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Imazethapyr plus Residual Herbicide Programs for Imidazolinone-Resistant Rice

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Field studies were conducted in 2008 and 2009 near Crowley, LA to evaluate the addition of a herbicide with soil-residual activity in mixture with imazethapyr applied very early POST followed by an application of imazethapyr or imazamox 2 wk after the initial application. Weeds evaluated included red rice, barnyardgrass, and alligatorweed. Weed control with treatments including a herbicide with soil-residual activity was equivalent to or higher than imazethapyr applied alone followed by imazethapyr or imazamox. Yield and economical returns were maximized with quinclorac or penoxsulam mixed with imazethapyr followed by imazethapyr or imazamox. The addition of quinclorac or penoxsulam proved to be beneficial in a total weed management program.

Nomenclature: Imazamox; imazethapyr; penoxsulam; quinclorac; alligatorweed, *Althernanthera philoxeroides* (Mart.) Griseb.; barnyardgrass, *Echinochloa crus-galli* (L.) Beauv; red rice, *Oryza sativa* L.

Key words: Clearfield rice, economics, economic returns.

En 2008 y 2009 se realizaron estudios de campo cerca de Crowley, Louisiana para evaluar la adición de un herbicida con actividad residual en el suelo, mezclado con imazethapyr aplicado en pos-emergencia muy temprana seguido de una aplicación de imazethapyr o imazamox dos semanas después de la aplicación inicial. Las malezas evaluadas incluyeron *Oryza sativa, Echinochloa crus-galli* y *Althernanthera philoxeroides.* El control de las malezas con tratamientos que incluyeron un herbicida con actividad residual en el suelo fue equivalente o mayor al obtenido con imazethapyr aplicado por sí solo seguido por imazethapyr o imazamox. El rendimiento y las utilidades netas se maximizaron con quinclorac o penoxsulam mezclado con imazethapyr seguido de imazethapyr o imazamox. La adición de quinclorac o penoxsulam probó ser benéfica en un programa integral de manejo de malezas.

Imidazolinone-resistant (IR) rice exhibits tolerance to the imidazolinone class of herbicides, which inhibit acetohydroxy acid synthase (EC 2.2.1.6), also known as acetolactate synthase (Stidham and Singh 1991; Stougaard et al. 1990). IR rice is sold under the tradename Clearfield®. IR rice was developed in 1993 through seed mutagenesis, allowing rice lines to be considered nontransgenic (Croughan 1994). Imazethapyr is labeled for use in IR rice at 70 to 105 g ai ha^{-1} applied to the surface as a PPI or PRE application followed by 70 to 105 g ha^{-1} applied POST.

Red rice has been recognized as a weed in U.S. rice fields for over 150 yr and has become increasingly troublesome in cultivated rice fields throughout the southern United States (Craigmiles 1978; Dowler 1994; Khodayari et al. 1987; Smith 1981; Webster 2004). Red rice competition with rice reduces grain yield and causes reduction in milling yields and grade (Webster and Levy 2009). 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 above 95% with imazethapyr applied at 70 and 140 g ha^{-1} to rice in the two- to three-leaf stage. Soil applications of imazethapyr at 70, 105, or 140 g ha^{-1} followed by 70 g ha^{-1} POST controlled barnyardgrass 88% or better (Masson and Webster 2001). A single POST application of imazethapyr at 140 g ha^{-1} 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, and Indian jointvetch (*Aeschynomene indica* L.).

Studies indicate that imazethapyr effectively controls 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, imazethapyr provides minimal control of hemp sesbania and Indian jointvetch (Webster and Masson 2001; Zhang et al. 2001). Herbicide mixtures have proven to be beneficial in improving efficacy and broadening the weed control spectrum in IR rice (Carlson et al. 2011; Pellerin et al. 2003), and the use of these mixtures is favorable to producers because of 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

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historically controlled barnyardgrass effectively; however, repeated use of propanil has resulted in the 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 in rice that can be applied PRE or within 7 d after planting, often referred to as delayed PRE (DPRE), to allow establishment of the crop with minimum weed competition. Clomazone, pendimethalin, penoxsulam, and quinclorac are herbicides labeled for use in rice with application flexibility of PRE and POST activity (LSU AgCenter 2011).

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,b; Webster et al. 1999; Zhang et al. 2004). As a residual herbicide, clomazone can be applied alone PRE or DPRE, or it can be applied in a mixture with other herbicides POST. Webster et al. (1999) reported that clomazone at 0.67 kg ha^{-1} applied DPRE controlled barnyardgrass 98%.

Applications of quinclorac at 560 or 751 g ai ha^{-1} applied 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 the spectrum of weeds controlled when applied as a DPRE or POST application (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. The addition of pendimethalin to imazethapyr has been reported to increase barnyardgrass control over imazethapyr alone (Arnold et al. 1993).

Penoxsulam is a selective herbicide that 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^{-1} controlled barnyardgrass 78% and when penoxsulam followed a PRE application of clomazone at 448 g ai ha^{-1} 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 POST application of imazethapyr followed by a second POST application of imazethapyr or imazamox on IR rice. Data from this study could prove to be essential when considering 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 Agricultural Center Rice Research Station near Crowley, LA on a Crowley silt loam 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^{-1} of 8–24–24 (N–P_2O_5–K_2O) fertilizer and a preflood application of 365 kg ha^{-1} 46–0–0 urea fertilizer was applied to the study area. The 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^{-1} 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 before harvest.

The experimental design was a randomized complete block with four replications. The herbicide programs evaluated were imazethapyr applied alone at 70 g ai ha^{-1} or imazethapyr at 70 g ai ha^{-1} (see Table 1 for sources of herbicides) plus a herbicide with soil-residual activity applied POST at the one- to two-leaf rice stage, referred to as very early POST (VEPOST) followed by an application of imazethapyr at 70 g ai ha^{-1} or imazamox at 44 g ai ha^{-1} 14 d after the VEPOST application. The soil-residual herbicides applied were: pendimethalin at 1,121 g ai ha^{-1}, clomazone at 336 g ai ha^{-1}, quinclorac at 560 g ai ha^{-1} (Facet, dry flowable, and penoxsulam at 49 g ai ha^{-1}. The imazethapyr followed by imazethapyr program was considered the standard program for comparison purposes. A crop-oil concentrate (COC) was added in each application at 1% v v^{-1}. Each application of herbicide was applied at 140 L ha^{-1} with a CO_2-pressurized backpack sprayer at a pressure of 145 kPa.

The study area was naturally infested with red rice, barnyardgrass, and alligatorweed at densities of 80, 60, and 8 plants m^{-2}, respectively. VEPOST applications were made on one- to three-leaf red rice, one- to two-leaf barnyardgrass, and one- to two-leaf alligatorweed. The second applications were made on three- to four-leaf red rice, one- to three-leaf barnyardgrass, and three- to five-leaf alligatorweed. Weed control ratings were collected 18, 28, and 38 d 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 four 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. Percent milling was determined by obtaining a 125-g sample of harvested rough rice from each plot and processed in a #2 McGill miller. Milling was recorded as percent whole kernels over the percent whole plus broken kernels. Milled samples were sent to Harrington Rice and Soybean Buyer (Harrington Rice & Soybean Buyer, Crowley, LA) for grading.

Economic applications were based on the average long-grain rice price for 2009 (WASDE 2009). Base rice price was \$285 Mg^{-1} with price deductions on the basis of rice grade. Actual rough rice market prices were adjusted by grade, and grade price discounts can vary across rice mills. In this study,

Table 1. Sources of materials.

Herbicide	Trade name	Form	Rate g ai ha^{-1}	Manufacturer	Address	Website
Imazethapyr	Newpath	2 AS	70	BASF Corporation	Fordam, NJ	http://www.agro.basf.com
Imazamox	Beyond	1 AS	44	BASF Corporation	Fordam, NJ	http://www.agro.basf.com
Pendimethalin	Prowl H_2O	3.8 AS	1121	BASF Corporation	Fordam, NJ	http://www.agro.basf.com
Clomazone	Command	3 ME	336	FMC Agricultural	Philadelphia, PA	http://www.fmccrop.com/
Penoxulam	Grasp	2 SC	0.08	Dow AgroScience	Indianapolis, IN	http://www.dowagro.com/
Quinclorac	Facet	75 DF	560	BASF Corporation	Fordam, NJ	http://www.agro.basf.com
Crop-oil-concentrate	Agri-Dex	100 L	1%	Helena Chemical	Collierville, TN	http://www.helenachemical.com

rough rice price deduction for grades 1 and 2 was $0.00. Price reductions for rice with grades 3, 4, 5, 6, and sample grade were $5.50, $12.00, $27.50, $33.00, and $44.00 Mg^{-1}, respectively. These price reductions are representative of actual market price discounts on the basis of the grade of rice for sale. The herbicides imazethapyr, imazamox, clomazone, pendimethalin, penoxsulam, and quinclorac were priced at $140 L^{-1}, $160 L^{-1}, $36.50 L^{-1}, $10.20 L^{-1}, $360 L^{-1}, and $125 kg^{-1}, respectively. A COC was included with every herbicide application at $4.00 L^{-1}. Profitability of the herbicide programs was 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 equal the total value product minus the herbicide program cost.

Data were subjected to the Mixed Procedure of SAS (SAS 2003). Year and replications (nested within year) were considered random effects. Herbicide treatments were fixed effects. Considering year as random effects permits inferences about treatments over a range of environments (Blouin et al. 2011; Carmer et al. 1989; Hager et al. 2003). A nontreated check was added for comparison purposes but removed from analysis because of lack of weed control and no rice yield. Type III statistics were used to test all possible effects of fixed factors and least-square means were used for mean separation at the 5% probability level ($P \leq 0.05$).

Table 2. Effects of imazethapyr plus a soil-residual herbicide followed by imazethapyr or imazamox programs on red rice and barnyardgrass control 18, 28, and 39 d after final application (DAFA), 2008 and 2009, Crowley, LA.[a]

				Red rice control			Barnyardgrass control		
Herbicide program[b]	Formulation	Rate	Timing	18 DAFA	28 DAFA	38 DAFA	18 DAFA	28 DAFA	38 DAFA
		g ai ha^{-1}		%					
Imazethapyr fb[c]	AS[c]	70	VEPOST[c]	92d	94b	94bc	93b	93c	92de
Imazethapyr	AS	70	2 WAA[c]						
Imazethapyr fb	AS	70	VEPOST	93bcd	94b	92c	93b	92c	90e
Imazamox	AS	44	2 WAA						
Imazethapyr +	AS	70	VEPOST	93bcd	95ab	95abc	93b	95abc	94bcd
Pendimethalin fb	SC[c]	1,121							
Imazethapyr	AS	70	2 WAA						
Imazethapyr +	AS	70	VEPOST	94abcd	96ab	94bc	94ab	95abc	93cde
Pendimethalin fb	SC	1,121							
Imazamox	AS	44	2 WAA						
Imazethapyr +	AS	70	VEPOST	93bcd	95ab	97ab	93b	94abc	97ab
Clomazone fb	ME[c]	336							
Imazethapyr	AS	70	2 WAA						
Imazethapyr +	AS	70	VEPOST	94abcd	95ab	94bc	93b	94abc	93cde
Clomazone fb	ME	336							
Imazamox	AS	44	2 WAA						
Imazethapyr +	AS	70	VEPOST	95abc	98a	97ab	95ab	97ab	97ab
Quinclorac fb	WDG[c]	560							
Imazethapyr	AS	70	2 WAA						
Imazethapyr +	AS	70	VEPOST	94abcd	98a	97ab	94ab	98a	98a
Quinclorac fb	WDG	560							
Imazamox	AS	44	2 WAA						
Imazethapyr +	AS	70	VEPOST	97a	98a	98a	97a	98a	98a
Penoxsulam fb	EC[c]	49							
Imazethapyr	AS	70	2 WAA						
Imazethapyr +	AS	70	VEPOST	96ab	98a	97ab	96ab	98a	98a
Penoxsulam fb	EC	49							
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: fb, followed by; AS, aqueous solution; SC, suspension concentrate; ME, microencapsulated; WDG, wettable dispersible granules; EC, emulsifiable concentrate; VEPOST, very early POST; WAA, weeks after application.

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Table 3. Effects of imazethapyr plus a soil-residual herbicide followed by imazethapyr or imazamox programs on alligatorweed control 18, 28, and 39 d after final application (DAFA), 2008 and 2009, Crowley, LA.[a]

Herbicide program[b]	Formulation	Rate	Timing	Alligatorweed control		
				18 DAFA	28 DAFA	38 DAFA
		g ai ha^{-1}		%		
Imazethapyr fb[c]	AS[c]	70	VEPOST[c]	73c	83c	75de
Imazethapyr	AS	70	2 WAA[c]			
Imazethapyr fb	AS	70	VEPOST	80abc	83c	76cde
Imazamox	AS	44	2 WAA			
Imazethapyr +	AS	70	VEPOST	77abc	84bc	78bcde
Pendimethalin fb	SC[c]	1,121				
Imazethapyr	AS	70	2 WAA			
Imazethapyr +	AS	70	VEPOST	84ab	88abc	89abc
Pendimethalin fb	SC	1,121				
Imazamox	AS	44	2 WAA			
Imazethapyr +	AS	70	VEPOST	76bc	83c	68e
Clomazone fb	ME[c]	336				
Imazethapyr	AS	70	2 WAA			
Imazethapyr +	AS	70	VEPOST	85a	89abc	84abcd
Clomazone fb	ME	336				
Imazamox	AS	44	2 WAA			
Imazethapyr +	AS	70	VEPOST	83ab	92a	90ab
Quinclorac fb	WDG[c]	560				
Imazethapyr	AS	70	2 WAA			
Imazethapyr +	AS	70	VEPOST	84ab	90ab	93a
Quinclorac fb	WDG	560				
Imazamox	AS	44	2 WAA			
Imazethapyr +	AS	70	VEPOST	82ab	87abc	91ab
Penoxsulam fb	EC[c]	49				
Imazethapyr	AS	70	2 WAA			
Imazethapyr +	AS	70	VEPOST	82ab	87abc	92a
Penoxsulam fb	EC	49				
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: fb, followed by; AS, aqueous solution; SC, suspension concentrate; ME, microencapsulated; WDG, wettable dispersible granules; EC, emulsifiable concentrate; VEPOST, very early POST; WAA, weeks after application.

Results and Discussion

Rice treated with imazethapyr plus quinclorac followed by imazethapyr or imazethapyr plus penoxsulam followed by imazethapyr or imazamox resulted in an increase in red rice control at 18 DAFA, compared with the standard program of imazethapyr at 70 g ha^{-1} followed by imazethapyr at 70 g ha^{-1} (Table 2). Herbicide programs that included quinclorac or penoxsulam resulted in an increase in red rice control to 98% at the 28 DAFA evaluation compared with 94% red rice control with the standard program. The addition of quinclorac or penoxsulam at VEPOST applications increased red rice control at the earlier rating dates; however, only penoxsulam followed by imazethapyr increased red rice control, compared with the standard program, at 38 DAFA. This extended period of control can contribute to increased rice yield and quality, which increases producer profits. An additional benefit is increased harvest efficiency with the reduced population of red rice.

Imazethapyr plus penoxsulam followed by imazethapyr resulted in 97% control of barnyardgrass, compared with 93% control with the standard program at 18 DAFA (Table 2). 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.

Imazethapyr plus pendimethalin or clomazone followed by imazamox and programs with quinclorac or penoxsulam increased alligatorweed control at 18 DAFA, compared with the standard program (Table 3). At 28 DAFA, the addition of quinclorac controlled alligatorweed 90 to 92% compared with 83% control with the standard program. At 38 DAFA, herbicide programs that included quinclorac, penoxsulam, or pendimethalin followed by imazamox increased alligatorweed control to 89 to 93%, compared with 75% control with the standard program.

Red rice, barnyardgrass, and alligatorweed control increased with herbicide 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, compared with the standard program (Table 4). Slight difference in height occurred within treatments; however plant height was 90 to 95 cm, compared with the standard program, 92 cm.

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Table 4. 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, LA.[a]

Herbicide program[b]	Formulation	Rate	Timing	Plant height	Rough rice yield	Milling[c]	Grade
		—— g ai ha^{-1} ——		—— cm ——	—— kg ha^{-1} ——	—— % ——	
Imazethapyr fb[d]	AS[d]	70	VEPOST[d]	92abc	6,200d	65/71	3
Imazethapyr	AS	70	2 WAA[d]				
Imazethapyr fb	AS	70	VEPOST	93abc	6,760cd	66/71	2
Imazamox	AS	44	2 WAA				
Imazethapyr +	AS	70	VEPOST	92abc	6,890bcd	66/71	3
Pendimethalin fb	SC[d]	1,121					
Imazethapyr	AS	70	2 WAA				
Imazethapyr +	AS	70	VEPOST	90c	6,890bcd	66/71	2
Pendimethalin fb	SC	1,121					
Imazamox	AS	44	2 WAA				
Imazethapyr +	AS	70	VEPOST	91bc	6,710cd	66/71	3
Clomazone fb	ME[d]	336					
Imazethapyr	AS	70	2 WAA				
Imazethapyr +	AS	70	VEPOST	92abc	7,220abc	66/71	3
Clomazone fb	ME	336					
Imazamox	AS	44	2 WAA				
Imazethapyr +	AS	70	VEPOST	94ab	7,790ab	66/72	3
Quinclorac fb	WDG[d]	560					
Imazethapyr	AS	70	2 WAA				
Imazethapyr +	AS	70	VEPOST	94ab	7,880a	67/71	3
Quinclorac fb	WDG	560					
Imazamox	AS	44	2 WAA				
Imazethapyr +	AS	70	VEPOST	95a	7,840a	66/71	3
Penoxsulam fb	EC[d]	49					
Imazethapyr	AS	70	2 WAA				
Imazethapyr +	AS	70	VEPOST	93abc	7,750ab	66/71	3
Penoxsulam fb	EC	49					
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, microencapsulated; WDG, wettable dispersible granules; EC, emulsifiable concentrate; VEPOST, very early POST; WAA, weeks after application.

Rice treated with the standard program, imazethapyr followed by imazethapyr, had a rough rice yield of 6,200 kg ha^{-1}, a milling yield of 65/71 (percent whole over percent whole plus broken rice kernels), and a rice grade of 3 (Table 4). Herbicide programs that included quinclorac or penoxsulam or clomazone followed by imazamox resulted in an increase in rough rice yield of 1,020 to 1,680 kg ha^{-1} compared with the standard program. However, little to no difference in milling yield or rice grade was observed for all herbicide programs evaluated. No difference in yield was observed with imazamox applied after any soil-residual herbicide evaluated compared with the same soil-residual herbicide with imazethapyr substituted for imazamox. Herbicide programs that included quinclorac or penoxsulam increased rough rice yield compared with clomazone followed by imazethapyr. Quinclorac followed by imazamox or penoxsulam followed by 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 followed by imazethapyr or imazamox resulted in increased rough rice yield due to the increased broad-spectrum weed control observed with these herbicide programs, when compared with the standard program (Tables 2 and 3).

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. The impact of the herbicide programs evaluated on rough rice yield and quality will directly affect total value product. 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 \$1,760 ha^{-1} (Table 5). The cost for the standard program was \$90 ha^{-1}, resulting in net returns above herbicide cost of \$1,670 ha^{-1}. Herbicide programs with quinclorac, penoxsulam, or clomazone followed by imazamox resulted in an increase in total value product of \$270 to \$450 ha^{-1} 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 (Table 5). The additive herbicide cost for clomazone followed by imazamox resulted in a net return similar to the standard program. Also, with any soil-residual herbicide evaluated in this study, total value product and the net returns above herbicide cost were similar when imazamox was applied as the second herbicide application compared with imazethapyr as the second

Table 5. Economical returns of imazethapyr plus a soil-residual herbicide followed by imazethapyr or imazamox programs on rice, 2008 and 2009, Crowley, LA.[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^{-1}		$ ha^{-1}			
Imazethapyr fb[d]	AS[d]	70	VEPOST[d]	90	1,760e	1,670c	0
Imazethapyr	AS	70	2 WAA[d]				
Imazethapyr fb	AS	70	VEPOST	110	1,930cde	1,820abc	150 (9%)
Imazamox	AS	44	2 WAA				
Imazethapyr +	AS	70	VEPOST	120	1,930cde	1,810abc	140 (8%)
Pendimethalin fb	SC[d]	1,121					
Imazethapyr	AS	70	2 WAA				
Imazethapyr +	AS	70	VEPOST	140	1,970bcde	1,830abc	160 (10%)
Pendimethalin fb	SC	1,121					
Imazamox	AS	44	2 WAA				
Imazethapyr +	AS	70	VEPOST	130	1,890de	1,760bc	90 (5%)
Clomazone fb	ME[d]	336					
Imazethapyr	AS	70	2 WAA				
Imazethapyr +	AS	70	VEPOST	150	2,030abcd	1,880abc	210 (13%)
Clomazone fb	ME	336					
Imazamox	AS	44	2 WAA				
Imazethapyr +	AS	70	VEPOST	180	2,210a	2,030a	360 (22%)
Quinclorac fb	WDG[d]	560					
Imazethapyr	AS	70	2 WAA				
Imazethapyr +	AS	70	VEPOST	200	2,200ab	2,000ab	330 (20%)
Quinclorac fb	WDG	560					
Imazamox	AS	44	2 WAA				
Imazethapyr +	AS	70	VEPOST	160	2,170abc	2,010ab	340 (20%)
Penoxsulam fb	EC[d]	49					
Imazethapyr	AS	70	2 WAA				
Imazethapyr +	AS	70	VEPOST	180	2,180ab	2,000ab	330 (20%)
Penoxsulam fb	EC	49					
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^{-1}.

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

herbicide application. When comparing herbicide programs that included a soil-residual herbicide, the total value product was greater with programs that included quinclorac or penoxsulam, compared with the clomazone followed by imazethapyr program. Herbicide programs that included quinclorac or when penoxsulam was followed by imazamox, total value product increased compared with pendimethalin followed by imazethapyr. Total value product was greater with quinclorac followed by imazethapyr, compared with pendimethalin followed by imazamox. The additive herbicide cost was significant enough, when comparing herbicide programs that included a soil-residual herbicide, that the net returns above herbicide cost were only increased with quinclorac followed by imazethapyr, compared with clomazone followed by imazethapyr.

These data indicate that quinclorac or penoxsulam in mixture with imazethapyr followed by imazethapyr or imazamox resulted in increased profits compared with the standard program, even though cost of treatment increased. This increase in profit was due to increased weed control (Tables 2 and 3) and higher rice yield (Table 4) increasing total value product (Table 5), which overcomes the additional herbicide cost.

In conclusion, the addition of quinclorac or penoxsulam in mixture with imazethapyr followed by imazethapyr or imazamox proved to be beneficial in a total weed management program. However, with any soil-residual herbicide evaluated in this study, 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. When weeds are controlled early, rice plants produce higher yields, which will produce higher returns and overall 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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