similar to the standard program. Also, with a given soil residual herbicide, total value product and the net returns above herbicide cost were similar when imazamox was applied as the second herbicide application compared with imazethapyr applied as the second herbicide application. When comparing herbicide programs that included a soil residual herbicide total value product was greater with programs that included quinclorac or penoxsulam, compared with clomazone fb imazethapyr. Herbicide programs that included quinclorac or when penoxsulam was fb imazamox total value product increased, compared with pendimethalin fb imazethapyr. Also, total value product was greater with quinclorac fb imazethapyr, compared with pendimethalin fb imazamox. However, the additive herbicide cost was significant enough, when comparing herbicide programs that included a soil residual herbicide that the net returns above herbicide cost was only increased with quinclorac fb imazethapyr, compared with clomazone fb imazethapyr. These data indicate that

Table 4.4. Economical returns of imazethapyr plus a soil residual herbicide followed by imazethapyr or imazamox programs on rice, 2008 and 2009, Crowley, Louisiana.[a]

Herbicide program[b]	Formulation	Rate	Timing	Program herbicide cost	Total value product	Net returns above herbicide cost	Increase in net returns[c]
		— g ai/ha —		$/ha			
imazethapyr fb[d]	AS[d]	70	VEPOST[d]	90	1760 e	1670 c	0
imazethapyr	AS	70	2 WAA[d]				
imazethapyr fb	AS	70	VEPOST	110	1930 cde	1820 abc	150 (9%)
imazamox	AS	44	2 WAA				
imazethapyr +	AS	70		120	1930 cde	1810 abc	140 (8%)
pendimethalin fb	SC[d]	1121	VEPOST				
imazethapyr	AS	70	2 WAA				
imazethapyr +	AS	70		140	1970 bcde	1830 abc	160 (10%)
pendimethalin fb	SC	1121	VEPOST				
imazamox	AS	44	2 WAA				
imazethapyr +	AS	70		130	1890 de	1760 bc	90 (5%)
clomazone fb	ME[d]	336	VEPOST				
imazethapyr	AS	70	2 WAA				
imazethapyr +	AS	70		150	2030 abcd	1880 abc	210 (13%)
clomazone fb	ME	336	VEPOST				
imazamox	AS	44	2 WAA				
imazethapyr +	AS	70		180	2210 a	2030 a	360 (22%)
quinclorac fb	WDG[d]	560	VEPOST				
imazethapyr	AS	70	2 WAA				
imazethapyr +	AS	70		200	2200 ab	2000 ab	330 (20%)
quinclorac fb	WDG	560	VEPOST				
imazamox	AS	44	2 WAA				
imazethapyr +	AS	70		160	2170 abc	2010 ab	340 (20%)
penoxsulam fb	EC[d]	49	VEPOST				
imazethapyr	AS	70	2 WAA				

continued

Table 4.4. Continued.

Herbicide program[b]	Formulation	Rate	Timing	Program herbicide cost	Total value product	Net returns above herbicide cost	Increase in net returns[c]
		— g ai/ha —			$/ha		
imazethapyr +	AS	70		180	2180 ab	2000 ab	330 (20%)
penoxsulam fb	EC	49	VEPOST				
imazamox	AS	44	2 WAA				

[a] Means within a column followed by the same letter were not statistically different according to the t-test on difference of least square means at P = 0.05.

[b] A crop oil concentrate (COC) was added at a rate of 1% v/v.

[c] Equals the dollar per hectare increase in net returns above herbicide cost, when compared with the standard imazethapyr program of 70 fb 70 g ai/ha.

[d] Abbreviations: fb, followed by; AS, aqueous solution; SC, suspension concentrate; ME, micro-encapsulated; WDG, wettable dispersible granules; EC, emulsifiable concentrate; VEPOST, very early postemergence; WAA, weeks after application.

quinclorac or penoxsulam in mixture with imazethapyr followed by imazethapyr or imazamox resulted in increased profits, even though cost of treatmen increased. This increase in profit was due to increased weed control (Table 4.1 and 4.2) and higher rice yield (Table 4.3) increasing total value product (Table 4.4), which overcome the additional herbicide cost.

In conclusion, the addition of quinclorac or penoxsulam in mixture with imazethapyr fb imazethapyr or imazamox proved to be beneficial in a total weed management program. However, with a given soil residual herbicide, applying imazamox in the second herbicide application instead of imazethapyr resulted in no economical advantages. Herbicide programs evaluated in this study resulted in higher rough rice yields and economic benefits when the initial application included quinclorac or penoxsulam; which maximized overall economic returns. Increased weed pressure, even over a short period of time, decreases rice yield. Therefore, producers should treat weed problems early. When weeds are controlled early, thus reducing weed competition, rice plants produce higher yields, which in turn will produce higher profits. In this study, economic returns were increased by 20 to 22% when quinclorac or penoxsulam was added to the first application of a standard imazethapyr program.

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Chapter 5

Summary

Three separate field studies were established in 2008 and 2009 to evaluate weed control programs in drill seeded imidazolinone-resistant (IR) rice production systems.

Research was conducted near Crowley, Louisiana and Stoneville, Mississippi to evaluate weed control, yield, and economical returns with imazethapyr programs at different rates and application timings. Imazethapyr was applied at emergence, 1 week after emergence (WAE), 2 WAE, 3 WAE, or 4 WAE followed by (fb) an application of imazethapyr 14 days after the initial application of each treatment. Imazethapyr was applied at either 70 g ai/ha for both applications, 105 g/ha for both applications, 105 fb 70 g/ha, or 70 fb 105 g/ha. Red rice (*Oryza sativa L.*) and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv] control was evaluated and rice yield was recorded. Rice samples were obtained at the Crowley, Louisiana location and milling yield and rice grade were evaluated. Economic applications were evaluated based on rice yield and quality. Prices were based on the average rough rice price for 2009.

The initial application of imazethapyr applied at rice emergence, averaged across rate, resulted in 89% red rice and 90% barnyardgrass control. By delaying the initial application of imazethapyr 1 to 4 WAE red rice and barnyardgrass control decreased below 60%. Averaged across application timings, an imazethapyr program application rate effect on red rice and barnyardgrass control was not observed.

The initial application of imazethapyr applied to rice at 1 WAE or later resulted in reduced rice plant height at harvest, 61 to 66 cm, compared with the initial application of imazethapyr applied at emergence, 82 cm. Initial applications of imazethapyr, averaged across rate, applied at rice emergence resulted in a rough rice yield of 4800 kg/ha, milling yield of

61/69, and a rice grade of 3. Delaying the initial imazethapyr application 1 to 3 WAE resulted in reduced rough rice yield, milling yield, and rice grade. Furthermore, delaying the initial application of imazethapyr to 4 WAE decreased rough rice yield 50%, compared with the initial emergence application, and resulted in a milling yield of 60/69 and a rice grade of 6. Averaged across timing, the standard imazethapyr program of 70 fb 70 g/ha resulted in a rough rice yield of 3260 kg/ha with a milling yield of 59/69 and a rice of grade 5. Imazethapyr programs evaluated in this study that included at least one 70 g/ha imazethapyr application resulted in a rough rice yield similar to the standard imazethapyr program. However, both applications of imazethapyr applied at 105 g/ha resulted in a increased rough rice yield, milling yield, and rice grade, compared with the standard program.

The initial application of imazethapyr applied at rice emergence, averaged across rate, resulted in a total value product of $1350/ha. Delaying the initial imazethapyr application 1 to 3 WAE resulted in decreased total value product. Delaying the initial imazethapyr application to 4 WAE resulted in a decrease in total value product of 55%, compared with the initial imazethapyr application applied at rice emergence. Averaged across timing, the standard imazethapyr program resulted in a total value product of $840/ha. The cost for the standard program was $90/ha resulting in net returns above herbicide cost of $750/ha. When imazethapyr was applied at 105 fb 70 g/ha and 70 fb 105 g/ha total value product was $840 and $850/ha, respectively. However, the cost of the 105 fb 70 g/ha and 70 fb 105 g/ha treatments were increased to $110/ha resulting in a net return decrease of 3 and 1%, respectively, compared with the standard program. Imazethapyr applied at 105 fb 105 g/ha resulted in a total value product of $1040/ha. This program resulted in the highest herbicide cost at $130/ha; however, the net returns for this program increased by 21%, compared with the standard program.

Research was conducted in 2008 and 2009 near Crowley, Louisiana to evaluate weed control, yield, and economical returns of several imazethapyr plus propanil mixtures. The herbicide programs evaluated were imazethapyr or imazethapyr mixed with a propanil formulation applied EPOST, two- to three-leaf rice stage, fb imazethapyr LPOST, four- to five-leaf rice stage, or imazethapyr EPOST fb imazethapyr or imazethapyr tank mixed with a propanil formulation LPOST. Propanil was applied as Stam M4®[13], Stam SC®[1], Stam EDF®[1], RiceShot®[14], or SuperWham®[2] at 3.4 kg ai/ha and imazethapyr was applied as Newpath®[15] at 70 g/ha. Red rice, barnyardgrass, Texasweed (*Caperonia palustris*), and alligatorweed [*Althernanthera philoxeroides* (Mart.) Griseb.] control was evaluated and rice yield was recorded. Rice samples were obtained to evaluate milling yield and rice grade. Economic applications were evaluated based on rice yield and quality. Prices were based on the average rough rice price for 2009.

For all evaluation dates, herbicide programs that included any propanil formulation in the initial application or SuperWham® or RiceShot® in the second application resulted in increased red rice and barnyardgrass control, compared with the standard imazethapyr program of 70 fb 70 g/ha. However, Texasweed and alligatorweed control was only increased when herbicide programs included an application of any propanil formulation in the initial application, except for Stam SC®, or SuperWham® in the second application.

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[13] Stam M4®, Stam SC®, and Stam EDF® herbicide label. United Phosphorus, Inc., 630 Freedom Business Center, Suite 402, King of Prussia, PA 19406.

[14] RiceShot® and SuperWham® herbicide label. RiceCo LLC., 5100 Poplar Avenue, Suite 2428, Memphis, TN 38137.

[15] Newpath® herbicide label. BASF Corporation, 26 Davis Drive, Research Triangle Park, NC, 27709.

A rice plant height at harvest response was observed in the rice crop with imazethapyr applied in mixture with propanil. Rice treated with the standard imazethapyr program resulted in a rough rice yield of 4270 kg/ha, a milling yield of 65/71, and a rice grade of 3. Herbicide programs that included an application of any propanil formulation in the initial herbicide application or SuperWham® in the second herbicide application resulted in an increase in rough rice yield, compared with the standard program. However, no differences in milling yield and rice grade were observed for all herbicide programs evaluated. Herbicide programs that included Stam M4®, Stam EDF®, and RiceShot® resulted in an increased rough rice yield when these herbicides were applied in the initial herbicide application, compared with these herbicides included in the second herbicide application. Also, when included in the initial herbicide application, Stam M4® and RiceShot® resulted in an increased rough rice yield compared with Stam SC® at this timing.

The standard imazethapyr program resulted in a total value product of $1210/ha. The herbicide cost for the standard program was $90/ha resulting in net returns above herbicide cost of $1120/ha. Herbicide programs evaluated that included an application of any propanil formulation in the initial application or SuperWham® applied in the second application resulted in an increase in total value product, compared with the standard program. Observations were similar for the net returns above herbicide cost. Except for Stam SC®, herbicide programs evaluated that included an application of any propanil formulation in the initial application or SuperWham® applied in the second application increased the net returns by 40 to 70%, compared with the standard program. Total value product and the net returns above herbicide cost increased when a propanil formulation was applied in the first application instead of the second for herbicide programs that included Stam M4®, Stam EDF®, and RiceShot®. When included in the initial herbicide application, Stam M4® and RiceShot® resulted in an increased total value product and net returns above herbicide cost compared with Stam SC® included at this timing.

Research was conducted in 2008 and 2009 near Crowley, Louisiana to evaluate weed control, yield, and economical returns with the addition of a herbicide with soil residual activity in mixture with imazethapyr. The herbicide programs of imazethapyr plus a soil residual herbicide applied VEPOST, one- to two-leaf rice stage, fb an application of imazethapyr or imazamox two weeks after VEPOST were evaluated. Imazethapyr was applied at 70 g/ha and imazamox at 44 g ai/ha. Herbicides with soil residual activity include: pendimethalin applied at 1,121 g ai/ha, clomazone at 336 g ai/ha, quinclorac at 560 g ai/ha, and penoxsulam at 49 g ai/ha. Red rice, barnyardgrass, Texasweed, and alligatorweed control was evaluated and rice yield was recorded. Rice samples were obtained to evaluate milling yield and rice grade. Economic applications were evaluated based on rice yield and quality. Prices were based on the average rough rice price for 2009.

Herbicide programs of quinclorac fb imazethapyr or penoxsulam fb imazethapyr or imazamox resulted in increased red rice control at all rating dates, compared with the standard program. Herbicide programs evaluated that included an application of quinclorac or penoxsulam resulted in increased barnyardgrass control at 28 and 38 DAFA, compared with the standard program. No differences in Texasweed control were observed for all herbicide programs evaluated, compared with the standard program. Herbicide programs with quinclorac or penoxsulam or pendimethalin fb imazamox increased alligatorweed control to 89 to 93% at 38 DAFA, compared to 75% control with the standard program.

A rice plant height at harvest response was not observed in the rice crop, regardless of herbicide program, compared to the standard program. Rough rice yield for the standard imazethapyr program was 6200 kg/ha, milling yield was 65/71 and the rice grade was 3. Herbicide programs evaluated that included an application of quinclorac or penoxsulam or clomazone fb imazamox resulted in an increase in rough rice yield, compared with the standard program. However, no differences in milling yield and rice grade were observed for all herbicide programs evaluated.

The standard imazethapyr program resulted in a total value product of $1760/ha. The cost for the standard program was $90/ha resulting in net returns above herbicide cost of $1670/ha. Herbicide programs evaluated that included an application of quinclorac or penoxsulam or clomazone fb imazamox resulted in an increase in total value product, compared with the standard program. Observations were similar for the net returns above herbicide cost. Herbicide programs evaluated that included an application of quinclorac or penoxsulam increased the net returns by 20 to 22%, compared with the standard program. However, the additive herbicide cost for clomazone fb imazamox resulted in net returns similar to the standard program.

In conclusion, these studies have shown that the effectiveness of imazethapyr is dependent on weed spectrum and application timing. Earlier imazethapyr applications were observed to be more advantageous in controlling red rice and barnyardgrass. The increase in broad spectrum weed control with the addition of propanil or a soil residual herbicide can be beneficial to producers by increasing control with little increase in herbicide cost and no increase in application cost. This extended period of weed control and broad spectrum weed control can also contribute to increased rice yield and quality which increases growers profit and also increases harvest efficiency. Imazethapyr programs evaluated in these studies resulted in increased rough rice yields and economical returns when the initial application of imazethapyr was in mixture with the propanil formulations of RiceShot® or Stam M4® or the soil residual herbicides quinclorac or penoxsulam. Overall, the addition of propanil or a soil residual herbicide to the initial application of imazethapyr has proven to be beneficial in a total weed management program. However, if rice producers were to apply imazethapyr alone the greatest economical return was observed with 105 fb 105 g/ha with the initial application being applied the first week of rice emergence. Increased weed pressure, even over a short period of time, decreases rice yield. Therefore, producers should treat weed problems early. When weeds are controlled early and the time interval of weed competition is reduced, rice plants produce higher yields, which in turn will produce higher profits.

Vita

Tyler Paul Carlson is the son of Thomas and Leticia Carlson. He was born in April of 1986 in Crowley, Louisiana. He was raised in Morse, Louisiana, on a small rice, soybean, and crawfish farm. Tyler attended high school at Midland High and graduated in 2004. He than enrolled at McNeese State University graduating *magna cum laude* in December 2007 with a Bachelor of Science degree in agricultural business. He then began his graduate career at Louisiana State University in the Department of Agricultural Economics and Agribusiness under the direction of Dr. Michael Salassi and Dr. Eric Webster in 2008 and is currently a candidate for the degree of Master of Science in agricultural economics.