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# Plant Biotechnology: Current and Potential Impact For Improving Pest Management In U.S. Agriculture An Analysis of 40 Case Studies

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## Herbicide Tolerant Rice

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**27. Rice**

**Herbicide Tolerant**

Production

Rice was harvested from 3.0 million acres in 2000 in the United States [1]. The value of this production was $1.0 billion [2]. Commercial rice production in the United States occurs primarily in three regions: California (Sacramento Valley), Gulf Coast region comprising Texas and southwest Louisiana, and the Mississippi Delta region that includes Arkansas, northeast Louisiana, Mississippi, and Missouri. California produces medium grain primarily while Mississippi produces only long grain [6] [7]. Arkansas, Louisiana, Texas, and Missouri produce medium and long grain rice types [4] [5]. Table 27.1 summarizes rice production by state.

Rice is a unique crop in that, unlike all other field crops, it is grown in flooded fields. It is grown mostly on fine-textured poorly drained soils and soils with impervious hardpans or clay pans. These soils are well suited as their low water permeability enhances water use efficiency, provides for easy ponding, and results in standing water conditions that rice requires.

Rice is planted either in a dry seeded system or waterseeded system. In dry seeding, rice is drilled or broadcasted and the fields are flushed with water to provide adequate moisture for germination and to activate preemergence herbicides. A permanent flood is established normally at the 3 to 4 leaf stage of crop growth. In waterseeding, a flood is established throughout the cropping season except for a short period after planting to allow the rice seeds to peg. As a result, water requirement for waterseeded rice is higher than dryseeded rice.

Weed Problems

Weeds are the most serious pests affecting rice production in the United States. Weeds compete with rice for nutrients, moisture, sunlight, and space. Weeds increase harvesting costs, cause drying problems, and result in reduced yields, quality, and market value [7]. About 80 species of weeds cause economic losses in rice in the United States [19]. These species belong to 40 genera classified as aquatic, semiaquatic, and terrestrial plants. Some germinate only in flooded soil, some germinate in an upland environment but grow in flooded soil, and some can germinate and grow in either environment. Consequently, weed control tactics must be effective on weeds that vary widely in their physical and physiochemical characteristics.

The ten most troublesome weeds in the six rice-growing states are listed in Table 27.2. Red rice is the most troublesome weed in rice production of Louisiana, Arkansas, and Missouri. Red rice and domesticated rice belong to the same genus and species, and share the same biological and physiological characteristics; thus it is difficult to selectively chemically control red rice in rice. Red rice at densities of 5, 108 and 215 plants/$m^2$ reduced rice grain yields by 22, 77, and 82%, respectively [18]. Waterseeding is a cultural method of controlling red rice as red rice cannot germinate and emerge in anaerobic conditions.

Barnyardgrass is the number one weed problem in California, Mississippi, and Texas and a significant problem in other rice growing areas also. Research has shown that one barnyardgrass plant per $m^2$ can reduce grain yields by 58 lb/A. When barnyardgrass is uncontrolled, yield losses of 25% are common and losses can range up to 50% [9]. Barnyardgrass is troublesome, as majority of the rice herbicides are sensitive to moisture conditions and somewhat weak on larger sized barnyardgrass. Thus, timing of herbicide application is crucial for barnyardgrass control.

## Weed Control

Management of weeds is critical for optimum rice yields. Mechanical weed control is of no value since rice is grown in rows of eight inches or less when drill seeded. Flooding and rotation with crops such as soybeans, wheat, milo, and cotton are the most commonly used cultural methods of weed control in rice. Flooding results in a saturated situation thus preventing seeds of terrestrial weeds such as barnyardgrass and sprangletop from germinating due to the absence of oxygen. However, flooding is not an effective tool for the control of aquatic weeds such as ducksalad and alligatorweed.

Waterseeding (muddy waterseeding or clear waterseeding) is used as a cultural method to control red rice, particularly in Louisiana. In the muddy water system, flood is established and presoaked rice seed is broadcast aerially. Before the rice seed is planted, the flooded field is tilled, thereby muddying the water and killing the germinated red rice which is the biggest weed problem that would emerge in clear water. After muddying, pre-germinated rice seeds are flown into water, floodwater is released, and the seedlings are allowed to peg in the soil. Once rice seedlings are anchored sufficiently, the flood is brought up slowly until a permanent flood is established. Another waterseeding system that is increasing in popularity is clear water planting in which after seedbed preparation, the field is flooded but not tilled, rice is planted, and clear water is released [11].

A total of 6.45 acre-feet of water is used to establish permanent flood in rice from seeding stage to 2 weeks before harvest [8]. Herbicides, such as thiobencarb, are applied into the flooded water after crop emergence for weed control. The treated waters are held on the fields or onsite for up to several weeks to allow the pesticides to degrade and are eventually diverted through a system of channels into local rivers. Concern for residual herbicide concentrations in irrigation return flows to local drainage has led to emphasis on lowering herbicide application rates in rice [8]. Additionally, in rice fields with 4 inches of flood water, suspended sediment concentration may be as high as 15,000 ppm due to muddying of water for seeding. Releasing muddied water can remove as much as 7.5 tons of soil sediment and nutrients per acre from a rice field [11]. Table 27.3 displays estimates of the extent of waterseeding of rice, which is practiced primarily for weed control.

Herbicide options and weed management strategies differ between dry seeding and waterseeding methods. However, managing both herbicides and water in a timely manner is critical in both the systems. In dry seeded system, four to six weeks may elapse between planting and permanent flood establishment and controlling weeds during this period is critical [13].

Based on the time of application, herbicides used in rice are categorized into preplant, preemergence (PRE), and postemergence (POST). Herbicides that are applied preplant include thiobencarb and molinate. Thiobencarb is used in water-seeded rice only while molinate is used in both dryland and waterseeded systems. Thiobencarb is effective on barnyardgrass and annual sedges and provides only suppression of red rice. Molinate's weakness is that it is a barnyardgrass-only herbicide, varying in efficacy on other weeds. The residual activity of molinate and thiobencarb is up to 8 and 20 days, respectively. Preemergence herbicides are quinclorac, pendimethalin, and thiobencarb. Quinclorac controls annual grasses and some broadleaf weeds but is ineffective on sprangletop. Pendimethalin controls annual grasses including sprangletop and broadleaf signalgrass.

Postemergence rice herbicides are propanil, molinate, fenoxaprop, quinclorac, bentazon, acifluorfen, bensulfuron, 2,4-D, and triclopyr. These herbicides are mixed in various combinations to achieve a broader range of weed control. Propanil is effective on barnyardgrass (1 to 4 leaf stage) and many other grasses and broadleaf weeds in rice fields. Fenoxaprop controls several grass weeds and is usually injurious to rice. Bentazon, acifluorfen, bensulfuron, 2,4-D, and triclopyr are broadleaf herbicides. Acifluorfen controls hemp sesbania while bensulfuron is an excellent herbicide for aquatic broadleaf weeds. Triclopyr controls alligatorweed, hemp sesbania, red stem, and jointvetch. Two herbicides that were recently registered for use in rice are clomazone and halosulfuron. Clomazone is inexpensive and controls all grass weeds and certain broadleaf weeds [16]. Halosulfuron is predominantly a nutsedge herbicide with activity on broadleaf weeds also.

Most of the POST rice herbicides need to be applied to the partial or fully drained fields to ensure coverage of the weeds with herbicide. The diverse weed flora (terrestrial and aquatic) in rice fields usually necessitate the use of two or more herbicides for the control of a range of weeds.

Reliance on a single herbicide can lead to the development of herbicide-resistant weeds in rice. Repeated use of propanil has resulted in the development of barnyardgrass biotypes resistant to propanil in Arkansas and California. In Louisiana and Mississippi, quinclorac-resistant barnyardgrass has been observed. Widespread use of quinclorac has also resulted in the abundance of escaped sprangletop species in Missouri, as quinclorac is a weak herbicide on this weed [5]. Aquatic weeds have developed resistance to bensulfuron in California (28% of the total acres were infested with resistant weeds) [11]. Controlling herbicide-resistant weeds with the available chemical choices is difficult due to lack of effective control. Non-selective herbicides such as glufosinate or glyphosate provide broad spectrum weed control and could help in controlling weeds that have developed resistance to the traditional rice herbicides due to their alternative mode of action. Table 27.4 displays estimates or current usage and cost of herbicides applied to rice acreage by state.

Herbicide Tolerant Rice

There are currently two varieties of transgenic herbicide tolerant rice being developed: Liberty Link (developed by Aventis) and Roundup Ready (developed by Monsanto). Liberty Link rice withstands the applications of the non-selective herbicide, glufosinate while Roundup Ready rice can tolerate the applications of glyphosate.

Research suggested that single or sequential applications of glufosinate provided excellent control of red rice, barnyardgrass, and broadleaf signalgrass [22] [23]. Researchers have reported excellent control (90% or greater) of 3-4 leaf red rice from sequential glufosinate rates as low as 0.27 lb AI/A compared to a single application of 1 lb AI/A [21]. In comparison, preplant incorporated molinate at 3 to 4 lb AI/A provided red rice control ranging from 56 to 70% only [17].

## Estimated Impacts

The main benefit offered by transgenic rice would be greater control of red rice which is a major problem in the Delta and Gulf Coast producing areas. In California where red rice is not a severe threat, production losses due to other weeds, such as barnyardgrass, that are resistant to common herbicides are a problem [12]. Use of transgenic rice would allow the postemergence applications of nonselective herbicides, glufosinate and glyphosate, for the effective control of the resistant weeds. Since these herbicides control a broad-spectrum of weeds that infest rice fields, the overall amount of active ingredients required for weed control will be reduced. Table 27.5 displays estimates of herbicide use reductions that would occur with the planting of glufosinate resistant rice on acres that are currently waterseeded.

With an effective herbicide for controlling red rice and resistant grasses, rice growers would no longer need to practice waterseeding, which is more costly than dry seeded rice due to additional costs for water, tillage and seed. Table 27.6 displays estimates of cost savings that would occur as a result of switching waterseeded acreage to dry seeding following the adoption of herbicide tolerant rice. Also shown in Table 27.6 are estimated net savings in herbicide use costs that would result from substituting glufosinate for current herbicides used on waterseeded acres.

Rice growers could reduce herbicide use by 3.8 million pounds/year with the adoption of the herbicide tolerant rice varieties. Savings to growers would amount to $19 million per year for reductions in land preparation and seed costs and $30 million from reduced herbicide expenses.

The states of California and Louisiana would experience the greatest impacts since waterseeding is currently practiced to a greater extent in those two states.

**Table 27.1 Rice Production by State (2000)**

| | Acres (000) | Production (million lbs) | Value (million $) |
|---|---|---|---|
| **AR** | 1410 | 8611 | 482 |
| **CA** | 548 | 4352 | 217 |
| **LA** | 480 | 2440 | 142 |
| **MS** | 218 | 1286 | 73 |
| **MO** | 169 | 963 | 52 |
| **TX** | 214 | 1434 | 83 |
| **US** | 3039 | 19086 | 1049 |

**Source: [1] [2]**

**Table 27.2 Ten most troublesome weeds in rice growing states of the US.**

| ***Rank*** | Arkansas | Louisiana | Mississippi | Texas | Missouri | California |
|---|---|---|---|---|---|---|
| ***1*** | Red rice | Red rice | Barnyardgrass | Barnyardgrass | Red rice | Barnyardgrass |
| ***2*** | Barnyardgrass | Paspalum species | Palmleaf morningglory | Junglerice | Barnyardgrass | Watergrass |
| ***3*** | Sprangletop | Nutsedge species | Pitted morningglory | Redrice | Giant foxtail | Sprangletop species |
| ***4*** | Nutsedge | Sprangletops | Red rice | Texasweed | Sprangletops | Umbrella sedge |
| ***5*** | Smartweed | Alligatorweed | Amazon sprangletop | Broadleaf signalgrass | Broadleaf signalgrass | Ricefield bulrush |
| ***6*** | Broadleaf signalgrass | Texasweed | Ducksalad | Sprangletops | Hemp sesbania | Redstem |
| ***7*** | Jointvetch | Ducksalad | Purple ammania | Dayflowers | Morningglory species | California arrowhead |
| ***8*** | Ducksalad/ Redstem | Dayflowers | Yellow nutsedge | Alligatorweed | Jointvetch | Ducksalad |
| ***9*** | Morningglory Species | Barnyardgrass species | Broadleaf signalgrass | Soft rush | Redstems | Water hyssop |

| | | | | | | |
|---|---|---|---|---|---|---|
| ***10*** | Hemp sesbania | Broadleaf signalgrass | Hemp sesbania | Flatsedges | Smartweeds | Common water plantain |

Source: [1] [3] [4] [6] [20].

| **Table 27.3** | **Waterseeded Rice Acres: US** | | |
|---|---|---|---|
| | (000 A) | % Waterseeded[1] | Acres Waterseeded |
| **AR** | 1410 | 1 | 14 |
| **CA** | 548 | 95 | 521 |
| **LA** | 480 | 75 | 360 |
| **MS** | 218 | 1 | 2 |
| **MO** | 169 | 15 | 25 |
| **TX** | 214 | 10 | 21 |
| **Total** | **3039** | | **943** |

[1]Sources: [24] [25] [26] [27] [28] [5]

| **Table 27.4** | **Herbicide Use: US Rice Acreage (2000)[1]** | | | | |
|---|---|---|---|---|---|
| | **Area Applied (%)** | **Rate per Crop Year (lbs/A)** | **Total Applied (000 lbs)** | **$/lb AI[2]** | **$/yr (000)** |
| **Arkansas** | | | | | |
| **2, 4-D** | 12 | 0.65 | 112 | 3 | 336 |
| **Acifluorfen** | 6 | 0.17 | 16 | 31 | 496 |
| **Bentazon** | 6 | 0.53 | 44 | 19 | 836 |
| **Clomazone** | 45 | 0.43 | 275 | 26 | 7150 |
| **Glyphosate** | 15 | 0.92 | 198 | 10 | 1980 |
| **Halosulfuron** | 6 | 0.05 | 4 | 282 | 1128 |
| **Molinate** | 19 | 2.33 | 631 | 6 | 3786 |
| **Pendimethalin** | 13 | 0.91 | 165 | 6 | 990 |
| **Propanil** | 75 | 3.31 | 3532 | 5 | 17660 |
| **Quinclorac** | 18 | 0.15 | 39 | 64 | 2496 |
| **Triclopyr** | 14 | 0.30 | 59 | 66 | 3894 |
| **(Total)** | | **3.57** | **5075** | **29** | **40752** |
| **California** | | | | | |
| **Bensulfuron** | 30 | | 7 | 2000 | 14224 |
| **2, 4-D** | | | 9 | 3 | 26 |
| **Fenoxaprop** | 4 | | 1 | 102 | 152 |
| **Glyphosate** | | | 6 | 10 | 62 |
| **MCPA** | | | 22 | 4 | 88 |
| **Molinate** | 59 | | 1026 | 6 | 6155 |
| **Pendimethalin** | | | 3 | 6 | 21 |
| **Propanil** | 60 | | 1357 | 5 | 6785 |
| **Thiobencarb** | 50 | | 1006 | 6 | 6038 |
| **Triclopyr** | 50 | | 78 | 26 | 2023 |
| **(Total)** | | **6.39** | **3515** | **65** | **35574** |
| **Louisiana** | | | | | |
| **2, 4-D** | 40 | 1.11 | 213 | 3 | 639 |
| **Bensulfuron** | 55 | 0.04 | 11 | 2000 | 22000 |
| **Glyphosate** | 5 | 1.00 | 25 | 10 | 250 |

| | | | | | |
|---|---|---|---|---|---|
| **Halosulfuron** | 6 | 0.02 | 1 | 282 | 282 |
| **Molinate** | 30 | 2.55 | 368 | 6 | 2208 |
| **Propanil** | 27 | 3.14 | 404 | 5 | 2020 |
| **Quinclorac** | 42 | 0.13 | 27 | 64 | 1728 |
| **(Total)** | | **2.16** | **1049** | **60** | **29127** |
| **Mississippi** | | | | | |
| **2, 4-D** | 41 | 0.77 | 70 | 3 | 210 |
| **Acifluorfen** | 10 | 0.22 | 5 | 31 | 155 |
| **Clomazone** | 68 | 0.56 | 84 | 26 | 2184 |
| **Glyphosate** | 28 | 0.98 | 61 | 10 | 610 |
| **Halosulfuron** | 11 | 0.04 | 1 | 282 | 282 |
| **Molinate** | 16 | 2.39 | 84 | 6 | 504 |
| **Propanil** | 43 | 4.07 | 385 | 5 | 1925 |
| **Quinclorac** | 43 | 0.24 | 22 | 64 | 1408 |
| **(Total)** | | **3.23** | | **33** | **7278** |
| **Texas** | | | | | |
| **Bensulfuron** | 24 | 0.13 | 7 | 2000 | 14000 |
| **Bentazon** | 32 | 0.51 | 35 | 19 | 665 |
| **Glyphosate** | 22 | 0.94 | 45 | 10 | 450 |
| **Halosulfuron** | 48 | 0.03 | 3 | 282 | 846 |
| **Molinate** | 38 | 2.08 | 172 | 6 | 1032 |
| **Propanil** | 82 | 3.13 | 552 | 5 | 2760 |
| **Quinclorac** | 58 | 0.12 | 15 | 64 | 960 |
| **Thiobencarb** | 16 | 1.75 | 59 | 6 | 354 |
| **(Total)** | | **4.13** | **888** | **98** | **21067** |

**[1]Source: [10] [14]**
**[2]Source: [15]**

**Table 27.5 Herbicide Use Impact: Transgenic Rice**

| | | Herbicide Use (lbs/A) | | | |
|---|---|---|---|---|---|
| | Acres Waterseeded (000) | Current | Herbicide Tolerant | Change | Total Change (000 lbs) |
| **AR** | 14 | 3.57 | .54 | -3.03 | -42 |
| **CA** | 521 | 6.39 | .54 | -5.85 | -3048 |
| **LA** | 360 | 2.16 | .54 | -1.62 | -583 |
| **MS** | 2 | 3.23 | .54 | -2.69 | -5 |
| **MO** | 25 | 3.57 | .54 | -3.03 | -75 |

| | | | | | |
|---|---|---|---|---|---|
| **TX** | 21 | 4.13 | .54 | -3.59 | -75 |
| **Total** | | | | | **-3828** |

**Table 27.6 Economic Impact of Herbicide Tolerant Rice**

**A) Change in Land Preparation/Seed Costs**

| | Acres (000) | $/A[1] | (000 $/yr) |
|---|---|---|---|
| **AR** | 14 | -25.60 | -350 |
| **CA** | 521 | -17.40 | -8857 |
| **LA** | 360 | -25.60 | -9000 |
| **MS** | 2 | -25.60 | -50 |
| **MO** | 25 | -25.60 | -625 |
| **TX** | 21 | -25.60 | -525 |
| | | | **-19407** |

[1]Source: [29] [30]

**B) Change in Herbicide Costs**

| | | $/A | | | |
|---|---|---|---|---|---|
| | Acres (000) | Current | Herbicide Tolerant | Change | (000 $) |
| **AR** | 14 | 29 | 33 | +4 | +56 |
| **CA** | 521 | 65 | 33 | -32 | -16672 |
| **LA** | 360 | 66 | 33 | -33 | -11880 |
| **MS** | 2 | 33 | 33 | 0 | 0 |
| **MO** | 25 | 29 | 33 | +4 | +100 |
| **TX** | 21 | 98 | 33 | -65 | -1365 |
| | | | | | **-29761** |

**C) Total Economic Impact (000 $)**

| | Land/Seed Costs | Herbicide Costs | Total |
|---|---|---|---|
| **AR** | -350 | +56 | -294 |
| **CA** | -8857 | -16672 | -25529 |
| **LA** | -9000 | -11880 | -20880 |
| **MS** | -50 | 0 | -50 |
| **MO** | -625 | +100 | -525 |
| **TX** | -525 | -1365 | -1890 |
| | **-19407** | **-29761** | **-49168** |

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