Crop Profile for Rice in California

Prepared: October, 1998

General Production Information

- California produces approximately 25% of the rice grown in the United States[1]. Though it produces only 0.4% of the world's rice crop, California contributes substantially to world trade[2].
- The primary type of rice grown in California is medium grain. California grew 72.3% of the US supply of this grain type in 1997[3].
- The farm-gate value of the California Rice crop was $347,196,000 in 1997[4]. Farm-gate value varies widely from year to year based on market conditions.
- Rice acreage in California fluctuates from year to year based on market conditions, weather, and other factors. Planted acreage was 510,000 in 1997, and 478,000 in 1998[5]. Acreage has ranged from 300,000 in 1977 to 608,000 in 1981[6].
- California produces specialty rice, such as short grain varieties, which was 91.5% of the United States production in 1997[7]. This variety category totaled 1,416,000 pounds of rice in 1997 which is 0.8% of the total United States rice production[8].
- Typical seasonal water delivery for California rice is estimated to be 4.5 to 7.5 acre-feet. Evapotranspiration requires 3 to 3.5 acre-feet, and in most rice soils 0.5 to 2 acre-feet go to deep percolation. The balance flows through the field and may be reused many times within irrigation districts before it is returned to public waters[9].
- The vast majority of the chemicals used on rice are applied prior to the mid-point of its development. This means that the chemicals are applied at the early plant development stages, prior to grain exposure, and that applied chemicals have ample time to degrade or dissipate prior to harvest.

Production Regions

The Sacramento Valley of California contains 96.4% in 1995 of rice acreage[10]. The remainder is in the north to central San Joaquin Valley. The leading rice-producing counties are Colusa, Butte, Sutter, and Glenn[11]. Approximately 600,000 acres in the Sacramento Valley are of a soil type restricting the crops to rice or pasture. The remainder of the acreage has greater crop flexibility[12].

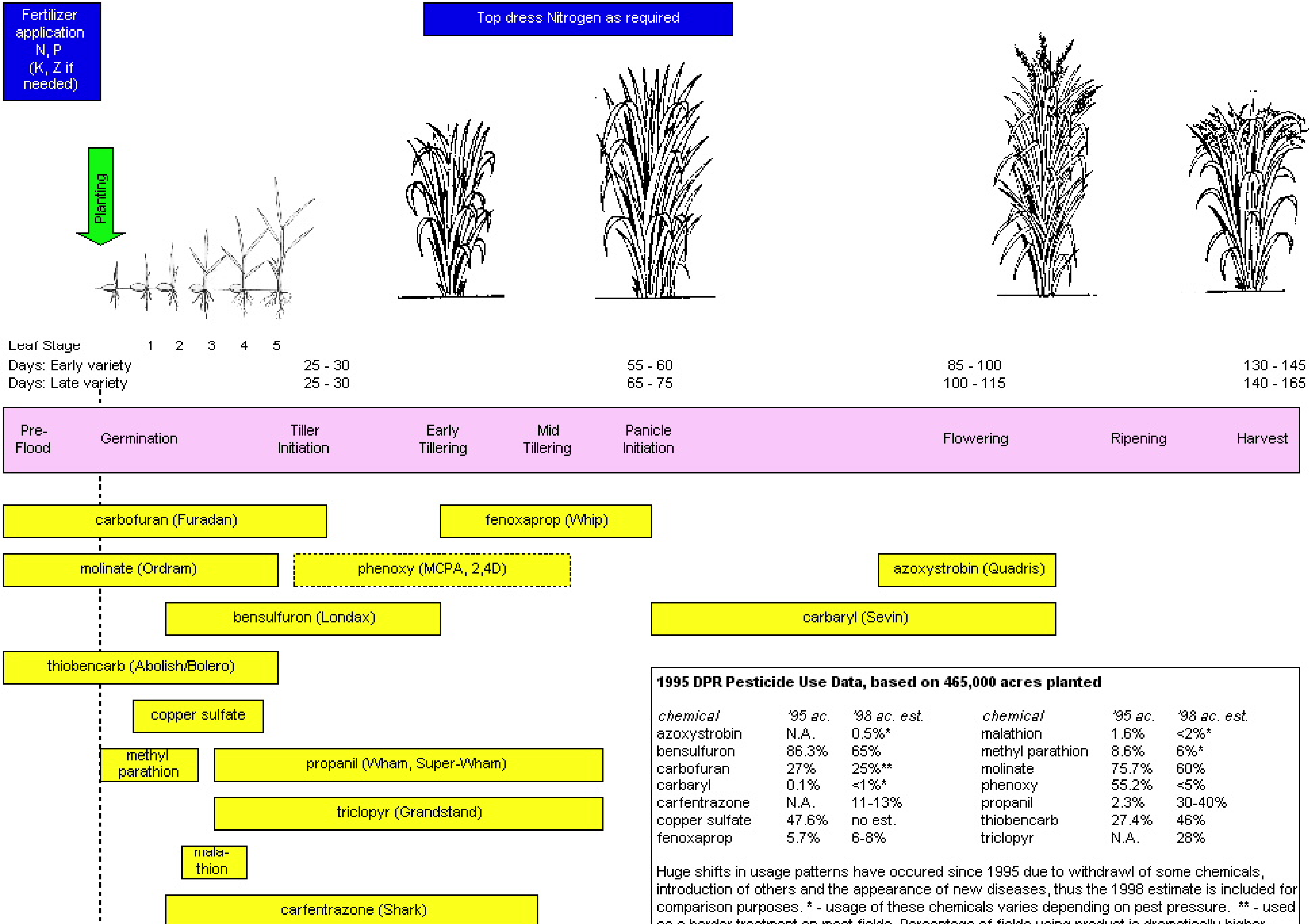
Cultural Practices

There are currently at least 14 varieties of rice grown in California, There are an equal number of proprietary varieties which would not be included in this count.

Rice production is highly mechanized and begins with land preparation and leveling for proper stand establishment, weed control and drainage. This is followed by fertilizer and insect control application. Once the land has been properly prepared, it is flooded with water and the seed is applied by airplane into the water. Rice in California is grown primarily in a continuously flooded, flow-through system. Weed control begins within days of planting and continues until the canopy closes over. Occasional "clean-up" operations are required for weeds after the canopy closes. Diseases are handled by residue burning, residue removal, fungicide application, or rotation out of rice for two to three years where possible. The water is drained two to three weeks prior to harvest allowing the field to dry enough to support heavy machinery. When the rice is harvested it is at 18 to 24 percent moisture, so a carefully controlled drying process is conducted to bring it down to 12 to 14 percent moisture. This drying process prevents spoilage and mold growth[13].

Rice is grown mostly on fine-textured, poorly drained soils and soils with impervious hardpans or claypans. These soils are principally in three textural classes: clays, silty clays, and silty clay loams, ranging from 25 to 70 percent clay. A few of the soils are loam in the surface horizon but are underlaid with hardpans. These soils are well suited to rice production since their low water permeability enhances water use efficiency[14].

The following page contains a chart that summarizes the life-cycle of rice. It also summarizes the application of fertilizer, pest control, weed control and disease control timing.



1995 DPR Pesticide Use Data, based on 465,000 acres planted

chemical	*'95 ac.*	*'98 ac. est.*	*chemical*	*'95 ac.*	*'98 ac. est.*
azoxystrobin	N.A.	0.5%*	malathion	1.6%	<2%*
bensulfuron	86.3%	65%	methyl parathion	8.6%	6%*
carbofuran	27%	25%**	molinate	75.7%	60%
carbaryl	0.1%	<1%*	phenoxy	55.2%	<5%
carfentrazone	N.A.	11-13%	propanil	2.3%	30-40%
copper sulfate	47.6%	no est.	thiobencarb	27.4%	46%
fenoxaprop	5.7%	6-8%	triclopyr	N.A.	28%

Huge shifts in usage patterns have occured since 1995 due to withdrawl of some chemicals, introduction of others and the appearance of new diseases, thus the 1998 estimate is included for comparison purposes. * - usage of these chemicals varies depending on pest pressure. ** - used as a border treatment on most fields. Percentage of fields using product is dramatically higher.

Insect Pests

Field pests

The rice water weevil (*Lissoroptus oryzophilus*) and the tadpole shrimp (*Triops longicaudatus*) are the two most important invertebrate pests in California rice culture. Other pests include the rice leafminer (*Hydrellia griseola*), rice seed midges (family Chironomide), armyworm (*Pseudaletia unipuncta*), western yellowstriped armyworm (*Spodoptera praefica*), and the crayfish (*Procambarus clarki*).

Rice water weevil is the most economically damaging of the invertebrate pests found in California. The adult weevil overwinters in weedy areas near rice fields or in soil crevices. In the early spring when night temperatures become warm, adults fly to the fields and lay eggs in the young rice plant. Observing feeding scars on the leaves of young plants can determine the presence of adults. The damage, however, is done by the larvae, which hatch and feed on the roots. Heaviest infestations usually occur around the field borders and adjacent to permanent levees. Symptoms include leaf-feeding scars and plants that are stunted and chlorotic as a result of root pruning. The rice water weevil is difficult to control with cultural practices and is currently controlled with approved insecticides.

Tadpole shrimp are crustaceans that feed on young roots and shoots and thereby uproot rice seedlings. Turbid water following rice seeding and before stand emergence is often indicative of tadpole shrimp. Muddy water caused by their digging reduces photosynthetic activity and growth of the young rice plant. Immediate seeding after flooding is the best prevention for tadpole shrimp. Their eggs hatch within two days of flooding. The longer the time between flooding and seeding, the greater the population and size of the tadpole shrimp at times when the rice is most susceptible to damage. Approved pesticides control this crustacean.

Rice seed midges resemble small mosquitoes, and are found in most rice fields. Midge larvae injure rice seedlings by feeding on seeds and the emerging shoot, young leaves, and newly developing root tips of rice seedlings. Symptoms include small holes in the seeds and floating, dislodged seedlings. Although rice seed midges are commonly found in the rice field, economic damage is most often associated with weather and water conditions that result in slow seedling growth, or when the time between flooding and seeding is long enough for large numbers and older midge larvae to develop. Rice seed midges are controlled only by field drainage.

Rice leafminer is a small, olive-green fly commonly found walking on the water surface or on rice leaves in the early season. Economic injury is usually confined to stressed plants which are growing in deep water, where eggs are laid singly on leaves floating horizontally on the water. The larvae cause damage by mining tunnels within the leaves. These mines appear yellow at first, and become transparent with time. Lowering the water level to encourage more rapid leaf emergence or by applying approved insecticides controls rice leafminer. The introduction of more erect-leaved semidwarf varieties and improved water management have greatly reduced injury from this pest.

Armyworms are occasionally found in rice in midsummer. After other food sources are depleted the adult moths may fly into rice fields and lay eggs. Armyworm damage is most serious during rice stem elongation and grain formation. Larvae defoliate the plants, typically by chewing angular pieces off the leaves. They may also feed on the panicle; however, yield losses depend primarily on the amount of defoliation. Armyworms are partially controlled by natural enemies, including predators, pathogenic microorganisms, and parasites. If necessary, they may be controlled by approved pesticides.

Crayfish are crustaceans that burrow into levees and around irrigation structures. Crayfish occasionally eat rice seeds and seedlings. Crayfish damage to rice seeds can be distinguished from other pest damage because the seed is crushed or macerated. Their economic damage to rice, however, is principally through the disruption of irrigation systems, especially by burrowing around rice boxes. After the field is drained crayfish burrow into the soil, producing soil chimneys around the edge of the burrow. Currently no pesticides are registered for the control of crayfish. One control strategy is to drain the field and drive the crayfish into their burrows in order to allow the seedlings to establish.

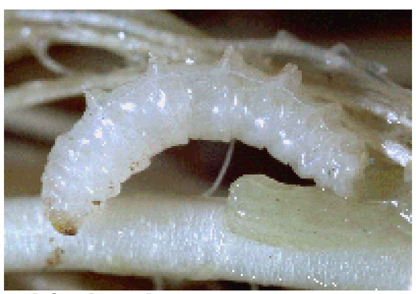
Mitten Crabs are a new pest whose impact is not currently known. Their economic damage to rice may be similar to Crayfish, but on a much larger scale due to their reproductive rate. Currently no pesticides are registered for the control of Mitten Crabs.

Mosquitoes can breed in rice fields, but their larvae do not feed on rice. Complete surface drainage, elimination of seep areas, use of the mosquitofish (*Gambusia affinis*), application of the bacterial product Bti (*Bacillus thuringiensis* var. *israelensis*), and synthetic chemical applications (by mosquito abatement districts) help reduce mosquito populations. Rice growers are required to make an effort to control mosquito populations in their fields.

Controls:

Pest Complexes & Key Pests

Various invertebrates infest rice paddies in California. They range from protozoans to large crustaceans, but only a few cause economic damage to rice plants[15]. In California the most serious problems occur from seeding to approximately six weeks after. During this time, tadpole shrimp (*Triops longicaudatus*), crayfish (*Procambarus clarki* & *Orconectes virilis*), mitten crabs, and rice seed midges (family-*Chironomidae*) can cause considerable damage in rice paddies by feeding on germinating seed and small seedlings. This feeding can weaken or kill young rice plants. From about 1 week after seeding to 8 weeks the rice water weevil (RWW), *Lissorhoptrus oryzophilus* Kuschel, can cause significant damage. During July and August, armyworms (family: *Noctuidae*) can cause significant damage to rice. For this evaluation, we will concentrate on RWW biology and management, but briefly also summarize tadpole shrimp, crayfish, mitten crabs, rice seed midges, and armyworms.



Rice water weevil was introduced to California in the late 1950's and is the major rice insect pest in the Sacramento and San Joaquin Valleys (Butte to Stanislaus County). Unique to California, only parthenogenic females exist[16]. The RWW adult (~ 0.125 inch or 4 mm long) has a prominent beak, is gray with a dark marking on its back from the base of its head to the middle of its wing covers[17]. The adults overwinter in a reproductive diapause at the base of grass clumps or debris in harvested basins, on levees, and ditch banks. In the spring during calm, warm (> 70° F) evenings between sunset to midnight, RWW adults fly and invade newly flooded rice paddies and feed on the emerging, young rice foliage. The distances they can fly is unknown, but believed to be several miles potentially. During the next few weeks, they crawl or swim to just below the waterline to lay their eggs in the leaf-sheath tissue[18]. Depending on temperatures, eggs hatch in four to nine days[19] and first instars forage in the leaf tissue for a short period and then move to the roots[20]. The milky-white, legless larvae spend the remainder of their life-cycle (~ 7 weeks) feeding on the roots of rice plants. When their growth is completed, larvae pupate in mud-coated cocoons that are attached to the rice roots. The adults emerge from July through September. The life-cycle from egg to adult in the field is approximately 65 days.

RWW Damage: The larvae are the most damaging stage in the RWW life cycle. Root pruning by larvae is the major cause of reduced yields. Plants with damaged roots may become stunted and lose yield through tiller and/or panicle reduction. Rice plant maturity may also be delayed and this may allow invasion by weeds in competition for nutrients and space. The heaviest larval densities and most serious damage can be expected to occur between late May and July within the first 30 feet of the margins of the fields. Rice water weevil larvae can reduce rice yield by up to 45% [21]. The propensity to infest rice borders most severely is unique to California RWW, and does not occur in the southern states.

Current Rice Water Weevil Management

Current management of RWW encompasses some cultural controls to minimize adult RWW population buildup and only one registered pre-plant chemical insecticide that kills RWW larvae feeding on the roots. Biological controls and host-plant resistance are not available at this time. New promising chemical control methods and reduced-risk insecticides appear to be viable options in the near future.

With the push to register and implement new RWW management strategies that will be predominantly post-flood products, scientists have been studying RWW oviposition (egg laying) times. Timing of post-flood biological or chemical insecticides with adult feeding and oviposition times will be imperative to achieve effective larval control below the economic injury level (<1 larva/plant) for California water-seeded rice.

The severity of a RWW infestation in any particular area can be related to several factors. These include past history of RWW in the field, availability of over-wintering sites, over-wintering survival, temperature and wind conditions during the evening and night hours when the adults fly, the sequence of flooding of rice fields in the area, and stand density.

RWW spring flight times have been monitored with a light trap at the Rice Experiment Station (near Biggs, CA) since 1962 [22]. Monitoring the levels and intervals of peak flight times over the years is important to establish a database on the intensity of the spring weevil flight. Cool, wet spring weather can delay adult RWW emergence from overwintering sites and prolong flight times. Peak flight periods, often for only a few days, can occur from mid-April to mid-June. The date of 90% flight completion has ranged from late April to late May.

Since RWW adults lay the majority of their eggs during the first 2 to 3 weeks after rice plant emergence through the water, monitoring should be done early in the rice growing season. Adults can be observed by monitoring for feeding scars on either of the two most newly emerged rice leaves (~2 to 4-leaf plant stage). The majority of adults are usually found within the first 30 feet from any field margin. For each sample, subsamples of 25 randomly selected plants are taken at four areas 20 to 30 feet apart walking parallel to the levee. Feeding scars appear as linear slits of varying lengths on the upper surfaces of the leaves. Depending on the intensity of the adult RWW population being monitored, there are guidelines for a post-flood treatment outlined in the latest University of California-Integrated Pest Management manual for rice[23]. Recent data indicate that the threshold is about 10% plants with feeding scars.

- **Cultural Controls:**

  Large **laser leveled fields** reduce the number of levees and field edges associated with RWW population buildup during the critical period of infestation at the beginning of the rice season. Removal of weeds on surrounding levees is also important to reduce the number of adult early-season feeding sites as well as adult over-wintering refuges. In addition, since RWW larvae prune the rice roots and cause reduced tillering, removal of aquatic weeds is important to alleviate the stress to rice plants from nutrient and space competition.

Winter-flooding of harvested rice fields may affect overwintering RWW adult survival (preliminary studies indicate reduction). This may lead to lower larval densities which will be investigated further in a future study. Delayed planting dates and temporary drainage strategies reduce RWW populations but these practices may cause problems to rice yields by stressing the plants, encouraging weed growth and delaying rice maturity. Drill-seeding rice, a process of planting the seed in a dry seed-bed and flushing with water but delaying the permanent flood, reduces RWW populations. However, the lack of flood also allows for weed growth, which cannot be controlled. Table 1. contains a summary of cultural control options.

Table 1. Rice water weevil cultural control options.

Technique	**Strengths**	**Drawbacks**
levee vegetation management	○ provides good RWW control ○ Reduces overwintering sites and nearby source of RWW	○ destruction of wildlife habitat ○ additional herbicide and/or tillage expense
delayed seeding	▪ Late planted rice avoids major flights	○ unpredictable performance ○ delaying seeding past mid-May reduces yield ○ RWW flight varies from year to year
drill-seeding	▪ provides good to excellent control prior to permanent flood ○ habitat is unsuitable for RWW egg-laying	○ not widely used practice in CA ○ may reduce yields compared with water seeding ○ potentially severe weed problems
winter-flooding	○ may kill overwintering RWW adults	○ unproven at this time
field drainage	○ may reduce larval populations	○ unpredictable ○ field must be drained during RWW flight period ○ does not kill larvae in soil

- **Biological Controls:**

In California, biological control of RWW is nil. The adults infest basins ~ 1 week after flooding; therefore, a crop canopy and arthropod community is lacking at this time. Later in the season, spiders capture some RWW adults, but this is after the critical period. The RWW larvae are within the flooded soil and protected from arthropod predators. No parasites of RWW are known in California. In Japan and China, there have been reports of RWW parasites, but establishing lines of communication has been difficult.

No **host plant resistance** is available in commercial varieties to RWW. Some experimental lines have moderate tolerance to RWW and work is continuing in this area. This tolerance may not prevent damage from high densities. An investigation of the effects of RWW herbivory on rice plant tolerance and resistance is currently being evaluated at the University of California, Davis.

- **Chemical Controls:**

The only registered chemical pesticide for use on RWW is carbofuran (Furadan® 5G). Because of environmental concerns, the registration of this product has been threatened since the early 1990's. The product was initially scheduled for removal in 1994 and then in 1996. Careful use by growers, and an extensive stewardship program, has enabled continued use. Presently, it was scheduled for cancellation in August 1998. Three products (Dimilin®, Icon™ & Warrior®) have been identified as possible replacements for Furadan in California. In previous studies, these products have provided RWW larval reduction and protection of rice grain yield equal to, if not better than, Furadan 5G. However, there are still questions about all three of these products. Registration of all of these three products and continued availability of Furadan would provide alternatives and considerable flexibility for growers.

Carbofuran - Furadan 5G is the only registered insecticide for RWW in California. This product was available under a Section 3 registration through 1996 and under a 24c label in 1997 and 1998. The original scrutiny of this product registration was stimulated by the avian toxicity. However, careful use through a stewardship program, soil incorporation, and the characteristics of the rice system (insecticide covered with soil and water so exposure to birds is minimal) have largely diminished these concerns. Presently, carbofuran is on the Food Quality Protection Act (FQPA) list 1 of insecticides scheduled to have their tolerances reassessed by August 1999. As a carbamate, the reassessment of carbofuran may result in elimination of some uses. Furadan can be applied either pre-flood, incorporated or post-flood, but the field must be drained. Post-flood applications directly into the water are illegal. This is the standard application method in the southern US and the post-flood into the water treatment has worked well in our research tests. Evidence from southern growers suggests it works for RWW control. The reason why the post-flood water treatment is illegal in California is not clear; however, it is believed that RWW control was poor with this treatment. A post-flood treatment directly into the water would appear to further limit exposure of birds to the active ingredient compared with a post-flood application to drained fields. In our tests, Furadan continues to provide good to excellent RWW control with all application methods. Furadan is systemic and moves into the rice roots and foliage. Other benefits of the product are the minimal effects on arthropod non-targets and on fish. In addition, monitoring programs for this active ingredient on key waterways and appropriate water-holding periods are in place. The water-holding period with Furadan presents an impediment to growers to using Furadan pre-plant. After use, if for any reason the grower needs to remove the flood (for herbicide application, to facilitate pegging, cool weather to improve seedling establishment), this cannot be done. Therefore, more growers are now using Furadan post-flood.

Diflubenzuron*:* Dimilin is an insect growth regulator that disrupts the deposition of chitin in the insect. On RWW, Dimilin causes the females to lay sterile eggs and also the product has shown activity on eggs deposited within the plants. Dimilin has no toxicity to RWW larvae. Therefore, application of this product must be timed before egg hatch and this will therefore necessitate a change in the management schemes for RWW in California. The application window for Dimilin is about 3 to 10 days after 50% plant emergence through the water (~3-5 leaf stages). Dimilin has no toxicity to applicators and to birds and mammals in general. The product does have toxicity to non-target arthropods, but research by Grigarick and others (1990) showed that only a few species are significantly affected and these effects dissipate in 10-14 days after application. A drawback with this product is that applications have to be made to entire basins rather than to only the borders (like Furadan). The change in RWW management approach, uncertainty with border treatments, lack of experience with the product in terms of grower use, and fit within the rice environment are drawbacks with this product.

***Fipronil**:* Icon comes from a new class of chemistry and in our tests has provided excellent RWW control. This product directly kills the RWW larvae. A pre-plant, incorporated application has shown the best control in California. In the southern U.S., a seed treatment has provided excellent RWW control, but this treatment has not been effective in California. The post-flood application has not been thoroughly researched. The use rate of Icon is very low (~0.0375 lbs. AI/A) so the amount of insecticide going into the rice system would be greatly reduced. The management scheme, pre-plant-incorporated (PPI), would be identical to that done with Furadan. Border treatments, like Furadan, would be possible. Among the potential disadvantages with Icon are: a lack of set water-holding periods, water monitoring protocols, and knowledge of the effects on non-targets.

***Lambda cyhalothrin**:* Warrior is a synthetic pyrethroid insecticide that was registered for RWW in the southern U.S. in 1997. It works by killing the RWW adults. To maximize the efficacy, the application must be made before oviposition and egg hatch; there is no toxicity to RWW larvae. Like Dimilin, this type of post-flood treatment may not be amenable to border applications. The influence of Warrior on non-targets (arthropods, fish, etc.) in the rice system is unknown. The preferred application window for Warrior is the 2-3 leaf stage. The change in RWW management approach, uncertainty with border treatments, lack of experience with the product in terms of grower use, and fit within the rice environment are drawbacks with this product. In addition, there is a possibility that two or more applications may be needed to provide acceptable RWW control.

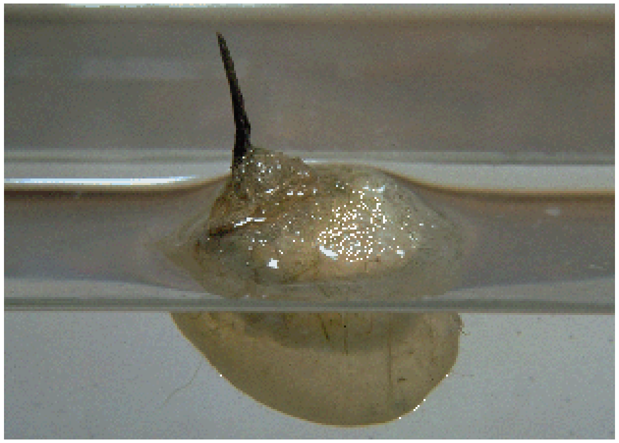
A summary of these candidate products is given in Table 2.

Table 2. Summary of key characteristics of RWW insecticides (Furadan replacements).

	Dimilin	**Icon**	**Warrior**
Type of chemistry	insect growth regulator	phenyl pyrazole	synthetic pyrethroid
Use for RWW	Post-flood	Pre-flood (seed treatment in South)	Post-flood
Activity on RWW	sterilizes adults	kills larvae, some adult activity	kills adults
Registration status on rice-California	no	no	no

- Southern states	no	no	yes
Potential impact on birds- based on toxicity data	none	low	low
Potential impact on nontarget arthropods- based on- tox. data - field data	moderate minimal (10-14 days on a few species)	moderate unknown	high unknown
Mammalian toxicity	low	moderate	low to moderate

Other Arthropod Rice Pest Management Guidelines



To prevent damage to rice seed and small seedlings early in the season, management guidelines for other pests such as crustaceans or seed midges are as follows: The best way to reduce the risk of tadpole shrimp invasion and damage is prevention. Flood the field as fast as possible and seed as soon as possible to hasten plant growth before the shrimp get too large. If you must treat, Copper sulfate pentahydrate or methyl parathion are chemical treatments used to control tadpole shrimp[24, 25].

Cultural controls used to prevent crayfish invasion: check the irrigation system for crayfish damage throughout the season. Repair damage to levees, paddy weir boxes, and major structures as soon as possible to prevent accidental drainage. Leave fields fallow for a season or two since high crayfish populations can buildup in fields that are continuously flooded and planted with rice year after year. No chemicals are registered for crayfish control in California.

Rice seed midges feed on germinating seeds and very young seedlings, thus seeding should be done as soon as possible after flooding, preferably within 2 days of initial flooding. Any delay will expose the germinating seed to older and larger numbers of larvae. In large fields that take longer than a few days to flood, seed parts of the field in sequence as they fill with water. Rapid root and shoot growth will reduce the period of time that the rice is susceptible to damage by midge larvae. The only currently known control to inhibit or kill the larvae is draining fields. No known chemical treatments are registered at this time for seed midge control. Experience with chemicals in other aquatic habitats have shown that midges are known to develop resistance to insecticides very rapidly. Draining can be effective; however, it may increase weed problems and if the field is drained too long, this may result in loss of fertilizer and added re-flooding costs. Re-seeding a field has had mixed results and is less likely to be successful if it is done later than the first week after the original planting.

Rice is not an ideal host for armyworms. Periodically two species, western yellowstriped armyworm, *Spodoptera praefica* (broadleaf weeds and alfalfa) and the armyworm, *Pseudaletia unipuncta* (grasses and wild grains), may invade rice fields. Only the larger larvae (fourth or fifth instar) feed on rice foliage. Western yellowstriped armyworm larvae feed during the day and the armyworm larvae feed at night. Damage by armyworms is most serious during periods of stem elongation and grain formation, causing developing kernels to dry before filling. Armyworms damage foliage from mid-July through August and rice panicles from August through September. Significant yield reduction can occur when defoliation is greater than 25% two to three weeks before heading[26]. The western yellowstriped armyworm is believed to limit its egg laying to broadleaf plants; and thus, early control of broadleaf weeds in rice fields may be important in limiting populations. Various natural factors cause mortality of armyworms in rice paddies. Many caterpillars drown during migration out of the fields to pupate. In addition, many are killed by natural enemies such as predators, pathogenic organisms, and parasites. Sevin is applied to foliage when > 25% defoliation occurs in a particular area and armyworms are present on the plants (day- western yellowstriped and night- armyworm).

Table 3. Summary of management options for sporadic rice arthropod pests.

	Cultural Controls	Insecticide Controls
Seed Midge	• seed as soon as possible after flooding • use conditions to quickly facilitate seedling emergence • drain field	• none
Tadpole Shrimp	○ seed as soon as possible after flooding • use conditions to quickly facilitate seedling emergence • drain field	• copper sulfate • methyl parathion
Crayfish	• fallowing for a year may help	• none
Rice Leafminer	• use shallow water and warm water to facilitate growth of rice past susceptible stage	• malathion
Armyworms	• weed control	• carbaryl

Pest Management Options under Review

Reduced-risk Insecticides- Two biorational control methods are currently being evaluated to combat RWW. These entomopathogenic agents may be useful tools in future RWW management. One is a fungal agent called *Beauveria bassiana*, and will target and infect the RWW adult stage. The other is a bacterial agent, *Bacillus thuringiensis* subsp. *tenebrionis* (Btt), whose mode of action may be through ingestion by the adults either on sprayed rice foliage or through contact with the bacteria by adults or neonate larvae in the water. At this point, all research on these materials has been conducted in the greenhouse and is preliminary.

Diseases

California's arid climate provides an unfavorable environment for foliar diseases when compared to humid tropical and subtropical rice areas. Seedling diseases, stem rot, and aggregate sheath spot are the most important rice diseases in California. Kernel smut is occasionally present, but is currently considered a minor disease.

Seedling diseases are caused by the water mold fungi, *Pythium* spp. and *Achyla klebsiana*, and can reduce seedling survival and result in poor rice stands. These diseases are especially severe when rice emergence is slowed by cool air and water temperatures during stand establishment. Vigorous seed, moderate water depths, and later planting dates minimize seedling diseases. Increased seeding rates can help offset seedling disease losses.

Stem rot (*Sclerotium oryzae*) and **aggregate sheath spot** (*Rhizoctonia oryzae-sativae*) are the most serious rice diseases in California. These fungi overwinter as small resting structures, the sclerotia, in infected crop residue or free in the soil. Stem rot sclerotia are small, round and black; aggregate sheath spot sclerotia are rectangular to globose, and brown and larger than stem rot sclerotia. In spring and early summer, the sclerotia float to the water surface and infect the rice plant at the water line. Stem rot symptoms first appear during tillering as small black lesions on leaf sheaths at the water line. As the disease progresses, infected sheaths die and the infection may penetrate the culm causing death of the panicle.

Aggregate sheath spot lesions first appear on lower leaf sheaths at the water line and are circular to elliptical with gray-green to straw-colored centers surrounded by distinct brown margins. Secondary infections progress up the stem and may spread to the flag leaf and panicle. Both diseases are managed by minimizing the carryover of inoculum to the next rice crop. Burning rice residue, removing infected residues from the field, or rotation out of rice for two to three years are the most effective control alternatives. Excessive N fertilizer or dense stands caused by seeding rates that are too high can increase the severity of stem rot. All currently grown public varieties of rice are susceptible to some degree.

Rice blast (*Pyricularia grisea*) is a new disease in California, and is considered to be one of the worst rice diseases worldwide. Under the right environmental conditions this disease is known to have multiple disease cycles in a single season, resulting in very high inoculum levels that can be highly damaging to the crop. The fungus can produce lesions on most of the shoot, including the leaves, leaf collar, stem, nodes, panicle, and grains, but not the leaf sheath. Successful control of blast requires an integrated management program including the use of resistant varieties, cultural practices, and chemical control.

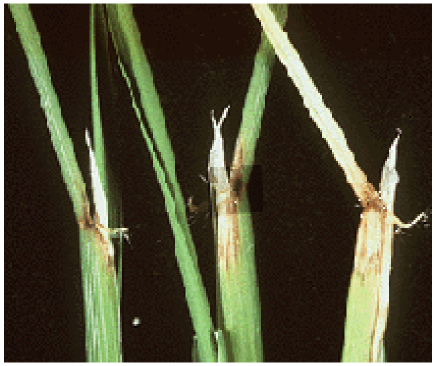
Controls

Historically, California's two worst rice diseases have been stem rot (*Sclerotium oryzae*) and aggregate sheath spot (*Rhizoctonia oryzae-sativae*). These diseases, their development, management, and control are fully described in Integrated Pest Management For Rice (1993) and in the IPM Guidelines for Rice (1997 and Appendix II).

The disease cycles of these two pests depends on the over-wintering of the inoculum as sclerotia in rice straw. Thus, fall burning of rice straw has provided the most complete and efficient method of disease control for California rice. But the practice of burning will be phased out for most rice producers by the year 2000.

With no chemical methods registered in California for control of these diseases, the rice industry, the University of California, the Rice Research Board, and the California Cooperative Rice Research Foundation, Inc. have joined forces on a number of large-scale, multiple year, residue-management projects. These groups along with the California Rice Industry Association and the California Rice Promotion Board have also participated in a task force aimed at finding economically viable alternative uses for rice straw.

For these reasons, the following discussion focuses on a **new and serious pest** in California rice: **rice blast** (*Pyricularia grisea*).



Rice blast, a new pest in California rice, was first detected in 1996. It is a fungal disease, considered by many rice scientists to be the most important worldwide disease of rice, because it can be highly destructive when environmental conditions are favorable. California rice cultivars show varied susceptibility to this disease, but are not considered resistant.

Recent studies[27] indicate that there is one race of blast in California: 'IG-1' and DNA fingerprints have indicated that the isolates are genetically homogenous. This race was common in Texas and Arkansas 20 years ago and is known to occur in Japan.

In 1997, the blast disease was much more widespread in Colusa and Glenn Counties than when it was first detected in 1996; it was also detected earlier in 1997. Blast appeared in Sutter County in 1997; the rapid spread of this disease suggests that it will continue to move into new areas in the future when conditions are right. Favorable conditions include long periods of free moisture, high relative humidity (89% or greater), and warm night conditions (63-73^{O} F) with little or no wind.

The fungus can infect and produce lesions on most of the shoot, including the leaves, leaf collar, stem, nodes, panicle, and grains, but not the leaf sheath. Under favorable conditions the fungus may undergo many disease cycles annually producing a tremendous load of destructive spores by season's end. The disease may progress through several phases, starting with leaf blast and followed by collar, panicle and node blast. When collar rot affects the flag leaf, or neck rot occurs early, or when panicle blast occurs, yields may be severely reduced.

Blast is easily recovered from residue after harvest and can also over-winter on seed; weeds may possibly be an alternate host but this is currently unproven. Observations in the field, particularly of leaf blast, suggest that residue is the primary source of initial inoculum for the early occurrences of leaf blast.

The cultural system of drill-seeding rice, and its attendant practices, is more conducive to blast development, but the majority of California producers practice water-seeding. However, certain regimes for controlling resistant weeds in rice use drill seeding so there may be interactions of these pest control methods.

In the Southern U.S. control of blast relies heavily on resistant varieties. However, since this is a new pest in California, strongly **resistant varieties may be years away** and resistance itself is not always completely effective. Therefore, cultural practices must be used and chemical controls sought.

- **Cultural Controls:**

  Crop residue destruction by burning is an important control measure for reducing over-wintering inoculum, but will not protect the field from other sources of this multiple-cycle, wind-borne disease. Nevertheless, burning remains an important tool because field observations indicate that residue is the primary source of initial inoculum for the early occurrence of leaf blast.

  Water seeding is recommended, over drill seeding to eliminate or reduce transmission of the disease from seed to seedling and extended drain periods should be avoided. Shallow water favors the disease and moderate (4-5inches) or deep (6-8 inches, late season) water flooding is also recommended.

  Excess nitrogen encourages blast, and should be avoided; fertilizer spills and overlaps can enhance disease development providing high levels of inoculum to infect the surrounding field.

  Clean seed, not infested with blast, seems to be a basic first step in prevention, but will not preclude infestation from other sources. There are no registered or effective seed treatments for cleaning infested seed in California.

- **Chemical Controls:**

  The only chemical control available for blast in California is **Quadris**[28] (azoxystrobin), registered under a Section 18 Emergency Exemption label in 1997 and 1998. Quadris is used primarily as a protectant from the devastating neckrot and panicle blast phase of the disease. Early applications prior to boot split and heading have little or no effect on the neck rot and panicle blast phases but may minimize loss to stem rot and aggregate sheath spot. Timing of Quadris applications is critical for the control of neck rot and panicle blast. Current recommendations for blast control are: – a first application in the interval from mid-boot to boot split; the second application should be made when 60 to 90% of the heads are emerged from the boot, or 7-14 days after the first application. Timing of Quadris is critical to disease control. A 15-day holding period applies after application.

  If temperatures, RH, and leaf wetness are not favorable for sporulation and infection by the blast fungus during the time a field is at boot split and heading, then applications of Quadris or any other fungicide would not be needed and could be avoided. Thus by only treating fields that are heading during a time conditions are favorable for sporulation and infection, the total amounts of fungicide used in a particular year could be minimized.

A weather monitoring network that radio-transmits data measurements at 15 minute intervals to a central data collection center and spore traps are being deployed in the rice production area known to be infested with the blast pathogen. This will allow testing the possibilities of predicting when protective applications of Quadris are expected to be effective in controlling losses to neck and panicle blast during the 1998 season. If this approach is successful, a similar system will be pursued for installation throughout the rice production area.

The potential reduction in total use of fungicides through monitoring "disease potential conditions" combined with careful residue, water, and nitrogen management are considered the best approach to reduce risk to both the rice crop and the environment while blast resistant cultivars are being sought by breeders.

The rapid spread of blast in 1997 suggests that this disease will continue to move into new areas in the future. However, environmental conditions play an important role in the spread of this disease, so its long-term impact cannot be accurately predicted.

Nevertheless, any reduction of inoculum and spread of blast contributes to less economic and environmental risk in the long run. Development of resistant varieties is likely to take years, so cultural and chemical methods will be the primary control options. Burning of residue, water seeding, and the correct use of Quadris are currently the best control methods available.

Residue Management

Crop residue management practices are in flux, primarily as the result of the regulatory phase down in straw burning. These changes represent significant challenges to rice producers as they grapple to find production alternatives to burning and disease management. Some producers have reported costs as high as $60/acre to manage straw, significantly cutting into the profit margin. In any event, adequate, early straw disposal will be important to managing California's three primary rice diseases.

Post Harvest Pest Control

Rice is a storable commodity and the facilities used for storage and processing, as well as the commodity, must be kept pest free. The compounds used after harvest are largely divided into two large groups; 1) materials used on the rice itself, and 2) materials used in or around the storage facility. Outlined below are two tables listing these categories. The tables are divided since the materials used in and around storage facilities are not applied directly to the rice. Therefore, though the material may contain rice uses on the label, it is not for direct application and would not have an anticipated residue.

Note that the use of trade names does not imply endorsement of the product or company.

Post-Harvest Materials Used ON Rice or Rice Shipping Containers

Technical material	*Usage*
Methyl Bromide	Fumigant: Mill structures, Finished products
Aluminum Phosphide	Fumigant: Storage facilities, Paddy rice, Finished products
Magnesium Phosphide	Fumigant: Storage facilities, Paddy rice, Finished products
Diatomaceous Earth	Insect control (not typically used post-harvest in CA)

Post-Harvest Materials Used IN or AROUND Storage Facilities (** = commonly used materials in CA)

Technical material	*Usage*
Temephos	Insecticide, site uses
Tetramethrin/Phenothrin	Industrial sites
Deltamethrin	Industrial equipment
N-Octyl Bicycloheptene	Insect fogger
Piperonyl butoxide **	Industrial/food storage areas
Chlorpyrifos **	Storage areas and processing equip.
DDVP **	Storage areas and processing equip.
Malathion	Insect control, crack and crevice treatment
Resmethrin	Crack and crevice treatment
Tetramethrin	Industrial equipment
Esfenvalerate	Storage facilities

Permethrin **	Storage/warehouse facilities
Hydrophene	Crack and crevice treatment
Cyfluthrin **	Food Storage
Bendiocarb	Crack and crevice treatment
Methyl Bromide **	Empty food storage facilities
Diatomaceous Earth	Walkways
Diazinon **	Crack and crevice treatment

Weeds

The Grass Complex: *Echinochloa* and *Leptochloa*
Description - In California, the *Echinochloa* complex, watergrass and barnyardgrass, are the most serious weeds in rice. They occur as three species: barnyardgrass (a terrestrial ecotype, *E. crus-galli*), and as early and late watergrass (both obligate aquatic ecotypes, *E. oryzoides and E. phyllopogon*). Both barnyardgrass and late watergrass occur as heterogeneous biotypes, while early watergrass appears to be more homogeneous which may be important to the genetic diversity available for selection against herbicides. Terrestrial barnyardgrass is the most widespread weed and the easiest to control by floodwater. In general, the late flowering form of watergrass is distributed more heavily in the north western Sacramento Valley. The early flowering type and barnyardgrass are ubiquitous. The *Echinochloas* are the most competitive weed in rice in California. As few as two watergrass or barnyardgrass plants per square yard can cause yield losses of 10%. Recently, biotypes of watergrass have shown multiple resistance to several herbicides normally used for their control.

Sprangletop (*Leptochloa fascicularis*) is much less competitive than barnyardgrass or the watergrasses in reducing rice yields unless it establishes a dense stand. It is a widespread weed and like barnyardgrass, can be found in both flooded rice as well as other cultivated crops. Sprangletop has generally been controlled by continuous flooding. Problems with sprangletop are increasing because more and more fields are drained for stand establishment or to apply foliar active herbicides.

The Annual Sedge/Rushes Complex
The principle annual sedges/rushes are smallflower umbrella sedge (*Cyperus difformis)*, and ricefield bulrush (*Scirpus mucronatus)*. Ricefield bulrush is a weak perennial, but behaves in the rice environment mostly as an annual reproducing from seed. Both of these weeds are distributed throughout the Sacramento and San Joaquin Valley

rice areas. In general, ricefield bulrush is more prevalent in the warmer environments of the northern end of the Sacramento Valley and the Firebaugh/Dos Palos rice region of Fresno and Merced counties. Smallflower umbrella sedge is the dominant species in the areas of Sacramento/ Placer and San Joaquin/Stanislaus counties south of Yuba City. Both species are prolific seed producers with a single smallflower umbrella sedge plant able to produce in excess of 20,000 seeds. The narrow, vertical and waxy leaf surfaces are a particular challenge for coverage and control by foliar active herbicides. Both are aquatic obligates surviving only in the flooded system. Due to their high seed load, infestations in excess of 100 plants per square foot may occur. The sedges are not as competitive as are the *Echinochloa* on an individual plant basis, but their sheer numbers may cause severe yield losses from direct competition and through increased crop lodging. In 1992, smallflower umbrella sedge was found to be resistant to the ALS inhibiting herbicide Londax and in 1993 similar resistance was confirmed in ricefield bulrush.

The Annual Broadleaf Complex

The broadleaf complex consists of a diversity of aquatic species. This Evaluation will focus on the most troublesome broadleaf weeds in rice; redstem (*Ammannia* spp.). California arrowhead (*Sagittaria montevidensis*), ducksalad (*Heteranthera limosa*), waterhyssop (*Bacopa* spp.) and common waterplantain (*Alsima triviale*). These weeds differ in growth habit and strategy for survival. Although they are widespread, none of them are as detrimental to rice yield as the grass or sedge weeds. Of the aquatic broadleaf weeds, redstem is the most serious pest. Redstem grows slowly after germination, and is often missed by foliar herbicides unable to penetrate the rice/weed canopy. Later in the season, redstem overtops rice, interfering with grain fill and slowing harvest. Its red fruit or berries contaminate the grain, raise the moisture levels and lower grain quality. California arrowhead is a weed which competes poorly with rice in good rice stands. But where stands are poor or in any open water areas, California arrowhead can flourish. Ducksalad and waterhyssop are low growing weeds that inhabit open water. Occasionally, they establish before the rice, creating a leafy mat on the water surface and crowding out rice stands. Common waterplantain is a weak perennial occurring as a problem in certain fields. It is the least widespread of the annual broadleaf weeds, but can be very troublesome to stand establishment.

The Perennial Weed Complex

The perennial weed complex consists of weeds reproducing by vegetative propagation. These include river bulrush (*Scirpus fluviatilis*), Gregg's arrowhead (*Sagittaria longiloba*) and cattail (*Typha* spp.). These weeds are found throughout the California rice areas, but tend to be localized problems where rice is grown continuously. Within the ricefield they are patchy in distribution due to their vegetative reproduction. While they do not cause the overall yield losses of the more widely distributed annual weeds, they are often more persistent and difficult to control due to their vegetative structures which can overwinter as dormant corms and rhizomes. They are often found in ditches and drains from where they move into rice fields.

The Submersed Aquatics: Algae, Naiad and Pondweed

The submersed aquatics are a mixed group of species characterized by their underwater growth habit. The algae are the most important among this group because they are ubiquitous in distribution and can cause problems with stand establishment. The filamentous algae are the most troublesome, but chara, resembling a higher plant, can cause problems in alkaline soils. The algae grow underwater on the soil surface. When the colonies are large, entrapped air floats them to the water surface in large mats that suppress the growth of young rice seedlings either physically or by shading. These mats can float into and clog irrigation structures such as rice boxes and drains. The algae have the potential to be a problem in any field. Typically, they create more problems when wet winters force growers into shortcuts in tillage, leaving fertilizer on the soil surface, followed by very hot conditions at stand establishment. The naiads (*Naja* spp.) are rooted, submersed aquatic species that reproduce by seed and vegetatively. They resemble chara to some extent and compete with young seedlings for light, primarily reducing rice tillering. The pondweeds (*Potamogeton* spp.) are perennials reproducing from tubers as well as seed. They are widespread in ditches and waterways, but only occasionally move into rice fields.

Controls:

A Note on Costs: Cultural and chemical controls for rice weed control are described below by weed complex. Biological controls are not used for weeds in California rice. The costs per acre of chemical weed control in California range from $30 to more than $120 dollars with average costs of about $90. In the past three years, these costs have increased from about $70 per acre reflecting the additional applications needed to control Londax-resistant weeds and the need to control drift with ground application rigs. The allocation of the cost of cultural practices such as tillage, water management, etc. between weed control and other aspects of agronomic management are difficult to estimate. Clearly, these practices are important to weed control, but essential to successful rice production even in the absence of weeds. However, the costs of water, tillage and other practices used specifically for weed control may range from less than $25 per acre to considerably higher, where opportunity costs of fallowing coupled with extensive irrigation/tillage is practiced to lower weed seed banks.

The Grass Complex--*Echinochloa* and *Leptochloa*

- **Cultural Controls:**

  Water Management. Continuous flooding is the most important cultural method of weed control in rice worldwide. In Asia, the practice of transplanting rice into flooded fields over the last four millennia is believed to have evolved from dry seeding primarily for weed control. The cultural system of water-seeding in California was established to control barnyardgrass which was spreading rampantly in the dry-seeded rice culture of the 1920s. The subsequent development of aerially seeding rice into the water and holding water at a depth of 8 inches was credited with saving the rice industry in California. Continuous flooding is still practiced to suppress the small-seeded barnyardgrasses and to a lesser extent, the large-seeded watergrasses. Sprangletop is almost completely controlled by continuous flooding, however, growers are increasingly complaining of biotypes that can survive flooding. Most of these problems, however, can be attributed to increased draining of rice fields to assist stand establishment before long water holding periods, or to expose weeds for the application of foliar-active herbicides. In addition to water depth, the time that is required for initial field flooding is also important. Rapid field flooding allows planting before weeds can establish themselves. Fields that require a week or more to flood may have grass weeds well ahead of the rice. The advent of laser-directed leveling in the 1970s significantly improved the grower's ability to manage water for rapid flooding, controlling water depth, and better water management as a cultural tool for suppression of these weeds.

Many rice herbicides require the combination of chemical activity and water suppression to provide acceptable control. For example, the first widely used herbicide for grass control, propanil, was foliar active so the weeds had to be exposed for treatment. However, covering the weeds with water within 24 hours was necessary for complete weed kill. The introduction of molinate in 1965 provided the first widely used herbicide that could be applied directly into the water. This was a great boost to weed control as it provided the dual effect of herbicidal activity and water suppression without requiring the water to be lowered for foliar exposure. More recently, growers have drained rice fields to help the rice recover. While the long water holding periods have alleviated problems with downstream chemical pollution, they have largely negated

the advantage of weed suppression by continuous flooding. Before the advent of long holding periods, growers drained only those few fields requiring stand recovery. Now large acreages are drained as a hedge against unforeseen stand losses due to long water holds. This often stimulates the germination of a new cohort of grass weed seed by allowing oxygen into the soil. Water management for broadleaf weed control may also affect the subsequent germination and reinfestation of barnyardgrass, watergrass, and sprangletop.

Tillage and Seedbed Preparation. Pre-plant tillage is an important factor in controlling watergrass and barnyardgrass by drying the seedbed and desiccating the seedlings. In-crop tillage is not practiced for control of the grass complex in broadcast seeded rice (dry or water-seeded) nor in drill-seeded rice. Experiments in the 1980s designed to cultivate poorly rooted barnyardgrass in well-rooted drill-seeded rice were a complete failure, primarily because field drainage stimulated more than 100 fold densities of the grass weeds compared to the levels found in continuous flooding. In wet years, or when rice is "mudded in" and the seedbed is not allowed to dry following tillage, barnyardgrass and watergrass may flourish because they are well established even before flooding and seeding. In addition to seedbed tillage, fall tillage may allow sufficient drying to reduce over-wintering propagules of perennial species in rice, but rodents and birds bury grass weed seed, protecting it from depredation during the winter period. While buried weed seed may eventually decay, evidence from recent straw incorporation studies indicates that seed banks will build up under fall tillage where weed seed is protected from rodents and birds by burial. Tillage controls only germinated weed seedlings. Other than burying some seed below the germination zone, tillage has little effect on ungerminated seeds. Hence, tillage by itself cannot be expected to provide sufficient weed control. Since the 1970s large rollers have been used to smooth and crease the seedbed. Smooth seedbeds have improved the uniformity of weed seed germination and growth stage. Hence, herbicides such as thiobencarb with a narrow window of application timing relative to weed growth stage, are much more successful on rolled seedbeds than on seedbeds grooved with an open disk or harrow. The creaser has also improved rice stand establishment by protecting the young rice seedlings at the bottom of the groove from wind and wave uprooting. However, the roller acts like a press-wheel sealing moisture into seedbeds that are too wet and encouraging barnyardgrass and watergrass germination and establishment.

Prevention. A high percentage of the California rice acreage is planted with certified seed. Although certifiable limits for barnyardgrass and watergrass seed are set at 10 seeds/lb. of rice seed, most certified lots contain little, if any seeds of these weeds. While small amounts of these weed species may have been introduced as contaminants of rice seed, it was not critical as long as they were controlled by the grass herbicides. The recent discovery of herbicide resistance in biotypes of late watergrass makes clean seed for planting an essential component of weed management to prevent their spread.

Varieties. Many believe that semi-dwarf cultivars are less competitive than their taller successors. However, the critical time for weed competition is within the first 20-30 days after seeding, long before stem elongation or apparent differences in height. Early seedling vigor is probably far more important than height in determining the competitive outcome with weeds–particularly barnyardgrass and watergrass. Long grain cultivars grown in California have poorer seedling vigor and canopy closure than the medium grain cultivars and as a result, are less competitive against weeds.

Crop Rotation. Rotation to other crops is an excellent method of controlling the grass weeds that infest rice. Cultivation, alternative herbicides and depredation play an important role in reducing the grass weeds. Rice, however, is grown on heavy clay and salt-prone soils of the Sacramento and San Joaquin Valleys unsuitable for most other crops. With 500,000 acres of rice planted, only about 40% of the rice soils can be successfully rotated to alternative crops and the rest must be fallowed as an alternative to rotation. Non-synthetic chemical (organic) rice cultures fallow for one to two years to control these weeds with the cost of not producing a crop on the land reflected in the price of organic rice.

- **Chemical Controls:**

Several herbicides may be used to control barnyardgrass, watergrass and sprangletop in rice. The following descriptions of herbicide use begins with the most widely used and progresses to the least used, discussing their integration with cultural practices as well as their limitations.

Molinate: Molinate or Ordram, is the best and most widely used of the current herbicides for watergrass and barnyardgrass control in California. It does not, however, control sprangletop or other rice weeds. Treated acreage has ranged from over 95% in 1989 to about 60% treated in 1997 (Figure 4).

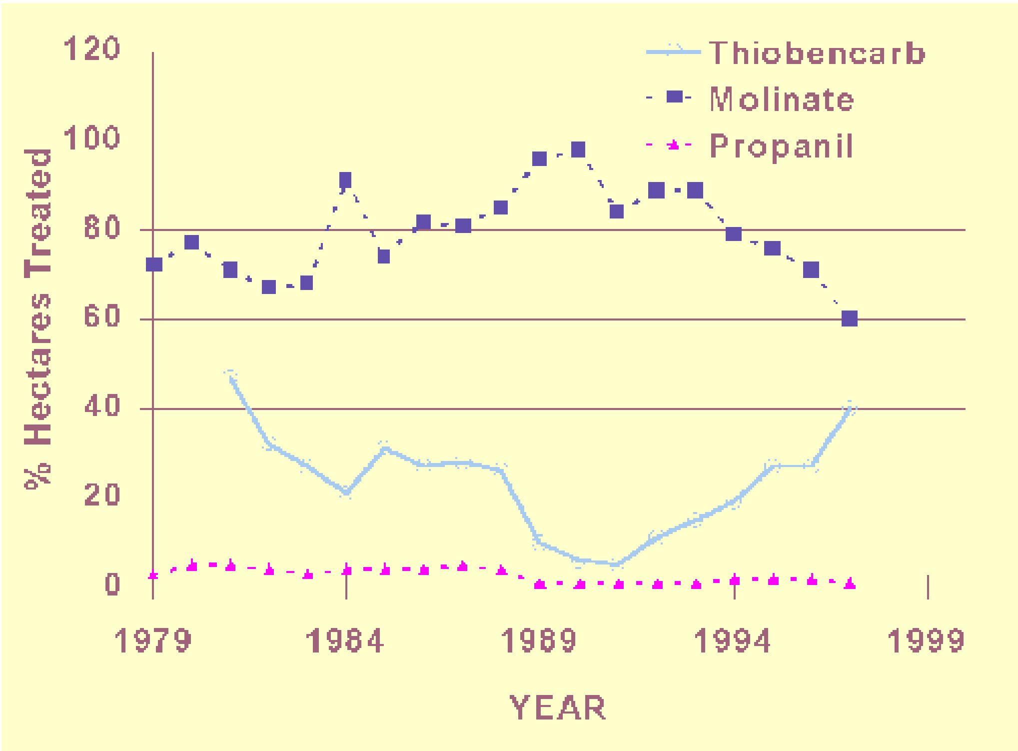
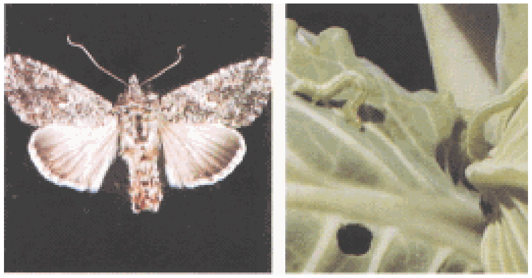


Figure 4. Changes in the number of applications of grass herbicides per acre, 1979 to 1997. In addition to grasses, thiobencarb may be used to control bensulfuron-resistant smallflower umbrella sedge: note the increase in its use since 1991-92. Data from the California Department of Food and Agriculture and Department of Pesticide Regulation Use Reports, 1979-1996.

Figure 5. Changes in broadleaf and sedge weed control per acre, 1979 to 1995. Note that bensulfuron-methyl use continues even as weed resistance is becoming widespread, **exacerbating selection pressure**. Note also, the **increase in MCPA / 2,4-D** use. Data from the California Department of Food and Agriculture and Department of Pesticide Regulation Use Reports, 1979-1996. Data gaps supplemented with industry sales figures, as needed.



The most significant attributes of molinate are safety to rice, a fairly broad application window (control of these species up to the 5-leaf stage) and most importantly, that it can be applied directly into the flood water with field drainage unnecessary. Molinate has a residual activity of about eight days: greater than foliar-only herbicides, but not long by comparison to other residual herbicides. Molinate's weakness is that it is an *Echinochloa*-only herbicide, varying in efficacy against other rice weeds, but inadequately controlling them. Thus, molinate must be used in a program including a broadleaf herbicide, and in some cases, a herbicide for sprangletop *(Leptochloa* spp.*)* control. After the use of propanil was restricted in 1969, molinate became the most widely used herbicide for barnyardgrass and watergrass reaching a peak use of over 95% of rice acreage following the introduction of Londax (bensulfuron) in 1989 (Figure 5). Molinate's use declined following the discovery of Londax-resistant weeds, not because it is less effective on the grasses, but because of its inability to control other weeds. Thiobencarb, for example, is somewhat less effective on watergrass and barnyardgrass, but controls Londax-resistant smallflower umbrella sedge. Increasingly, lower rate applications of molinate and thiobencarb have been used sequentially to expand the narrow window of thiobencarb against watergrass and barnyardgrass, plus controlling smallflower umbrella sedge. Molinate was one of two barnyardgrass and watergrass herbicides to move off-site into agricultural drains and public waters. This is no longer a problem due to rice farmer adoption of improved irrigation systems that have held molinate on site. The total mass flow of molinate in the Sacramento River has been reduced by over 98 percent. An emerging problem is the recent discovery of biotypes of watergrass with resistance to molinate. This is an extremely serious problem for the future of weed management in rice.

Thiobencarb. Thiobencarb was introduced in the early 1980s primarily for barnyardgrass and watergrass control and secondarily for the control of sprangletop, ducksalad and sedge weeds (discussed below). Thiobencarb was originally introduced as a granular formulation (Saturn) for an into-the-water application. Like Ordram, one of Bolero's strengths is that it can be applied without the need for field drainage. Thiobencarb also has a residual of about 20 days, over twice as long as Ordram. The acreage treated with Bolero reached a peak of 40% shortly after its introduction in 1981 (Figure 4), but declined with sales restrictions due to off-site movement. Its use declined sharply with the introduction of Londax which controlled smallflower umbrella sedge. The decision to use Bolero rather than molinate was based on its broader spectrum of weed control, particularly its ability to control smallflower umbrella sedge and a few other broadleaf weeds along with barnyardgrass and watergrass. This feature eased the pressure on subsequent applications of MCPA or Basagran (bentazon). More recently, the EC formulation of thiobencarb, Abolish, was introduced for barnyardgrass, watergrass, and sprangletop control. This "liquid" formulation can be tank mixed with other products as well as provide more uniform coverage in direct applications to drained rice fields as a pre-flood surface application. In part, this was made possible by the introduction of rice rollers which smoothed the seedbed surface as compared to the cloddy seedbeds typical at the time of the introduction of Bolero. Pre-flood surface applications, however, are now rarely used because too much residual activity is lost before and during the initial flood and prior to weed germination. Abolish is now used predominantly as a pinpoint, post-flood application to the drained soil surface shortly after planting, thus extending the residual activity to nearly canopy closure. The overriding weakness of thiobencarb is its narrow window of application. Rice stands must be at least 70% in the two leaf stage to withstand injury and barnyardgrass or watergrass must be no larger than two leaf. Sprangletop can be controlled at the three leaf stage. Even the slightest delay can result in poor control or under inclement conditions, the inability to use thiobencarb. Wet years allow germination of watergrass and barnyardgrass prior to field flooding, thus rice would seldom if ever reach the safety of the two leaf stage before the grasses exceeded the outer limits for control. Another problem with thiobencarb is the Delayed Phytoxicity Syndrome (DPS) caused by the production of a de-chlorinated metabolite of thiobencarb from aerobically active micro-flora. This metabolite appears at mid- to late-tillering and is approximately 20 times more toxic to rice than the parent compound. Thus far, the problem has occurred mostly on the red granitic soils of the east-side of the Sacramento Valley. Rice symptoms are typical of early thiocarbamate injury with dark green coloring, leaf hooking, and brittle stems. The problem is ameliorated by field drainage to oxygenate the soil and reduce the activity of the anaerobes. In 1983 an off taste in the Sacramento municipal drinking water was attributed to thiobencarb sulfoxide and triggered long water holding times for Bolero use in water-seeded rice. By 1989 growers could completely control all weeds with a combination of Londax and Ordram. Coupled with the acreage restrictions due to off-site movement on water and the high degree of efficacy of Ordram/Londax combinations, Bolero use dropped to less than 10% of the acreage by 1989 (figure 5). The problem of offsite movement, as with Ordram, was solved by the adoption of improved ricefield irrigation systems. Abolish (8EC) appears to dissipate from water more favorably than Bolero (10G), has fewer water hold requirements, and is preferred by growers to reduce the risk of losing stands during long water holding periods. Recently, a biotype of watergrass has been identified as resistant to thiobencarb as well as to Ordram, representing a serious threat to the future of rice production in California.

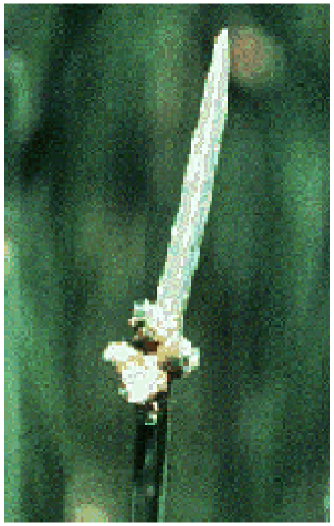
Propanil. Propanil was the first selective herbicide for barnyardgrass and watergrass. Introduced in the 1960s, it was widely used in California. Treated acreage rose rapidly. Relative to molinate and thiobencarb, propanil has a much wider spectrum of weed control as well as a relatively wider window of application timing. However, propanil is foliar active, thus it cannot be used as an into-the-water granular application. At least partial, if not complete, drainage for early applications is required. Unlike molinate and thiobencarb, propanil has no residual activity so weed re-growth from poor coverage or newly germinated weeds will survive. A major problem of propanil, at least in the early years following its introduction, was its potential to damage deciduous trees from drift. In 1968, damage to sensitive tree crops such as prunes was so severe that propanil use was limited to the southernmost rice growing area of the Sacramento Valley and the San Joaquin Valley representing less than 10% of the acreage. Molinate had been introduced in 1965 and largely replaced propanil. In the 1980s roughly 4% of the acreage was added in a special propanil zone on the west-side of the Sacramento Valley. The question of what caused propanil drift is still uncertain, but it was undoubtedly a combination of too much product in too short of time, a drift prone formulation, and poor application technology (both equipment and climatological information). Aerial drift was thought to be from both air saturation and so-called lift-off of crystals from the rice leaf surface. In 1997, the area of propanil use was expanded to assist in controlling resistant sedges and broadleaf weeds. With the advent of multiple herbicide resistance to molinate, thiobencarb and fenoxaprop, propanil may become more important in the battle against resistant grass weeds. However, propanil-resistant grasses have been reported widely in other rice areas and now have been confirmed in California.

Fenoxaprop. Fenoxaprop or Whip was introduced in the early 1990s in California rice to control barnyardgrass and watergrass that have escaped previous treatments or to clean up sprangletop. It is used on only about 5% of the acreage. Its principle strength is that it will control barnyardgrass and watergrass over a wide range of growth stages. Its major weakness is that it has a relatively narrow rate range for crop selectivity, hence non-uniform applications result in both a lack of weed control and crop injury, making this herbicide the most demanding in application coverage of any rice herbicide. Recently, a biotype of late watergrass has been shown to be resistant to fenoxaprop.

The Annual Sedge Complex

- **Cultural Controls:**

Water Management. Smallflower umbrella sedge and Ricefield bulrush are obligate aquatic weeds. Neither can be controlled in water-seeded rice by regulating water depth. There is some evidence that smallflower umbrella sedge may be partially suppressed by 6-8 inch or deeper water. Ricefield bulrush, however, does very well in deep water. These sedges will not establish under dry soil conditions. Thus, drill- or dry-seeding has been used to delay their emergence until the permanent flood after the rice is well established and able to compete. However, dry seeding, as was originally done in California, creates a haven for the grass weeds which must be controlled at infestation levels far exceeding those of water-seeded rice.



Crop Rotation. Crop rotation has been previously discussed as a method of reducing the grass weeds. While the grass weeds grow in both aquatic and terrestrial environments, the sedges are obligate aquatic species. The seed of these species will lie dormant in upland rotational crops, hence destruction by other cultivation or alternative herbicides is not possible. Fallowing can reduce, but not eliminate the seed bank of sedge weeds, however, alternating flood and cultivation cycles must be repeated to allow germination and destruction of these weeds.

- **Chemical Controls:**

Several herbicides have been used to control the annual aquatic sedges in rice. These methods have been coupled to water management primarily to allow for uniform weed growth for subsequent herbicide timing and control.

Londax. Londax (bensulfuron) is currently the most widely used herbicide for aquatic sedge control in California rice. Treated acreage reached nearly 100% in 1990, in only the second year following its introduction, but its use has declined to about 65% of the acreage due to weed resistance. Londax was the first aquatic sedge and broadleaf herbicide used into-the-water. Because of its activity in the water, it was a perfect match for Ordram as a one-two punch against all major weeds of rice–missing only perennial weeds derived from vegetative propagules. Londax also provided partial control of the *Echinochloa* complex, thus alleviating some of the pressure on the "grass" herbicides. Londax was the first of a new generation of "low-rate" chemicals for weed control in rice applied in ounces rather than in pounds per acre, a fundamental strength with respect to chemical loading in the environment. Another attribute is its specificity in biochemical activity to plants and not animals, thus having low toxicity to organisms other than target species. Londax is active in water and can be applied "direct-dry" into the water with precision applicators (1.7 oz/acre of total product) or as a spray. Direct dry application permitted non-treated buffers near drains and ditches to avoid direct hits while the herbicide migrated into the buffer areas through the floodwater. The direct-dry method also avoided spray tank cleaning problems and the inadvertent application of contaminated sprays to sensitive crops. However, the need to tank mix with other herbicides to counter weed resistance to Londax has caused an increase in spray applications. Both smallflower umbrella sedge and ricefield bulrush have developed widespread resistance to Londax. The major difficulty in both the development of resistance and its control is the lack of herbicides with alternative mechanisms of action. The de-registration of bentazon (Basagran) for rice at the time of Londax registration was a major setback in combating resistance. Had bentazon remained available, resistance of the annual aquatic sedges and other broadleaf weeds would not be as widespread today.

Phenoxy Herbicides--MCPA, 2,4-D. The phenoxy herbicides were introduced shortly after WW II as the first selective herbicides for sedge (and broadleaf) weed control in rice. The herbicide 2,4-D was the first used, but MCPA was found to be safer to rice and relatively close in efficacy to 2,4-D and became the herbicide of choice. Records based on available data indicate that about 60-70% of the acreage was treated with phenoxy herbicides throughout the 1950s (Hill and Hawkins, 1996).

The primary weeds controlled by phenoxy herbicides are smallflower umbrella sedge and ricefield bulrush, but, they are somewhat inconsistent–due to differences in weed stage of growth and weather conditions at the time of application. Although the phenoxys are translocated, approximately 70% of the weed leaf surface must be exposed to achieve adequate control. Furthermore, the sedges must be treated before main-stem flowering and tiller bud development. In plants too advanced, the main stalk is killed, but the herbicide is not translocated to the small tiller buds which subsequently produce new plants. The phenoxy herbicides have two major disadvantages. First, they are growth regulators and most broadleaf crops are sensitive–cotton being 1000-fold more sensitive than rice. Damage to broadleaf crops can occur with only the slightest drift from suspended droplets. Secondly, rice is invariably injured by phenoxy herbicides, but generally competition from the sedge weeds causes far more damage to yield than does crop injury due to the herbicide. Still, growers are reluctant to use the phenoxy herbicides when other products are available. For example, growers still used Londax despite the presence of sedge resistance, rather than risk injury from the phenoxy herbicides. To minimize injury, the phenoxy herbicides are used between early tillering and panicle initiation at 25 to 45 days after seeding. Thus, where weed infestations are high, competition has begun to reduce crop yield potential by the time phenoxys are applied.

Triclopyr. Triclopyr (Grandstand) has recently been registered in California rice to assist with the management of resistant ricefield bulrush and where phenoxy herbicides cannot be used. The herbicide was first tested in the 1970s, but not developed because MCPA and 2,4-D were more effective as general sedge herbicides. For example, triclopyr does not adequately control smallflower umbrella sedge. Triclopyr is less injurious (but not injury free) at early stages of rice growth compared to the phenoxy herbicides. It also has less propensity for drift damage than 2,4-D and can be used with less restrictions on the distance to sensitive crops. Triclopyr is an important tool to fill in the gaps created by resistance, the loss of phenoxy herbicides, etc., but is not a primary sedge herbicide. It is useful for zones where phenoxys cannot be used and for redstem.

Propanil. One of the great strengths of propanil (Stam/Super Wham) is its broad spectrum of activity on ricefield weeds, including smallflower umbrella sedge and ricefield bulrush. For this reason, propanil is the backbone of rice weed control in the southern US, Latin America and other places where rice is dry seeded. When it was introduced in California's water-seeded culture in the 1960, not only did it control watergrass, but also assisted in the control of sedge weeds missed or erratically controlled by the phenoxy herbicides. Because of the deep water flooding at that time, propanil was often used later in the season than recommended today. Because it is only active as a foliar spray, today's early applications require drainage; and because it has no residual, weeds emerging after the application will not be controlled. Combining propanil with thiobencarb either in sequentially or in tank mixes can increase the residual period as well as broaden the application window. With widespread Londax resistance, propanil is probably more important for sedge than for grass control. Propanil safety to rice is antagonized by applications of organophosphate or carbamate insecticides within two weeks before or after propanil is used. These insecticides block the metabolic breakdown of propanil which is the selective mechanism providing safety to rice while killing weeds.

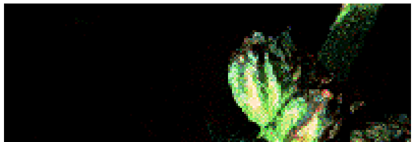
Thiobencarb. Thiobencarb (Bolero/Abolish) is active on smallflower umbrella sedge and used primarily where this weed has developed resistance to Londax. Because it provides grass control as well, growers use thiobencarb as the primary herbicide where both resistant smallflower umbrella sedge and barnyardgrass/watergrass are present. Although thiobencarb partially controls ricefield bulrush, it is too erratic to be used as the primary herbicide, so growers generally use molinate for grass control and another herbicide for ricefield bulrush control. The problem with DPS has been discussed previously, but it frequently occurs in areas that are heavily infested with smallflower umbrella sedge. Thus growers with DPS cannot use thiobencarb for resistant smallflower (nor Londax) and must find an alternative herbicide.

Carfentrazone. Carfentrazone (Shark) is a new rice herbicide with a Section 18 registration in 1998. Shark controls an array of broadleaf weeds including all those resistant to Londax. Although we have a fair knowledge of Shark, many questions remain about its use into the water and the need for adjuvants to improve coverage.

The Annual Broadleaf Complex

- **Cultural Controls:**

Water management. A continuous flood suppresses the growth of the grass weeds; however, the broadleaf aquatic weeds flourish in standing water. Once the permanent flood is established in about three weeks, rice has a head start on the weeds. In contrast, Broadleafs germinate and grow poorly in dry-seeded rice systems where seed is planted pre-flood and rice may be irrigated, but not permanently flooded, until the 3-4 leaf stage. Pinpoint flooding or other short discontinuous drains are inadequate to prevent establishment of the broadleaf aquatic weeds. Dry or drill-seeding to discourage the broadleaf aquatic weeds and/or sedges, encourages the much more competitive grasses. The idea of rotating rice establishment between dry and flooded systems to break weed cycles has merit, but is wholly dependent on having good grass control herbicides.



Crop Rotation. The broadleafs are obligate aquatic species. Their seed will lie dormant under upland conditions, hence destruction by cultivation or alternative herbicides is minimal in the rotation crop. Fallowing can reduce, but not eliminate the seed bank of the broadleaf aquatic weeds, however, alternating flood and cultivation cycles must be repeated to allow germination and destruction of these weeds.

Tillage. Though seedbed tillage is highly important for control of early germinated grass weeds, it is ineffective on the broadleaf aquatic species, most of which require flooded conditions to germinate.

- **Chemical Controls:**

Several herbicides have been used to control the broadleaf aquatic weeds. These herbicides range in effectiveness against individual broadleaf species. Integration of herbicide use with water management is critical to achieve good coverage of the foliar active chemicals, and to prevent re-infestations of the grass weed species following broadleaf weed exposure.

Londax. Londax (bensulfuron) is currently the most widely used herbicide for aquatic broadleaf control, killing all species before the development of resistance to redstem and California arrowhead. Please refer to the information under The Annual Sedge Complex section for detailed information on Londax. Both redstem and California arrowhead have developed widespread resistance to Londax. The major difficulty in both the development of resistance and its control is the lack of herbicides with alternative mechanisms of action. The de-registration of bentazon (Basagran) for rice at the time of Londax registration was a major setback in combating resistance. Had bentazon remained available, resistance of the annual aquatic broadleaf weeds would not be as widespread today.

Phenoxy Herbicides--MCPA, 2,4-D. The broadleaf aquatic species are highly sensitive to the phenoxy herbicides. Although the phenoxys are translocated, approximately 70% of the leaf surface must be exposed to achieve adequate control. Upright aquatic species such as California arrowhead, waterplantain, and redstem seldom have problems with coverage, with the exception that early applications (25-35 DAS) may miss redstem not emerged through the canopy. Waterhyssop and ducksalad, which lie on the water surface, may also have problems with coverage after the rice canopy has closed above them. Please refer to the information under The Annual Sedge Complex section for detailed information on Phenoxy Herbicides.

Triclopyr. Triclopyr has recently been registered in California rice to assist with the management of resistant redstem (and ricefield bulrush as previously described) and where phenoxy herbicides cannot be used. Triclopyr suppresses some of the other broadleaf aquatic weeds, but does not adequately control them. Please refer to the information under The Annual Sedge Complex section for detailed information on Triclopyr.

Propanil. One of the strengths of propanil (Stam/Super Wham) is its broad spectrum of activity on rice field weeds, including the aquatic broadleaf species. With widespread Londax resistance, propanil is important for control of the broadleaf weeds. Propanil safety to rice is antagonized by applications of organophosphate or carbamate insecticides within two weeks before or after propanil is used. These insecticides block the metabolic breakdown of propanil which is the selective mechanism providing safety to rice and killing weeds.

Thiobencarb. Thiobencarb (Bolero/Abolish) provides minimal control of the broadleaf aquatic weeds. It is most active on ducksalad and will suppress waterhyssop and redstem, but it is not a first line of defense against these weed species.

Carfentrazone. Carfentrazone (Shark) is a new rice herbicide with an expected Section 18 registration in 1998 and a full registration in 1999. Shark controls an array of broadleaf weeds including all those resistant to Londax. Although we have a fair knowledge of Shark, many questions remain about its use into the water and the need for adjuvants to improve coverage.

The Perennial Weed Complex

- **Cultural Controls:**

Water Management. The aquatic perennials thrive in the water environment and with their vegetative reproductive structures, have the capability of surviving short drains or delayed initial flooding. Thus, little can be done with water management alone to prevent their spread once they are established.

Tillage. Tillage is an important cultural practice to reduce the incidence of the perennial aquatic weeds. In continuous rice where these weeds are the most invasive, fall tillage as early as possible can physically cut the over-wintering structures into small pieces and field drying will destroy them by desiccation.

Crop Rotation. Crop rotation is the most important cultural practice to break the aquatic cycle and reduce the perennial aquatic weeds. Tillage in the out-of-rice year allows for thorough drying and more complete destruction of the vegetative structures.

- **Chemical Controls:**

Herbicides must have the ability to translocate and kill the vegetative reproductive structures in order to control the perennial aquatic weeds. While foliar herbicides such as propanil and bentazon (when it was registered) burned the foliage, they did not kill the underground structures that allow these weeds to propagate vegetatively. Thus, most perennials recovered from the temporary burn back caused by these herbicides. The phenoxy herbicides, 2,4-D and MCPA, are translocated and provided better, but not complete control of the perennial weeds. Other herbicides, such as glyphosate, can be used on ditch banks to keep perennials such as cattail or river bulrush from spreading, but cannot be used once these weeds have invaded rice. Londax used as a foliar application later in the season has been reported to kill Gregg's arrowhead. Londax applied as the direct-dry application actually released Gregg's arrowhead causing it to be the most rapidly spreading weed between 1989 and 1993 (before Londax resistance to the annuals caused a return to the phenoxy herbicides).

The Submersed Aquatics--Algae, Naiad and Pondweed

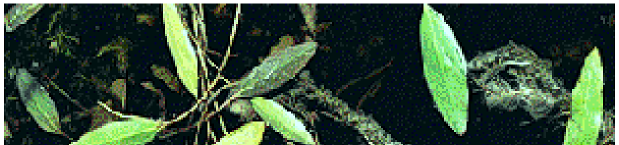
- **Cultural Controls:**

Water Management. All of the submersed aquatics flourish in the water environment and are probably among the best survivors of deep water. Since they are obligate water species, draining the field, or using a dry-seeded, discontinuous flood culture can disrupt their life cycles and delay their occurrence until the permanent flood. Draining to kill filamentous algae must be done while the colonies are submersed on the soil surface. Draining after large floating mats are formed will drag the young rice seedlings to the soil surface where they may be unable to recover. Short-term draining will have little effect on infestations of the pondweeds as their vegetative structures will be able to survive.

Fertilizer Management. Placement of fertilizers, especially phosphorus, on the soil surface encourages algal bloom when the conditions are right for growth. Phosphorous should also be shallow incorporated into the rice root zone to prevent uptake by algae as this nutrient is relatively immobile in the soil. This management strategy is critical to prevent algal blooms and the rapid growth of other submersed aquatics.

Straw Management. Increasingly, rice growers are incorporating straw to comply with the Straw Burning Reduction Act of 1991. Straw left on the soil surface acts as a substrate for algae, contributing to algal blooms, hence making it important to achieve good straw decomposition and incorporation.

Tillage. Tillage has little impact on the algae and naiads, but can cut and desiccate the rhizomes and tubers of the pondweeds given sufficient time for drying.



- **Chemical Controls:**

Herbicides have not been developed specifically to control the submersed aquatics in rice. However, herbicides developed for ditches and waterways occasionally are registered in rice, such as was endothall (Hydrothol) for the control of pondweeds. And occasionally, herbicides registered for rice will control the submersed aquatics such as Londax which controls the naiads. The critical herbicide for algae is copper sulfate, discussed independently below.

Copper Sulfate. Fine crystalline formulations of copper sulfate have long been an effective tool against algae (and tadpole shrimp). Large acreages are treated every year and in years when the conditions favor algal growth, multiple applications have been used. Since copper is an element and does not break down, there is some concern about its continuous buildup to levels toxic to rice. From an environmental perspective, concern has been expressed about the possible movement of copper off-site from rice fields. Studies indicate that copper is tightly bound to the soil and does not move from rice fields into downstream waters. While this is good from an environmental perspective, it underscores the need to prevent continuous loading of copper in rice soils.

Consequences of Loss

Few materials are currently approved for direct application to rice as a fumigant, and their continued use and availability is critical to maintain the food product in a wholesome and merchantable form. Aluminum and magnesium phosphide are used as fumigants of storage facilities, paddy rice, and finished goods for both domestic and international shipments. They are the only fumigants that are DOT approved for use in-transit in bulk railcar commodity shipments to domestic customers. They are also critical for ship-hold fumigation. However, phosphides are corrosive to many electronic components and are not commonly used for fumigating processing facilities where electronic components are prevalent.

Methyl bromide is routinely used for fumigating finished goods prior to domestic and international shipments, when the product cannot be fumigated in-transit, and when shipment lead-time is an issue. It is also used for static fumigation of ship holds. Due to the less corrosive nature of methyl bromide, it is commonly used for periodic fumigation of processing facilities and structures as part of an integrated pest management and plant sanitation strategy. To date, no reasonable alternative has been identified for these critical applications.

Rice is a nutritious grain and is attractive to several insects that bore into the rice kernels to feed and reproduce. Such infestations cannot be readily destroyed through processing alone, and if allowed to get out of control in the paddy rice, can lead to severe quality deterioration prior to processing. Therefore, it is critically important to the value of the commodity and the industry to maintain the continued availability of these fumigants and other materials that can be used to interrupt the life cycles of the these insects, and to maintain pest free storage and processing facilities. Loss of these materials would likely result in substantial, if not catastrophic, economic hardship to the rice industry.

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References

1. Bayer, D. E., Hill, J.E., E. Roncoroni, D. Brandon, D. Roush, S.C. Scardaci, J.F. Williams, R.G. Mutters. 1996. Weed control in rice. Annual Report Comprehensive Rice Research - 1996. P. 57-87.

2. Bowling, C. C. 1972. Note on the biology of rice water weevil, *Lissorhoptrus oryzophilus*. Ann. Entomol. Soc. Am. 65: 990-991.

3. Carter. H.O., R. Coppock, M. Krieth, I. Rodriguez, S.W. Smith. 1996. Voices of California Farmers: Effects of Regulation. University of California Agricultural Issues Center. Davis, CA. 150 pp.

4. Carter, H.O., ed. 1992. Maintaining a Competitive Edge in California's Rice Industry. University of California Agricultural Issues Center. Davis, CA. 50 pp.

5. California Rice Industry Association. 1996. Fourth Quarter 1996 - California Rice Statistics and Related National and International Data. 10 pp.

6. Eke, A.U. S.C. Scardaci, S.R. Roberts, J.E. Hill, J.A. Young, and R.E. Plant. 1996. Rice water management system adoption trends in California. Proceedings, 26th Rice Technical Working Group. San Antonio, TX. p.182.

7. Fischer, A., H.V. Ramirez, and J. Lozano. 1997. Suppression of junglerice [(Echinochloa colona (L.) Link)] by irrigated rice cultivars in Latin America. Agronomy J. 89:516-521.

8. Fischer, A..J., A.L. Chavez, D.N. Varela, and H.V. Ramirez. 1995. Detection of resistance to propanil in *Echinochloa colona* populations. ANNP-16th Columa Conference International Meeting on Weed Control. 6pp.

9. Fisher, A.J., E. Granados, and D. Trujillo. 1993. Propanil resistance in populations of junglerice (Echinochloa colona) in Columbian rice fields. Weed Sci. 41:201-206.

10. Flint. M.L., 1993. Integrated Pest Management in Rice, 2nd ed. University of California Statewide Integrated Pest

Management Project. DANR Publication # 3280.

11. Flint. M.L. 1996. UC IPM Guidelines for Rice. www.ipm.ucdavis.edu

12. Godfrey, L.D., D. Palrang, D.M. Brandon, J.E. Hill, S.C. Scardaci, J.F. Williams. 1994-2, Stewardship Program for Granular Carbofuran. Agronomy Fact Sheet Series. 1994-2.

13. Godfrey, L. D., D. M. Brandon, J. E. Hill, S. C. Scardaci, J. F. Williams and R. G. Mutters. 1994. Stewardship Program for Granular Carbofuran. Agronomy Fact Sheet Series, 1994-2. Dept. of Agronomy and Range Science, Univ. of Calif., Davis.

14. Godfrey, L. D. , and T. D. Cuneo. 1996. Protection of rice from invertebrate pests. 28th Annual Report: A Summary of Research from 1996 to the California Rice Growers. P. 24-25.

15. Godfrey, L. D., and A. T. Palrang. 1996. Rice yield response to rice water weevil infestation in California- 1993-95. Proceedings: Twenty-sixth Rice Technical Working Group. Plant protection: 117.

16. Godfrey, L. D., C. Wick, S. C. Scardaci, R. Webster, J. Hill, D. E. Bayer, and J. F. Williams. 1997. UC IPM Pest Management Guidelines: Rice. C.13-C.15.

17. Grigarick, A. A., and G. W. Beards. 1965. Ovipositional habits of the rice water weevil in California as related to a greenhouse evaluation of seed treatments. J. Econ. Entomol. 58: 1053-1056.

18. Grigarick, A. A., and R. K. Washino. 1992. Invertebrate- RWW section. Integrated Pest Management for Rice, 2nd edition. Univ. of California, Statewide Integrated Pest Management Project- Division of Agricultural Sciences. Publ. 3280: 61-65.

19. Gunsoulos, J.L.. 1994. Herbicide Resistance Weeds. North Central Regional Extension Publication # 468. 10 pp.

20. Hill, J.E., W.M. Canevari, B.P. Caton, R.G. Mutters, S.R. Roberts, S.C. Scardaci, J.F. Williams. 1997. Weed control in rice. Annual Report Comprehensive Research on Rice. 48- 68.

21. Hill, J.E., S.R.Roberts, S.C. Scardaci, and J.F. Williams. 1997. Rice herbicides and water quality: A California success story in government and industry coordination. 1997 Asian Pacific Weed Conference . Kuala Lampur, Malaysia. (in press).

22. Hill, J.E., Brouder, S.M., S.R. Roberts, J.F. Williams, S.C. Scardaci, and C.M. Wick. 1994. A survey of water management practices of California rice growers. Natural Resources and Life Science Education. 23:2:119-124.

23. Hill, J.E., S.R. Roberts, D.M. Brandon, S.C. Scardaci, J.F. Williams, C.M. Wick, B.L. Weir. 1992. Rice Production in California. University of California, Division of Natural Resources, Publication 21498. 22pp.

24. Hill, J.E., S.C. Scardaci, S.R. Roberts, J. Tiedeman, and J.F. Williams. 1991. Rice Irrigation Systems for Tailwater Management, University of California, Division of Natural Resources, Publication 21490. 15pp.

25. Hill, J.E., M. Lee, B.J. Finlayson, R.J. Schnagl, and S.R. Roberts. 1990.Reduction of herbicides in rice field drain waters of

the Sacramento Valley. Agronomy Abstracts, 1990 Annual Meetings.p. 9.

26. Hill, J.E., S.R. Roberts, D.E. Bayer, and J.F. Williams. 1990. Crop response and weed control from new herbicide combinations in water-seeded rice. Weed Technology. 4:838-842.

27. HRAC (Herbicide Resistance Action Committee) http://ipmwww.ncsu.edu/orgs/hrac/

28. Klonsky, K., J. Williams, C.Mutters, S.C. Scardaci, P. Livingston. 1998. UCCE Sample Costs to Produce Rice, Sacramento Valley - Rice Only Rotation. 17 pp.

29. Klonsky, K., J. Williams, C.Mutters, S.C. Scardaci, P. Livingston. 1998. UCCE Sample Costs to Produce Rice, Sacramento Valley - Multiple Crop Rotation. 17 pp.

30. Lange, W. H., and A. A. Grigarick. 1959. Rice water weevil. Beetle pest in rice growing areas of southern states discovered in California. Calif. Agric. 13: 10-11.

31. Londax Resistance Management Working Group. 1993. Londax Resistance Management Strategies. Agronomy Fact Sheet Series 1993-3. 2pp.

32. Miller, B.C., J.E. Hill, S.R. Roberts. 1991. Plant population effects on growth and yield in water-seeded rice. Agronomy Journal. 83:291-297.

33. Raksarat, P. and P. Tugwell. 1975. Effect of temperature on development of rice water weevil eggs. Environ. Entomol. 4: 543-544.

34. Salassi, M. 1992. U.S. Rice Production Practices and Costs, 1988. United States Department of Agriculture, Economic Research Service. Agricultural Economic Report # SB-837. 56 pp.

35. Scardaci, S.C., A. U. Eke, J.F. Williams, J.E. Hill, S.R. Roberts and B.R. Hanson. Rice irrigation systems and water quality. 1994. Proceedings, Temperate Rice Conference, Yanco, NSW, Australia.

36. Scardaci, S.C., R.K. Webster, J.E. Hill, J.F. Williams, and D.M. Brandon. 1997. Rice Blast: A New Disease in California. Agronomy Fact Sheet 1997-2. 2pp.

37. Setia, P., N. Childs, E. Wailes, J. Livezey. 1994. The U.S. Rice Industry. United States Department of Agriculture, Economic Research Service. Agricultural Economic Report # 700.

38. Spradley, J.P.. 1995. The Biologic and Economic Assessment of pest Management in Rice. United States Department of Agriculture, National Agricultural Pesticide Impact Assessment Program. Document Number 2-CA-95.;

39. Tibbitts, G.D., S.R. Roberts, J.E. Hill, B.C. Miller, J.F. Williams, and S.C. Scardaci. 1996. Water depth dffects on yield components in California cultivars - implications for quality? Proceedings, 26th Rice Technical Working Group. San Antonio, TX. p.168

40. Webster, R.K., N. Cintas, C. Greer, S.C. Scardaci, D.M. Brandon, J. F. Williams, C. Johnson. 1997. Cause and control of rice diseases. Annual Report Comprehensive Rice Research. - 1997. P.71-95

41. Williams, J.F. C.Wick, S.C. Scardaci, K. Klonsky, D. Chaney, P. Livingston, L. Tourte. 1992. UC Cooperative Extension Sample Costs to Produce Organic Water Seeded Rice In the Sacramento Valley. 23 pp.

42. Williams, J.F. C.Wick, S.C. Scardaci, K. Klonsky, D. Chaney, P. Livingston, L. Tourte. 1992. UC Cooperative Extension Sample Costs to Produce Organic No-Till Drill Seeded Rice In the Sacramento Valley. 23 pp.

43. Williams, J.F., S.R. Roberts, J.E. Hill, S.C. Scardaci and G. Tibbits. 1990. Managing water for weed control in rice. California Agriculture. 44:5:7-10.

Endnotes

1. National Agricultural Statistics Service; Agricultural Statistics Board, USDA; October 9, 1998; Crop Production Report.
2. Rice Production in California; Cooperative Extension, University of California, Division of Agriculture and Natural Resources; Publication 21498, p. 18.
3. California Field Crop Report; Vol. 19, No. 8; August 17, 1998
4. National Agricultural Statistics Service; Agricultural Statistics Board, USDA; October 9, 1998; Crop Production Report.
5. National Agricultural Statistics Service; Agricultural Statistics Board, USDA; October 9, 1998; Crop Production Report.
6. Rice Production in California; Cooperative Extension, University of California, Division of Agriculture and Natural Resources; Publication 21498, p. 1.
7. California Field Crop Report; Vol. 19, No. 8; August 17, 1998 Ibid
8. Rice Production in California; Cooperative Extension, University of California, Division of Agriculture and Natural Resources; Publication 21498, p. 13.
9. 1996 California Agricultural Resource Directory, CDFA, p. 72. Ibid
10. Maintaining the Competitive Edge in California's Rice Industry, University of California Agricultural Issues Center, pp. 32-35.
11. 1996 California Agricultural Resource Directory, CDFA, pp 7-18. Ibid, p. 3.
12. Grigarick, A. A., and R. K. Washino. 1992. Invertebrate- RWW section. Integrated Pest Management for Rice, 2nd edition. Univ. of California, Statewide Integrated Pest Management Project- Division of Agricultural Sciences. Publ. 3280: 61-65.

13. Lange, W. H., and A. A. Grigarick. 1959. Rice water weevil. Beetle pest in rice growing areas of southern states discovered in California. Calif. Agric. 13: 10-11.
14. Godfrey, L. D., C. Wick, S. C. Scardaci, R. Webster, J. Hill, D. E. Bayer, and J. F. Williams. 1997. UC IPM Pest Management Guidelines: Rice. C.13-C.15.

15. Grigarick, A. A., and G. W. Beards. 1965. Ovipositional habits of the rice water weevil in California as related to a greenhouse evaluation of seed treatments. J. Econ. Entomol. 58: 1053-1056.

16. Raksarat, P. and P. Tugwell. 1975. Effect of temperature on development of rice water weevil eggs. Environ. Entomol. 4: 543-544.
17. Bowling, C. C. 1972. Note on the biology of rice water weevil, *Lissorhoptrus oryzophilus*. Ann. Entomol. Soc. Am. 65:

990-991.
18. Godfrey, L. D., and A. T. Palrang. 1996. Rice yield response to rice water weevil infestation in California- 1993-95. Proceedings: Twenty-sixth Rice Technical Working Group. Plant protection: 117.

19. Godfrey, L. D. , and T. D. Cuneo. 1996. Protection of rice from invertebrate pests. 28th Annual Report: A Summary of Research from 1996 to the California Rice Growers. P. 24-25.

20. Grigarick, A. A., and R. K. Washino. 1992. Invertebrate- RWW section. Integrated Pest Management for Rice, 2nd edition. Univ. of California, Statewide Integrated Pest Management Project- Division of Agricultural Sciences. Publ. 3280: 61-65. Ibid
21. Godfrey, L. D., C. Wick, S. C. Scardaci, R. Webster, J. Hill, D. E. Bayer, and J. F. Williams. 1997. UC IPM Pest Management Guidelines: Rice. C.13-C.15.

22. Grigarick, A. A., and R. K. Washino. 1992. Invertebrate- RWW section. Integrated Pest Management for Rice, 2nd edition. Univ. of California, Statewide Integrated Pest Management Project- Division of Agricultural Sciences. Publ. 3280: 61-65.

23. Webster, R.K., N. Cintas, C. Greer, S.C. Scardaci, D.M. Brandon, J. F. Williams, C. Johnson. 1997. Cause and control of rice diseases. Annual Report Comprehensive Rice Research. - 1997. P.71-95

24. Quadris (azoxystrobin) is in a new class of broad-spectrum fungicides which has low mammalian toxicity, low risk to aquatic species and birds, and is harmless to beneficial insects; it does not persist in the environment (Krause, 1997). It disrupts processes that require high energy in fungi, such as sporulation and spore germination.
