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Invited Lecture

# Integrated Weed Management in Rice in the USA[a)]

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## INTRODUCTION

Although rice[b)] is probably the leading food crop of the world, it is a major crop in the U.S. only in certain areas[1)]. Rice production in the U.S. is centered in the Southern states of Arkansas, Louisiana, Mississippi, Missouri, and Texas and in California. It is the principal crop in many counties and parishes in states where it is grown. Rice in the U.S. during 1978-1981 was grown on 1.2 to 1.4 million hectares; average annual production in this period was about 6.7 million metric tons valued at $1.5 billion[30)].

Annual losses due to weeds in rice have been estimated at about 17% of potential production or 1 million metric tons valued at $205 million.[7)]

The objectives of weed management in a rice production system are: (a) to prevent or minimize losses in grain yield due to weed competiton; (b) to prevent or minimize quality losses and subsequent lower value of rough and milled rice; (c) to permit highly efficient use of costly production inputs such as high-yielding cultivars, fertilizers, insect and disease control and irrigation water; (d) to lower water and energy requirements for production of rice; and (e) to minimize potential damage to the environment and nontarget organisms that we do not want to affect adversely.[13, 26, 29)]

Effective weed-control programs for rice integrate preventive, cultural, mechanical, chemical and biological practices.[26, 28)] Nonchemical methods may include some or all of the following practices: the planting of weed-free seed, crop rotation, land leveling, seedbed preparation, selection of the proper seeding method, and proper management of water and fertilizer. Chemical methods involve the use of herbicide treatments that selectively control weeds when applied correctly. Biological methods include use of endemic fungi[6, 8, 23)] and the use of wild ducks[27)]. Various types of weed-management methods are combined in the weed-control program and the weed-control inputs are integrated with other pest management and production practices for rice.[23)]

## WEEDS AND THEIR BIOLOGY

More than 50 weed species infest direct-seeded rice in the U.S.[5, 28)] The seven plants or groups

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b) Scientific names for plants are given in Table 1.

of plants most frequently reported as weeds of rice fields were barnyardgrass, broadleaf signalgrass, ducksalad, hemp sesbania, red rice, sprangletop, and sedges (bulrush, spikerush and umbrella-plant).[7,28] Of the seven, four are grasses (Poaceae), two are broadleaf weeds (Fabaceae and Pontederiaceae) and one is a sedge (Cyperaceae). Two of these are single species (broadleaf signalgrass and hemp sesbania) while the other five are weed groups containing two or more species and/or genera.

In the U.S. many ecological and crop-production principles influence the presence and abundance of species or groups of weeds in rice fields. Important factors include seeding method and soil moisture regime, crop rotation, air and soil temperature, land preparation, fertilization, rice cultivar, weed-control technology and the interactions of these factors.[20] Selected examples on the effect of a few of these factors on weed infestations will be discussed.

Seeding method and soil moisture affected weed infestations in rice. Direct seeding of rice into the floodwater reduced problems with annual grasses in the Southern U.S. but enhanced problems with aquatic weeds.[28] Presprouted rice, water-seeded with aerial equipment on a well-prepared and smoothed-in-the-water seedbed, reduced barnyardgrass, but this practice increased problems with aquatic weeds such as blue-green algae, redstem, waterhyssop and ducksalad.

The occurrence of a particular weed species in rice was often associated with the crop rotation. In a 10-year experiment, cropping systems included either soybeans or rice grown continuously or a rotation of soybeans and rice in a 2-year cycle.[25] All plots contained low weed infestations in 1960 when the experiment began. In plots planted continuously to rice, infestations of barnyardgrass, red rice and flatsedge increased with time, but plots in the rice-soybean rotation contained few of these weeds during the tenth year.

Land preparation influenced weed infestations in rice. Repeated tilling of the soil at 1- to 3-week intervals before dry-seeding rice reduced barnyardgrass and other annual grass infestations, but this practice did not control blue-green algae, ducksalad, redstem and annual species of spikerush and umbrellaplant.[28]

**Table 1.** Common and scientific names of plants.

| Common Name | Scientific Name |
|---|---|
| **Crops** | |
| Grain sorghum | *Sorghum bicolor* (L.) Moench |
| Rice | *Oryza sativa* L. |
| Soybeans | *Glycine max* (L.) Merr. |
| **Weeds** | |
| Barnyardgrass | *Eichnochloa crusgalli* (L.) Beauv. |
| Blue-green algae | *Anabaena* sp., *Lyngbya* sp., *Nostoc* sp.,and *Phormidium* sp. |
| Broadleaf signalgrass | *Brachiaria platyphylla* (Griseb) Nash |
| Bulrushe | *Scirpus* spp. |
| Ducksalad | *Heteranthera limosa* (Sw.) Willd. |
| Eclipta | *Eclipta alba* (L.) Hassk. |
| False pimpernal | *Lindernia* spp. |
| Flatsedge | *Cyperus* spp. |
| Hemp sesbania | *Sesbania exaltata* (Raf.) Cory |
| Northern jointvetch | *Aeschynomene virginica* (L.) B.S.P. |
| Pondweed | *Potamogeton* spp. |
| American | *Potamogeton nodosus* Poir. |
| Horned | *Zannichellia palustris* L. |
| Red rice | *Oryza sativa* L. |
| Redstem | *Ammannia* spp. |
| Smartweed | *Polygonum* spp. |
| Spikerush | *Eleocharis* spp. |
| Sprangletop | *Leptochloa* spp. |
| Amazon | *Leptochloa panicoides* (Presl.) Hitchc. |
| Bearded | *Leptochloa fascicularis* (Lam.) Gray |
| Spreading dayflower | *Commelina diffusa* Burm. f. |
| Umbrellaplant | *Cyperus* spp. |
| Waterhyssop | *Bacopa rotundifolia* (Michx.) Wettst. |
| Winged waterprimrose | *Jussiaea decurrens* (Walt.) DC. |
| Yellow foxtail | *Sataria lutescens* (Weigel) Hubb. |

Fertilization affected weed infestations. Phosphorus applied preplant to rice stimulated the growth of many weeds including annual grasses such as barnyardgrass and broadleaf signalgrass, and aquatic weeds such as blue-green algae, ducksalad, redstem, and waterhyssop.[28] In fields

**Table 2.** Common and chemical names of herbicides and other pesticides.

| Common name | Chemical name |
|---|---|
| acifluorfen | 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid |
| alachlor | 2-chloro-2′,6′-diethyl-N-(methoxy methyl)acetanilide |
| aldrin | 1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-1,4-endo-exo-5,8-dimethanonaphthalene |
| atrazine | 2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine |
| benomyl | methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate |
| bentazon | 3-isopropyl-1H-2,1,3-benzothiadiazin-4 (3H)-one. 2,2-dioxide |
| bifenox | methyl 5-(2,4-dichlorophenoxy)-2-nitrobenzoate |
| butachlor | N-(butoxymethyl)-2-chloro-2′, 6′-diethylacetanilide |
| carbaryl | 1-naphthyl N-methylcarbamate |
| carbofuran | 2, 3-dihydro-2, 2-dimethyl-7-benzofuranyl methylcarbamate |
| fentin hydroxide | triphenyltin hydroxide |
| fluchloralin | N-(2-chloroethyl)-2, 6-dinitro-N-propyl-4-(trifluoro-methyl) aniline |
| fluazifop-butyl | butyl 2-[4-(5-trifluoromethyl-2-pyridinyloxy)phenoxy] propanoate |
| MCPA | [(4-chloro-o-tolyl)oxy] acetic acid |
| mefluidide | N-[2,4-dimethyl-5-[[(trifluoromethyl) sulfonyl] amino] phenyl] acetamide |
| methyl parathion | O, O-dimethyl O-p-nitrophenyl phosphorothioate |
| metolachlor | 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide |
| metribuzin | 4-amino-6-tert-butyl-3-(methylthio)-as-triazin-5(4H)-one |
| molinate | S-ethyl hexahydro-1H-azepine-1-carbothioate |
| oxadiazon | 2-tert-butyl-4-(2, 4-dichloro-5-isopropoxyphenyl)-$\Delta^2$-1,3,4-oxadiazolin-5-one |
| paraquat | 1, 1′-dimethyl-4, 4′-bipyridinium ion |
| pendimethalin | N-(1-ethylpropyl)-3, 4-dimethyl-2, 6-dinitrobenzenamine |
| propanil | 3′, 4′-dichloropropionanilide |
| propazine | 2-chloro-4, 6-bis (isopropylamino)-s-triazine |
| sethoxydim | 2-[1-ethoxyamino)-butyl)-5-(2-ethylthio)-propyl]-3-hydroxy-2-cyclohexene-1-one |
| silvex | 2-(2,4,5-trichlorophenoxy)propionic acid |
| 2,4,5-T | (2,4,5-trichlorophenoxy)acetic acid |
| 2,4-D | (2,4-dichlorophenoxy)acetic acid |
| thiobencarb | S-[(4-chlorophenyl)methyl] diethylcarbamothioate |
| toxaphene | chlorinated camphene |
| trifluralin | α,α,α-trifluoro-2, 6-dinitro-N, N-dipropyl-p-toluidine |

severly infested with annual grasses and aquatic weeds, application of phosphorus to another crop in the rotation prevented stimulation of weed growth that would be expected after direct applications to the rice crop.

Weed-control technology used affected weed infestations. The use of propanil[c)] or molinate, which do not control spreading dayflower, permitted infestations of this weed to increase.[21)] The use of combination treatments of propanil with residual herbicides such as bifenox, butachlor or thiobencarb controlled spreading dayflower and prevented it from increasing. The use of thiobencarb alone, which does not control broadleaf signalgrass, permitted increased infestations of this weed (R.J. Smith, Jr., unpublished). The use of combination treatments of thiobencarb and propanil or the use of other residual herbicides such as bifenox, butachlor, oxadiazon, or pendimethalin controlled broadleaf signalgrass and prevented its increase.

## WEED COMPETITION AND INTERFERENCE

Weeds interfere with rice production and processing in the following ways.[12,28)]

1. They reduce rice yields and quality.
2. They intensify problems with insects, diseases, and other pests by serving as hosts.
3. They reduce harvesting and processing efficiency.
4. They reduce efficiency of irrigation systems

by restricting the availablity and flow of water in reservoirs, canals, and ditches.

5. They cause consumption of energy for their control.
6. They may be pqisonous and injure animals and humans.
7. They reduce the value and productivity of land.

Species of weeds vary in the losses they inflict. Weed competition in field experiments in the U.S. indicated that season-long competition of barnyardgrass, bearded sprangletop, Amazon sprangletop, ducksalad, hemp sesbania, northern jointvetch and spreading dayflower reduced grain yields from 13 to 70% (Table 3).

**Table 3.** Yield losses due to competition of different weed species grown in direct-seeded paddy rice.[1/]

| Weed | Length of competition: 4 weeks | 8 weeks | 12 weeks | Season-long |
|---|---|---|---|---|
| Barnyardgrass | 8 | 34 | 43 | 70 |
| Bearded sprangletop | -- | -- | -- | 36 |
| Amazon sprangletop | -- | -- | -- | 35 |
| Hemp sesbania | 2 | 6 | 9 | 19 |
| Northern jointvetch | 2 | 8 | 8 | 17 |
| Ducksalad | 15 | 27 | -- | 21 |
| Spreading dayflower | -- | -- | -- | 13 |

1/ Data adapted from 14, 18; and R.J. Smith, Jr., unpublished for data on bearded sprangletop and spreading dayflower.

The effect of weed density on rice yields has been established in research plots for several rice field weeds in the U.S. Season-long competition of barnyardgrass at densities of 11 to 269 plants/$m^2$ reduced grain yields 25 to 79% in an optimum stand of rice (Table 4). In the same experiment, season-long competition of barnyardgrass at a density of 11 plants/$m^2$ reduced grain yields less as rice plant densities increased from 32 to 334 plants/$m^2$ (Table 5).

Season-long competition of bearded sprangletop at densities of 11 to 108 plants/$m^2$ reduced grain yields of rice 9 to 36% (Table 6).

**Table 4.** Yield losses from competition of barnyardgrass densities.[1/]

| Weed density | Yield loss |
|---|---|
| (Plants/$m^2$) | (%) |
| 11 | 25 |
| 54 | 49 |
| 269 | 79 |

1/ Adapted from 14a. Season-long competition of the weed in a stand of 334 rice plants/$m^2$.

**Table 5.** Yield losses from barnyardgrass competition in three rice stands.[1/]

| Rice Stand | Yield loss |
|---|---|
| (Plants/$m^2$) | (%) |
| 32 | 57 |
| 108 | 40 |
| 334 | 25 |

1/ Adapted from 14. Season-long competition of the weed at 11 plants/$m^2$

**Table 6.** Yield losses from competition of bearded sprangletop densities.[1/]

| Weed density | Yield loss |
|---|---|
| (Plants/$m^2$) | (%) |
| 11 | 9 |
| 22 | 18 |
| 54 | 20 |
| 108 | 36 |

1/ R.J. Smith, Jr., unpublished. Season-long competition of the weed in stands of 215 to 270 rice plants/$m^2$.

Densities of two broadleaf leguminous weeds affected rice less than did barnyardgrass. Season-long competition of hemp sesbania at densities of 1 to 11 plants/$m^2$ reduced grain yields of drill-seeded rice an average of 10 to 40% in a 3-year experiment (Table 7). In a similar experiment northern jointvetch at the same densities reduced drillseeded rice yields 4 to 19%.

The duration of weed-rice competition influenced rice yields. In numerous field experiments in the U.S., yields decreased with increasing length of competition. Barnyardgrass reduced drill-seeded

Table 7. Yield losses from competition of hemp sesbania and northern jointvetch densities.1/

| Weed density | Yield losses by species | |
|---|---|---|
| | Hemp sesbania | Northern jointvetch |
| (Plants/$m^2$) | (%) | |
| 1 | 10 | 4 |
| 3 | 15 | 7 |
| 5 | 27 | 11 |
| 11 | 40 | 19 |

1/ Adapted from 14. Season-long competition of the weeds in an optimum stand of rice.

Table 8. Yield losses from barnyardgrass competition as influenced by duration of competition.1/

| Duration of competition | Yield loss |
|---|---|
| | (%) |
| 20 days | 9 |
| 40 days | 20 |
| 50 days | 35 |
| 65 days | 43 |
| Season-long | 79 |

1/ Adapted from 14.

Table 9. Yield losses from hemp sesbania and northern jointvetch competition as influenced by duration of competition.1/

| Duration of competition | Yield losses by species | |
|---|---|---|
| | Hemp sesbania | Northern jointvetch |
| | (%) | |
| 4 weeks | 2 | 2 |
| 8 weeks | 6 | 8 |
| 12 weeks | 9 | 8 |
| Season-long | 19 | 17 |

1/ Adapted from 14.

rice yields of standard cultivars by 9 to 79% when competition lasted for about 20 days to season-long (Table 8). Hemp sesbania and northern jointvetch reduced rice yields 2 to 19% and 2 to 17%, respectively, when competition lasted for 4 weeks to season-long (Table 9).

## WEED-CONTROL TECHNOLOGY

Rice in the U.S. in direct-seeded by drilling or broadcasting into moist soil or by broadcasting dry or sprouted seed into the floodwater. Drill- or broadcast-seeded rice is flooded after emergence and grown as paddy rice.

### Cultural-mechanical methods

Crop rotation, seedbed preparation, seeding method, water and fertilizer management and cultivar selection are important components of integrated weed control programs for rice.

Rotation of upland crops with rice is the only means of controlling many hard-to-kill weeds such as red rice.[4,19] Because red rice is the same species as white rice, it is difficult to control in the rice crop. Rotating upland crops with rice permits the use of herbicides that control red rice effectively in soybeans or grain sorghum. If red rice is controlled for two years in the upland crop, rice can be grown in the third year without severe competition from red rice.

Thorough seedbed preparation helps control weeds that infest rice fields.[28] The goal is to eliminate all weed growth up to the time of seeding rice. Weeds that germinate and emerge with the rice are easier to control with herbicides.

Weeds are controlled by the seeding method selected. Seeding rice in water and maintaining the floodwater on the crop reduced problems with weeds such as barnyardgrass, broadleaf signalgrass, red rice, hemp sesbania, and northern jointvetch.[22,24,28] However, aquatic weeds such as American and horned pondweed, blue-green algae, ducksalad, redstem and waterhyssop are not controlled by water-seeding and, consequently, become troublesome in this culture.

Water management may be used judiciously to control weeds in rice.[28] Floodwater applied 1 to 2 days after treatment with propanil prevented barnyardgrass from reinfesting rice fields. Maintaining the floodwater on rice fields for 2 to 3 weeks after applying molinate is essential for control of large, tillering barnyardgrass.

Time of applying nitrogen may be managed to reduce competition of barnyardgrass with rice (Table 10). Nitrogen applied before seeding or soon after emergence of barnyardgrass stimulated weed growth. Nitrogen applied after barnyardgrass headed benefited rice more than earlier applications. However, nitrogen applications can be managed most efficiently only when weeds are controlled.

Some rice cultivars were more competitive with weeds than others. Therefore, cultivar selection influenced grain yields of rice. Seasonlong competition of barnyardgrass reduced grain yield of 'Starbonnet' and 'Bluebell' cultivars 40 and 64%, respectively (Table 11). Lebonnet was less competitive than Starbonnet with spreading dayflower (Table 12). Competitiveness is thought to be associated with maturity; Starbonnet, matures in 145 days, Nova 66 and Lebonnet in 135 days, and Bluebelle in 125 days.

Although cultural-mechanical methods of weed control for rice are beneficial and essential components of an integrated weed-management pro gram, nonchemical methods alone seldom control weeds adequately.[28] They control weeds more effectively when combined with herbicide treatments.

### Herbicides

Use of herbicides for control of weeds in rice is an important component of an integrated weed program for rice. The principal herbicides used for weed control in the U.S. are propanil, molinate, butachlor, thiobencarb, pendimethalin, 2,4,5-T, 2,4-D, silvex, MCPA, bentazon and acifluorfen.[10,28] Small amounts of bifenox and oxadiazon have been used.

Propanil: The weed-control program for rice in the Southern U.S. is built around propoanil. This herbicide is used on only a small amount of the rice in California because it injures certain non-target crops. Propanil is applied postemergence when grass weeds are in the 1- to 4-leaf stages of growth (Table 13).[28] It is usually applied aerially in spray volumes of 47 to 94 l/ha or may be applied by ground equipment in volumes of 140 to 187 l/ha. sequential applications are made to about 70% of the rice in the Southern U.S.

The activity of propanil is influenced by rainfall and temperature. At least 8 hours without rain after propanil treatment are required for effective weed control. Best control of weeds by propanil occurs when daily maximum air temperatures range from 21 to 32°C and daily minimums are above 16°C. Propanil may injure rice severely if temperatures are 35°C or above.

Irrigation water must be managed properly to obtain satisfactory weed control with propanil. If the soil is dry, irrigating the rice field 2 to 5 days before propanil treatent increased weed control. Flooding rice 8 to 10 cm deep within 1 to 5 days after treatment prevented germination of more grass weeds. Also, floodwater, lowered to expose weeds to propanil, increased control.

Molinate: When molinate is applied postemergence it is incorporated into the floodwater when barnyardgrass ranges from the 4-leaf to latetiller-

**Table 10.** Effect of time and rate of nitrogen application on yield of rice heavily infested with barnyardgrass.1/

| Stage of barnyardgrass2/ | Nitrogen rate | Rice yield |
|---|---|---|
| | (kg/ha) | (kg/ha) |
| Untreated | 0 | 2230 |
| Heading | 67 | 2620 |
| Heading | 134 | 3360 |
| Heading | 202 | 3840 |
| Mature | 67 | 2370 |
| Vegetative and heading | 67-67 | 2080 |
| Vegetative and mature | 67-67 | 2250 |
| Heading and mature | 67-67 | 3100 |
| LSD at 5% | | 910 |

1/ Adapted from 28.

2/ Vegetative, heading and mature stages were 3, 8 and 12 weeks after emergence of rice and barnyardgrass.

Table 11. Effect of barnyardgrass on yield of rice cultivars as influenced by duration of competition.[1/]

| Cultivar | Weed-free yield[2/] | Length of barnyardgrass competition | | | | | |
|---|---|---|---|---|---|---|---|
| | | 10 days | 20 days | 40 days | 60 days | 80 days | Season-long |
| | (kg/ha) | (% yield reduction compared with weed-free rice)[3/] | | | | | |
| Starbonnet | 7050 | 4ab | 4ab | 6ab | 14c | 30d | 40e |
| Nova 66 | 7730 | 0a | 3ab | 7b | 28d | 38e | 38e |
| Bluebelle | 7200 | 0a | 6ab | 17c | 41e | 56f | 64g |

1/ Adapted from 17.

2/ No weed competition as barnyardgrass was removed at emergence of rice and kept out season-long.

3/ Values followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

ing stages of growth (Tables 13 and 14).[16,28] Dry- and water-seeded rice is tolerant to molinate if the plants have grown above the floodwater. Postemergence applications into the floodwater control weeds better and injure rice less than preplant applications. Granular formulations applied into the floodwater control barnyardgrass better than emulsifiable formulations.[15] Water management is critical for effective weed control when using molinate. A flood period of 12 days after molinate treatment controlled barnyardgrass and broadleaf signalgrass better than shorter flood periods (Table 15). As grass weeds get larger, longer flood periods are required to kill or suppress them. Granular molinate is applied aerially to large commercial fields.

Phenoxy herbicides: Phenoxy herbicides such as 2,4-D, MCPA, 2,4,5-T, and silvex are applied as postemergence sprays (Table 13).[28] They are usually applied aerially at spray volumes of 28 to 94 l/ha but may be applied by tractor or hand-operated equipment at volumes of 47 to 140 l/ha. The stage of growth greatly influences the response of rice plants to phenoxy herbicides (Table 16). Rice in the early jointing stage is not injured by phenoxy herbicides. The tolerant stage can be positively identified when the basal internodes begin to elongate from 0.3 to 1.3 cm or by use of a degree-days system based on temperature accumulations.[2] Rice cultivars vary in the length of time required to reach this tolerant growth stage. Also, environmental and cultural practices influence the period required for rice to reach the tolerant stage.

Table 12. Effect of spreading dayflower on yield of rice cultivars.[1/]

| Cultivar | Weed-free yield | Yield loss |
|---|---|---|
| | (kg/ha) | (%) |
| Starbonnet | 6200 | 9 |
| Lebonnet | 5960 | 17 |

1/ R.J. Smith, Jr., unpublished. Season-long competition of the weed with rice.

Environment and nitrogen fertilization may influence the activity of phenoxy herbicides on rice and weeds.[28] Application of nitrogen 15 days before phenoxy herbicide treatments stimulated growth of rice after 4 or 5 days. At the time herbicides were applied, rice was green and growing rapidly. Thus, the herbicides caused chlorosis and reduced yields. Rice was not injured when nitrogen was applied from 5 days before to 5 days after the herbicide, but yields were reduced when nitrogen was applied 15 days after applying a phenoxy herbicide at tolerant stages. Nitrogen applied within 5 days after a phenoxy treatments helped the rice recover from phenoxy injury even when herbicides were applied at the tolerant stages of growth.

Phenoxy herbicides control weeds effectively if rain occurs no sooner than 6 hours after treatment. Even when rice is treated during the tolerant stages, high temperature (above 34°C) may increase rice injury by phenoxy herbicides. Temperatures below 15°C during the week before treatment

**Table 13.** Herbicide treatments for weed control in U.S. rice.[1/]

| Time of application | Herbicide and rate (kg/ha) | Weeds controlled |
|---|---|---|
| Preplant incorporated | Molinate, 4.5 | Barnyardgrass, partial control of red rice |
| Preemergence | Bifenox, 3.4 | Sprangletop |
| | Thiobencarb, 4.5. | Barnyardgrass, sprangletop |
| Postemergence Early season | Propanil, 3.4-6.7 (may be applied sequentially) | Barnyardgrass, broadleaf signal grass, hemp sesbania, northern jointvetch, spikerush, flatsedge, yellow foxtail, eclipta, false pimpernal |
| | Propanil + molinate, 3.4+2.2–3.4 | Same as for propanil + sprangletop and spreading dayflower |
| | Propanil + butachlor 3.4+2.8+3.9 | Same as for propanil + sprangletop, spreading dayflower and residual control of grasses and aquatic weeds. |
| | Propanil + thiobencarb, 3.4+3.4–4.5 | |
| | Propanil + pendimethalin, 3.4+0.8–1.1 | |
| | Propanil + oxadiazon 3.4+0.8–1.1 | |
| | Propanil + 2,4,5-T 3.4+0.6–1.1 | Same as for propanil + aquatic weeds, broadleaf weeds, and sedges. |
| | Bentazon, 0.6–1.1 | Spreading dayflower, smartweed and redstem |
| | Propanil + bentazon 3.4–5.6+0.6–1.1 | Same as for propanil + spreading dayflower, smartweed and redstem |
| Post flood | Molinate, 3.4–5.6 | Barnyardgrass, sprangletop, and suppression of large barnyardgrass and sprangletop. |
| Mid season (internode elongation stage) | 2,4-D, 0.6–1.4 | Many broadleaf, aquatic and sedge weeds. |
| | 2,4,5-T, 0.6–1.4 | |
| | Silvex, 0.6–1.4 | |
| | MCPA, 0.6–1.4 | |
| | 2,4–D + 2,4,5–T, 0.8+0.8 | |
| | 2,4–D + silvex, 0.8+0.8 | |
| | Propanil + 2,4,5–T 3.4+0.8–1.1 | Same as for phenoxys + grasses |
| | Propanil, 2.2–3.4 | Hemp sesbania |
| | Acifluorfen, 0.1–0.3 | |
| | C.g.a., 188 x $10^9$ spores/ha | Northern jointvetch |
| | Bentazon, 0.6-1.1 | Redstem, smartweed |

1/ Source: Arkansas Cooperative[3,10,28]. Partial listing of herbicides and rates used and weeds controlled. For specific use information, confer latest pesticide label.

may slow weed growth and reduce control.

Other herbicides: Several new herbicides have been used in rice.[10,21,28] They control many species of weeds that standard herbicides such as propanil, molinate, and phenoxy herbicides fail to control. Some also possess better preemergence or residual activity than standard herbicides. New herbicides recently registered for use in rich in the U.S. are acifluorfen, butachlor, pendimethalin, and thiobencarb. These herbicides frequently give better weed control when combined in tank-mixture or sequential applications with propanil (Table 13).

### Biological control

An endemic anthracnose disease of northern jointvetch, incited by the fungus *Colletotrichum gloeosporioides* (Penz.) Sacc. f. sp. *aeschynomene* (c.g.a.), and a similar disease of winged waterprimrose, incited by the fungus *C. gloeosporioides* f. sp. *jussiaeae* (c.g.j.) controlled these weeds in rice fields.[6,8] The microbial herbicide, c.g.a. registered for use in rice in 1982, is the first herbicide of this type cleared for weed control in an agronomic crop. Tank mixtures of spores of the two fungi, c.g.a. and c.g.j., controlled both weeds in the rice field. Tank mixtures of c.g.a. with selected herbicides that do not injure the fungus control more weed species than either alone.[11] Tank mixtures of c.g.a. and acifluorfen controlled northern jointvetch and hemp sesbania while tank mixtures of c.g.a. and bentazon controlled northern jointvetch and redstem. However, many herbicides, as well as fungicides and insecticides, injure spores of c.g.a. when applied in tank-mixture or sequential treatments.[23] Herbicides, including propanil, 2,4,5-T, 2,4-D and slivex, injure c.g.a. when applied in tank mixtures with the mycoherbicides. Likewise, fungicides, including benomyl and fentin hydroxide, injure c.g.a. when tank mixed with the fungus. However, timely sequential applications of c.g.a. followed by these toxic pesticide treatments do not inhibit activity of the mycoherbicide.

### Integrated weed management in the rice crop

The complex of weed species that infests the crop is controlled by integrating week-control practices. Early-season control of annual grass, broadleaf, sedge and aquatic weeds is accomplished by combining (a) preplant tillage to kill all weed growth at the time of seeding rice, (b) seeding rice in such a way as to obtain stands of fast-growing plants that compete with and shade the weed plants, (c) the use of timely tank-mixture or sequential treatments of propanil, molinate, butachlor, pendimethalin, or thiobencarb to kill the weed plants during the early season before they compete with the crop (Table 13), and (d) timely flooding or proper water management before and after herbicide treatments.[28]

Annual grass weeds that escape these early treatments are controlled by timely postemergence treatments of molinate after flooding the rice (Table 13). Aquatic, broadleaf and sedge weeds that germinate after flooding the crop are controlled by early season postemergence treatments of bentazon alone or tank mixtures of propanil + 2,4,5-T, or propanil + bentazon. Weeds present at mid-season, when rice internodes are 0.3 to 1.3 cm long, are controlled with phenoxy herbicides alone; phenoxys + propanil, bentazon, acifluorfen, or c.g.a. Weeds on rice field levees are controlled with treatments of phenoxys alone or in tank mixtures with propanil. Control of many aquatic weeds in the paddy is enhanced when drying the soil follows the phenoxy herbicide treatment.[28]

Weed-control programs must be integrated with other pest management practices in rice. Some fungicides and insecticides may interact adversely with specific weed-control technologies. For example, carbamate and organophosphate insecticides (carbaryl, carbofuran, and methyl parathion) inhibit an enzyme (aryl acylamidase) in the rice plant that detoxifies propanil, resulting in phytotoxicity to rice from propanil.[28] These classes of insecticides must be applied by specific timing guidelines to prevent adverse interactions with propanil and subsequent phytotoxicity to rice. Chlorinated hydrocarbon insecticides (aldrin and toxaphene) that do not affect this enzyme or interact adversely with propanil, may be substituted for carbamate and organophosphate insecticides for insect control in rice.

**Table 14.** Effect of time and rate of molinate treatments on barnyardgrass control and rice yield.[1/]

| Plant height at treatment | | Molinate rate (kg/ha) | | | | |
|---|---|---|---|---|---|---|
| Rice | Barnyardgrass | 0 | 22 | 3.4 | 4.5 | 6.7 |
| ——(cm)—— | | (% barnyardgrass control) | | | | |
| 2.5-13 | 0.6-5 | 0 | 98 | 98 | 94 | 98 |
| 10-15 | 2.5-10 | 0 | 91 | 95 | 96 | 97 |
| 10 20 | 2/ 2.5-15 | 0 | 76 | 94 | 92 | 95 |
| 2/ 15-25 | 2/ 8-25 | 0 | 80 | 82 | 90 | 90 |
| | | (kg/ha rough rice yield)[3/] | | | | |
| 2.5-13 | 0.6-5 | 6410b | 7740a | 7680a | 7440a | 7690a |
| 10-15 | 2.5-10 | 6140b | 7520a | 7820a | 7550a | 7500a |
| 10-20 | 2/ 2.5-15 | 5150c | 7390a | 7450a | 7850a | 7550a |
| 2/ 15-25 | 2/ 8-25 | 4270c | 7550a | 6920a | 7100a | 7170a |

1/ Adapted from 16.

2/ Largest barnyardgrass and rice plants were tillerting.

3/ Yields followed by the same letter are not significantly different at the 5% level by Duncan's Duncan's multiple range test.

**Table 15.** Control of weed grass as influenced by length of period flooded after treatment with molinate.[1/]

| Flooded-period | Weed species | |
|---|---|---|
| | Barnyardgrass | Broadleaf signalgrass |
| (days) | (% weed control) | |
| 2 | 70 | 27 |
| 7 | 86 | 53 |
| 12 | 96 | 80 |

1/ Adapted from 28. Granular molinate at 3.4 kg/ha was applied into the floodwater when drill-seeded rice was 20-cm tall and grass weeds were 5- to 13-cm tall.

**Integrated weed management in the croopping system**

Integrated weed-control systems for hard-to-kill weeds, such as red rice, are complex and require attacking the weed in crops rotated with rice, as well as in the rice crop.[4,19)] Present technology for control of red rice in the rice crop is very limited. Therefore, cropping-herbicide-cultivation systems are essential for control of red rice. A well-planned program for red rice includes (a) use of weed-free crop seed, irrigation water free of red rice seed, and clean equipment; (b) crop rotation with control of red rice in all crops; (c) mech-

**Table 16.** Responsee of rice to phenoxy herbicides as influenced by stage of treatment.[1/]

| Herbicide | Stage of treatment[2/] | | | |
|---|---|---|---|---|
| | Early-tillering | Late-tillering | Early-jointing | Booting |
| | (% increase/decrease in yield compared with untreated)[3/] | | | |
| 2,4-D | -17 | +4 | -3 | -16 |
| 2,4,5-T | 0 | +2 | 0 | -20 |
| MCPA | -14 | - 2 | +2 | -13 |
| Silvex | +4 | - 3 | +1 | -11 |

1/ Adapted from 28.

2/ Herbicides applied 5, 8, 11 and 14 weeks after rice emergence for the indicated stages respectively.

3/ Average yield of untreated = 4750 kg/ha.

Table 17. Control of red rice in water-seeded rice by molinate and water management.[1/]

| Water culture[2/] | Molinate rate (kg/ha) | | | |
|---|---|---|---|---|
| | 0 | 3.4 | 4.5 | 6.7 |
| | (% red rice control)[3/] | | | |
| Drained | Of | 39d | 54c | 74c |
| Drained-flooded | 28e | 56c | 70b | 88a |
| Flooded | 60c | 77b | 87a | 93a |

1/ From 22.

2/ Rice water-seeded. Drained dulture – plots drained 4 days after seeding (DAS) and reflooded 34 DAS. Drained-flooded culture – plots drained 4, 16 and 28 DAS and reflooded 11, 23 and 34 DAS. Flooded culture – plots drained 28 DAS and reflooded 34 DAS.

3/ Values followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

anical cultivation; (d) careful crop and water management; and (e) herbicides.

The most effective way to control red rice is by crop rotation combined with effective cultivation and herbicide treatments. Rotations include 2 years of either soybeans or grain sorghum followed by rice the third year; or 1 year of grain sorghum followed by soybeans the second year, then rice the third year.[10,19]

During the years in which soybeans are grown, several herbicide treatments can be used to control red rice. Preplant, soil-incorporated herbicides, which usually are more effective than preemergence treatments, are combined with follow-up postemergence directed or overtop herbicide treatments. Effective preplant, incorporated herbicide treatments include alachlor, metolachlor, trifluralin, fluchloralin, pendimethalin or metribuzin. Tank mixtures of the acetanilide and dinitroaniline herbicides are frequently more advantageous than a single herbicide, especially when weeds other than red rice are also present. Several postemergence treatments including over-the-top sprays of bentazon + mefluidide, fluazifop-butyl, or sethoxydim or directed sprays of paraquat control red rice missed by preplant treatments. Cultivation is essential to complete the program in soybeans.

Including grain sorghum in the rotation is another effective approach to red rice control. Grain sorghum is treated preplant with propazine or metolachlor, or postemergence with atrazine (overtop) or paraquat (directed) for red rice control. When metolachlor is used the grain sorghum seed is treated with a chemical o protect the crop from injury of this herbicide. Rice, grown the next year, may be injured by propazine residues, but soybeans are less likely to be injured. Metolachlor is less likely than propazine to injure the following rice crop. Cultivation is required to control red rice missed by the herbicide treatments.

When rice is seeded during the third year, conventional herbicide treatments fail to control red rice. However, infestations are reduced by applying molinate preplant-incorporated, water-seeding the rice and maintaining the floodwater or keeping the soil moist by frequent irrigations for several weeks after seeding (Table 17).[4,22] After harvesting rice, red rice may be further reduced by flooding the field during the winter to attract wild ducks that eat the red rice seeds.[27] Research indicated that wild ducks reduced red rice seeds in soil 97% by winter feeding in flooded rice fields.

Recent field research indicated that red rice can be controlled in a dry-seeded rice culture.[9] The planting seeds were treated with calcium peroxide to supply oxygen to the crop seeds covered by soil and water and a chemical to protect the crop from injury by molinate. The herbicide was incorporated preplant, rice was drill-seeded, the plots were flooded immediately after constructing levels, and the floodwater was maintained for 4 to 5 weeks after which the plots were drained for control of straighthead, a physiological rice disorder, and aquatic weeds that germinated and infested the plots during the flooded period. More research, however, is required before this technology is developed for farm use.

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