Economic Impact Statement Addendum

Introduction

This report presents an analysis and review of the potential avoided yield loss of the California Rice Industry caused by Weedy Rice (*Oryza sativa*) infestation in already identified areas. This information supplements the Economic and Fiscal Impact Statement (Std. 399).

Background

The Rice Certification Act Committee has confirmed that weedy rice has rapidly spread to every rice producing county in the Sacramento Valley and San Joaquin County since the first detection of weedy rice in 2006. This is especially concerning because the weedy rice is the same species as the cultivated rice grown in the state (*Oryza sativa*). This is significant because any herbicide used on weedy rice would also kill cultivated rice. There is also potential for transferring weedy traits across species. Additionally, because this is a new pest in California, research relevant to California rice production and weedy rice is minimal and strategies for eradication are limited.

Weedy rice has a vigorous growth that makes it a significant competitor for space and nutrients, and when present in cultivated rice fields, rice yields will unavoidably be reduced. In addition, weedy rice has an abnormal reproductive cycle in which seed production (heading) may occur over a prolonged period of time producing seeds that disperse (shatter) easily at maturity. A single weedy rice plant left in a field can result in several hundred plants the next year, and thousands of plants the year after. Weedy rice seed that falls to the ground but does not germinate within the first two years, can remain dormant for up to ten years and still be a threat to infest rice fields. This dormancy leads to challenges in developing an effective management strategy.

Weedy rice is also a cause of concern at rice mills. The presence of weedy rice can lower the grade of milled rice. The presence of more than .5 kernels per 500 grams results in a quality downgrade. Removing the weedy rice seeds at the mill may be done by using optical sorters and additional milling, this process results in increased costs to the miller and in a reduced price for the producer.

10,000 acres have currently been impacted by Weedy Rice in California. Based on the aforementioned behavior of weedy rice and the lack of eradication methods, this number will easily climb if eradication measures are not employed. A recent paper from the Crop Protection Journal stated that, "… yield losses due to weedy rice could range from as low as <5% to as high as 100% in severely infested areas." In those cultivars that are less competitive, losses could be 80% or higher[1].

In Arkansas, a 2008 survey showed that 62% of fields are infested with weedy rice[2]. In the Southern United States, high infestation of weedy rice has resulted in yield reductions over 60%. These rice growing regions manage the infestation through herbicide resistant rice varieties and rotation with

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[1] "Clearfield rice: its development, success, and key challenges on a global perspective," Crop Protection 1, February 20, 2013.

herbicide resistant crops. However such strategies are not yet available in California. Similar studies to those in Arkansas have not yet been conducted in California to determine distinct yield reductions, however this analysis will provide indicators that will allow us to determine potential avoided yield loss in already identified areas.

Methodology

The following avoided yield loss calculation incorporates affected land, percentage yield loss, yield of rice per acre and price where:

- YL is monetary value of the yield loss recouped by implementing the regulation ($).
  - This value was calculated by equating the following:
    - AL is the size of affected land.
      - This value was derived from the Rice Commission calculation of total affected land within the California Rice Industry (10,000 acres). It is important to disclose that when weedy rice is found to be present within a field, that entire field is considered "affected area". As a result, the reviewer should understand that when total acreage is discussed, this does not define affected area as every square foot of each acre reported, is infiltrated with weedy rice.
    - PL is the percentage yield loss.
      - Recent research from the Journal of Crop Protection claims that yield loss can be as high as 86% in fields affected with Weedy Rice[2]. As we are unaware of actual yield loss due to the recent detection of weedy rice in California, it was decided to draw upon this percentage as research suggested this number of yield loss occurs among older cultivars and which most closely aligns with California's rice production. Additionally low, medium and high ranges were calculated in order to understand the potential range of avoided yield loss.
    - y is the yield of rice per acre.
      - Data drawn from the National Agricultural Statistics Service (NASS) calculated an average California rice yield of 8,840, measured in Ibs/acre in 2016[3].
    - Price; spot price.
      - Data drawn from the National Agricultural Statistics Service (NASS) which states 2016 California rice price averaged $13.70 per 100 pounds[4].

        *Within this calculation we divide the first three terms by 100, because the spot price is set for a bag of 100 pounds, so the 100 is to make the appropriate unit conversion (pounds to bags of 100 pounds).

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[2] "Clearfield rice: its development, success, and key challenges on a global perspective," Crop Protection 1, February 20, 2013.
[3] "Rice Yield, Measured in Lb/Acre Quick Stats-2016." USDA/NASS QuickStats Ad-hoc Query Tool. National Agricultural Statistics Service, n.d. Web. 06 July 2017.
[4] USDA/NASS QuickStats Ad-hoc Query Tool. National Agricultural Statistics Service, 2016. Web. 05 July 2017.

Analysis

YL= [(AL *PL* y)/100]*price

= [(10,000 * .86 *8,840)/100] * $13.70

=$10,415,288

The value of the potential yield loss recouped by implementing these regulations equate to $10,415,288. This calculation was derived using a high range number (86%) to calculate potential percentage impact from yield loss, so it is possible that the potential value of return by implementing these Weedy Rice regulations could possibly be higher.

To provide a thorough understanding of potential monetary value return of low, medium and high ranges we calculate the same equation drawing upon potential percentage yield loss of 5%, 50% and 100%.

Low Range:

YL= [(AL *PL* y)/100]*price

= [(10,000 * .05 *8,840)/100] * $13.70

=$605,540

Medium Range:

YL= [(AL *PL* y)/100]*price

= [(10,000 * .50 *8,840)/100] * $13.70

=$6,055,400

High Range:

YL= [(AL *PL* y)/100]*price

= [(10,000 * 1.00 *8,840)/100] * $13.70

=$12,110,800

Addressing the potential yield loss recouped in monetary value based on low, medium and high ranges affords additional understanding of potential economic variation in yield loss, but also the value of the return by implementing regulations which will decrease the spread of Weedy Rice.

Conclusion

This report presented an analysis and review of the potential avoided yield loss, in monetary terms, of the California Rice Industry, if Weedy Rice regulations are adopted in already identified Weedy Rice infested areas. The analysis disclosed that the yield loss recouped in monetary terms ranged between six hundred thousand dollars and twelve million dollars dependent on high, medium, or low percentage yield loss. Drawing upon these calculations, it is reasonable to conclude that there is economic value in implementing these regulations.

Crop Protection 49 (2013) 40–51

Contents lists available at SciVerse ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Review

Clearfield® rice: Its development, success, and key challenges on a global perspective

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ARTICLE INFO

Article history:
Received 4 August 2012
Received in revised form
19 February 2013
Accepted 20 February 2013

Keywords:
Clearfield® rice
Weedy rice
Imidazolinone-resistant rice
Gene flow
Herbicide soil persistence

ABSTRACT

Weedy rice (*Oryza sativa*) is a close relative of domesticated rice and a noxious weed prevalent in rice fields in world regions where rice is grown. Weedy rice management has remained challenging to farmers, mainly due to the weed's physiological and morphological resemblance to rice cultivars. The introduction of Clearfield® rice provides an alternative solution and an additional tool for integrated weed management. Clearfield® rice-based programs result in the cleanest rice fields in the southern U.S. However, persistent application of the imidazolinone herbicides (imazethapyr, imazamox, and imazapic) in Clearfield® rice raises concerns about the possible evolution of resistance to ALS-inhibitor herbicides in weedy rice and the transfer of resistance trait. The risk of resistant weedy rice evolution is much higher in Asia, Latin America, and other tropical regions where there is no winterkill and rice is planted at least twice each year. Herbicide carryover to rotational crops is also a concern. We summarized the progress of commercialization of Clearfield® rice in 15 countries across the continents of America, Asia and Europe. In some countries, imidazolinone-resistant weedy rice outcrosses have been found abundant, thereby negating the utility of Clearfield® technology. The persistence of imidazolinone herbicide residues in the soil is a concern in regions where multiple crops are planted in a year, or the following year. These challenges should be anticipated by countries that are considering adopting Clearfield® rice technology. Issues associated with gene escape, resistance evolution in weedy rice, and herbicide carryover to rotational crops remain to be resolved. Research to achieve sustainable solutions for weedy rice management, must be continued and intense educational programs for growers must be sustained.

1. Introduction

Oryza sativa f. *spontanea*, commonly known as weedy/red rice, is one of the most difficult weeds to control in rice production. Weedy rice can be found heavily infesting paddy fields, competing with cultivated rice (*O. sativa* L.) (Delouche et al., 2007). Yield losses due to weedy rice could range from as low as <5% to as high as 100% in severely infested areas (Gunawardana, 2008; Kwon et al., 1991; Shivrain et al., 2009a; Smith, 1988; Vo et al., 2000). The impact on yield varies widely among locations depending on the level of infestation, duration of interference, the type of rice cultivar being grown, and the farmers' crop management practice. In the U.S., one weedy rice plant/m^2 caused yield losses between 100 and 755 kg/ha in four rice cultivars 'CL161', 'Cocodrie', 'LaGrue', 'Lemont', and 'XL8' (Ottis et al., 2005). The latter is a hybrid rice, which was the most competitive and was least impacted by weedy red rice. The semi-dwarf Lemont was most affected. An earlier study reported 86% yield loss in Lemont with weedy rice competition (Kwon et al., 1991). Older U.S. cultivars seemed less competitive with weedy rice with yield losses being 80% or higher (Kwon et al., 1991; Smith, 1988). When 12 weedy rice ecotypes, representing different morphological traits and phenology, were competing with inbred rice CL161 at three planting dates, rice yield losses ranged from 14% to 45% (Shivrain et al., 2009a) showing a wide range of competitive abilities among ecotypes. The same 12 ecotypes caused less yield impact on hybrid rice CL-XL8, but also broadly different with 6%–35% yield loss. Malaysia had lost 30–50% of total rice yield on

Abbreviations: IMI, Imidazolinone; EMS, Ethyl methanesulfonate; ALS, Acetolactase synthase; HR, Herbicide resistant.

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http://dx.doi.org/10.1016/j.cropro.2013.02.013

average due to weedy rice (Watanabe et al., 2000); South Korea reported 5–10% reduction of their total rice production (Chen et al., 2004); while Vietnam reported an average loss of up to 17% (Vo et al., 2000). Eradication of weedy rice is difficult because it is of the same species as cultivated rice, with similar physiological characteristics (Gealy et al., 2003). Thus, herbicides that kill weedy rice would also injure cultivated rice (McClain, 2003).

To solve this problem, the Louisiana State University Agricultural Center (LSU AgCenter) introduced imidazolinone-resistant cultivated rice varieties, known as Clearfield® rice. Clearfield® rice offers an opportunity to selectively control weedy rice with imidazolinone (IMI) herbicides (Croughan, 2003). To generate IMI-resistant rice lines, rice seeds were treated with the mutagen ethyl methanesulfonate (EMS). One rice plant harboring a mutation in the acetohydroxyacid synthase or acetolactate synthase (ALS) enzyme was encountered (Croughan, 2001). The ALS enzyme is responsible for the biosynthesis of branched-chain amino acids (valine, leucine, and isoleucine) in plants (Shaner, 1991). IMI herbicides act as non-competitive inhibitors of the ALS enzyme and halt the production of these amino acids. Without these amino acids, plants will slowly die due to their inability to synthesize proteins, which are important for cell division (Shaner et al., 1984). The mutant *ALS* gene in Clearfield® rice makes it insensitive to IMI herbicides.

Clearfield® rice is deemed a safe product because it does not contain any microbial transgene. In layman's term, it is not genetically modified. The IMI herbicides are harmless to animals because the ALS biosynthetic pathway is only present in plants and some bacteria (Levy Jr., 2004). Additionally, IMI herbicides are generally used at low dosage to control other weeds, such as *Echinochloa crus-galli* (L.) P. Beauv., *Urochloa platyphylla* (Munro ex. C. Wright R. D. Webster), *Digitaria* spp., *Panicum dichotomiflorum* Michx., *Cyperus iria* L., *Cyperus esculentus* L., and some broadleaf weeds such as *Physalis angulata* L. and *Polygonum lapathifolium* L. (Ottis et al., 2003; Pellerin et al., 2004; Scott et al., 2012). Imazethapyr is also effective on one of the world's worst weeds, *Cyperus rotundus* L., in non-flooded crop culture such as peanut (Dotray and Keeling, 1997). The Clearfield® technology is a very valuable tool in rice weed management because the imidazolinones, i.e. imazethapyr, has soil and foliar activity. Combined with other herbicides, imazethapyr can provide season-long weed control in rice production. In the southern U.S., imazethapyr is used as the base component of various site-specific, pre- and post-emergence weed management programs for Clearfield® rice, which includes several herbicide modes of action such as clomazone, quinclorac, pendimethalin, thiobencarb, propanil, bensulfuron, cyhalofop, and others (Scott et al., 2012).

Because of the aforementioned advantages, Clearfield® rice commercialization proceeded smoothly without the additional regulatory requirements levied on transgenic food crops (Croughan, 2003). However, scientists are raising concerns about the escape of the resistance trait from Clearfield® rice to weedy rice in the throes of large scale adoption of the technology. In the U.S., it was predicted that the Clearfield® rice technology would last only about 8–10 years because of accelerated evolution of herbicide-resistant (HR) weedy rice, primarily, from gene flow. Today, Clearfield® rice technology is still the mainstay in southern U.S. rice weed management. The imidazolinone herbicides, together with other rice herbicide modes of action, result in weed-free rice fields season-long. The situation would be significantly different in tropical areas. This paper aims to provide an overview on the development and commercialization of Clearfield® rice around the world and the challenges following implementation of this technology. Potential measures to counteract weedy rice and/or hybrid weedy rice problems will also be discussed.

2. Development and commercialization of Clearfield® rice

2.1. North America

Clearfield® rice was first commercialized by Louisiana State University (LSU) in 2002, by releasing the first two Clearfield® varieties, CL121 and CL141 (Tan et al., 2005). Clearfield® rice was developed from U.S. rice cultivar, AS3510 (M_0) harboring a mutation at G_{654}Glu, using the mutagen EMS (Fig. 1A). The mutated AS3510 (M_1) was selfed to produce the M_2 offspring (Fig. 1B). Of all M_2 plants, one M_2 individual survived a full dose of imazethapyr 0.14 kg ai/ha applied preemergence and 0.07 kg ai/ha applied postemergence (Croughan, 2001). This resistant mutant was then coded 93-AS3510 (Fig. 1C). This mutant line eventually produced CL121 and CL141, through hybridization with Cocodrie and Maybelle as the recurring parents, respectively (Wenefrida et al., 2007). However, CL121 and CL141 did not last long in the market because of their lower yield potential relative to the top conventional rice varieties. These were replaced with a higher yielding variety, CL161, in 2003 (McClain, 2003). CL161 was developed from Cypress, which has higher yield than AS3510, Cocodrie, or Maybelle. CL161 also has higher tolerance to IMI herbicides (~5-fold compared with CL121), increasing its popularity among farmers (McClain, 2003; Wenefrida et al., 2007). This was originally called the PWC16 mutant line, which harbors a Ser_{653}Asn mutation (Tan et al., 2005).

Currently, LSU is collaborating with other institutions such as the BASF Co., the University of Arkansas, and Mississippi State University to continue developing new Clearfield® rice varieties, among which are CL171-AR, CL131, CL151, CL111, CL261, and CL152 (Table 1). These new varieties were commercially released in the 2007–2011 period (Buehring, 2008; Linscombe and Sha, 2011). Generally, newer Clearfield® rice cultivars have higher tolerance to IMI herbicides than the earlier releases (Buehring, 2008). Several commercial hybrid rice lines also now carry the Clearfield® trait. Clearfield® rice technology has thus helped increase rice cultivar diversity which benefits the rice farming industry.

Clearfield® hybrid rice offers some advantages over Clearfield® inbred cultivars. In recent trials at the Rice Research Station, LSU AgCenter, Clearfield® hybrid rice produced higher total yield, from the main crop and ratoon crop, compared with the Clearfield® inbred cultivars, conventional cultivars, and non-HR hybrid lines, with the exception of CL151 (Deliberto and Salassi, 2010). Besides high yield, hybrid rice also has the advantage of being more competitive with weedy rice than the inbred cultivars. Experiments conducted at the University of Arkansas Rice Research and Extension Center (UA-RREC), Stuttgart, Arkansas, showed that a Clearfield® hybrid rice, CL-XL8, incurred 5–10% less yield loss compared with a Clearfield® variety CL161 when grown in full-season competition with weedy rice (Shivrain et al., 2009a). This is primarily because CL-XL8 hybrid rice tillered more and was more vigorous than CL161 inbred rice. On the other hand, hybrid rice technology comes with some challenges. Hybrid rice seed costs more than that of inbred cultivars, but because of its high yield potential (Deliberto and Salassi, 2010), hybrid rice adoption is increasing in the U.S. To reduce seed input cost, hybrid rice is planted at about one-third the seeding rate (33 kg/ha) of inbred cultivars (100 kg/ha) (Deliberto and Salassi, 2010). In addition to higher seed cost, research has also shown that CL-XL8, has a higher outcrossing rate with weedy rice than the inbred Clearfield® variety CL161 (Shivrain et al., 2009b). It appears that hybrid rice may have higher genetic compatibility with weedy rice than conventional cultivars. However, gene flow from hybrid rice, or any other cultivated rice, does not always occur because in some cases the flowering period of cultivated rice and the associated weedy rice ecotype does not synchronize. The other challenge associated with

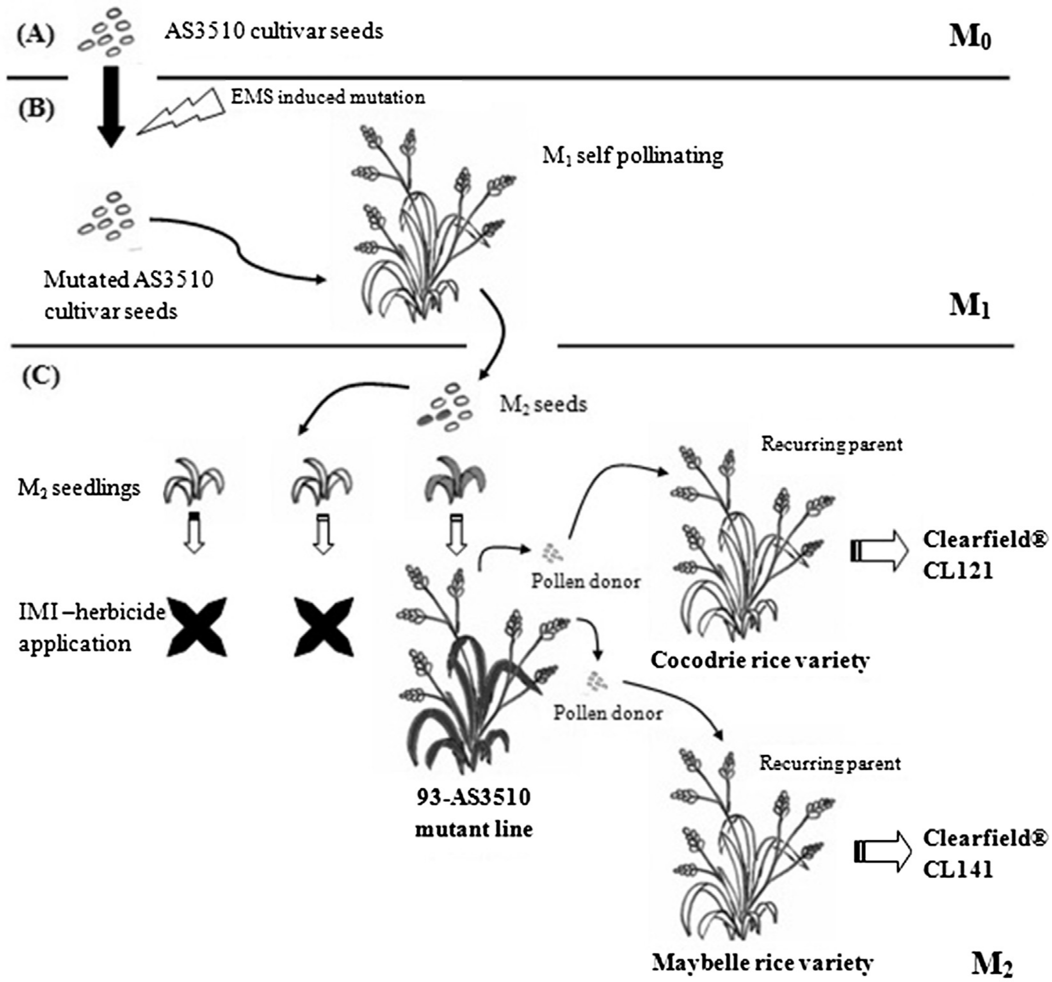

Fig. 1. Development of early Clearfield® rice varieties, CL121 and CL141. Clearfield® CL121 and CL141 were developed from **(A)** AS3510 seeds that were mutated using ethyl methanesulfonate (EMS); **(B)** mutated AS3510 was allowed to self-pollinate to produce M_2 seeds; **(C)** M_2 seedlings were sprayed with imazethapyr, and a single survivor (93-AS3510) was recovered; this was utilized as pollen donor for Cocodrie and Maybelle cultivars.

Clearfield® hybrid rice that is relevant to the evolution of weedy rice populations is the higher incidence of volunteer rice in the succeeding season. This is primarily related to the degree of seed shattering that would occur in the previous season, but this also indicates the ability of F_2 seeds to survive the winter. In the southern U.S., rice is planted in the spring (March to early May); harvesting is generally finished in September. Except for a small acreage of ratooned rice, only one rice crop can be produced in a year because of the onset of suboptimal temperatures in October and on to the winter months when temperatures can fall below freezing occasionally. In the more southern latitudes, e.g. Louisiana, toward the Gulf of Mexico where temperatures remain warm for a longer period, a ratoon crop of rice is produced. The F_2 volunteer plants, arising from seeds surviving the winter, will segregate with respect to morphology and the resistance trait, but the resistant ones will present more chances for outcrossing with the natural weedy rice population. Some F_2 plant types themselves could also be weedy.

2.2. Central and South America

Soon after Clearfield® rice technology gained reputation among U.S. farmers, other countries with weedy rice problems were encouraged to adopt this technology. Central and South American countries were among the first to follow the U.S., including Nicaragua (2003), Panama (2003), Colombia (2003), Brazil (2003), Costa Rica (2004), Uruguay (2005), Argentina (2005), Paraguay (2005), Bolivia (2005), Dominican Republic, and Honduras (2011) (Table 1). The majority of these countries developed their local Clearfield® cultivars using U.S. Clearfield® rice as pollen donor and their preferred local cultivars as recurrent parents (Gressel and Valverde, 2009; Kharkwal and Shu, 2009).

The demand for Clearfield® rice was especially high in Brazil and Costa Rica. In Costa Rica, one-third of rice fields were planted with Clearfield® rice within two years of its introduction in the country (Gressel and Valverde, 2009). Clearfield® rice varieties in Brazil are being developed by Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) and Instituto Rio Grandense do Arroz (IRGA) (Table 1). These research institutions released the first Clearfield® cultivar in Brazil, IRGA 422-CL in 2004 (Dewar, 2007). This cultivar was developed from the 93-AS3510 mutant line (Roso et al., 2010). The development of improved local varieties continued. BRS Cinuelo-CL was planned to be released in the 2011/2012 planting season (Rangel et al., 2010). By the end of the 2012 season, four Clearfield® inbred varieties were planted in Brazil including Puitá INTA-CL (INTA/BASF), SCS 117-CL (Epagri, Santa Catarina), IRGA 428 (IRGA, Rio Grande do Sul), and Guri (INTA/BASF) (Jose A. Noldin, pers. communication). The U.S. hybrid rice company, RiceTec, has also

Table 1
Global status of Clearfield® rice development and adoption.

Country/area (ha)[a]	Current status of Clearfield® rice	Year released/planted	Variety/hybrid	Reference
United States 736,200	Grown	2001	CL121 & CL141	Linscombe and Sha, 2011
		2002	CL161	Buehring, 2008; Linscombe and Sha, 2011
		2003	CL121, CL141, CL161	Sunny Bottoms, Horizon Ag, pers. communication
		2005	CL131	Buehring, 2008; Linscombe and Sha, 2011
		2007	CL171-AR	Buehring, 2008
			CL-XL729	http://www.ricetec.com/Products/Hybrids/clearfield
			CL-XL745	http://www.ricetec.com/Products/Hybrids/clearfield
		2008	CL151	Buehring, 2008; Blanche et al., 2011; Linscombe and Sha, 2011
			CL111 & CL261	
		2010	CL152 & CL162	Linscombe and Sha, 2011
			CL181 & CL142	Sunny Bottoms, Horizon Ag. pers. communication
		2011	CL-XP756	Linscombe and Sha, 2011; Solomon et al., 2012 http://www.ricetec.com/Products/Hybrids/clearfield
		2012	CL142-AR	University of Arkansas, 2011
Brazil 600,000	Withdrawn and re-developed	2003	IRGA 422-CL	Caetano, 2011
		2008	PUITÁ INTA-CL	Caetano, 2011
		2011/2012	BRS Cinuelo-CL	Rangel et al., 2010
			IRGA 428-CL	V. Menezes, pers. communication
			SCS 117-CL (Epagri)	J. Noldin, pers. communication
			Guri (INTA/BASF)	J. Noldin, pers. communication
			AVAXI-CL, INOV-CL & ECCO-CL[c] (Hybrids)	http://www.ricetec.com.br/hibridos_arroz.php
Colombia N/A	Grown	2003	CF205®	Fory et al., 2005, 2007; Gressel and Valverde, 2009
Panama N/A	Grown	2003	CF205®	Fory et al., 2007; Gressel and Valverde, 2009
Nicaragua N/A	Grown	2003	CF205®	Fory et al., 2007; Gressel and Valverde, 2009
Costa Rica N/A	Withdrawn	2004	CFX-18/CL161	Valverde, 2005; Gressel and Valverde, 2009
Uruguay ~70,000	Grown	2005	CL161	Delouche et al., 2007; Pazos, 2007
		2011	PUITÁ INTA-CL, Gurí INTA-CL, INOV-CL hybrid	Saldain, E., unpublished data
Argentina 32,400	Grown	2005	PUITÁ INTA-CL	Gressel and Valverde, 2009; Kharkwal and Shu, 2009; Livore et al., 2011
Paraguay N/A	Grown	2005	PUITÁ INTA-CL	Kharkwal and Shu, 2009
Bolivia N/A	Grown	2005	PUITÁ INTA-CL	Kharkwal and Shu, 2009
Dominican Republic N/A	Grown	N/A	N/A	Gressel and Valverde, 2009
Honduras N/P	Introduced	N/A	N/A	Anonymous, 2011
Malaysia ~95,000	Grown	2010	MR220CL1 & MR220CL2	Azmi et al., 2010; BASF, 2010; Alex Tong, BASF Malaysia, pers. communication
Vietnam N/P	Under development	N/A	OM5749-5[b]	Duong et al., 2007; Nguyen and Bui, 2007; Nguyen T. Lang, pers. communication
Italy 60,000[d]	Grown	2006	Libero	Busconi et al., 2012
		2009/2010	Sirio-CL	SAPISE, 2010
		2011	Sole-CL, Luna-CL, & Mare-CL	SAPISE, 2010
		2012	CL71, CL26	Aldo Ferrero, pers. communication

[a] N/A = not available, N/P = not planted.
[b] Temporary name for unreleased Vietnamese Clearfield® rice variety.
[c] Hybrid lines currently commercialized in Brazil; year of first release not indicated.
[d] Expected to reach 80,000 ha within 3 years.

released Clearfield® hybrid lines in Brazil including INOV-CL and Avaxi-CL. In 2011–2012, Brazil has at least 52% of rice area in Rio Grande do Sul State planted with Clearfield® rice, equivalent to 580,000 ha (Valmir Menezes, pers. communication). The cultivar PUITÁ INTA-CL from Argentina was planted in 54% of this area.

Argentina developed local Clearfield® rice cultivars that are distinct from U.S. materials (Livore et al., 2011). The most popular thus far, is the cultivar PUITÁ INTA-CL, which was released in 2005 and has gained popularity quickly in South America. Besides its popularity among Brazilian farmers, farmers in Paraguay and Bolivia also plant this Argentinean Clearfield® cultivar (Kharkwal and Shu, 2009). On the other hand, Uruguay's National Agriculture Research Institute (INIA) and Costa Rica released the U.S. Clearfield® rice, CL161 (Pazos, 2007), in advance of locally developed Clearfield® rice cultivars, to make the technology available to farmers sooner (Delouche et al., 2007). Uruguay has about 200,000 ha of total rice production. In the 2011–2012 season, surveys showed about 13,000 ha of rice fields had medium to heavy infestation levels of weedy rice (INIA, unpublished data). The adoption of Clearfield® technology in Uruguay is expected to increase significantly in 2013. It is expected that Clearfield® rice will be planted in about 35% of rice fields in the next season (Nestor Saldain, pers. observation). The cultivars currently planted in Uruguay include PUITÁ INTA CL, Gurí INTA CL, and the Ricetec hybrid INOV CL. The latter was developed using CL161 as maternal parent and INIA Olimar, a cultivar developed at INIA, as the male parent. In the 2013 season, INIA expects to release a new cultivar, CL212, which is also blast-resistant. It is noteworthy that all cultivars developed in Uruguay are *Indica* types, which is the same group as weedy rice. This could mean higher gene flow rates to weedy rice.

More recently, BASF has signed an agreement with a private rice mill company in Honduras, Beneficio de Arroz Progreso, S.A. de C.V. (BAPROSA), to supply certified Clearfield® rice seeds along with two IMI herbicides, imazethapyr and imazethapyr + quinclorac premix. This agreement allows BAPROSA to distribute the certified Clearfield® rice seeds for usage in Honduras (Anonymous, 2011). Meanwhile, other countries, such as the Dominican Republic, Colombia, Nicaragua, and Panama, have developed their local Clearfield® rice by incorporating IMI-resistance to their respective local rice varieties (Gressel and Valverde, 2009). Colombia and some Central American countries use their local Clearfield® rice cultivar CF205® (Fory et al., 2007).

2.3. Asia and Europe

Although the Clearfield® rice technology was readily accepted in the Americas, it was slow to gain foothold in Asia and Europe where weedy rice is also a major problem. As of 2012, only Malaysia, Vietnam, and Italy have expressed interest in developing and commercializing Clearfield® rice. Malaysia and Italy have released Clearfield® rice cultivars and are currently promoting the production of Clearfield® rice to reduce weedy rice infestation. Malaysia has released two cultivars; MR220CL1 and MR220CL2 (BASF, 2010). Both of these varieties were derived from crosses between CL1770 from LSU with a Malaysian local rice variety, MR220 (Azmi et al., 2012a). The genetic similarity between MR220 to MR220CL1 and MR220CL2 is 98.5% and 92.5%, respectively (Azmi et al., 2012b; Azmi, M., pers. communication). To enforce the proper utilization of the Clearfield® technology, OnDuty® herbicide and the stewardship guidelines were included with the sale of certified rice seeds (Azmi et al., 2012a; M. Azmi, pers. communication). Currently, Clearfield® rice cultivars have been introduced to eight granary areas in Malaysia, including Kedah, Perlis, Terengganu, Kelantan, Perak, Selangor, Penang and Perak, with satisfying outcome (Azmi et al., 2012b; M. Azmi, pers. communication). BASF Malaysia reported that yields from fields planted with Clearfield® rice had doubled from 3.5 metric tons/ha to 7 metric tons/ha. The challenge is to sustain this yield advantage by minimizing the evolution of HR weedy rice populations. This is very difficult because rice monoculture is widely practiced in Asia, with 2–3 rice plantings per year. Therefore, the buildup of Clearfield® volunteer rice and the risk of outcrossing with weedy rice are expected to be several times higher than what was observed in the North America or in regions where diversified cropping systems are practiced.

Italy, like Uruguay, has a small rice production area (235,000 ha in 2012), but has a major weedy rice problem. Of the total rice area, 60,000 ha were planted with Clearfield® cultivars in 2012 and this is expected to reach 80,000 ha in 3 years (Aldo Ferrero, pers. communication). Thus far, Italy has released five cultivars; Libero, Sirio-CL, Sole-CL, Luna-CL, and Mare-CL (SAPISE, 2010; Busconi et al., 2012) (Table 1). In 2012, the most popular were CL71, CL26, and Sirio-CL. In the next 2 years, Clearfield® hybrid rice is expected to enter the Italian market (Aldo Ferrero, pers. communication).

Vietnam is still developing a high-yielding local Clearfield® cultivar (Nguyen and Bui, 2007). Field testing of one mutant line in Vietnam has shown satisfactory tolerance to IMI herbicides; this line also produced higher yield with better grain quality than the non-Clearfield® cultivars (Duong et al., 2007). However, no HR cultivar is yet deemed suitable for commercialization in Vietnam, as they are still waiting for approval from authorities (Nguyen T. Lang, pers. communication).

3. Challenges with Clearfield® rice production

The popularity of Clearfield® rice among farmers does not always produce positive consequences. Implementation of this technology without long-term planning, appropriate stewardship, institutional collaboration and oversight could have adverse ecological impact in terms of gene escape to weedy or wild relatives. The appearance of Clearfield® rice-weedy rice hybrids that could eventually result in stabilized HR weedy rice populations is of utmost concern. The lifespan of the technology depends on the rate of evolution of such HR weedy rice populations. Another concern is the residual activity of IMI herbicides that could potentially injure the rotational crops. This is a serious obstacle in tropical areas where rice is grown in sequence with other crops in a one-year period. Overcoming these challenges requires a concerted effort among all sectors involved – public researchers, extension workers, private industry, and government policy makers.

3.1. Evolution of IMI-resistant weedy rice populations

A few years after Clearfield® rice commercialization, the occurrence of IMI-resistant weedy rice outcrosses had been observed in some countries, including the U.S., Brazil, Colombia, Costa Rica, Italy, and Uruguay (Table 2). Clearfield® rice-weedy rice outcrosses can increase the diversity of weedy rice because the offsprings segregate various morphotypes (Shivrain et al., 2007; Zhang et al., 2006) and some of these could become stabilized weedy populations. This would complicate the effort to eradicate weedy rice. Resistant weedy rice could evolve from: (1) resistance gene transfer from Clearfield® rice and (2) continuous exposure

Table 2
Reported occurrence of gene flow between Clearfield® rice and weedy rice in some commercial fields.

Clearfield® rice fields location	Clearfield® rice variety	Year released	Year resistant hybrids reported	Average gene flow frequency	References
Louisiana, U.S.	CL121, CL141, CL161	2001/2002	2002	0.17%	Zhang et al., 2006
Arkansas, U.S.	CL161	2002	2003	0.109% – with strawhull 0.434% – with blackhull[b] 0.763% – with brownhull[b]	University of Arkansas, 2006; Burgos et al., 2007
Santa Maria, Rio Grande do Sul, Brazil	IRGA 422CL	2003	2004/2005	0.065%	Villa et al., 2006; Caetano, 2011
Valle del Cauca, Colombia	CF205	2003	2006	<1% in 1 crop cycle	Fory et al., 2005, 2007; Gressel and Valverde, 2009
Central Pacific and Guanacaste, Costa Rica	CFX-18/CL161	2004	2007	N/A[a]	Valverde, 2005, 2007
Po Valley, Italy	Libero	2006	2010	N/A	Busconi et al., 2012

[a] N/A = not available.
[b] From surveys escaped weedy rice in commercial fields.

to IMI herbicides that selects for resistance-conferring natural mutation(s).

Due to the close genetic relatedness between cultivated rice and weedy rice, gene transfer between these two rice types is inevitable. Although rice is predominantly self-pollinating, interbreeding within and among rice species is possible (Fig. 2A). Natural outcrossing experiments between CL161 rice and weedy rice at the UA-RREC has confirmed the 'leakage' of mutated *ALS* gene that confers IMI resistance in CL161 (Rajguru et al., 2005). Rice plants that survived a commercial dose of imazethapyr, in the plots where CL121 and strawhull weedy rice were planted adjacent to each in the previous year, carried DNA markers from both CL121 and weedy rice parents (Estorninos Jr. et al., 2003). Thus, gene flow occurs when cultivated and weedy rice co-exist and they flower synchronously. The natural outcrossing rate between Clearfield® rice and weedy rice had been studied in commercial fields of both the U.S. and Brazil. The outcrossing rate in the U.S. ranged from 0% to 1.26% (Shivrain et al., 2009b; Zhang et al., 2006). Low levels of outcrossing were detected as soon as one year after planting Clearfield® in some cases (Table 2), although the occurrence of outcrossing was usually not monitored starting from the first season of commercialization. The average outcrossing rate in Brazilian fields was lower, 0.065%, than that in the U.S. (Villa et al., 2006). Outcrossing rates are expected to vary significantly between geographic locations and seasons as successful hybridization is dependent not only on the genotypes involved, but also on environmental conditions (Shivrain et al., 2009b). Effective pollen flow from Clearfield® rice to weedy rice has been detected as far as 6 m in the U.S., with this distance being the limit of the experiment, producing resistant weedy rice outcrosses (Shivrain et al., 2007). In commercial fields, effective pollen flow can occur much farther (Burgos et al., 2010) because of higher pollen load and the overall landscape ecology. The resistance gene transfer from Clearfield® rice to weedy rice is evident, and without proper mitigation, the established HR weedy rice populations will increase. Without conscientious stewardship by farmers, the escalation of this problem will be higher in tropical areas where there is no killing frost, and two cropping seasons of rice occur in one year. This has already happened in Costa Rica, resulting in the withdrawal of Clearfield® rice from the Costa Rican market (Bernal E. Valverde, pers. communication).

There is yet a dearth of information on the impact of Clearfield® rice on weedy rice problems in commercial fields. Most of the studies done to address this problem were conducted in the greenhouse or experimental plots (Gealy et al., 2003; Shivrain et al., 2007). The outcrossing rates reported in experimental plots are underestimations of actual events that occurred in commercial fields, whereby hundreds of hectares of rice are grown (Burgos et al., 2008). It is also expected that because of the high pollen load in commercial fields, effective pollen flow can occur over longer distances than what can be detected in small-plot experiments.

Resistance to IMI herbicides may also emanate from spontaneous mutations in the *ALS* gene of weedy rice. The ALS enzyme is highly prone to spontaneous mutation, resulting in insensitivity to ALS inhibitors, such as IMI herbicides (Tranel and Wright, 2002). ALS inhibitors are high-risk herbicides that could induce weed resistance evolution after 10 or fewer applications (Beckie et al., 2006). To date, there are at least 118 weed species reported to be

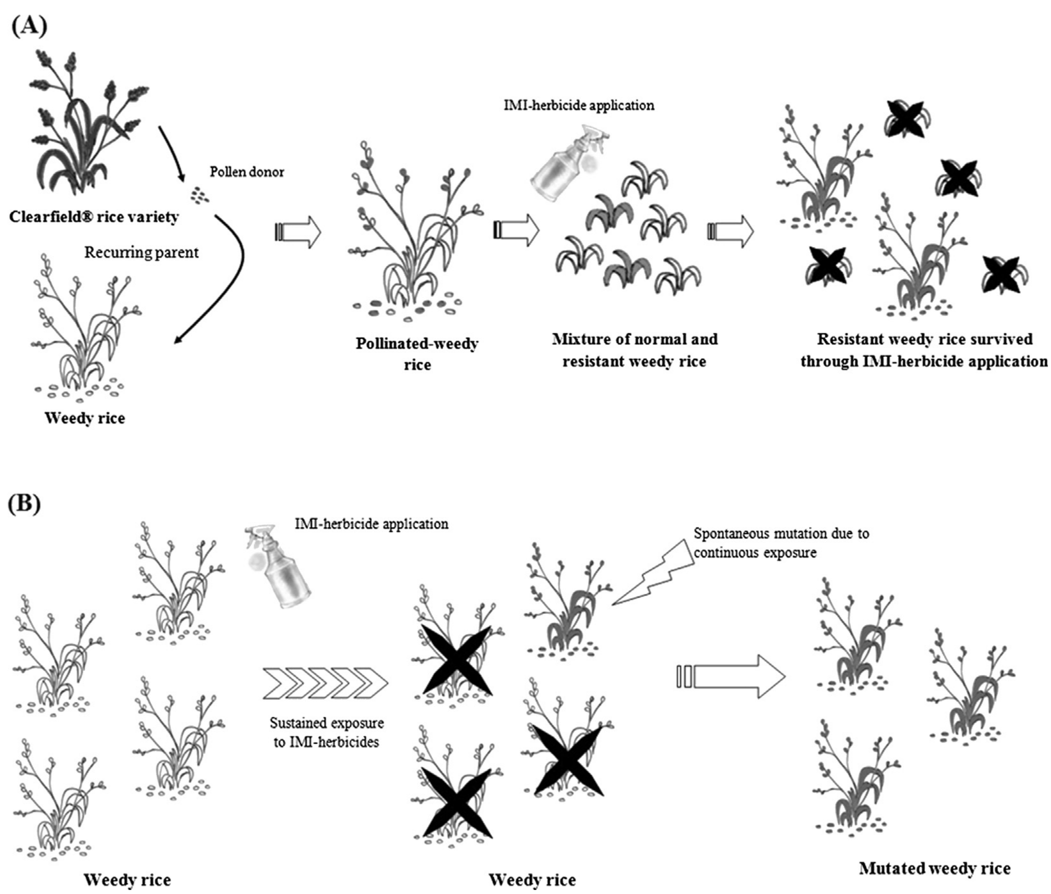

Fig. 2. Evolution of IMI resistance in weedy rice. IMI-resistance in weedy rice could be present due to **(A)** gene flow from Clearfield® rice to weedy rice, or **(B)** spontaneous mutation selected by sustained exposure to IMI-herbicides.

resistant to ALS inhibitors (Heap, 2012). There are 25 non-synonymous mutations found across eight sites in the *ALS* gene that confer resistance to ALS inhibitors in weeds (Beckie and Tardif, 2012). The selection for any one of these mutations would be hastened if the plants are continuously exposed to ALS inhibitors (Fig. 2B). The mutation frequency for ALS-herbicide resistance in rice ranges from 10^{-8} to 10^{-9} (Olofsdotter et al., 2000), which is very high compared to other types of herbicides. In contrast, the mutation frequency within the *psbA* gene that is targeted by PSII inhibitors such as triazine herbicides in corn or propanil herbicide in rice, is only 10^{-20} (Warwick and Stewart, Jr., 2005). This indicates that if weedy rice is continuously exposed to IMI herbicides, it can certainly evolve resistance within a short period of time. In Arkansas, U.S., two weedy rice accessions were found tolerant to IMI herbicides without having been exposed to Clearfield® rice technology (Sales et al., 2008). These accessions tested negative for hybridization with Clearfield® rice and also harbored a different mutation in the *ALS* gene than the cultivars commercialized in 2002 (Kuk et al., 2008; Sales et al., 2008). The high incidence of ALS-resistant alleles is caused by widespread usage, strong selection pressure and long residual effect of ALS-inhibitor herbicides (Tranel and Wright, 2002; Beckie and Tardif, 2012). Although spontaneous mutations may contribute to the evolution of *ALS*-resistant weedy rice, pollen flow from Clearfield® rice to weedy rice has accelerated the evolution of ALS-resistant weedy rice, up to 10 times faster than the expected mutation rate (Warwick and Stewart, Jr., 2005).

In a few countries, the evolution of HR weedy rice has caused more complications in managing weedy rice. Researchers in Uruguay are currently exploring ways to resolve the HR weedy rice problem (Crop Biotech Update, 2010). Costa Rica has completely withdrawn Clearfield® rice cultivars from the market due to severe infestation of resistant weedy rice in their rice fields (Gressel and Valverde, 2009). In Brazil, detection of HR weedy rice after the first season of planting Clearfield® rice, along with disputes with local farmers due to unauthorized planting of Clearfield® rice, has led BASF to withdraw their agreement with Brazil temporarily (Dewar, 2007; Gressel and Valverde, 2009). Resistant weedy rice crosses in Brazil are also unique, as Brazilian farmers have planted three Clearfield® rice cultivars harboring different *ALS* mutations. This has resulted in resistant weedy rice with multiple mutations in the *ALS* gene (Roso et al., 2010), with the expected morphological diversity common among rice-weedy rice crosses. Similar problems are reported in Italy with the occurrence of IMI-resistant weedy rice in eight of nine locations. Three of these areas have 100% resistant weedy rice biotypes in the field (Busconi et al., 2012). The severity of IMI resistance spread among Italian weedy rice was also indicated by the homozygosity of IMI-resistant allele in all resistant weedy rice tested. This suggests that these resistant weedy rice populations are beyond the F_1 generation and the resistance trait has been fixed in these populations (Busconi et al., 2012).

3.2. Volunteer Clearfield® rice

Volunteer rice is often found in the succeeding crop in tropical climates, again, because of no winterkill of dropped seeds or germinating seedlings. The density of volunteer plants depends on the efficiency of rice harvest, the shattering trait of the cultivar, and the growers' ability to remove volunteer plants between cropping seasons. If occurring in a rotational crop such as soybean, corn, cotton or others, volunteer rice is managed by the farmer like other grassy weeds. If growing with a rice crop, then it becomes part of harvested rice. This is not a problem if the volunteer is of the same grain type as the planted cultivar, but becomes a grain quality issue if otherwise. Volunteers from a hybrid rice crop are a problem because it is a population of segregating F_2 plants with different morphology, phenology, yield potential, and grain quality. Some of these plants are just plain weedy, competing with the planted cultivar but inferior yield potential. Volunteer plants from Clearfield® rice is a bigger problem because these are effective agents of gene flow to weedy rice in addition to all issues already mentioned. Therefore, weedy rice management in-season and out-of-season is even more critical in the Clearfield® rice system.

3.3. Seed systems

The most complex challenge in sustainable adoption of HR rice technology is the nature and dynamics of rice seed distribution structure and seed sourcing in different countries. The fact is, weedy rice problem emanates from rice culture; the weed is introduced into new regions with the rice seed. A case in point is weedy rice in North America where rice is not an endogenous species. From the point of introduction, it is then spread to other farms through farming activities, irrigation systems, animals, grain transport, and eventually to other states by seed distribution. Seed laws can help curtail the spread of weedy rice. There is zero tolerance for weedy rice in certified seed in some countries including Brazil (Valmir Menezes, pers. communication), Philippines (Martin, E., pers. communication), Sri Lanka (Anuru Abeysikera, pers. communication), and the U.S. (http://plantboard.arkansas.gov/Seed/Pages/LawsRegulations.aspx; accessed December 29, 2012). Stringent seed laws help curtail the spread of weedy rice and the HR trait. In many countries, however, seed regulation is not as strict. For example, there is no regulation for weedy rice contamination in rice seed in Vietnam; Thailand allows 4 weedy rice seed/kg of certified seed (Chanya Maneechote, pers. communication); Malaysia does not have a clear regulation of weedy rice contamination in certified seed of conventional rice, but is imposing zero tolerance for weedy rice in Clearfield® rice seed (Man Azmi, pers. communication). This is just barely unraveling the issue. For those countries with seed regulations, it is one thing to have seed laws; implementing these by regulatory agencies and adoption by farmers are entirely different realities. In Brazil, for example, where there is zero tolerance for weedy rice contamination in certified seed, it is estimated that 50% of rice seed being planted are contaminated with weedy rice (Valmir Menezes, pers. communication). This is because in places where there are hundreds of certified seed growers, intensive monitoring of fields is impossible. Farmers occasionally use their own seed, or share seed among themselves, thereby perpetuating the weedy rice infestation. Having a good seed system that benefits the whole industry requires tight collaboration across all sectors – academia, government agencies, private industries, and farmers. If one of these spokes is broken or weak, the whole industry eventually collapses. The sustainability of Clearfield rice technology also depends greatly on having a streamlined, pure seed distribution system that growers utilize 100%.

3.4. Carryover effect of IMI herbicides

Although IMI herbicides are not harmful to humans and animals, several of these herbicides have residual activity in the soil. Repeated application of imazethapyr and imazapic in Brazilian Clearfield® rice fields has increased the persistence of these herbicides in treated soils (Kraemer et al., 2009). The herbicide residue is particularly concentrated in the top soil (0–5 cm), and could be detected up to 20 cm below (Kraemer et al., 2009). This residue is injurious to non-tolerant rotational crops, such as grain sorghum [*Sorghum bicolor* (L.) Moench], ryegrass (*Lolium multiflorum* Lam.), corn (*Zea mays* L.), cucumber (*Cucumis sativus* L.), wheat (*Triticum aestivum* L.), and edible bean (*Phaseolus vulgaris* L.). Grain sorghum, corn, and cucumber are very sensitive to residues of imazethapyr and imazapic in the soil, showing severe injury and significant yield reduction when planted after Clearfield® rice (Ulbrich et al., 2005; Pinto et al., 2009a). Experiments conducted in two locations in Uruguay between 2007 and 2010 showed that yield of conventional rice following Clearfield® rice was not reduced when imazethapyr (180 g ae/ha) + imazapic (70 g ae/ha) was used (Table 3). This was true regardless of soil type. The forage crop *Sorghum bicolor* × *S. sudanensis* (sorghum-sudan) was also tolerant to residues of the herbicide mixture, producing an average shoot biomass of 9.9 mt/ha at the rates mentioned. However, early growth of the forage crop was reduced when seeded 300 days after application of imazethapyr + imazapic. The problem occurred when *Lolium multiflorum* Lam., the most widely used pasture grass in the region, was seeded following Clearfield® rice. Rotation of rice with cattle is a common practice in Uruguay and ryegrass is seeded after rice harvest as supplemental forage. Ryegrass biomass was reduced 23% on average across three years when planted after Clearfield® rice in soil containing 48% sand; silty clay soil. Injury on ryegrass was observed only once in three years. Thus, ryegrass is most vulnerable to residues of imidazolinone herbicides than other rotational crops in their region. In Brazil, IMI herbicide residue also affected ryegrass germination and growth up to 180 days after application when planted following Clearfield® rice (Pinto et al., 2009b). Wheat and edible bean are relatively sensitive to IMI residues, but generally have higher tolerance than grain sorghum, corn, and cucumber. Soybean [*Glycine max* (L.) Merr.] is the most tolerant rotational crop to IMI herbicide residues (Ulbrich et al., 2005); in fact imazamox, imazaquin and imazethapyr are labeled for use on soybean and imazapic is labeled for use on peanut in the U.S.

Despite the absence of residual effect of IMI herbicides on non-tolerant rice in Uruguay, some non-tolerant rice varieties can be injured by IMI herbicide residue in soil, under certain environmental or edaphic circumstances. In Brazil, the yield of conventional rice was reduced up to 55% when planted one year after IMI herbicide application (Villa et al., 2006; Marchesan et al., 2010). At 705 days after IMI herbicide application, injuries on non-tolerant rice were still observed, but with no more yield loss. This study was conducted in irrigated albaqualfs soil type (pH 4.5) with imazethapyr, 0.075 kg ai/ha + imazapic, 0.025 kg ai/ha using a premixed formulation (Marchesan et al., 2010).

4. Approaches to weedy rice management

To mitigate the problem of resistant weedy rice arising from lax adherence to stewardship guidelines associated with the adoption of Clearfield® rice technology, steps should be taken to reduce the 'leakage' of herbicide resistance gene to weedy rice and minimize the spread of weedy rice seed. Recommended best management practices and empowering farmers are discussed in the following section. Some researchers have recommended the implementation of tandem construct of herbicide resistance with a second gene to mitigate gene flow as discussed in the following section (Al-Ahmad et al., 2004; Al-Ahmad and Gressel, 2006). However, this technology will be classified as transgenic and will not be acceptable in the global market as the current perception and regulation stands. Also, this technology has not gone far beyond the proof-of-concept phase in the rice system. A lot of research is still needed in this area. Utilization of different types of HR rice varieties was also suggested to prevent the widespread of HR gene among weedy rice (Gressel and Valverde, 2009).

4.1. Adoption of best management practices

The short-life span prediction for the Clearfield® rice technology, when it was first released, did not come to pass in the U.S. This is a very welcome turn of events for the technology and the U.S. rice industry. Such positive development is attributed to two factors: (1) the reduced fitness of F_1 outcrosses between Clearfield® rice and weedy rice and (2) the winter-kill of germinated seed and most leftover seed in the soil. In the southern U.S., Clearfield® rice × weedy rice crosses produce F_1 plants that are late to flower; the majority of which are unable to produce seed before temperature drops to suboptimal level in the fall (Nilda R. Burgos, pers. observation). Still, many fields today with history of Clearfield® rice have *ALS*-resistant weedy rice at various frequencies (Burgos et al., unpublished data). This is because there are still cases where F_1 outcrosses can produce seed when temperatures remain high enough for a prolonged period in the fall and into the early part of winter. In tropical regions, all outcrosses and remnant weedy rice plants contribute to the soil seedbank and are carried forward to the next crop cycle. Because farmers in tropical areas grow generally two rice crops per year (sometimes three), the evolution of HR weedy rice populations can occur in two years as what was observed in Latin America (Bernal E. Valverde, pers. communication).

Thus, prolonging the utility of Clearfield® rice technology rests on the following best weed management principles: (1) use of certified seed; (2) implementation of herbicide programs that incorporate all possible modes of action available for rice production; (3) adoption of best management practices that ensure maximum efficacy of the herbicide; (4) minimizing the synchronization of flowering between HR rice and weedy rice (by knowing the phenology of the weedy rice relative and adjusting planting dates accordingly); (5) preventing escaped weedy rice in a Clearfield® rice field, and remnant weedy rice after crop harvest, from producing seed; (6) preventing the seed production of volunteer rice or weedy rice in the next crop cycle by controlling it in a rotational crop such as IMI-tolerant legumes, pasture, or other compatible commodity; (7) practicing zero-tillage or minimum

Table 3
Effect of imazethapyr + imazapic on crops following Clearfield® rice, Paso la Laguna (UEPL) and Rio Branco (RB) Research Stations, Uruguay, 2007–2010.[a]

Imazethapyr + imazapic g ae/ha	Italian ryegrass shoot biomass, UEPL[b,c] kg/ha	'El Paso 144' yield, UEPL kg/ha	Italian ryegrass shoot biomass, RB kg/ha	'INIA Olimar'[d] yield, RB kg/ha	Sorghum-sudan[e] shoot biomass, RB kg/ha
0 + 0	3281	6442	3797	5654	9112
90 + 35	2571	7128	2932	5511	9225
180 + 70	2692	6735	2918	5275	9906
$LSD_{0.05}$	423	NS	357	NS	NS

[a] Except otherwise indicated, means are calculated across three years and six replications.
[b] UEPL soil has 27% clay, 46% silt, 27% sand with 1.3% organic matter, pH 5.4; RB soil has 18% clay, 33% silt, 48% sand with 0.96% organic matter and pH 5.5.
[c] 2008–2009 season only; no effect was observed in other years (data not shown).
[d] INIA – Instituto Nacional de Investigación Agropecuaria; Olimar is a conventional rice cultivar produced at INIA.
[e] Sorghum-sudan (*Sorghum bicolor* × *S. sudanensis*) is a forage crop variety.

tillage; (8) stale seedbed – reducing the potential population density of weedy rice in a season by allowing a big batch of weedy rice germinate prior to rice planting and killing these seedlings either by a second tillage or with a non-selective or grass herbicide; (9) mechanically harvesting clean fields first before harvesting weedy rice-infested fields; and (10) rotating Clearfield® rice with other crops to break the weedy rice cycle.

Growing a broadleaf crop after rice allows for the use of selective grass herbicides that will control weedy rice. We propose that practicing no-till or minimum tillage after a large seed rain of weedy rice will significantly minimize deposits to the soil seedbank because seeds left on top of the soil surface are subject to various avenues of losses. Seeds on the top soil can germinate and be controlled by non-selective herbicides such as glyphosate or glufosinate prior to planting the next crop. Not burying the weedy rice seeds also ensures maximum emergence of new seed deposits and the highest possible control by other herbicides or cultivation in the rotational crops. On-going research at the University of Arkansas indicates that seeds buried deeper in the soil profile remain viable for at least four years. Anecdotal experience of Arkansas rice growers also show that fields that were once free of weedy rice infestation became infested with weedy rice immediately after top soil was moved to different parts of the field in the process of field leveling. Chauhan (2012) reported that more than 80% of the weedy rice emerged after 21 days when the seeds were sown on the soil surface in a screenhouse. Seeds sown deeper still emerged, albeit more slowly. For example, seed burial depth of four cm resulted in a significant decrease in seedling emergence of weedy rice as compared with that buried at one and two cm (Chauhan, 2012). These, and other studies (Guss and Brown, 1939), indicate that weedy rice can emerge from greater depths than what is recommended for rice planting and buried weedy rice seeds can remain viable for variable lengths of time.

Once the resistance trait is introgressed into the weedy rice population, it can be transferred to other weedy rice populations or to non-HR rice cultivars (Shivrain et al., 2009a). This is a significant issue in regions where farm holdings are small, with rice paddies of different farmers just separated by a foot path levee sometimes less than 1 m wide. Therefore, weedy rice needs to be controlled not only in the rice paddies but also along field edges and irrigation ditch banks. Irrigation water is an effective means of transporting weed seeds, just as land transportation are agents of seed dispersal along highways and railways. Intermixing of weed populations along irrigation systems or river flood plains is common knowledge.

4.2. Farmer trainings and technical support

To achieve a high level of adoption of best management practices, educational activities and technical support for farmers need to be intensified. Farmer field days need to be conducted every year, in strategic locations with the goal of having all farmers growing Clearfield® rice (and potential adopters) receive firsthand information about the technology. The field day should be set up to demonstrate different phases of crop production, including crop rotation systems. Field days and farmer trainings are intrinsic in most agriculture programs worldwide, with various topic foci. Of these, integrated pest management (IPM) training is probably one of the most widely promoted agricultural activities. Academic institutions, ministries of agriculture, national agricultural research institutions, and international non-profit organizations [e.g. Food and Agriculture Organization (FAO), International Rice Research Institute (IRRI)] are conducting this type of activity. Special trainings on proper herbicide application, learning herbicide mode-of-action groups, and weedy rice scouting need to be conducted. One way to do this is through Farmer Field School (FFS), which was started in Asia. This approach is one of the more successful strategies in achieving lasting impact on farmer education and technology adoption. In Indonesia, for example, FFS was started with the goal of training rice farmers about IPM (Soejitno, 1999) and empowering farmers to make the right management decisions (Braun et al., 2006). It then expanded to other topics including soil fertility management, livestock, and literacy training. The same approach was used by FAO personnel in training rice farmers from Central and South America about weedy rice in 2005 (Nilda R. Burgos, pers. observation). A case study conducted in the Philippines indicated that graduates from FFS effectively applied the knowledge that they acquired from the school (Rola et al., 2002); therefore, the training improved technology adoption and farm productivity. Thus, it is highly beneficial for the private industry promoting the HR rice technology to collaborate with existing institutions in conducting educational activities. This is necessary to increase awareness and the skill level of farmers so that they can adopt the technology properly and sustain it. BASF-Asia is working with government authorities in Malaysia to make weedy rice management training compulsory before farmers are given certified Clearfield® rice seeds. Follow-up trainings of these farmers are necessary as they in turn become agents for proper technology adoption and stewardship.

4.3. Transgenic approaches for future consideration

Transgenic food crops are generally not accepted in the global market. This is a barrier to the development and commercialization of crops with genetically engineered traits, not only herbicide and pest resistance, but also improved agronomic and quality traits. Nevertheless, some genetically modified fiber and food crops are already commercialized in Asia including Bt-resistant cotton (*Gossypium hirsutum* L.) in India (James, 2011), ringspot virus-resistant papaya (*Carica papaya* L.) and phytase-producing maize (*Z. mays* L.) in China (Chen et al., 2008; Anonymous, 2010; James, 2011), and glyphosate-resistant maize in the Philippines (Anonymous, 2008). A valid concern is not knowing the long-term ecological risk of such transgenic plants and products. With respect to rice and its weedy relative, we know that gene escape can occur to the weedy population, the native landraces, and the wild relatives (Lu, 2008). Nevertheless, we mention the existing hypotheses concerning utilization of transgenic approaches here for any possibility of change in future direction of science and technology.

Tandem gene insertion technique could be employed to minimize the risk of genetic introgression from Clearfield® rice to weedy rice. This second gene could be: (1) unfit genes that will be disadvantageous to the weedy rice outcross (Al-Ahmad and Gressel, 2006) or (2) a bentazon-sensitive gene (Lin et al., 2008). The second gene would be transferred along with herbicide resistance gene, therefore the hybrid weedy rice would either be morphologically unfit or sensitive to bentazon herbicide.

Genes that are intended to confer morphological unfitness to the weedy rice outcross should be positive or neutral to the crop of interest. The dwarfing gene has been demonstrated to successfully mitigate gene transfer from transgenic tobacco (*Nicotiana tabacum* L.) and oilseed rape (*Brassica napus* L.) to their weedy relatives (Al-Ahmad et al., 2004, 2005; Al-Ahmad and Gressel, 2006). The dwarfing gene produces a crop phenotype that forms more inflorescence, which translates to increased yield. However, outcrosses of the dwarf phenotype with the weedy relative are less competitive than the crop and especially with the wild type (Al-Ahmad et al., 2005). This method could put the outcrosses at a disadvantage and minimize the introgression of HR gene to its weedy relatives. On the other hand, dwarf and semi-dwarf weedy rice phenotypes already exist in rice fields, although in lower frequencies than tall weedy phenotypes (Nilda R. Burgos, pers. observation). Thus, the dwarfing gene would be of less value in mitigating genetic introgression to weedy rice than other techniques such as the bentazon-sensitive gene or reduced shattering. An anti-shattering gene would be a good choice as an unfit gene for the rice model (Gressel and Valverde, 2009). It would be neutral to Clearfield® rice, but will have a negative impact on weedy rice outcrosses, because it will reduce the number of shattered seeds from the HR weedy outcrosses. Thus, the soil seedbank will not be replenished and the establishment of HR populations will be minimized.

A bentazon-sensitive gene would be another choice for a gene to be introduced in tandem with HR gene or other genes of interest. Naturally, rice is resistant to bentazon because of the cytochrome P450 enzyme *CYP81A6*, which oxidizes bentazon to an inactive form (Pan et al., 2006). Inserting an inverted repeat sequence of *CYP81A6* gene in tandem with glyphosate resistance gene into rice would make the rice resistant to glyphosate, but sensitive to bentazon (Lin et al., 2008). By substituting the glyphosate resistance gene with IMI resistance gene, a bentazon-sensitive Clearfield® rice can be produced. This would provide an opportunity to remove IMI-resistant weedy rice outcrosses from the field with bentazon application. This technology, however, does not control the wild-type weedy rice or other weeds (Gressel and Valverde, 2009) because bentazon has a narrow spectrum of activity on broadleaf weeds.

4.4. Rotation of different herbicide-resistant rice varieties

Planting multiple HR rice varieties in rotation was suggested as one of the methods to prevent the spread of HR gene among weedy rice populations (Beckie, 2006; Beckie and Tardif, 2012). Gressel and Valverde (2009) proposed a six-season crop rotation program, which employs three types of rice varieties: (1) transgenic rice with glyphosate resistance and glufosinate + bentazon susceptibility, (2) transgenic rice with glufosinate resistance and glyphosate + bentazon susceptibility, and (3) non-transgenic rice (Table 4). They proposed that this method, along with appropriate herbicides in each season, could minimize the occurrence of HR hybrid weedy rice and volunteer weedy rice (Gressel and Valverde, 2009). Both glufosinate-resistant and glyphosate-resistant transgenic rice have not been approved for commercial use (Kumar et al., 2008; Demont et al., 2009). Glufosinate-resistant Liberty Link® rice had been grown previously in LSU AgCenter, U.S. for field demonstration purposes between 1999 and 2001 (Vermij, 2006). At the same period, field testing of glyphosate-resistant rice (Baldwin, 1999) and Liberty Link® rice (Burgos, N. R. unpublished data) were being conducted at the University of Arkansas Rice Research Center, also in the southern U.S. (Baldwin, 1999). However, the inadvertent escape of Liberty Link® rice seed into some batches of U.S. rice grain, and the ensuing public uproar, most likely prompted Monsanto to stop the field testing of glyphosate-resistant rice (Kumar et al., 2008) and caused Bayer Crop Science to drop its rice program in the US.

Table 4
Hypothetical crop technology sequence for a six-season rotation to control weedy rice and possible hybrid and volunteer weedy rice.[a]

Season	Rice varieties		Herbicides
	Resistance[c]	Susceptible	
1	GLY	GLU + BEN	GLY
2	GLU	GLY + BEN	GLU
3	GLY	GLU + BEN	GLY
4	GLU	GLY + BEN	GLU
5	GLY	GLU + BEN	GLY
6[b]	BEN	GLY + GLU	BEN

[a] If and when transgenic rice becomes acceptable to the public, options for weedy rice management in rice will include these available technologies.
[b] All hybrid and volunteer weedy rice will be eliminated at season 6, but normal weedy rice will be resistant to bentazon.
[c] GLY = glyphosate, GLU = glufosinate, BEN = bentazon.
Adapted from Gressel and Valverde (2009).

The implementation of transgenic approaches to weed management will be hindered by consumer refusal to use transgenic rice varieties (Croughan, 2003). One of the most notorious issues regarding transgenic rice is the contamination of Liberty Link® rice in U.S. rice export storage bins (Vermij, 2006). Traces of Liberty Link® contamination had been reported in Germany, Italy, Switzerland, Netherlands, and Mexico rice market (Vermij, 2006; Quirasco et al., 2008). This had resulted in the imposition of tighter regulations for companies developing transgenic food crops (Vermij, 2006). Sharing of knowledge on resistance gene among herbicide companies or biotechnology companies would be the most difficult obstacle in implementing this strategy (Gressel and Valverde, 2009). Furthermore, the complexity of this strategy would result in low adoption rates by farmers or no adoption at all.

5. Conclusion

The introduction of Clearfield® rice technology is a breakthrough in solving severe weedy rice infestation. This is reflected by the widespread adoption of Clearfield® rice to tackle weedy rice. However, this technology is not without its predicaments as the evolution of *ALS*-resistant weedy rice and the persistence of IMI herbicides in the soil are major concerns. In a few countries, *ALS*-resistant weedy rice outcrosses have been found abundant, which nullified the utility of Clearfield® rice. Persistence and leaching of IMI herbicides in the soil has injured sensitive rotational crops. These problems should be anticipated by countries that are considering adopting Clearfield® rice technology. Strict adherence to stewardship guidelines should be the norm and best management practices recommendations should be followed. This entails prioritizing sustained educational campaigns to growers and seed producers about the sensible use of this technology as well as overhauling the seed production and distribution systems of countries adopting Clearfield® rice. Currently, there is no single best way to counteract the evolving *ALS*-resistant weedy rice problem which arose from stewardship failures and factors beyond the growers' control. It is still most effective to integrate Clearfield® rice technology into existing weed management systems and adhere to best rice production practices.

Acknowledgments

The authors specifically thank Sunny Bottoms (Horizon Ag, USA); Drs. David Gealy, Man Azmi, Nguyen T. Lang, Bernal E. Valverde, Valmir Menezes, Aldo Ferrero, Chanya Maneechote, and Anurudika Abeysikera for providing supplemental information and helpful comments. Having worked on this review during a sabbatical period, BK Song thanks the Washington University in St. Louis and Monash University Sunway Campus for hospitality and support.

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Agricultural and Food Policy Center
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August 2010

ECONOMIC CONTRIBUTIONS OF THE US RICE INDUSTRY TO THE US ECONOMY

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This research was funded in part by the USA Rice Federation.

Research Report 10-3

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ECONOMIC CONTRIBUTIONS OF THE US RICE INDUSTRY TO THE US ECONOMY

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Introduction

Over the past three years the number of rice planted acres increased from 2.76 million acres to 3.04 million acres (Table 1). U.S. rice production reached a four year high of 219.9 million cwts in 2009. The value of U.S. rice production at the farm level exceeded $3 billion in 2009.

Given the recent growth in the U.S. rice industry it is time to update estimates of the economic impacts and contributions of the industry on the local and state economies. The purpose of this report is to estimate the economic contributions of rice farmers, millers, and selected end users on the U.S. economy and, to the extent possible, the state economies.

Methodology

The latest version of the Minnesota IMPLAN Group, Inc. model, IMPLAN V3, was used for the analysis. IMPLAN is an input/output model that traces the economic contributions of an industry's production, costs and receipts on 440 other industries in the U.S. economy. By summing the contributions of the rice industry to all other U.S. industries one can estimate rice's impacts on the U.S. economy and a state's economy.

IMPLAN uses data from the latest (2007) Survey of Manufacturers to develop the necessary multipliers for the 440 industries at all the state and U.S. levels. For the present study we coupled the state and national multipliers in IMPLAN V3 with the 2009 economic activity for the U.S. rice industry. This combination of model, multipliers, and economic activity gives one the most current estimate of economic contributions for the U.S. rice industry.

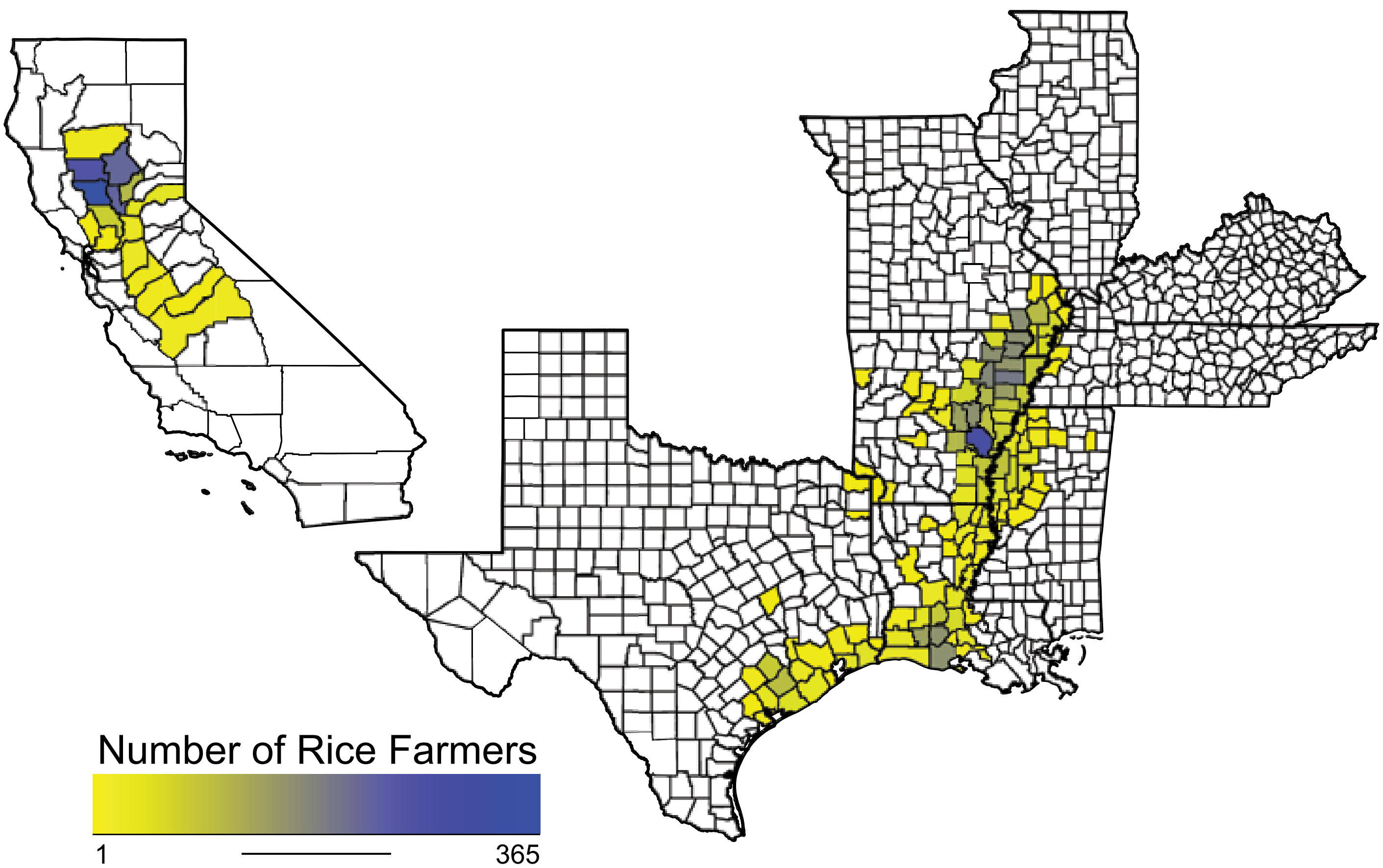

Figure 1: Number of Rice Farmers, by County.

Table 1. US Rice Industry Summary Information, 2006-2009.

States	Planted Acres (1)	Harvested Acres (1)	Average Yield (1)	Production	Average Price Rough Rice (1)	Farm Operators (2)	Base Acres (3)	Number of Rice Mills (4)	Milled Rice (1)	Average Price Milled Rice (1)
	(Acres)	(Acres)	(CWT/Acre)	(Cwts.)	($/CWT)	(No.)	(M.Ac.)	(No.)	(Cwts.)	($/CWT)
2006										
Arkansas	1,406,000	1,400,000	69.00	96,600,000	9.43				63,852,583	18.23
California	526,000	523,000	76.60	40,061,800	13.00				30,021,057	23.56
Louisiana	350,000	345,000	58.80	20,286,000	9.83				13,479,223	18.26
Texas	150,000	150,000	71.70	10,755,000	10.00				7,638,421	17.53
Mississippi	190,000	189,000	70.00	13,230,000	9.38				6,955,701	18.23
Missouri	216,000	214,000	64.00	13,696,000	9.38				10,402,999	18.23
Total	2,838,000	2,821,000	68.35	194,628,800					132,349,983	
2007										
Arkansas	1,331,000	1,325,000	72.30	95,797,500	12.10	4,602		16	63,322,130	20.64
California	534,000	533,000	82.00	43,706,000	16.20	2,518		17	32,751,906	26.08
Louisiana	380,000	378,000	61.40	23,209,200	12.70	1,303		7	15,421,571	21.00
Texas	146,000	145,000	65.50	9,497,500	12.40	667		10	6,745,319	21.10
Mississippi	190,000	189,000	73.50	13,891,500	12.60	621		2	7,303,486	20.64
Missouri	180,000	178,000	69.00	12,282,000	11.90	720		1	9,328,974	20.64
Total	2,761,000	2,748,000	70.62	198,383,700		10,431		53	134,873,386	
2008										
Arkansas	1,401,000	1,395,000	66.60	92,938,000	15.00				61,432,001	29.33
California	519,000	517,000	83.20	43,030,000	27.50				32,245,333	32.34
Louisiana	470,000	464,000	58.30	27,037,000	15.40				17,964,989	28.44
Texas	175,000	172,000	69.00	11,868,000	15.70				8,428,896	29.58
Mississippi	230,000	229,000	68.50	15,687,000	15.40				8,247,474	29.33
Missouri	200,000	199,000	66.20	13,173,000	13.80				10,005,746	29.33
Total	2,995,000	2,976,000	68.63	203,733,000					138,324,439	
2009										
Arkansas	1,486,000	1,470,000	68.00	99,960,000	13.40		1,851,328		66,073,542	38.32
California	461,000	556,000	86.00	47,816,000	18.60		615,919		35,831,811	50.62
Louisiana	470,000	464,000	63.00	29,232,000	12.60		792,724		19,423,477	36.05
Texas	171,000	170,000	77.70	13,209,000	12.50		590,052		9,381,302	33.01
Mississippi	245,000	243,000	67.00	16,281,000	12.80		395,699		8,559,770	38.32
Missouri	202,000	200,000	67.10	13,420,000	13.10		218,756		10,193,359	38.32
Total	3,035,000	3,103,000	71.47	219,918,000					149,463,261	

Sources:
(1) Values come from various NASS-USDA reports
(2) Values come from 2007 Census of Agriculture
(3) Values come from USDA-FSA
(4) Values come from 2007 Census of Manufactures

Scope of the Industry

The USDA census reports that in 2007 there were 10,431 rice farm operators[1] with 44% of them in Arkansas (Table 1). About 24% of rice farmers are in California with the remainder in Louisiana, Mississippi, Missouri and Texas. Figure 1 shows the concentration of rice farmers by county and Table A1 presents the numbers for Figure 1. Planted acres of rice correspond closely to where rice farmers are located (Figure 2). Base acres of rice indicate historical production of rice (Figure 3). For example, Texas is presently under planting base acres of rice so the planted acres and base acres for Texas do not show the same concentration. County base acres are presented in Table A1 and state level base acres are presented in Table 1.

Rice millers are located in all six rice producing states (Table 1). The number of rice mills reported in Table 1 comes from the 2007 U.S. Survey of Manufacturers. Locations of millers and merchants are summarized in Figure 4.

[1] A farm operator is the person who runs the farm, making the day-to-day decisions.

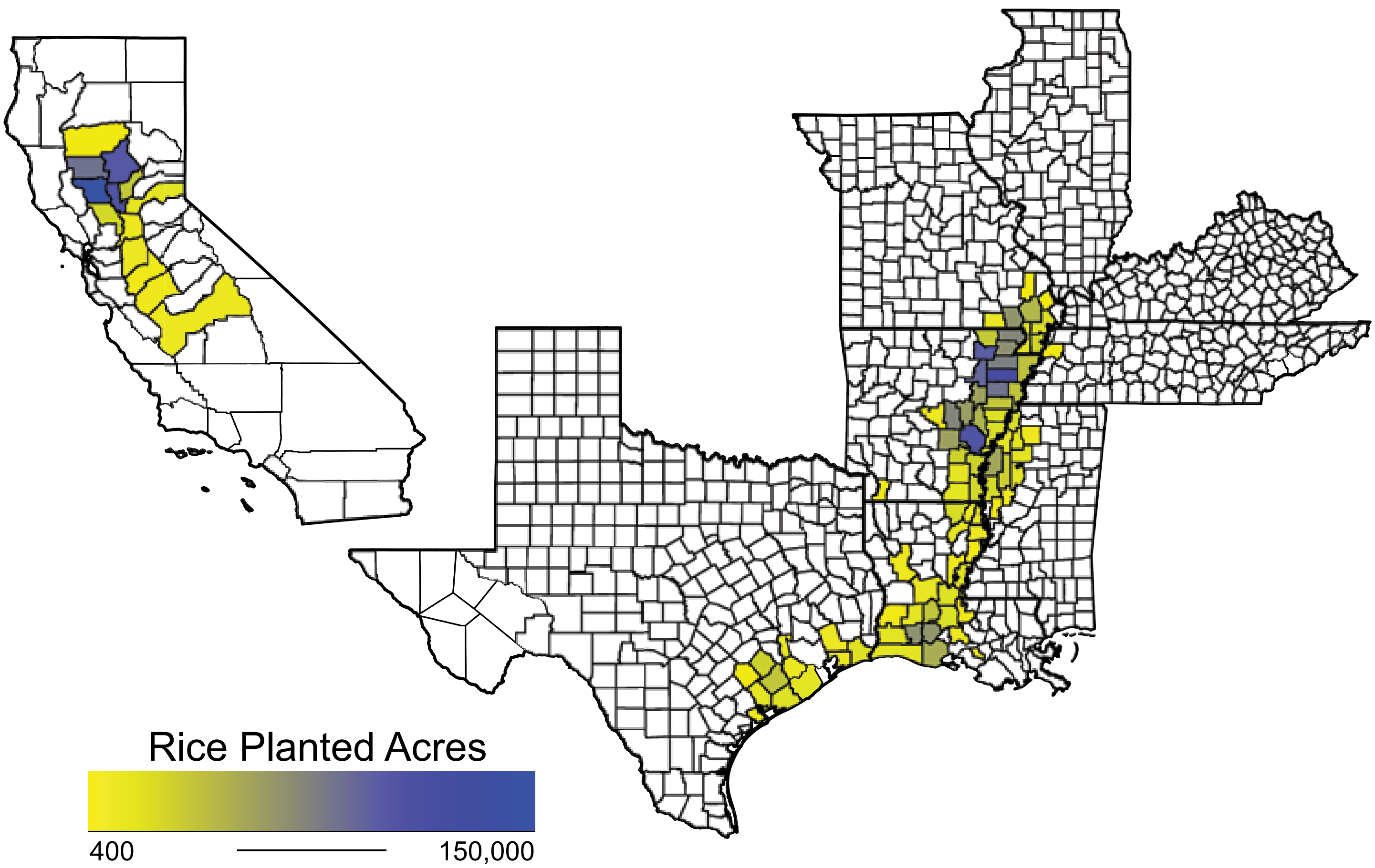

Figure 2: Planted Rice Acres, by County.

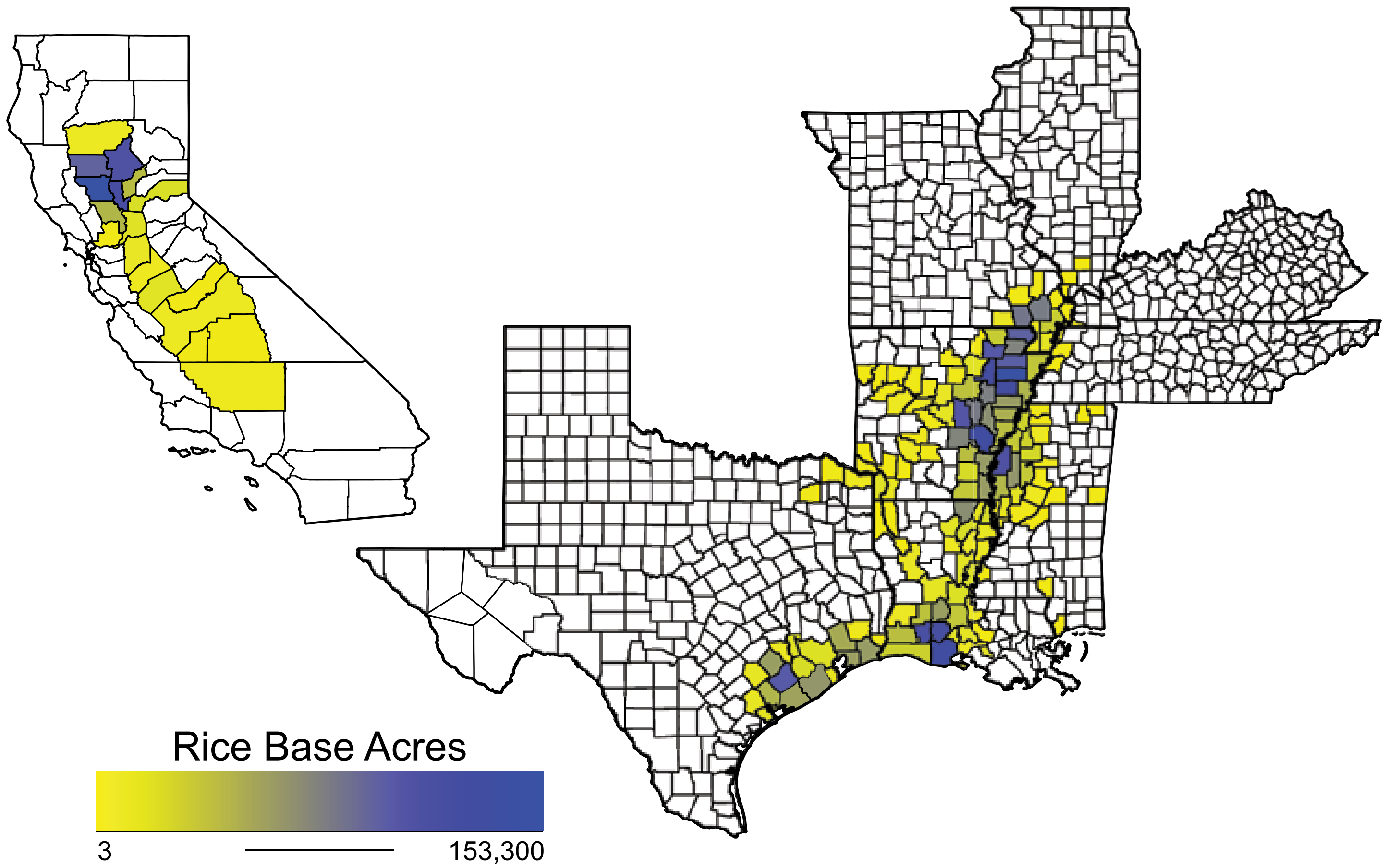

Figure 3: Rice Base Acres, by County.

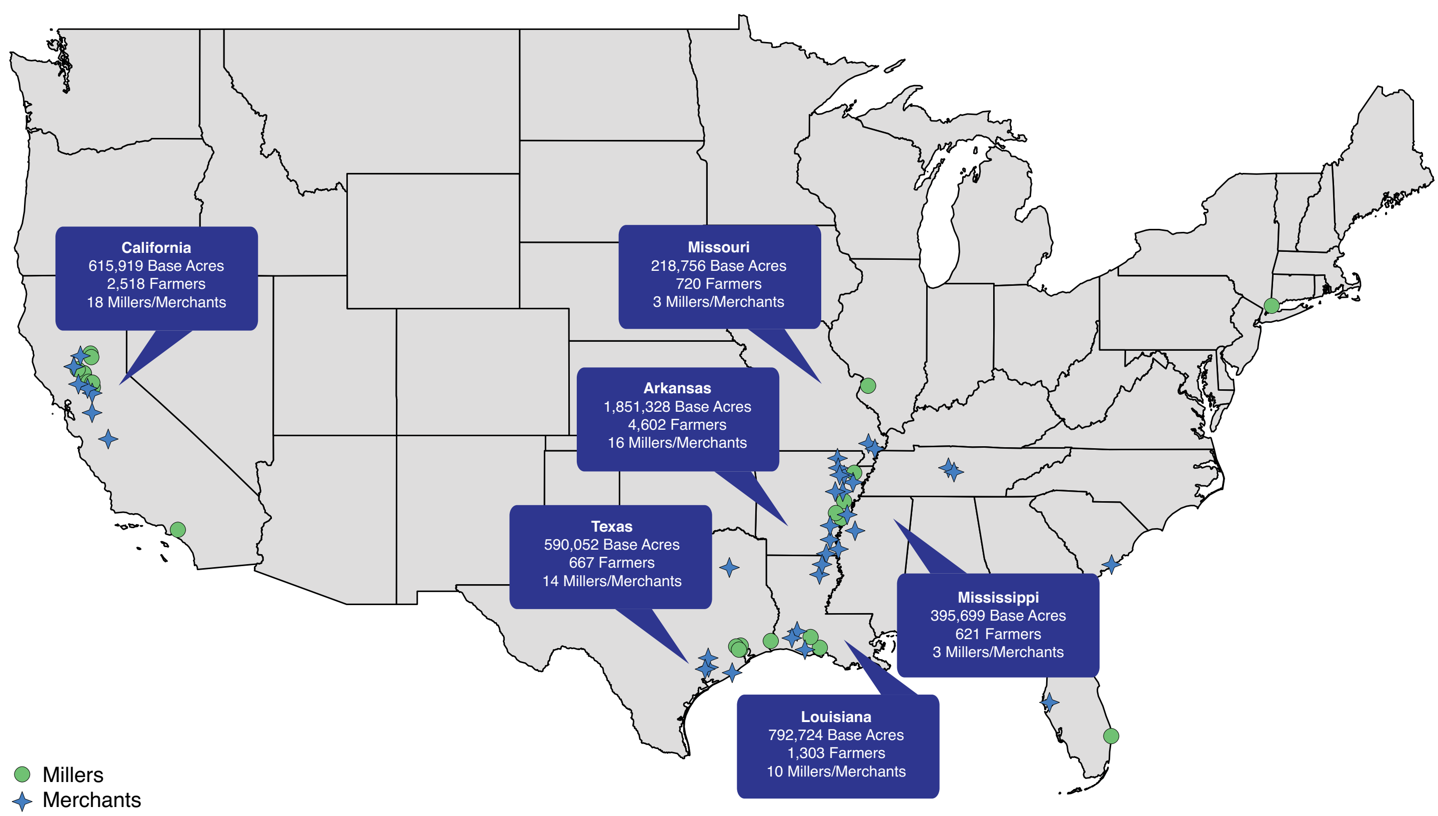

Figure 4: Location of US Rice Mills and Merchants.

Economic Contributions

The economic contributions of the U.S. rice industry are presented in three parts: farmers, millers, and end users. For each sector of the industry we reported estimates for: output, value added, and number of jobs supported. To provide further detail the contributions are disaggregated into four types of effects: direct, indirect, induced, and total.

Direct effects amount to the sum of contributions that are directly attributable to farmers, millers, or end users. In the case of employment, the direct effect is the number of jobs supported by farmers, millers, or end users. The indirect effects are the economic activity and jobs supported by businesses that supply inputs to farmers, millers, or end users. The induced effect is the economic activity created through purchases and jobs created by the employees of input suppliers and their suppliers.

The three main economic contribution categories (output, value added, and jobs) are defined in the box below.

Definitions for IMPLAN Economic Contribution Categories

Output is a measure of the value of goods and services produced in the State as a result of the increased demand created by expenditures by rice farms and rice mills. Output is measured by purchases of all intermediate production inputs and value added.

Value Added is the total wages and salaries plus business profits generated by the economic activities of a particular industry. In this case value added is the direct and indirect wages, salaries and profits generated in a state by the activities of buying inputs and production products by rice farmers, rice millers, or end users.

Number of Jobs is the number of all wage and salary employees as well as self-employed jobs resulting from total expenditures by rice farmers and mills. The number of jobs does not accumulate, because it is an annual measure.

Farmer Contributions

The net economic contributions of rice farming on the local and U.S. economies are summarized in Table 2. The total output effect on the U.S. economy was $5.347 billion in 2009. The total number of jobs supported by rice farmers was 36,480 and the value added amounted to about $2.6 billion.

At the state level, Arkansas rice farmers support about the same number of direct jobs as California (7,845 vs. 7,772) and more indirect jobs (1,952 vs. 1,381). California has a much greater (3,503 vs. 2,500) induced employment contribution resulting in the California rice farmers supporting 12,656 jobs while Arkansas farmers support 12,297 jobs. Louisiana rice farmers support about 4,320 jobs while, Missouri, Mississippi, and Texas support 2,062, 2,423, and 2,723 jobs, respectively.

Total output contributions for Arkansas and California of $1.89 billion and $1.79 billion, respectively, are three times greater than Louisiana's output contribution. Due in part to lower production 29.2 billion cwt. vs. 99.9 billion cwt. for Arkansas and 47.8 billion cwt. for California. Another factor that reduces Louisiana's output is lower prices reported for rice in 2009 (Table 1). The 2009 output contributions for Missouri, Mississippi, and Texas were in the $283 to $394 million range.

The farmer contributions through value added to the state's GDP show California leads with $997 million in 2009. Arkansas was second with $746 million in value added. The remaining states' contributions to their states' value added is in the $128 million to $279 million range.

Millers Contribution

Economic contributions of rice millers in 2009 to the U.S. economy were estimated to be $6.4 billion in value added, 38,092 jobs, and $10.97 billion in increased output (Table 3). These large economic contributions were attributed to the six states with rice mills. The greatest economic contributions from millers was in Arkansas where the industry supported output of $4.19 billion, employment of 13,538 jobs, and value added of $2.5 billion. California rice millers contributed about $2.1 billion in value added to the state's economy. Louisiana rice millers contributed almost $750 million while Mississippi and Texas millers contributed about $358 million each.

Table 2. Economic Contributions of Rice Production by State and US for 2009, Calculated Using the 2010 IMPLAN Model for 2008 Business Census Data

	Output	Employment	Total Value Added
	(Millions $s)	(Number)	(Millions $s)
Arkansas			
Direct Contributions	1,320.84	7,845	441.14
Indirect Contributions	307.64	1,952	153.84
Induced Contributions	264.88	2,500	151.66
Total Contributions	1,893.37	12,297	746.65
California			
Direct Contributions	910.85	7,772	528.33
Indirect Contributions	322.07	1,381	151.51
Induced Contributions	557.60	3,503	317.90
Total Contributions	1,790.52	12,656	997.73
Louisiana			
Direct Contributions	392.67	2,787	160.03
Indirect Contributions	140.55	628	58.61
Induced Contributions	105.67	905	60.19
Total Contributions	638.90	4,320	278.83
Missouri			
Direct Contributions	174.89	1,319	71.43
Indirect Contributions	55.51	300	26.72
Induced Contributions	52.88	443	30.56
Total Contributions	283.28	2,062	128.71
Mississippi			
Direct Contributions	222.52	1,348	145.90
Indirect Contributions	39.75	254	17.54
Induced Contributions	84.86	821	48.47
Total Contributions	347.14	2,423	211.92
Texas			
Direct Contributions	211.05	1,622	134.76
Indirect Contributions	65.96	250	32.55
Induced Contributions	117.54	851	67.72
Total Contributions	394.55	2,723	235.03
Total			
Direct Contributions	3,232.82	22,692	1,481.59
Indirect Contributions	931.49	4,765	440.77
Induced Contributions	1,183.44	9,023	676.50
Total Contributions	5,347.74	36,480	2,598.86

Table 3. Economic Contributions of Rice Milling by State and US for 2009, Calculated Using the 2010 IMPLAN Model for 2008 Business Census Data

	Output	Employment	Total Value Added
	(Millions $s)	(Number)	(Millions $s)
Arkansas			
Direct Contributions	2,960.40	2,240	1,773.35
Indirect Contributions	510.96	4,538	289.57
Induced Contributions	715.86	6,760	409.95
Total Contributions	4,187.22	13,538	2,472.86
California			
Direct Contributions	2,022.63	1,629	1,211.75
Indirect Contributions	726.30	5,096	378.76
Induced Contributions	883.44	5,560	503.82
Total Contributions	3,632.37	12,285	2,094.33
Louisiana			
Direct Contributions	818.11	1,648	490.13
Indirect Contributions	284.74	1	121.90
Induced Contributions	236.05	2,023	134.48
Total Contributions	1,338.90	5,308	746.51
Mississippi			
Direct Contributions	423.89	854	253.95
Indirect Contributions	98.75	793	44.37
Induced Contributions	103.46	1,003	59.12
Total Contributions	626.10	2,649	357.44
Texas			
Direct Contributions	355.05	715	212.71
Indirect Contributions	127.08	756	66.20
Induced Contributions	137.58	998	79.26
Total Contributions	619.71	2,468	358.18
Missouri			
Direct Contributions	403.33	305	241.60
Indirect Contributions	69.61	618	39.45
Induced Contributions	97.53	921	55.85
Total Contributions	570.47	1,844	336.91
Total			
Direct Contributions	6,983.42	7,390.33	4,183.49
Indirect Contributions	1,817.44	11,801.24	940.26
Induced Contributions	2,173.91	17,265.14	1,242.48
Total	10,974.78	38,092.39	6,366.22

Table 4. Summary of Economic Contributions for Rice Farmers and Millers, by State in 2009.

States	Output (Million $s)	Employment Jobs	Value Added (Million $s)
Arkansas	6,081	25,835	3,220
California	5,423	24,941	3,092
Louisiana	1,978	9,627	1,025
Missouri	854	3,906	466
Mississippi	973	5,073	569
Texas	1,014	5,191	593
Total	16,323	74,572	8,965

- Output is total goods and services produced due to the increased demand created by purchases by rice farmers and millers
- Employment is total number of jobs supported directly and indirectly by rice farmers and millers.
- Value Added is total wages and salaries plus business profits generated directly and indirectly by economic activities of rice farmers and millers.

State Level Contributions by Farmers and Millers

The total economic contribution of rice farmers and millers to each state's economy is summarized in Table 4. By state, Table 4 shows the sum of the total output, job creation, and value added for rice farmers and millers. The values come from the total contributions reported in Tables 2 and 3. Total contribution to economic production in Arkansas was $6.081 billion, 25,835 jobs were supported, and total wages, salaries and profits earned in the state amounted to $3.22 billion in 2009. California is second with their rice farmers and millers supporting 24,941 jobs, adding $5.423 billion to economic output, and $3.092 billion to the state's wages, salaries and profits. The national contribution from rice farmers and millers in 2009 was $16.323 billion in increased economic output, 74,572 jobs, and $8.965 billion of wages, salaries, and profits.

Table 5. US Economic Contributions for Rice Exporters, Food Processors, Brewers, and Pet Foods
Calculated Using the 2010 IMPLAN Model for 2008 Business Census Data

Sector/Impact	Output	Employment	Total Value Added
	(Million $s)	Jobs	(Million $s)
Exporters			
Direct Contributions	2,477	1,982	1,977
Indirect Contributions	714	4,616	421
Induced Contributions	2,890	7,680	1,543
Total Contributions	6,082	14,277	3,942
Processed Food			
Direct Contributions	2,146	1,502	467
Indirect Contributions	2,869	14,074	1,272
Induced Contributions	1,832	6,224	979
Total Contributions	6,848	21,800	2,717
Brewery Industry			
Direct Contributions	405	217	126
Indirect Contributions	525	1,985	217
Induced Contributions	262	1,686	140
Total Contributions	1,192	3,888	483
Pet Food			
Direct Contributions	395	349	77
Indirect Contributions	593	2,544	224
Induced Contributions	243	1,561	130
Total Contributions	1,231	4,454	430
Other Users			
Direct Contributions	892	630	215
Indirect Contributions	1,230	5,325	504
Induced Contributions	629	3,277	336
Total Contributions	2,751	9,232	1,055
Total			
Direct Contributions	6,315	4,680	2,862
Indirect Contributions	5,932	28,544	2,638
Induced Contributions	5,857	20,428	3,128
Total Contributions	18,103	53,651	8,628

Table 6. Summary of Economic Impacts of the US Rice Industry on the US Economy.

	Output	Jobs Supported	Value Added
	(M$s)		(M$s)
Farming Sector	5,348	36,480	2,599
Milling Sector	10,975	38,092	6,366
Final Users	18,103	53,651	8,628
Total	34,426	128,224	17,593

End User Contributions

There are numerous end users for rice, however, the quantities of rice used becomes quite small after we consider exporters, processed food manufacturers, brewers, and pet food manufacturers. The 2009 economic contributions for exporters, food processors, brewers, and pet food, in terms of contributions directly related to the rice they purchased and processed, are reported in Table 5.

Rice exporters purchased, transported, warehoused, and exported about 90.5 million cwts in 2009. For this level of trade the IMPLAN economic contributions were estimated at: $6.1 billion of economic output, 1,982 direct jobs and 14,277 total jobs supported, and about $4 billion of value added to the U.S. economy (Table 5).

The processed food sector had a smaller direct jobs impact (1,502 jobs) but the sector has much greater indirect jobs multipliers (Table 5). The indirect jobs contribution result comes from the industry purchasing other inputs from many more industries than the export sector. The processed food sector in total supported 21,800 jobs that can be traced to its purchasing and processing of rice. Value added to the U.S. economy from food processors was $2.7 billion.

The brewery industry contributed 3,888 jobs and a value added of $483 million that is attributable to its use of rice in 2009. Pet food manufacturers use rice but like breweries, their labor efficiency is so great that the number of jobs directly attributable to rice was small (349) in 2009. Total U.S. economic output from rice use by pet food manufacturers is small at $1.2 billion, as well as the total value added contribution of $430 million.

These four end users for rice do not account for all rice used by end users. To account for the many other end users we created a residual or other users sector and assumed the average multipliers for the processed food, brewery and pet foods sectors. The economic contributions for all other rice end users is reported in Table 5. After accounting for the other users an estimate of the total 2009 economic contributions of rice end users was $18 billion of output, 53,651 jobs and $8.6 billion in value added.

Summary

The impacts of the U.S. rice industry on the United States' economy are summarized in Table 6. More than 128,000 jobs were supported directly and indirectly by rice production in 2009. Rice contributed more than $17.6 billion to U.S. wages, salaries, and profits. Rice was also responsible for more than $34 billion of economic output nationally.

Appendix Table

Table A1. County Values for the Number of Rice Farmers, Rice Planted Acres and Rice Base Acres.

State	County	Farmers	Planted Acres	Base Acres
Alabama	Baldwin	0	0	49
Arkansas	Arkansas	275	106,000	128,225
Arkansas	Ashley	21	11,200	32,484
Arkansas	Chicot	56	25,100	59,013
Arkansas	Clark	0	0	3,253
Arkansas	Clay	158	73,500	94,882
Arkansas	Cleburne	0	0	53
Arkansas	Conway	1	0	1,446
Arkansas	Craighead	150	78,200	96,720
Arkansas	Crawford	1	0	364
Arkansas	Crittenden	73	36,800	45,302
Arkansas	Cross	140	85,200	119,492
Arkansas	Dallas Cleveland	0	0	197
Arkansas	Desha	83	27,600	59,974
Arkansas	Drew	34	10,300	21,567
Arkansas	Faulkner	2	0	5,686
Arkansas	Franklin	0	0	275
Arkansas	Greene	165	67,700	73,931
Arkansas	Hempstead	0	0	419
Arkansas	Hot Spring	1	0	1,307
Arkansas	Independence	36	0	12,357
Arkansas	Jackson	170	92,500	119,732
Arkansas	Jefferson	102	58,200	72,844
Arkansas	Johnson	0	0	46
Arkansas	Lafayette	9	2,100	8,320
Arkansas	Lawrence	157	98,500	99,901
Arkansas	Lee	46	17,900	47,849
Arkansas	Lincoln	45	26,600	38,782
Arkansas	Little River	2	0	2,539
Arkansas	Logan	0	0	681
Arkansas	Lonoke	134	73,700	101,654
Arkansas	Miller	2	0	13,610
Arkansas	Mississippi	75	37,500	34,077
Arkansas	Monroe	89	46,700	67,027
Arkansas	Nevada	0	0	152
Arkansas	Perry	1	0	2,782
Arkansas	Phillips	66	19,900	38,533
Arkansas	Poinsett	192	117,500	151,439
Arkansas	Pope	4	0	1,039
Arkansas	Prairie	158	60,000	79,376
Arkansas	Pulaski	14	3,800	8,676
Arkansas	Randolph	52	32,600	30,294
Arkansas	Saline	0	0	20
Arkansas	Sevier	0	0	18
Arkansas	Sharp	0	0	26
Arkansas	St Francis	76	34,300	58,992
Arkansas	Stone	0	0	11
Arkansas	Unassigned	0	31,100	0
Arkansas	White	60	0	36,285
Arkansas	Woodruff	102	56,500	76,378
Arkansas	Yell	0	0	3,300

Table A1. Contiued

State	County	Farmers	Planted Acres	Base Acres
California	Butte	217	102,000	106,530
California	Colusa	365	155,000	153,302
California	Fresno	7	2,900	3,304
California	Glenn	249	86,500	93,482
California	Kern	0	0	2,128
California	Kings	0	0	213
California	Madera	1	0	46
California	Merced	5	2,600	12,720
California	Napa	1	0	0
California	Placer	26	10,500	18,798
California	Sacramento	15	3,700	14,622
California	San Joaquin	12	4,800	6,583
California	Solano	1	0	75
California	Stanislaus	6	1,700	2,652
California	Sutter	222	106,000	115,086
California	Tehama	6	800	3,503
California	Tulare	0	0	455
California	Yolo	69	23,800	43,304
California	Yuba	102	33,700	39,116
Florida	Glades	0	0	779
Florida	Gulf	0	0	20
Florida	Hendry	0	0	6
Florida	Palm Beach	7	11,376	16,870
Illinois	Alexander	3	0	182
Illinois	Union	0	0	6
Illinois	Williamson	0	0	8
Kentucky	Fulton	0	0	146
Louisiana	Acadia	154	64,800	114,730
Louisiana	Allen	27	11,300	36,584
Louisiana	Avoyelles	25	14,700	17,522
Louisiana	Beauregard	4	1,100	4,308
Louisiana	Bossier	0	0	108
Louisiana	Caddo	0	0	118
Louisiana	Calcasieu	23	12,600	38,646
Louisiana	Caldwell	1	0	3,000
Louisiana	Cameron	15	11,400	27,505
Louisiana	Catahoula	9	2,400	11,457
Louisiana	Concordia	12	11,700	16,005
Louisiana	East Carroll	25	6,600	23,420
Louisiana	Evangeline	78	35,400	57,918
Louisiana	Franklin	2	0	3,534
Louisiana	Iberia	5	0	2,956
Louisiana	Iberville	0	0	109
Louisiana	Jefferson Davis	134	66,800	112,881
Louisiana	Lafayette	11	0	9,290
Louisiana	Lincoln	4	0	0
Louisiana	Madison	12	5,200	10,503
Louisiana	Morehouse	35	21,900	67,814
Louisiana	Natchitoches	2	3,800	5,581
Louisiana	Ouachita	3	0	10,830
Louisiana	Pointe Coupee	2	2,400	4,265

Table A1. Contiued

State	County	Farmers	Planted Acres	Base Acres
Louisiana	Rapides	13	7,600	9,031
Louisiana	Red River	0	0	457
Louisiana	Richland	12	9,500	19,183
Louisiana	St Landry	55	18,700	32,795
Louisiana	St Martin	18	4,700	8,329
Louisiana	Tensas	2	1,100	6,714
Louisiana	Unassigned	0	12,500	0
Louisiana	Vermilion	157	50,000	126,272
Louisiana	West Carroll	8	3,700	10,858
Mississippi	Adams	0	0	97
Mississippi	Alcorn	0	0	8
Mississippi	Attala	0	0	11
Mississippi	Bolivar	86	54,500	106,604
Mississippi	Carroll	1	0	19
Mississippi	Coahoma	25	12,200	32,040
Mississippi	Desoto	5	0	1,921
Mississippi	Grenada	0	0	3,011
Mississippi	Hancock	0	0	130
Mississippi	Holmes	2	0	2,503
Mississippi	Humphreys	10	2,100	12,865
Mississippi	Issaquena	1	0	3,778
Mississippi	Lafayette	1	0	0
Mississippi	Lee	1	0	0
Mississippi	Leflore	29	10,800	31,962
Mississippi	Madison	0	0	400
Mississippi	Marion	0	0	42
Mississippi	Noxubee	0	0	31
Mississippi	Panola	7	3,800	3,645
Mississippi	Quitman	24	13,900	26,325
Mississippi	Sharkey	2	1,200	10,919
Mississippi	Sunflower	56	30,000	63,155
Mississippi	Tallahatchie	24	11,400	23,950
Mississippi	Tate	3	0	1,050
Mississippi	Tippah	0	0	3
Mississippi	Tunica	24	21,500	26,783
Mississippi	Unassigned	0	5,600	0
Mississippi	Washington	38	23,000	42,679
Mississippi	Yazoo	2	0	1,767
Missouri	Bollinger	2	800	870
Missouri	Butler	161	65,000	82,669
Missouri	Cape Girardeau	2	0	0
Missouri	Dunklin	36	16,200	7,849
Missouri	Mississippi	6	0	1,132
Missouri	New Madrid	57	19,900	29,931
Missouri	Pemiscot	55	26,300	10,917
Missouri	Ripley	14	6,200	5,594
Missouri	Scott	5	900	1,099
Missouri	Stoddard	97	43,800	78,677
Missouri	Unassigned	0	900	0
Missouri	Wayne	0	0	18

Table A1. Contiued

State	County	Farmers	Planted Acres	Base Acres
Oklahoma	Leflore	0	0	341
Oklahoma	Mccurtain	0	0	2,372
Oklahoma	Sequoyah	3	0	51
South Carolina	Kershaw	0	0	3
South Carolina	Marlboro	0	0	20
Tennessee	Dyer	3	1,267	985
Tennessee	Lake	2	0	627
Tennessee	Lauderdale	1	0	271
Texas	Austin	0	0	4,418
Texas	Bowie	1	0	3,423
Texas	Brazoria	24	11,700	62,709
Texas	Calhoun	10	2,100	11,357
Texas	Chambers	29	8,400	57,276
Texas	Colorado	74	27,000	58,284
Texas	Fort Bend	16	5,000	19,913
Texas	Galveston	2	0	10,477
Texas	Hardin	1	0	1,871
Texas	Harris	3	0	17,074
Texas	Hopkins	0	0	1,481
Texas	Jackson	23	10,300	44,761
Texas	Jefferson	35	14,300	59,395
Texas	Lavaca	5	1,100	7,622
Texas	Liberty	7	4,500	50,604
Texas	Marion	1	0	0
Texas	Matagorda	43	17,200	54,732
Texas	Orange	1	0	1,713
Texas	Red River	0	0	1,063
Texas	Robertson	1	0	0
Texas	Unassigned	0	2,800	0
Texas	Victoria	1	0	7,011
Texas	Waller	14	6,100	15,474
Texas	Wharton	94	35,500	99,394

SOURCE:

Number of farmers come from the 2007 Census of Agriculture, State and County Reports. The full report can be found at: http://www.agcensus.usda.gov/Publications/2007/Full_Report/index.asp

Planted acres by county come from USDA NASS, Quick Stats, Annual Statistics by Subject and can be found at: http://quickstats.nass.usda.gov/by_commodity

Base acres come from the USDA, ERS Data Sets for Farm Program Acres and is available at: http://www.ers.usda.gov/Data/BaseAcres/

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