RICE WEED MANAGEMENT IN THE SOUTHERN USA

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ABSTRACT

The United States of America is the 3rd largest rice exporter globally. US rice production is mainly located in the southern region with about 55% produced in Arkansas. The most dominant cropping system is rice-soybean rotation. The majority of rice is drill-seeded in conventionally prepared fields. The most common weed problems are *Echinochloa crus-galli* (barnyardgrass), *Eurochloa platyphylla* (broadleaf signalgrass), *Oryza sativa* (weedy red rice), *Sesbania herbacea* (hemp sesbania), *Althernanthera philoxeroides* (alligatorweed), *Commelina* spp. (dayflowers), *Heteranthera limosa* (ducksalad), *Ammannia* spp.(redstems), *Aeschynomene* spp. (jointvetch), *Leptochloa* spp. (sprangletops) and annual and perennial sedges. Weeds are managed primarily with herbicides, integrated with tillage and flooding of rice paddies. Major herbicides used include clomazone, imazethapyr (for herbicide-resistant rice), propanil, quinclorac, some selective grass (ACCase inhibitor) herbicides, and some ALS inhibitors. Evolution of herbicide-resistant weeds from herbicide selection pressure and gene flow from HR rice to weedy red rice are major concerns. Various weed species have already evolved resistance to the modes of action used, with *Echinochloa* having evolved resistance to propanil, quinclorac, clomazone, and imazethapyr. More integration of weed management tools is being researched and recommended.

DOMINANT RICE CROPPING SYSTEMS

The Unites of America is the 3rd largest exporter of milled rice worldwide (USDA-ERS 2010), although it has only 2.75 million acres of rice production in 2010 (http://www.nass.usda.gov/Statistics_by_Subject/). This is because 55% of US rice is exported (NASS 2010). The southern US rice belt includes Arkansas, Louisiana, Missouri, Mississippi, and Texas (Snyder and Slaton 2002). Some rice is also produced in the west, in California.

Rice growers usually alternate rice with other crops such as soybean, cotton, wheat, and corn to manage weeds as well as to maintain soil fertility (Fuller et al. 2003; Burgos et al. 2008). Rotating crops with different morphology and growth requirements limits the adaption of certain weeds to a crop (Labrada 2006). The most dominant cropping system among the southern states is rice-soybean rotation followed by continuous rice or rice-cotton (Table 1). Rice-soybean-soybean three-year rotation is being used in areas where weedy red rice is a problem (Burgos et al. 2008).

METHODS OF RICE ESTABLISHMENT

Rice in the southern US is typically planted by drill-seeding in a conventionally prepared field (several tillage and harrowing operations). Crop stand establishment and yield are influenced by cultivar choice; seeding method, date, and rate; seedling vigor; seed treatments; soil properties; environment and geographic locations (Buehring et al. 2008; Slaton and Cartwright 2006). Uniform seedling growth and optimum seedling stand are dependent on good seedbed preparation particularly in heavy textured soil (Shipp 2005). A good crop stand and seedling vigor help rice compete with weeds early. The majority (96%) of rice in Arkansas is dry-seeded with delayed flooding; the rest (4%) is water-seeded (Wilson and Branson 2003). Broadcast water-seeding is occasionally used on heavy clay soils, to minimize weedy red rice infestation. The same applies to Mississippi (Shipp 2005), Missouri (Beck 1998), and Texas (Klosterboer et al. 2005). Louisiana has the largest area of

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water-seeded rice, in the gulf region where red rice is a severe problem (Levy et al. 2006). Seeding on reduced tillage, either on stale seedbed or no-till, has gained popularity in recent years mostly prompted by labor- and fuel-saving goals.

MAJOR PROBLEM WEEDS

The most common weeds are *Echinochloa crus-galli*, *Eurochloa platyphylla* (broadleaf signalgrass), *Oryza sativa* (weedy red rice), *Sesbania herbacea* (hemp sesbania), *Althernanthera philoxeroides* (alligatorweed), *Commelina* spp. (dayflowers), *Heteranthera limosa* (ducksalad), *Ammannia* spp.(redstems), *Aeschynomene* spp. (jointvetch), *Leptochloa* spp. (sprangletops) and annual and perennial sedges (Shipp 2005). The five most troublesome weeds in Arkansas, Louisiana, Missouri, Mississippi, and Texas are *E. crus-galli*, *O. sativa*, *E. platyphylla*, *Leptochloa* spp., and *Cyperus* spp. (Table 2). *Echinochloa* is most widespread, but weedy rice is the most difficult to control when present. Weedy red rice has persisted despite attempts to minimize its impact (Burgos et al. 2008).

Ipomoea spp. (morningglories), specifically *I. wrightii* (palmleaf morningglory) and *Commelina* spp. are also troublesome in Arkansas, Louisiana, and Mississippi. *Caperonia palustris* (Texasweed) is troublesome in Louisiana, Mississippi, and Texas, but now is also observed in Arkansas. *Polygonum hydropiperoides* (swamp smartweed) is troublesome in Louisiana and Mississippi; *Digitaria* spp. (crabgrass) in Arkansas and Missouri; *Echinochloa colona* (junglerice) in Texas; and *Eclipta alba* (eclipta) in Louisiana and Missouri. In Arkansas, *E. crus-galli* and *O. sativa* are the major grass weeds and *A. virginica* and *P. hydropiperoides* are the problematic broadleaved weeds (Norsworthy et al. 2007a, 2007b). Several herbicides can control *E. crus-galli*, if there is no resistance problem. This, along with others such as *E. platyphylla*, *Cyperus* spp., *S. herbacea*, and *E. alba* infest both rice and upland crops.

METHODS OF WEED MANAGEMENT

***Non-Chemical methods*.** Proper seedbed preparation by tillage and harrowing is the first step to achieving good weed control. Zero-till and minimum tillage are also adopted to some extent; however, this needs to be done in conjunction with herbicides before seeding. Cultural weed control methods consist of crop rotation and water management. For years, the quest for allelopathic rice lines and utilization of rice by-products for weed suppression has been pursued. Dilday et al. (1994) screened 10,000 rice accessions and found 3.4% showing allelopathic potential against *H. limosa*. Kuk *et al.* (2001) identified rice by-products possessing allelopathic potential that controls *Amaranthus palmeri* (Palmer amaranth), *Ipomoea hederacea* (ivyleaf morningglory), *Senna obtusifolia* (sicklepod), *S. herbacea*, and *Sida spinosa* (prickly sida). Gealy and Moldenhauer (2005) have identified some rice cultivars that suppressed *H. limosa*, *E. crus-galli*, and *Ammannia* spp. Research on weed-suppressive rice lines is on-going.

***Chemical methods*.** The availability of effective and economical herbicides for rice resulted in improved yield and quality of grains (Beck 2004). There are several herbicides and herbicide mixture options for different grower conditions. To achieve season-long weed control, multiple herbicide applications is necessary, using numerous herbicides (Table 3), (Buehring and Bond 2008; Chandler and McCauley 2005; Kendig et al. 2003; Scott et al. 2011). Propanil (Stam), quinclorac (Facet), clomazone (Command), bentazon (Basagran), halosulfuron (Permit), acifluorfen (Blazer), bensulfuron (Londax), triclopyr (Grandstand), and imazethapyr (Newpath) for Clearfield™ rice are the most common. In Arkansas, the primary herbicide program for conventional rice consists of quinclorac plus clomazone preemergence followed by propanil pre-flood, and/or postemergence grass herbicides as needed. Other herbicides are used for special purposes such as halosulfuron to control *Cyperus esculentus* and *C. iria* and bensulfuron to control aquatic weeds particularly *Heteranthera limosa* and *H. reniformis*.

HERBICIDE-RESISTANT RICE

The weedy rice problem was the impetus for the development of herbicide-resistant rice (Croughan et al. 1996), which was commercialized in 2002. The area planted to Clearfield™ rice has increased significantly since then, amounting to about 20% of rice acreage planted to Clearfield™ rice in 2006 (Wilson and Branson 2006) and 55% in 2010 (C. Wilson, AR Rice Specialist, pers. comm.) in Arkansas. Of the HR cultivars planted in Arkansas in 2010, 48% were hybrid rice. In the Clearfield™ rice system, imazethapyr is used with quinclorac preemergence or early postemergence for a broadspectrum weed control, followed by a second application of imazethapyr pre-flood and an application of imazamox at booting stage, as needed, to prevent seed production of escaped weedy rice. Although the majority of growers follow the stewardship recommendations to mitigate gene flow into weedy rice (Burgos et al. 2008), a few growers could not adhere to the crop rotation and other gene flow mitigation practices for various reasons. Thus, we are now seeing herbicide-resistant (HR) progenies of outcrosses between Clearfield™ rice and weedy rice. Detectable gene flow to various weedy rice types from Clearfield™ rice 'CL161' is relatively low 0–0.25% (Shivrain et al. 2008; Shivrain et al. 2009). This would even be lower in some varieties, i.e. 0.003% for 'CL121' vs. 0.008% for CL161 with Stuttgart strawhull red rice (Shivrain et al. 2007), but higher in others such as with hybrid rice CLXL8 (0-1.26%) vs. CL161 (0-0.21%) (Shivrain et al. 2009a). Some weedy rice types, e.g. Gre-5 and Ash-1, are more genetically compatible with CL161 rice than others (Shivrain et al. 2008) and the genetic compatibility of weedy rice is higher with the hybrid rice CLXL8 than with the nonhybrid, CL161 as indicated previously. The risk of gene flow is nil in some weedy rice types and generally low to non-existent in late plantings (Shivrain et al. 2009a). The outcrossing rate of nonhybrid and hybrid rice with weedy rice is affected differently by different factors. For example, the outcrossing rate of CL161 is most strongly affected by the weedy rice biotype rather than temperature or relative humidity. On the other hand, the outcrossing rate of CLXL8 is most strongly affected by relative humidity than weedy rice biotype or other factors (Shivrain et al. 2009). This is probably because there is less genetic barrier in cross-pollination between hybrid rice and weedy rice than between nonhybrid rice and weedy rice. The same rate of gene flow can happen in the other direction, from the weedy populations to cultivated rice (Shivrain et al. 2009b), which means that the introgression of resistance genes into the weedy populations, and gene flow into conventional cultivars, can also be aided by the cyclical gene movement from crop to weed and *vice versa*.

BIOLOGICAL METHODS OF WEED CONTROL

Some examples of biological method are the use of host-specific insects such as weevils attacking water hyacinth and water fern (Wilson 2007). Researchers at the University of Arkansas, Fayetteville, discovered *Colletotrichum gloeosporoides* sp. *aeschynomene* to control *Aeschynomene virginica* (Northern jointvetch), a weed in rice and soybean, which led to the commercial production of the bioherbicide "Collego" in 1982 (Watson 1998). The pathogen causes anthracnose disease in *Aeschynomene* and *S. herbacea.* The resulting bioherbicide, Collego, is produced and formulated as dry spores. The market for Collego is limited to fields infested with the leguminous weeds and its efficacy is dependent on environmental conditions surrounding the time of application. A similar biocontrol agent, *Colletotrichum truncatum*, is also reported to control *S. herbacea* and its efficacy is enhanced by the addition of an emulsion of unrefined corn oil in water and Silwet L-77 surfactant (Boyette et al. 2007). Besides *Colletotrichum*, no other biological control tool for rice weeds is available in the southern USA and research in this area is virtually non-existent.

HERBICIDE-RESISTANT WEEDS IN RICE CULTURE

The southern US has its share of HR weed problems (Heap 2011, Kendig and Fishel 1996, Scott et al. 2008). *E. crus-galli* resistant to propanil have been reported in Arkansas, Missouri, Louisiana, and Texas. Resistance to quinclorac in *E. crus-galli* was reported only in Arkansas and Louisiana. There are several options for management of HR weeds in rice. Rotating crops with different cultural requirements allows the use of combinations of physical, chemical, and cultural methods of weed control (Prater et al. 2000). Rotating herbicides with different mechanisms of action would control existing HR weeds and delay the resurgence of resistant weeds by reducing seed input into the soil seed bank. The decades (since 1959) of continuous use of propanil in rice production resulted in the evolution of propanil-resistant *E. crus-galli* in Arkansas (see review by Talbert and Burgos 2007). Starting in 1992, quinclorac alone, or in combination with propanil, was recommended to control propanil-resistant *E. crus-galli,* among other weeds, but its continuous use resulted in the evolution of propanil- and quinclorac-resistant *Echinochloa* in 1999 (Malik et al. 2010). Several years before the confirmation of quinclorac-resistant *E. crus-galli*, a less volatile but effective formulation of clomazone (Command 3ME) was developed. This new formulation is now the primary tool for the management of multiple-resistant *E. crus-galli*. In Arkansas, chemical control options for multiple-resistant *E. crus-galli* in rice include clomazone followed by cyhalofop or fenoxaprop, mixing two or more soil-active herbicides but different herbicides every year, and alternating propanil with other herbicides (Talbert and Burgos 2007). However, a localized clomazone-resistant *E. crus-galli* was documented in 2007 in Arkansas (Norsworthy et al. 2008). The clomazone-resistant biotype has twice the herbicide tolerance of the susceptible biotype. Quinclorac and imazethapyr applied preemergence and thiobencarb applied delayed preemergence effectively controlled this biotype. Crop rotation was also recommended to prevent the spread or further evolution of HR weeds. Lately, cases of ALS-resistant *E. crus-galli* have been confirmed in Arkansas where Clearfield™ rice have been planted for several seasons.

Propanil-resistant *E. crus-galli* in Missouri was confirmed in 1994. The biotype was also possibly cross-resistant to other photosynthesis inhibitors. Propanil-resistant *E. crus-galli* was also confirmed in Louisiana in 1995. Growers use quinclorac to manage propanil-resistant *E. crus-galli* in both states, as what is done in Arkansas. Quinclorac-resistant *E. crus-galli*, was also confirmed in Louisiana in 1998 and in Texas in 1991. Documentation of HR *E. crus-galli* is on-going in Mississippi (J. Bond, Mississippi Rice Extension Specialist, pers. comm.) where resistance to quinclorac and ALS inhibitors is suspected. However, a glyphosate-resistant *C. canadensis* was reported in 2003, most likely from the glyphosate-resistant cotton and soybean crops grown in rotation with rice. Glyphosate-resistant *C. Canadensis* can become a problem in levees and is observed surviving flooded conditions. This poses a serious challenge to crop rotation as a component of weed management programs.

EMERGING WEED PROBLEMS AND WEED MANAGEMENT ISSUES

Continuing evolution of herbicide-resistant weeds. The evolution of weeds with multiple herbicide resistance is a serious threat to rice production because it could severely limit weed management options. *Echinochloa* populations resistant to propanil, quinclorac, clomazone, and acetolactate synthase (ALS)-inhibitors (imazethapyr, bispyribac) eliminate primary herbicides for rice. If the clomazone-resistant *E. crus-galli* in Arkansas is not contained, it would certainly alter the *E. crus-galli* management strategy because clomazone is the cornerstone of conventional (non-Clearfield™) rice weed control program after the evolution of propanil- and quinclorac-resistant biotypes. Unlike propanil, clomazone is weak on broadleaved weeds and is not effective on sedges. Some weeds that were effectively controlled by propanil and quinclorac are becoming difficult to control. Clomazone has to be followed by, or mixed with, broadleaved weed herbicides. Because Clearfield™ rice has intensified the selection pressure for ALS-resistant grasses, the southern US is poised to face a rapid increase in occurrence of ALS-resistant weed populations. Of 65 *E. crus-galli* samples tested in 2010, 30 were resistant to propanil, 21 to quinclorac, and 4 to ALS-inhibiting herbicides imazethapyr and bispyribac-sodium (Norsworthy et al. 2010).

The use of halosulfuron (Permit) has selected for ALS-resistant *Cyperus iria* (rice flatsedge) in Arkansas. Six cases of ALS-resistant rice flatsedge have been confirmed (Norsworthy et al. 2010). In Mississippi, rice flatsedge with resistance to ALS inhibitors has also been confirmed (J. Bond, Extension Weed Specialist, MS, pers. comm.).

Glyphosate-resistant *C. canadensis and Lolium multiflorum* (Italian ryegrass) are emerging weed problems in preplant burndown programs. This is especially true for *C. canadensis* because it tends to adapt to flooded rice culture where it has traditionally been excluded from (J. Bond, MS Weed Specialist, pers. communication).

Genetic introgression between cultivated and weedy rice. Gene flow from HR rice to weedy rice is an increasing concern. Herbicide-resistant volunteer rice contributes to the introgression of resistance gene in the weedy rice population. This could proliferate stabilized populations of weedy white rice. Meanwhile, segregating volunteer rice from hybrid rice (herbicide-resistant or not) is causing significant reduction in rice yield and grain quality (L. Schmidt, Horizon Ag. Technical Representative, pers. comm.). Red rice outcrosses from Clearfield^{TM} rice have been observed, albeit in low frequencies, in various counties of Arkansas (Robert Scott, Extension Weed Specialist, AR, USA; N. Burgos, on-going research). These HR red rice progenies, if not eliminated, will become established as ALS-resistant populations. In addition, a random sampling of red rice populations in Arkansas revealed two accessions that tolerated the commercial rate of imazethapyr, with the same level of tolerance as the older Clearfield^{TM} cultivar, CL121 (Sales et al. 2008). The proliferation of HR weedy rice can negate the utility of Clearfield^{TM} rice.

Two populations of *Leptochloa panicoides* (Amazon sprangletop) in Louisiana has been confirmed resistant to the ACCase inhibitor herbicides, cyhalofop and fenoxaprop (J. Norsworthy, Weed Scientist, University of AR, pers. comm.). The Clearfield^{TM} rice acreage is expanding and imazethapyr and imazamox are not effective against *L. panicoides*. Control strategies will be more challenging when the weed problem shifts to *L. panicoides* in Clearfield^{TM} rice (Baldwin 2008). In the meantime, thiobencarb + propanil (RiceBeaux) has shown effectivity on *L. panicoides,* and could be an excellent alternative to the ACCase herbicides.

Other potential weed problems in rice. *Leersia oryzoides* (rice cutgrass) is an emerging weed problem in Arkansas (Norsworthy et al. 2009). This weed usually grows in ditches and canals, but encroaches into the rice field especially in monoculture reduced-tillage rice fields. Several applications of imazethapyr controlled *L. oryzoides* in Clearfield^{TM} rice and preflood application of propanil + bispyribac in non-Clearfield^{TM} rice.

Irrigation water. The availability of irrigation water and the cost of pumping it are the ultimate challenges to US rice production, not only in yield per se, but also in weed management. No dryland rice is produced in the southern U.S. Growing rice without permanent flood will present serious weed management problems and currently, there are no solutions for this.

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Table 1. Crop rotation systems in the southern United States

Cropping system	Arkansas	Louisiana	Mississippi	Missouri	Texas
Rice -Soybean	**x**	**x**	**x**	**x**	**x**
Rice-Rice		**x**	**x**	**x**	
Rice-Soybean-Soybean			**x**		**x**
Rice-Cotton	**x**	**x**	**x**		
Rice-Corn	**x**		**x**	**x**	
Rice-Wheat					
Rice-Grain sorghum					**x**
Rice-Soybean-Grain sorghum					**X**
Rice-pasture					**X**

Table 2. Most troublesome weeds in southern USA rice production.

Species	AR[1]	LA[2]	MO[3]	MS[4]	TX[5]
Echinochloa crus-galli	1	x	x	x	x
Oryza sativa	2	x	x	x	x
Eurochloa platyphylla	6	x	x	x	x
Lepthochloa spp.	5	x	x	x	x
Cyperus spp.	7	x	x	x	x
Althernanthera philoxeroides		x			x
Ipomoea spp.	11	x		x	
Sesbania herbacea	9	x		x	
Heteranthera limosa		x		x	
Ammannia spp.		x		x	
Caperonia palustris	14	x		x	x
Paspalum spp.		x			
Echinochloa colona	16				x
Commelina spp.	13	x		x	x
Digitaria spp.	10		x		
Aeschynomene spp.	3	x	x		
Eclipta spp.	16	x	x		
Polygonum hydropiperoides		x	x	x	
Polygonum spp.	4				
Conyza canadensis				x	

Source[1]: Ranked according to severity of problem (Norsworthy et al. 2007)
Source[2]: Weed survey. 2004 Proceedings, Southern Weed Science Society. Vol. 57.
Source[3]: 2011 Missouri Pest Management Guide. http://extension.missouri.edu/explorepdf/manuals/m00171.pdf
Source[4]: Weed survey. 2008 Proceedings, Southern Weed Science Society. Vol. 61.
Source[5]: Weed survey. 2000 Proceedings, Southern Weed Science Society. Vol.53.

Table 3. Herbicides used in rice production, southern USA.

Common name	Trade name	Application Timing[1]	Mode of Action[2]	Southern States				
				AR[3]	LA[4]	MO[5]	MS[6]	TX[7]
acifluorfen	Blazer	POST, after flood	E/14	x	x	x	x	x
Bensulfuron-methyl	Londax	Early postflood	B/2	x	x	x	x	x
bentazon	Basagran	Early POST, preflood	C3/6	x	x	x	x	x
bispyribac-sodium	Regiment	Early POST, preflood or postflood	B/2		x	x	x	x
carfentrazone	Aim	Early POST; preharvest	E/14		x	x	x	x
clomazone	Command	PRE/delayed PRE, dry-seeded only	F3/13	x	x	x	x	x
cyhalofop	Clincher	POST, prior to or after flood	A/1		x	x	x	x
fenoxaprop	Ricestar HT	POST, preflood	A/1		x	x	x	x
flumioxazin	Valor	preplant				x		
halosulfuron	Permit	POST, preflood or postflood	B/2	x	x	x	x	x
glyphosate	Various forms	Preplant burndown	9	x				
Glyphosate + bensulfuron, or thifensulfuron + tribenuron, or clomazone, or halosulfuron, or 2,4-D	See individual components	Preplant burndown	see components	x				
Glyphosate + thiobencarb	Roundup + Bolero	preplant burndown; delayed PRE		x		x		
Glyphosate + pendimethalin	Roundup + Prowl	Delayed PRE				x		
imazethapyr	Newpath	PPI or PRE followed by POST, preflood	B/2	x	x	x	x	x
imazamox	Beyond	Postflood, boot stage	B/2	x	x	x	x	x
molinate	Ordram	PRE	N/8		x	x		x
orthosulfamuron	Strada	Preplant; early POST to after flood	B/2	x	x	x	x	
pendimethalin	Prowl, Prowl H_2O	Delayed PRE, dry-seeded rice only	K1/3	x		x	x	x

Continue…

Table 3. Continuation...

Common name	Trade name	Application Timing[1]	Mode of Action[2]	Southern States				
				AR[3]	LA[4]	MO[5]	MS[6]	TX[7]
penoxsulam	Grasp	Early POST in dry- or water-seeded rice; preflood or postflood	B/2	x	x	x	x	
propanil	Stam M-4, SuperWham, Propanil	POST	C2/7	x	x	x	x	x
propanil/bensulfuron	Duet	POST, preflood	C2/7+B/2			x		x
propanil + molinate	Arrosolo	POST	C2/7+N/8			x		x
quinclorac	Facet	delayed PRE or early POST, dry-seeded rice only	O/4	x	x	x	x	x
quinclorac + imazethapyr	Clearpath	delayed PRE or early POST, dry-seeded rice only	O/4 + B/2	x	x	x	x	x
thiobencarb	Bolero	Delayed PRE in dry-seeded rice; PPI in water-seeded rice	N/8	x		x	x	x
triclopyr	Grandstand	POST, preflood or postflood	O/4	x	x	x	x	x
2,4-D	2,4-D	Preplant; POST	O/4	x			x	

Source[1]:Recommended chemicals for weed and brush control – MP44
Source[2]: http://www.plantprotection.org/hrac/MOA.htm
Source[3]: Arkansas Rice Production Handbook-MP192.
Source[4]: Rice crop timeline for southern states of Arkansas, Louisiana, and Mississippi
Source[5]: Rice: Evolution, History, Production and Technology.
Source[6]: Mississippi Rice growers Guide
Source[7]: 2005 Texas Rice production Guidelines.