# Weed Control Programs

## Introduction

Weed resistance to the herbicides used in California rice is a relatively new event. However, weed populations have always been dynamic and the continuous use of almost any management practice has resulted in the loss of weed control. About the only certainty in California rice weed management is change. Within a few years after the introduction of rice in 1914, weeds were running rampant in the dry-seeded culture established at the time. Dr. Jenkins Jones wrote in 1924 that "practically all, if not all of the lands—and these represent the major portion of the rice acreage—are quite foul with water grass," and that on these lands it was "practically impossible to grow profitable rice crops." Jones' research led to water-seeding, but large seeded biotypes of water grass better able to emerge through the continuous flood became the dominant weed problem along with a new set of aquatic species. These included the sedge species, the aquatic broadleaf species and the late watergrass biotypes or so-called "mimics" which evolved in Asia from selection pressure of hand weeding. As weeds that looked different from rice were hand pulled the ever evolving survivors looked more and more like rice; hence, the name "mimic." Since 1992, several weed species that commonly infest California rice fields have evolved resistance to herbicides. Even multiple resistances, the resistance to more than one type of herbicide action, has evolved. This and the advent of mostly foliar applied herbicides have greatly increased the difficulty of watering and hence weed control. Adding to the complexity of rice weed management are regulatory aspects related to herbicide drift, buffer zones and water holding periods that limit weed control choices and shape decisions. The following discussion and tables provide a framework for decision-making in the increasingly complex business of rice weed control.

*Weed populations have always been dynamic and the continuous use of almost any management practice has resulted in the loss of weed control*

## The Weeds: Species, Recordkeeping and Resistance

Proper identification of weed species is essential to successful weed management in rice. When the broad-spectrum combination of Londax and Ordram was the primary treatment, rice weed control was very simple, but this is no longer true. For example, many of the new herbicides control one or only a few species, so incorrect weed identification can lead to poor control. It is not enough to group weeds broadly into sedges, "lilies" and grasses. Rather, we need to know with certainty that the weed is ricefield bulrush instead of smallflower umbrella sedge; or to know with certainty that the weed is California arrowhead rather than ducksalad or some other broadleaf species. Moreover, knowledge of the species and its competitive ability are critical to target the most important and potentially damaging weeds. For example, even though

California arrowhead may be the dominant species in a field, will it be the most damaging? Weed species common to California rice are listed in Table 1.

*Table 1. The common and scientific names of major weeds in California rice.*

| Group | Common Name | Scientific Name |
|---|---|---|
| Grasses | barnyardgrass | *Echinochloa crus-galli* |
| | watergrass (early) | *Echinochloa oryzoides* |
| | watergrass (late) | *Echinochloa phyllopogon* |
| | sprangletop | *Leptochloa fascicularis* |
| Sedges | smallflower umbrella sedge | *Cyperus difformis* |
| | ricefield bulrush | *Schoenoplectus mucronatus* |
| Broadleaf | California arrowhead | *Sagittaria montevidensis* |
| | Gregg's arrowhead | *Sagittaria longiloba* |
| | redstem | *Ammannia* spp. |
| | ducksalad | *Heteranthera limosa* |
| | common waterplantain | *Alsima triviale* |
| | waterhyssop | *Bacopa* spp. |

Field history is a valuable tool for understanding the changes in weed populations. Although it is common to keep field records of varieties, yields and quality, it is relatively uncommon to see good records and maps of the weed species present in a field. Records of weeds (complete with field maps) coupled with good documentation of management and herbicide practices provide very useful information about the buildup of certain weed species, weed resistance and other aspects related to weed control (such as whether or not the weed infestations are related to field operations—field equipment, etc.). Furthermore, the ability to use certain herbicides depends on the ability to document resistant weed populations in the field. Most importantly, good field records will likely improve the ability to select management practices and herbicides to minimize weed problems.

Record keeping is even more important with the advent of herbicide resistance. It is now not enough just to identify a particular species, but whether or not it exhibits herbicide resistance is of paramount importance to selecting the correct herbicide, combination or sequence. Currently, the only diagnostic services to determine whether or not weeds are resistant are provided by UC Davis at the Rice Experiment Station at Biggs or by the companies whose products are involved. Submitting samples to the UC weed program requires specific records related to field history, cultural management, water delivery system and farming operations. Thus, such diagnosis depends on the records of field history. Aside from diagnostic confirmation of weed resistance, the best indicator is whether or not properly applied herbicides are able to control the weeds. If not, the chances are good that the species may be resistant. However, other possibilities should be eliminated before concluding that the weed is resistant. One telltale sign, assuming that all conditions such as weed growth stage, weather and management practices were ideal, is the survival of a single, normally susceptible species while all others are controlled. The survival of a single species year after year when it was previously controlled is also a reasonable indicator of resistance. However, allowing weeds to reproduce over time eliminates the option of prevention to keep resistant weed seed banks at low levels in the soil. Certainly, the early identification of weed resistance and even draconian efforts to reduce weed seed production are essential to combat resistant weeds—especially on a farm scale where resistant populations could be restricted to single fields rather than be allowed to spread.

## Weed Management: Prevention

Prevention can be an important part of rice weed control. Prevention sounds good but unfortunately is not practiced as much as it should be. The use of certified seed is probably the best example of weed prevention in California. By comparison to most other areas of the world, California has one of the highest percentage of planted acres in certified seed — nearly 100% at its peak, but with economic downturns this has been somewhat lax at a time when resistant watergrass should have made it imperative. Certified seed standards do not permit red rice or noxious weed seeds and have eliminated red rice from California—with the exception of periodic, isolated finds such as in 2003. The maximum allowable is 0.10 weed seeds by weight, and further limits watergrass and barnyardgrass seeds to less than 0.01 by weight. Irrigation water and farm machinery frequently transport weed seeds or other plant propagules into the field. The first Whip-resistant watergrass was clearly introduced into a second field by a combine sampling for grain moisture. The introduction of weed seed, tubers, and rhizomes can be reduced by cleaning farm implements when they are moved from field to field.

## Weed Management: Cultural Methods

The value of good cultural practices cannot be underestimated in their importance to weed management. Although they are generally not enough by themselves, good practices can greatly suppress weeds and enhance the effectiveness of herbicides used in combination with them. Most, if not all of these cultural methods will be a necessary part of crop management anyway, so in controlling weeds, they become extremely cost effective. For example, good water management can be the most efficient method available to suppress weed species such as sprangletop, barnyardgrass, and even watergrass, to the point that herbicides can finish them off easily.

**Tillage and Field Preparation**

Tillage, land leveling, and preplant fertilizing all influence weed germination and growth. These management practices are covered in other chapters of this workbook and will be discussed here only in reference to weed management. Tillage and field preparation have changed dramatically with the advent of rice straw incorporation and winter flooding. Generally, the soil is wetter for longer periods and thus drying of over wintering rhizomes and corms of perennial weeds is not possible unless heavily infested fields are specifically targeted for dry tillage. Additionally, straw incorporation by wet rolling and especially discing or plowing in the fall incorporates weed seed, creating an over wintering seed bank that cannot be reduced by bird and small mammal depredation. In the spring, inadequate grading or planing of the field can leave high spots for weed germination or low areas where weeds remain under the floodwater during the application of foliar-active herbicides.

**Water Management**

Proper water management is the most important factor in controlling weeds in rice. Careful land grading and seedbed preparation before planting help maintain uniform water depths in rice fields. Ideally, fields should be flooded continuously to a depth sufficient to suppress weeds, particularly the grasses and smallflower umbrella sedge—generally 4-8" deep. However, this works only if the herbicides are effective when applied into the water. The advent of weed resistance to many of the into-the-water herbicides has necessitated a change to foliar-active or contact herbicides. Foliar herbicides require good coverage on the weed, thus if used early in the season when weeds are small, the field must be drained. Rapid reflooding for weed suppression and to prevent a new flush of germination is also necessary. This will be next to impossible on fields that take several days to flood or where water is insufficient to reflood rapidly. Adequate canals, drains, and water control structures are necessary to provide for efficiently regulating the flow of irrigation water. Where irrigation structures or water availability do not allow for rapid drainage and reflooding, it may be necessary to reduce field size. Large fields may be made smaller, or each basin managed independently with separate inflows and outflows to achieve the necessary water precision to optimize foliar herbicides. Land leveling, grading, and efficient irrigation management are equally important to meet state mandated water holding regulations following herbicide applications. Inefficient irrigation may allow too much water in the lower end of a field with no recourse but to hold deep water.

**Rotation**

Not all rice soils can be rotated to other crops. However, rotation out of rice can greatly reduce weed populations in subsequent rice crops. Rotating to crops for which effective weed controls are available, such as sugarbeet, tomato, safflower, cereal crops, or cotton, is one of the best ways to manage weeds that cannot be selectively controlled with herbicides and cultural practices in rice. Non-flooded conditions, seedbank decay and alternative herbicides in the rotation crop all contribute to reducing future weed infestations. In fields where perennial weeds with tubers, rhizomes, or large rootstocks such as cattail, pondweed, Gregg's arrow-head, bulrush, and spikerush, a dry fallow rotation out of rice may be necessary. Plowing the rice field to a depth of 8 to 12 inches (20 to 30 cm) during the fallow season can add to these benefits. In rice-only soils, a rice-rice rotation of the cultural method such as flooding one year and dry seeding or stale seedbed techniques the next, coupled with non-selective preplant herbicides, may help in controlling weed species resistant to normally used rice herbicides.

## The Herbicides

When Londax and Ordram dominated the California market for weed control in water-seeded rice in the early 1990s, there was relatively little interest in new products. With the onset of widespread weed resistance, many old and new products have entered, or are about to enter the market (Table 2).

*Table 2. The common and trade names of current herbicides for rice in California.*

| | |
|---|---|
| bensulfuron | Londax® |
| bispyribac | Regiment® |
| carfentrazone | Shark® |
| clomazone | Cerano® |
| cyhalofop | Clincher® |
| halosulfuron | Sempra® |
| fenoxyprop | Whip®, Ricestar® |
| molinate | Ordram® |
| pendimethalin | Prowl® |
| propanil | Stam®, SuperWham® |
| thiobencarb | Abolish®, Bolero® |
| triclopyr | Grandstand® |

While all the new products hold promise for improving weed management in rice, they add to the puzzle of information needed to use them safely and efficiently. For example, if a foliar applied herbicide is translocated in the plant, it may not be necessary to completely drain the field provided enough foliage is above the water; but in combination with a foliar herbicide that does not translocate (contact), weed control could be greatly compromised by not having the field completely drained to fully expose the weeds. If the field is completely drained, of course, there is the very real possibility for a new flush of weeds such as sprangletop. Thus, it is extremely important to know the behavior of each herbicide in the plant and the environment. Most of the newly introduced herbicides are somewhat limited in the spectrum of weeds controlled, requiring the proper selection either alone, in combination or in sequence to give adequate weed control. The weed spectra and water management regimes for the currently available herbicides are shown in Figure 1a and 1b. Potential weed control given in the tables is based on both company and UC Davis research and represents the control that could be consistently expected of a particular product, assuming that the weed species are not resistant. Different uses of the same product, application timing, field management and environmental conditions (weather) may all increase or decrease control. For example, SuperWham or Stam (propanil) works better at or above 75º F and with eight or more hours of sunlight following application. Light is required because propanil blocks photosynthesis. Shark into-the-water may control a broader range of species than indicated in Figure 1 if used as a foliar applied herbicide, but higher rates are required. For best control, carefully read and follow the label which will state the rates, adjuvants, combinations and other requirements of the product. By mixing and matching the herbicides in Figure 1 a complete spectrum of weed control may be possible. However, in addition to the weed spectrum, it is important to know how the herbicide is taken up by the weed, if it is translocated in the plant, the range of application timings for weed control and crop safety, if the herbicide has residual activity, whether or not the weeds are resistant and if tank mixes or sequences are antagonistic.

**Herbicide Combinations**

Tank mixtures may be used when two or more herbicides are compatible. This requires that not only must they be chemically compatible, but best management practices for their application such as timing and water depth are the same. Tank mix combinations can reduce the cost of application and often reduce the rates of one or more herbicides. The purpose of combinations is to broaden the spectrum of weed control such that each herbicide in the mix will control the weeds missed by its partner (Figure 2). Even though some herbicides compliment each other in timing and weed spectrum, they cannot be mixed because of antagonism. Antagonism can be manifested in either injury to rice or as a lack of weed control—that is one herbicide increasing the injury to rice by the other or reducing the normal effect of the other on weed susceptibility. It is important to follow the label of each herbicide with regard to tank mixes.

**Herbicide sequences**

To achieve good broad-spectrum weed control, most herbicides must be used in sequence rather than as tank mixes. This is because of differences in the behavior of the herbicides with respect to timing, water management, antagonism, translocation and other factors. Probably the most important aspect of these sequences is to protect against the buildup of weed resistance by using different modes of action. For example, a sequence of Clincher followed by propanil will take out any remaining watergrass with resistance to Clincher. Figures 3, 4 and 5 show the weed susceptibility of herbicide sequences with Regiment, Cerano and Clincher, respectively. Unlike herbicide tank mixes, sequences can be complicated by the need to raise and lower water depths to meet the requirements of each herbicide in the sequence. Water management requirements for the different herbicide sequences are also shown in Figures 3, 4 and 5.

## Behavior of Herbicides

Table 3 provides additional information on the behavior of current and future herbicides respectively.

*Table 3. Behavior of currently used herbicides*
*(lsr = rice leaf stage; mt = mid-tillering; ** = both foliar & soil activity)*

| Herbicide | Foliar | Applied in Water | Translocation Index, 0=low | Timing Window | Residual (days) | Weed Resistance |
|---|---|---|---|---|---|---|
| Abolish | Yes | **Yes**** | 3 | 1-2 lsr | 20-25 | Yes |
| Bolero | No | Yes | 3 | 1-2 lsr | 20-25 | Yes |
| Cerano | No | Yes | 6 | 0-1 lsr | 5 in water | Ltd in late wg |
| Clincher | Yes | No | 4 | 2 lsr - mt | 0 | Yes |
| Ordram | No | Yes | 6 | 0-5 lsr | 5-8 | Yes |
| Regiment | Yes | No | 4 | 5 lsr - mt | 0 | Yes |
| SuperWham | Yes | No | 3 | 3 lsr - mt | 0 | No |
| Stam | Yes | No | 3 | 3 lsr - mt | 0 | No |
| Whip | Yes | No | 4 | 5 lsr - mt | 0 | Yes |
| Londax | Yes | **Yes**** | 4 | 0-5 lsr | 35-40 | Yes |
| Sempra | Yes | **Yes**** | 4 | 0-5 lsr | 35-40 | Yes |
| Grandstand | Yes | No | 8 | 5 lsr - mt | 0 | No |
| Shark | Yes | **Yes**** | 2 | 4 lsr - mt | 5-8 | No |
| Prowl | No | No | 0 | Soil cracking | 20 days dry<br>5 days in water | No |

### Foliar or Soil Activity

Most of the newer herbicides are active only as foliar sprays. However, Abolish, Bolero, Cerano, Londax and Ordram have soil activity. Generally, when the product is formulated and used as a granule such as Ordram 15G and Bolero 10G, the activity is through the soil. Abolish, which is the same active ingredient as Bolero, is also active through the soil, but the product is designed as a spray which improves foliar uptake for pinpoint flood management. Like Abolish, Londax is also soil active when sprayed into the water. Generally, rates can be lower when used as a foliar spray than when applied into the water, but each chemical varies so the manufacturer's label should be followed. Products that are effective when applied into the water are weakly adsorbed and concentrated by the soil from where they are released and taken in through the plant roots. Field drainage to expose the weeds is very important for most foliar-only herbicides.

### Contact or Translocated

Another important factor affecting the proper use of herbicides is whether or not they move in the plant. Two herbicides may be foliar active but are used quite differently with respect to field management. Translocated herbicides, such as Grandstand move from the site of uptake to other parts of the weed to kill the growing point. Contact herbicides move very little from the point of impact, and kill only that part of the plant covered by the spray. Shark, SuperWham or Stam (propanil) hardly move at all, whereas Whip, Clincher and Regiment move small distances. Cerano moves, but only upward in the translocation stream, so it will not move down from a foliar application. The translocation indices given in Table 3 are indicators of the relative movement of rice herbicides in the plant. Numbers above seven mean that the herbicide is highly mobile and below four generally means little movement. Matching water management to the translocation characteristics of the herbicide is extremely important to the success of the application. For example, the label for Grandstand, a translocated herbicide, specifies that only 70% of the foliage need be exposed, whereas some contact-only herbicides may require complete drainage.

### Window of Application

Herbicides vary widely in their ability to kill weeds of different sizes and in their safety to rice at different stages of growth. The application timing on the product label is given to minimize rice injury and optimize weed control and is the "application window." Abolish and Bolero (thiobencarb) and Cerano have the smallest application windows. Abolish and Bolero require rice to be at least 1 ½ leaf but watergrass not greater than two leaf. Cerano also has a narrow window of application from just before planting to the 1 leaf stage of rice but watergrass must be less than 1 ½ leaf for most effective control. Many of the new herbicides have relatively broad windows of application timing both with respect to crop safety and weed control. Some, like Whip, require rice to be in early tillering before the crop is safe. Regardless of the window, it is important to remove weeds before competition reduces yield. Most research shows that the onset of weed competition is about twenty days after seeding, depending on the severity of the weed pressure and rate of growth. Competition notwithstanding, the new herbicides offer the opportunity to remove weeds where applications have been delayed by weather or to cleanup where weeds have been missed by earlier applications.

### Residual Activity

Residual activity is an important attribute in preventing reinfestation by subsequent germination of a new flush of weeds. Residual activity is generally determined by the amount and strength of soil adsorption and by the rate of degradation of the herbicide in the environment. Ordram, for example, has a half-life of only about five days and hence a short residual activity, whereas Londax residual is 35 days. Residual activity is much more important for early applications before the rice canopy is capable of shading out weeds. Mixing a residual herbicide with early applications of foliar herbicides such as propanil can sustain control long enough for the rice canopy to cover. It is, however, a double-edged sword in that selection pressure for weed resistance continues as long as the herbicide remains active in the soil.

### Mechanisms of Action

It is essential to know which herbicides have similar mechanisms of action because weeds are resistant to the mechanism that kills them, not to the herbicide *per se*. Once the weeds become resistant to a herbicide with a particular mechanism of action, all other herbicides with a similar mechanism of action will likely fail to control the weed. Table 4 shows the current rice herbicides grouped by mechanism of action. Thus, it would not be a good idea to use Abolish or Bolero (thiobencarb) where resistance to Ordram has been documented. To prevent the further buildup of resistant weed seed banks, herbicides with different mechanisms of action should be rotated or used in sequence or combination to prevent resistant species from setting seed.

*Table 4. Herbicides mechanism of action*

| Group | Active Ingredient | Mechanism of Action |
|---|---|---|
| **Thiocarbamates** | molinate (Ordram)<br>Thiobencarb (Abolish, Bolero) | VLCFA (Very long chain fatty acids) |
| **Aryloxyphenoxy-propionates** | fenoxaprop (Whip)<br>cyhalofop-butyl (Clincher) | ACCase inhibitors |
| **Amide** | propanil (SuperWham, Stam) | Photosystem II inhibitor |
| **Sulfonylurea** | bensulfuron (Londax)<br>halosulfuron (Sempra) | ALS inhibitor |
| **Phrimidinyl-thiobenzoates** | bispyribac (Regiment) | ALS inhibitor |
| **Dinitroaniline** | pendimethalin (Prowl) | Tublin inhibitor (mitosis inh.) |
| **Isoxazolidinone** | clomazone (Command) | Carotenoid biosynthesis |

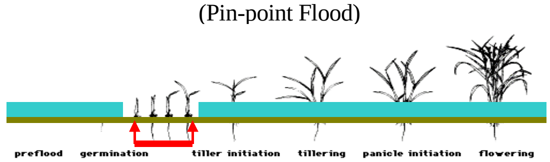
**Figure 1a**. *Weed Susceptibility, application timing and water management regimes for California rice herbicides.*

| | barnyardgrass | watergrass | sprangletop | smallflower umbrella | ricefield bulrush | CA arrowhead | Gregg's arrowhead | ducksalad | redstem | monochoria |
|---|---|---|---|---|---|---|---|---|---|---|
| Abolish or Bolero | +/R | +/R | + | + | - | - | - | - | - | - |
| Cerano, Bombard | + | +/R | +/R | - | - | - | - | - | - | - |
| Clincher | +/R | +/R | +/R | - | - | - | - | - | - | - |
| Grandstand | - | - | - | - | + | - | - | - | + | - |
| Granite | + | +/R | - | +/R | +/R | + | - | + | + | - |
| Londax | - | - | - | +/R | +/R | +/R | - | + | +/R | - |
| Regiment | +/R | +/R | - | ±/R | ± | +/R | - | ± | - | ± |
| Shark | - | - | - | + | + | + | - | ± | ± | ± |
| Stam or Superwham | + | + | - | +/R | +/R | ± | - | ± | ± | ± |
| Sandea | ± | ± | - | +/R | +/R | +/R | - | + | +/R | - |
| Prowl | + | + | + | ± | - | - | - | - | - | - |

\+ control
\- no control
± suppression
R resistant, poor control

## Abolish

(Pin-point Flood)



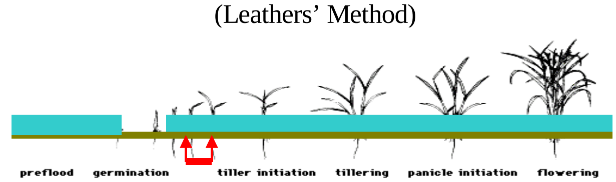

| | |
|---|---|
| Emrg. shoot, 1st. lf. | Yes |
| Appl'd in water | No |
| Translocated | Little |
| Timing | 1-3 lsr |
| Resistance | Yes |

Application timing-

**1.0 to 3.0 lsr (4 lb ai/ac)**

## Bolero

(Leathers' Method)

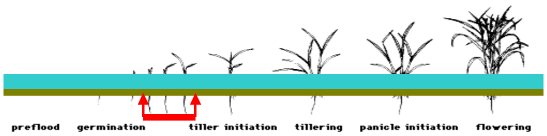



| | |
|---|---|
| Emerg. shoot | Yes |
| Appl'd in water | Yes |
| Translocated | Little |
| Timing | 2 lsr |
| Resistance | Yes |

Application timing

**2.0 lsr (4.0 lb ai/ac)**

# Bolero
(Permanent Flood)

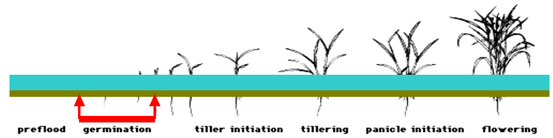



| | |
|---|---|
| Emerg. shoot | Yes |
| Appl'd in water | Yes |
| Translocated | Little |
| Timing | 1-2 lsr |
| Resistance | Yes |

Application timing

**1.0 to 2.0 lsr (4 lb ai/ac)**

# Cerano, Bombard
(Permanent Flood)

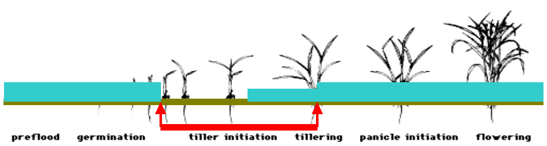



| | |
|---|---|
| Roots, emerg. Shoots | Yes |
| Appl'd in water | Yes |
| Translocated | Yes |
| Timing | preseed-lsr |
| Resistance | Yes |

Application timing

**Preseed to 1.0 lsr (0.6 lb ai/ac)**

# Clincher
(Pin-point Flood)

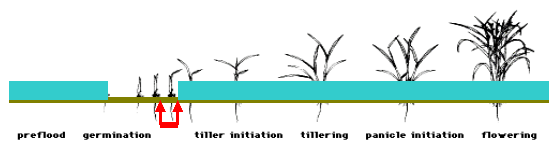



| | |
|---|---|
| Foliar | Yes |
| Appl'd in water | No |
| Translocated | Yes |
| Timing | 2 lsr-midtil |
| Resistance | Yes |

Application timing

**2.0 lsr to til (0.25 to 0.31 lb ai/ac)**

# Clincher
(Leathers' Method)

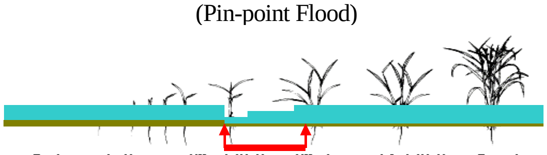



| | |
|---|---|
| Foliar | Yes |
| Appl'd in water | No |
| Translocated | Yes |
| Timing | 2 lsr |
| Resistance | Yes |

Application timing

**2.0 lsr (0.25 lb ai/ac)**

# Grandstand
(Pin-point Flood)




| | |
|---|---|
| Foliar | Yes |
| Appl'd in water | No |
| Translocated | Yes |
| Timing | 1 till-maxtil |
| Resistance | No |

Application timing

**1.0 til to maxtil (0.25 to 0.375 lb ai/ac)**

# Londax, Sandea
(Permanent Flood)

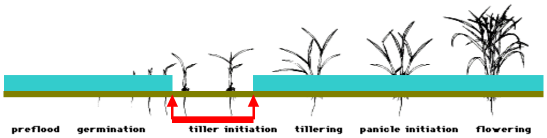

| | |
|---|---|
| Foliar and roots | Yes |
| Appl'd in water | Yes |
| Translocated | Yes, moderate |
| Timing | 0-5 lsr |
| Resistance | Yes |

Application timing

**1.0 to 3.0 lsr (0.06 lb ai/ac)**

# Londax, Sandea

(Pin-point Flood)



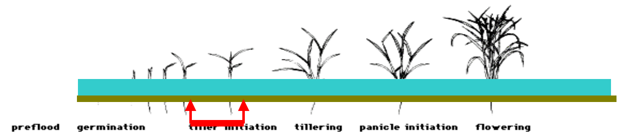

| | |
|---|---|
| Foliar and roots | Yes |
| Appl'd in water | Yes |
| Translocated | Yes, moderate |
| Timing | 0-5 lsr |
| Resistance | Yes |

Application timing

**3.0 lsr to 1-2 til (0.06 lb ai/ac)**

# Granite GR

(Continuous Flood)



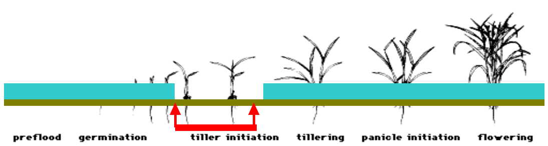

| | |
|---|---|
| Foliar and roots | Yes |
| Appl'd in water | Yes |
| Translocated | Yes, moderate |
| Timing | 2-3 lsr |
| Resistance | Yes |

Application timing

**2-3 lsr (0.04 lb ai/ac)**

# Granite SC

(Pin-point Flood)



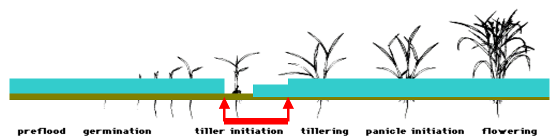

| | |
|---|---|
| Foliar and roots | Yes |
| Appl'd in water | No |
| Translocated | Yes, moderate |
| Timing | 2 lsr to 1 Till |
| Resistance | Yes |

Application timing

**2 lsr to 1-2 til (0.035 lb ai/ac)**

# Regiment

(Pin-point Flood)




| | |
|---|---|
| Foliar and roots | Yes |
| Appl'd in water | No |
| Translocated | Yes, moderate |
| Timing | 5 lsr-1 til |
| Resistance | Yes |

Application timing

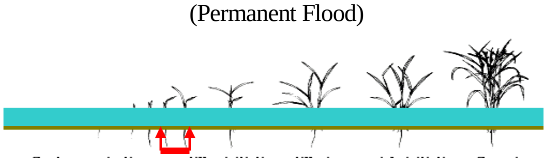
**1.0 til to midtil (15 g ai/ac) (18 g ai/ac*)**

*** For resistant late watergrass**

# Shark

(D.D.A./D.S.A.)

(Permanent Flood)



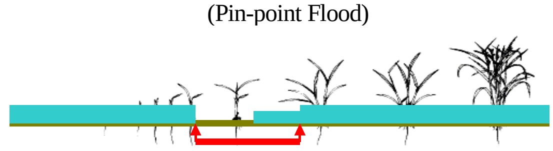

| | |
|---|---|
| Foliar | Yes |
| Appl'd in water | Yes |
| Translocated | No |
| Timing | 2-3 lsr |
| Resistance | No |

Application timing

**2.0 to 3.0 lsr (0.20 lb ai/ac)**

# propanil

(Pin-point Flood)



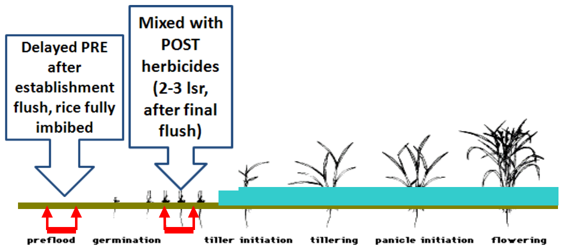

| | |
|---|---|
| Foliar | Yes |
| Appl'd in water | No |
| Translocated | No |
| Timing | 3 lsr-midtil |
| Resistance | No |

Application timing

**3.0 lsr to midtil (3 to 6 lb ai/ac)**

# Prowl

(Dry-seeded)



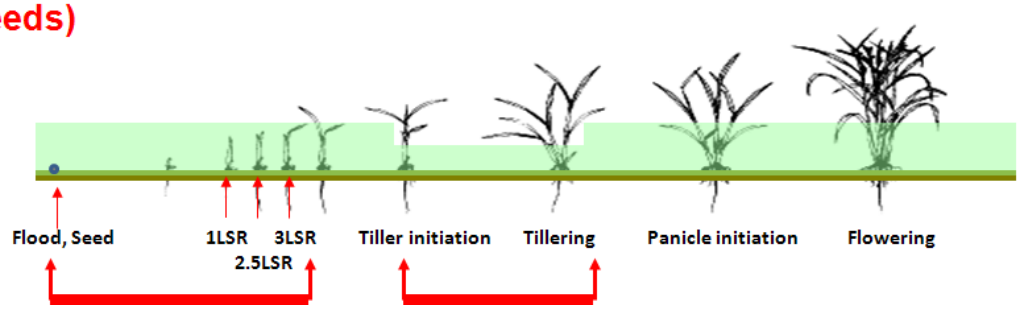

| | |
|---|---|
| Foliar | No |
| Appl'd in water | No |
| Translocated | No |
| Timing | Delayed PRE<br>or 2-3 lsr (as PRE) |
| Resistance | No |

Application timing

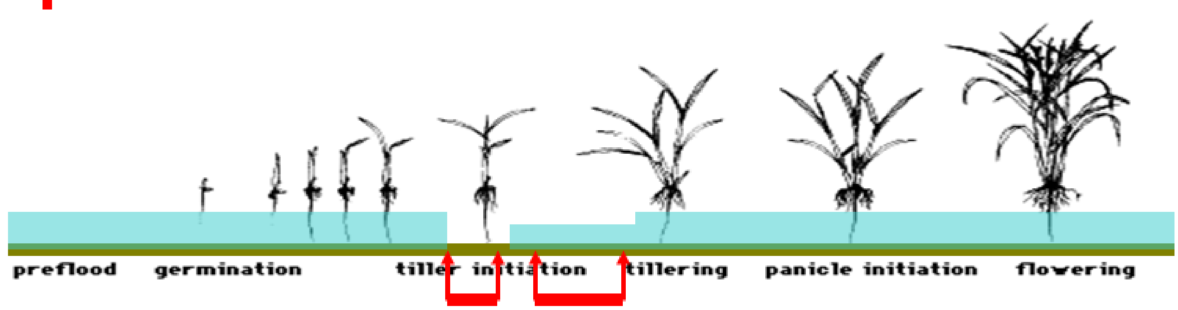
**DPRE (1 lb ai/ac)**

**Figure 1b**. *Major herbicide-based weed control systems for rice in California.*

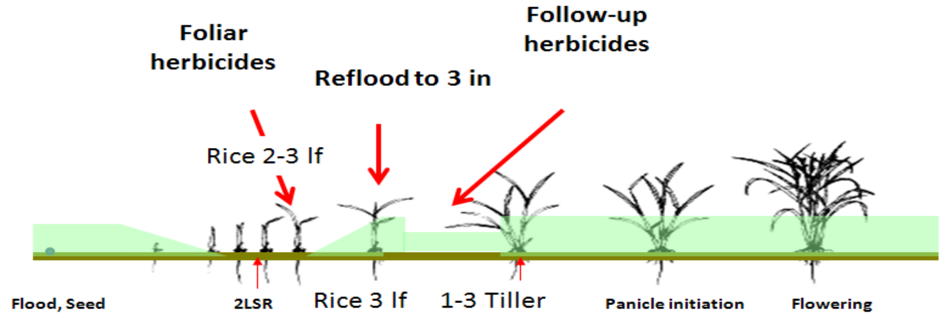
## Permanent Flood (use granular herbicides into the water at early stages, then lower the water to spray foliar herbicides onto weeds)



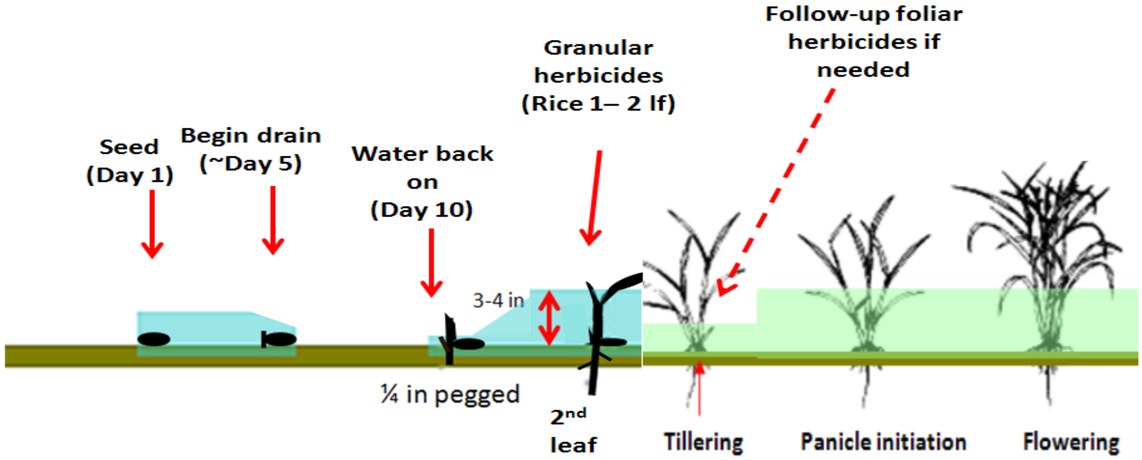

## Pin-point Flood



## Early Drain-foliar (Pin-point Flood/Leathers'): Drain to spray weeds while they are small; Then lower water to expose weed foliage to second spray)




## Early Drain-granule: for granular herbicides into the water after reflood (requires ability for rapid reflood)




## Drill-seeded (field is initially dry and then is gradually flooded deeper)

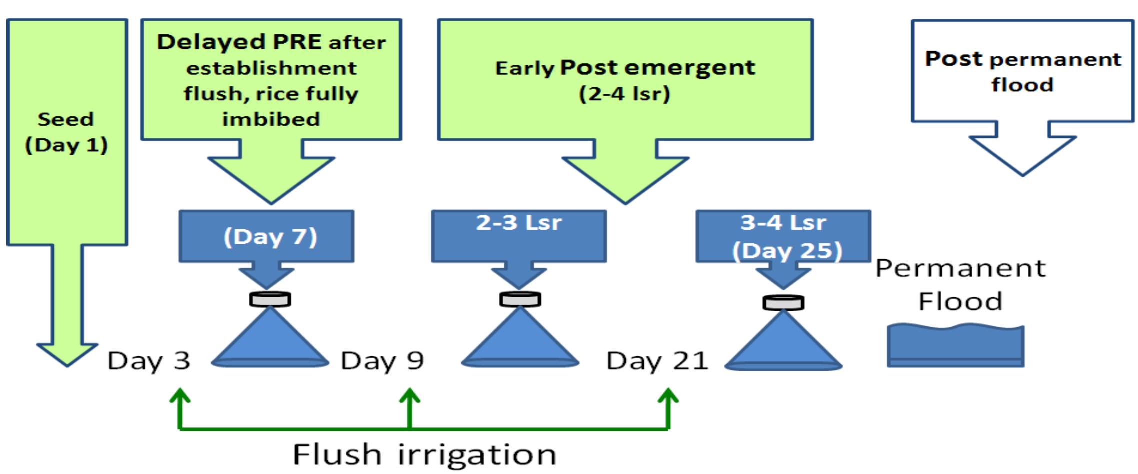


**Figure 1b (continued)**. *Major herbicide-based weed control systems for rice in California.*

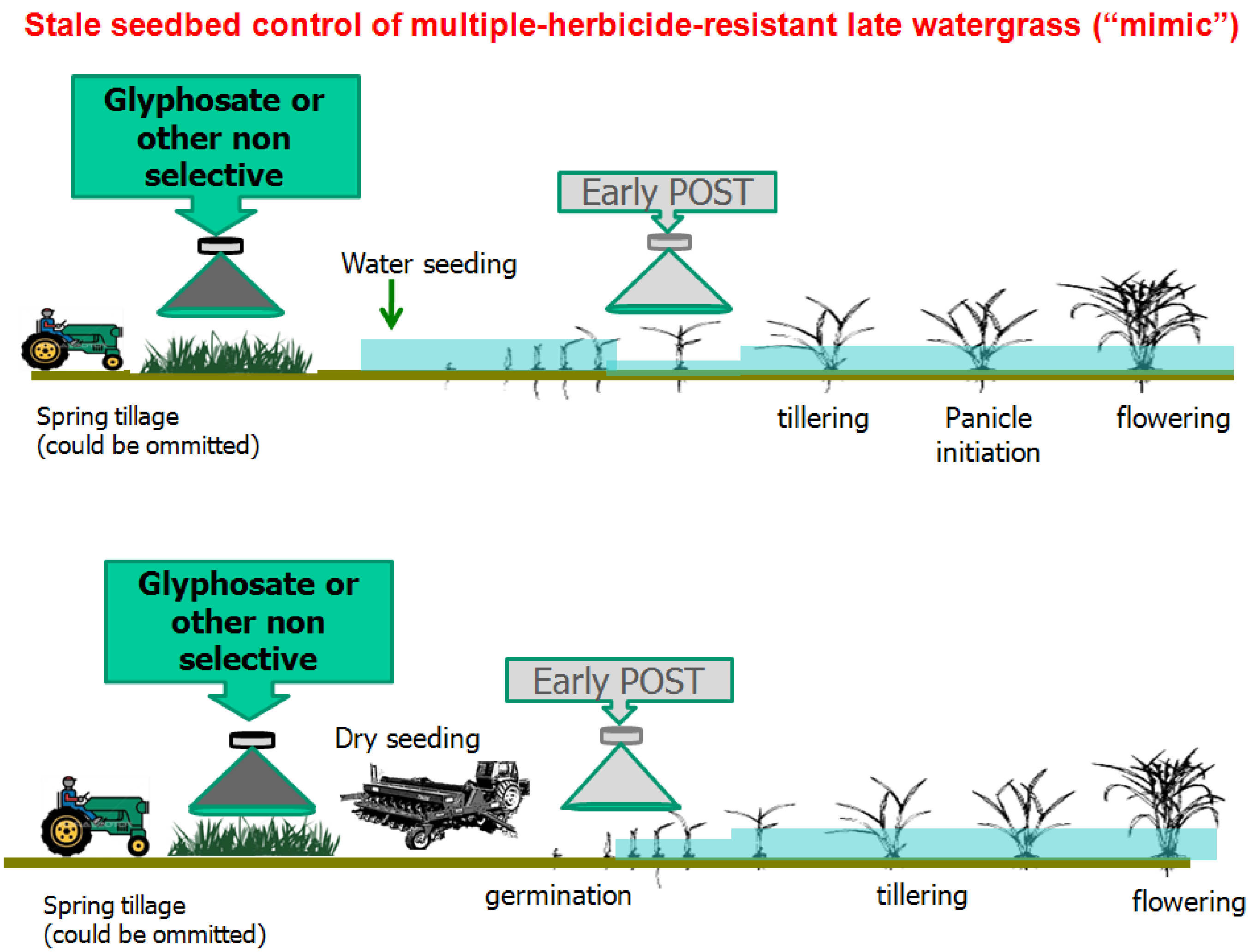


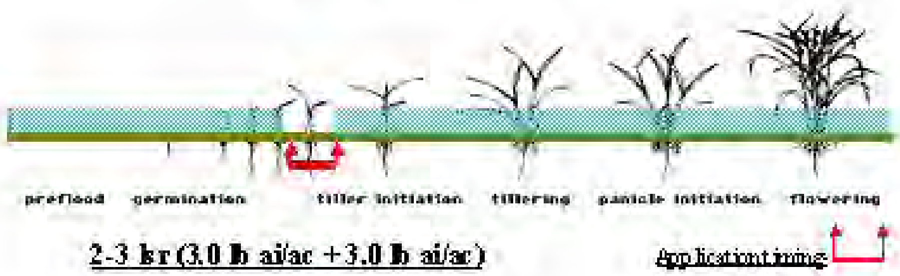
**Figure 2.** *Weed susceptibility, application timing and water management regimes for tank-mixed herbicides in California rice*

## Weed susceptibility of tank mixes

| | barnyardgrass | watergrass | sprangletop | smallflower umbrella | ricefield bulrush | CA arrowhead | Gregg's arrowhead | ducksalad | redstem | monochoria |
|---|---|---|---|---|---|---|---|---|---|---|
| Stam or Superwham | + | + | - | + | + | ± | - | ± | ± | ± |
| Tank mixed with | | | | | | | | | | |
| Abolish | + / R | + / R | + | + | - | - | - | - | - | - |

\+ control
\- no control
± suppression
R resistant

# Propanil + Abolish
(Pin-point Flood)




## Weed susceptibility of tank mixes

| | barnyardgrass | watergrass | sprangletop | smallflower umbrella | ricefield bulrush | CA arrowhead | Gregg's arrowhead | ducksalad | redstem | monochoria |
|---|---|---|---|---|---|---|---|---|---|---|
| Regiment | + / R | + / R | - | - | + / R | + / R | - | ± | - | ± |
| Tank mixed with: | | | | | | | | | | |
| Abolish | + / R | + / R | + | + | - | - | - | - | - | - |
| Shark | - | - | - | + | + | + | - | ± | ± | ± |

\+ control  - no control  R resistant  ± suppression

# Regiment + Abolish*

**(Pin-point Flood)**


*** Synergistic mixture intended only for late watergrass**

Application timing

5-6 lsr (10-15 g ai/ac + 2.0-3.0 lb ai/ac)

- Can also have effect on small flower and ricefield bulrush

# Regiment + Shark

(Pin-point Flood)


Application timing

- Broad-spectrum

4-5 lsr (12-15 g ai/ac + 0.20 lb ai/ac)

# Regiment + Whip

(Pin-point Flood)


Application timing

- Adds sprangletop

4-5 lsr (12-15 g ai/ac + 0.43 lb ai/ac)

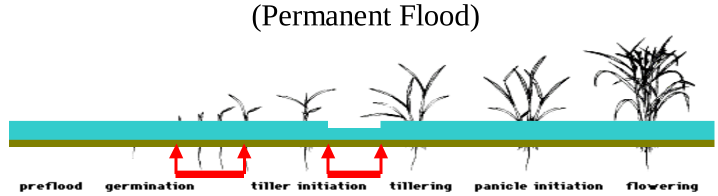
**Figure 3.** *Weed susceptibility, application timing and water management regimes for herbicide sequences with Regiment.*

| | barnyardgrass | watergrass | sprangletop | smallflower umbrella | ricefield bulrush | CA arrowhead | Gregg's arrowhead | ducksalad | redstem | monochoria |
|---|---|---|---|---|---|---|---|---|---|---|
| Bolero | +/R | +/R | + | + | - | - | - | - | - | - |
| Followed by | | | | | | | | | | |
| Regiment | +/R | +/R | - | - | +/R | +/R | - | - | - | ± |

\+ control
\- no control
± suppression
R resistant

# Bolero fb. Regiment

(Permanent Flood)




**1.0 to 2.0 lsr (4.0 lb ai/ac)**

Application timing

**Fb.**

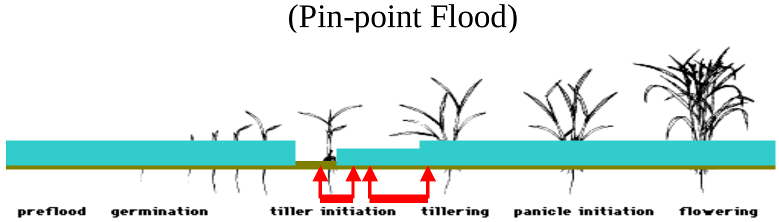
**1-3 til (15 g ai/ac)**

| | barnyardgrass | watergrass | sprangletop | smallflower umbrella | ricefield bulrush | CA arrowhead | Gregg's arrowhead | ducksalad | redstem | monochoria |
|---|---|---|---|---|---|---|---|---|---|---|
| Regiment | +/R | +/R | - | - | +/R | +/R | - | - | - | ± |
| Followed by | | | | | | | | | | |
| Stam or Superwham | + | + | - | + | + | ± | - | ± | ± | ± |

\+ control
\- no control
± suppression
R resistant

# Regiment fb. propanil

(Pin-point Flood)




Application timing

NO WATERGRASS RESISTANCE TO PROPANIL

**5 lsr to 1 til (15 g ai/ac)**

**Fb.**

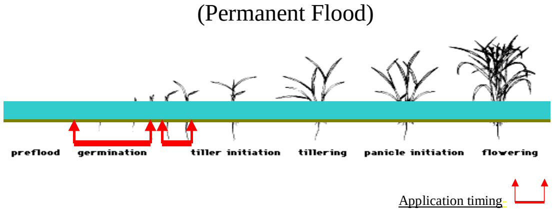
**2-3 til (6 lb ai/ac)**

**Figure 4.** *Weed susceptibility, application timing and water management regimes for herbicide sequences with Cerano in California rice.*

| | barnyardgrass | watergrass | sprangletop | smallflower umbrella | ricefield bulrush | CA arrowhead | Gregg's arrowhead | ducksalad | redstem | monochoria |
|---|---|---|---|---|---|---|---|---|---|---|
| Cerano | + | + / R* | + / R | - | - | - | - | - | - | - |
| Followed by: | | | | | | | | | | |
| Londax | - | - | - | + / R | + / R | + / R | - | + | + / R | - |
| Regiment | + / R | + / R | - | ± / R | ± | + / R | - | ± | - | ± |
| Shark | - | - | - | + | + | + | - | ± | ± | |
| Stam or Superwham | + | + | - | + / R | + / R | ± | - | ± | ± | ± |
| Grandstand | - | - | - | - | + | - | - | - | + | - |

Cerano fb. Londax

(Permanent Flood)



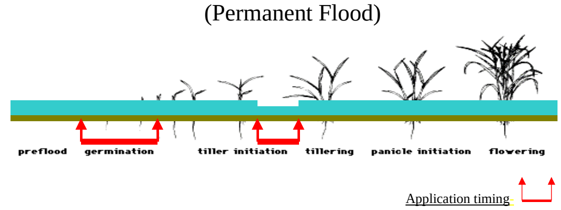

**Preseed to 1.0 lsr (0.6 lb ai/ac)**

**Fb.**

**2-3 lsr (0.06 lb ai/ac)**

Cerano fb. Regiment

(Permanent Flood)



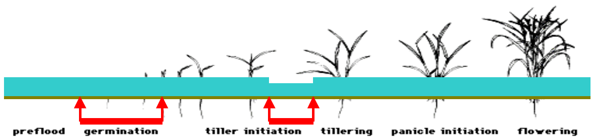

**Preseed to 1.0 lsr (0.6 lb ai/ac)**

**Fb.**

**2-3 Tiller (15 g ai/ac)**

# Cerano fb. propanil

(Permanent Flood)




Application timing-

NO RESISTANCE TO PROPANIL

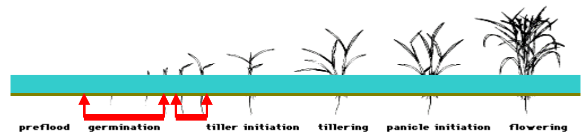
**Preseed to 1.0 lsr (0.6 lb ai/ac)**

**Fb.**

**1-3 til (6 lb ai/ac)**

# Cerano fb. Shark

(Permanent Flood)



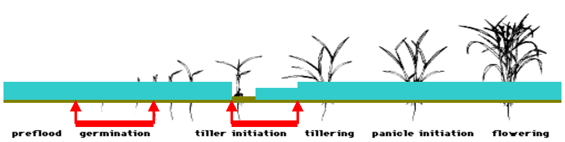

Application timing

**Preseed to 1.0 lsr (0.6 lb ai/ac)**

**Fb.**

**2-3 lsr (0.2 lb ai/ac)**

# Cerano fb. propanil + Grandstand




Application timing-

**Preseed to 1.0 lsr (0.6 lb ai/ac)**

**Fb.**

**1-3 til (6.0 lb ai/ac + 0.25 lb ai/ac )**

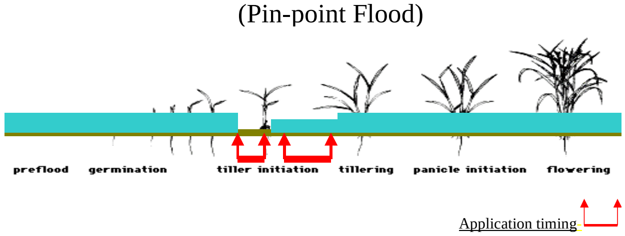
**Figure 5.** *Weed susceptibility, application timing and water management regimes for herbicide sequences with Clincher in California rice.*

| | barnyardgrass | watergrass | sprangletop | smallflower umbrella | ricefield bulrush | CA arrowhead | Gregg's arrowhead | ducksalad | redstem | monochoria |
|---|---|---|---|---|---|---|---|---|---|---|
| Clincher | + / R | + / R | + R | - | - | - | - | - | - | - |
| Followed by: | | | | | | | | | | |
| Londax | - | - | - | + / R | + / R | + / R | - | + | + / R | - |
| Regiment | + / R | + / R | - | ± R | + / R | + / R | - | ± | - | ± |
| Stam or Superwham | + | + | - | + R | + R | ± | - | ± | ± | ± |
| Shark | - | - | - | + | + | + | - | ± | ± | |

\+ control - no control R resistant ± suppression

## Clincher fb. Londax

(Pin-point Flood)



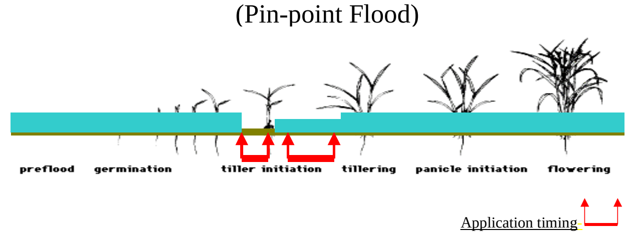

**3.0 to 6.0 lsr (0.25-0.28 lb ai/ac)**

**Fb.**

**2-3 til (0.06 lb ai/ac)**

## Clincher fb. Regiment

(Pin-point Flood)



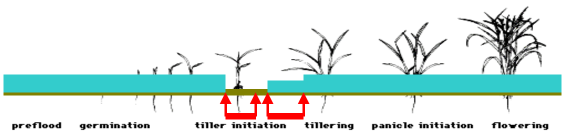

**3.0 to 6.0 lsr (0.25-0.28 lb ai/ac)**

**Fb.**

**2-3 til (15 g ai/ac)**

# propanil fb. Clincher

(Pin-point Flood)




Application timing

NO WATERGRASS RESISTANCE TO PROPANIL

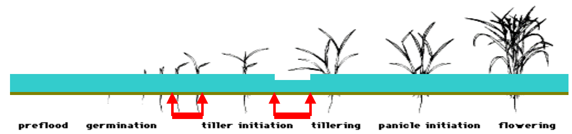
**5-6 til (6.0 lb ai/ac)**

**Fb.**

**1 to 3 til (0.28 lb ai/ac)**

# Shark fb. Clincher

(Pin-point Flood)




Application timing

NO SEDGE RESISTANCE TO SHARK

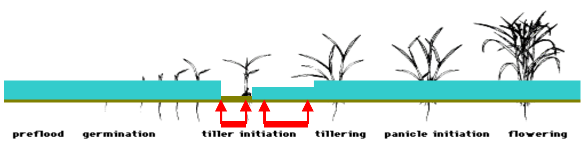
**2-3 lsr (0.2 lb ai/ac)**

**Fb.**

**1 to 3 til (0.28 lb ai/ac)**

# Clincher fb. propanil

(Pin-point Flood)




Application timing

NO WATERGRASS RESISTANCE TO PROPANIL

**3.0 to 6.0 lsr (0.25-0.28 lb ai/ac)**

**Fb.**

**2-3 til (6.0 lb ai/ac)**

**Figure 6.** *Weed susceptibility, application timing and water management regimes for herbicide sequences with Granite. In the case of watergrass, resistance is strongest with late watergrass ("mimic"); resistance to ALS inhibitors may or may not involve all herbicides in that group.*

| | barnyardgrass | watergrass | sprangletop | smallflower umbrella | ricefield bulrush | CA arrowhead | Gregg's arrowhead | ducksalad | redstem | monochoria |
|---|---|---|---|---|---|---|---|---|---|---|
| Granite | + | + / R | - | + / R | + / R | + | - | + | + | - |
| Followed by | | | | | | | | | | |
| Stam or Superwham | + | + | - | + / R | + / R | ± | - | ± | ± | ± |

+ control

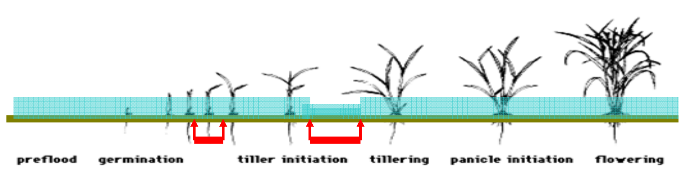
- no control

± suppression

R resistant, poor control

## Granite (GR) fb Propanil

(Permanent Flood)



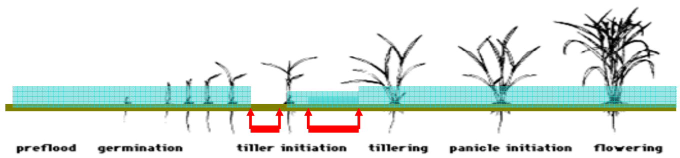

Application timing-

•If the WG population is already widely R to Granite, this sequence will not protect propanil

2.5 lsr (0.04 lb ai/ac)
Fb.
1-3 til (6 lb ai/ac)

# Granite (SC) fb Propanil

(Pin-point Flood)




Application timing-

- Will not control sprangletop
- But Granite can be mixed with Clincher

3.0 to 4.0 lsr (0.031 lb ai/ac)
Fb.
2-3 til (6 lb ai/ac)

UC DAVIS PLANT SCIENCES
County Cooperative Extension Offices

# HERBICIDE RESISTANCE STEWARDSHIP IN RICE

J.E. Hill, A.J. Fischer, C.A. Greer, & R.G. Mutters

University of California Cooperative Extension

April 2006

## What is Weed Resistance?

- Herbicide resistance is the ability of certain biotypes within a weed species to survive a herbicide treatment that would normally have killed it
- Herbicide-resistant biotypes are present within a weed species' population as a part of normal genetic variation
- Repeated use of the same herbicide or mode of action (MOA) will select for herbicide-resistant biotypes
- In California, we have two types of herbicide resistance: 1) **Target Site** resistance and 2) **Enhanced Metabolic Degradation** resistance
- Certain weed biotypes can be simultaneously resistant to herbicides that differ chemically and in their MOA
- Weeds that are not on the label will tolerate the herbicide, but are not resistant biotypes

## Symptoms of Weed Resistance in the Field

***Resistance needs to be ultimately confirmed by a specific test. Failure to control weeds can occur due to factors such as faulty spraying, incorrect dose or timing, weeds too large, subsequent weed germination after treatment, very large infestations, poor coverage, and other factors. The presence of resistance in the field is characterized by the following:***

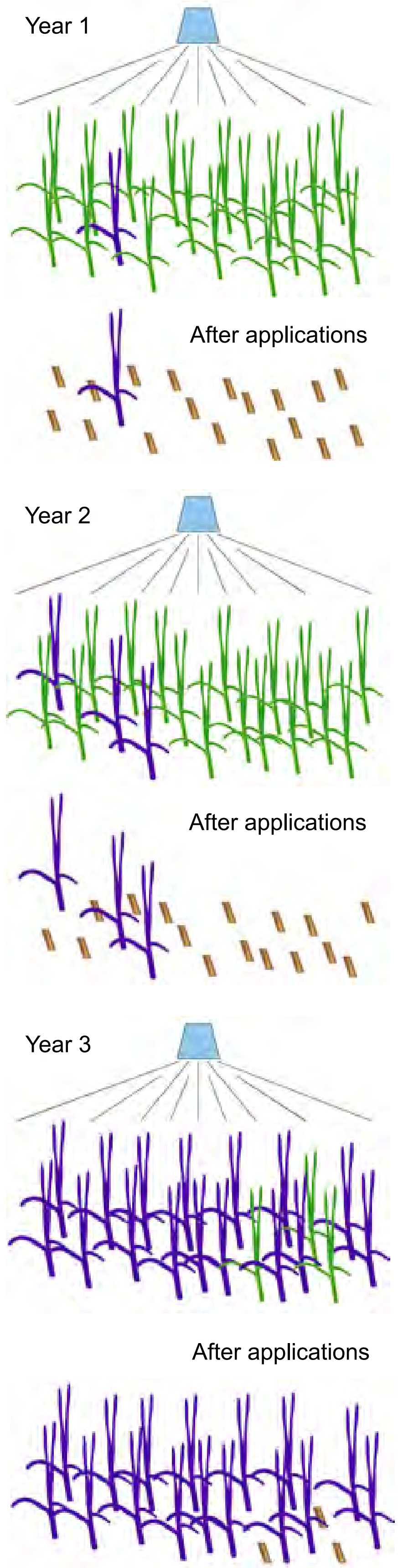
- There are healthy looking plants alongside dead plants of the same species after treatment
- One susceptible species is poorly controlled, while other adjacent susceptible species are well controlled
- The species was previously well controlled by the same herbicide and rate but a gradual decline in control has been noticed over time
- The same herbicide (or herbicides with the same MOA) has been used repeatedly on the same site
- Discrete patches of the target weed persistently survive treatment with a given herbicide(s)
- Resistance in the same weed species and herbicide occurs in neighboring field

## What Factors Favor the Evolution of Resistance?

- Excessive reliance on chemical control and repeated sequential use of the same MOA
- A monoculture of continuous rice production
- Weeds that produce lots of seeds with little dormancy and short longevity
- A herbicide that has high efficacy on a specific wee species
- A herbicide with prolonged residual activity

**Endorsed by the California Rice Commission and the California Rice Research Board**

## How resistant biotypes are selected




There is always some finite probability certain plants within a population are genetically resistant to the herbicide.

The only survivors, if the application is done correctly, will be the resistant plants which will grow and set seed.

Now there are more resistant individuals in the population. Application of the same herbicide or products with the same MOA will increase these individuals even more.

The remaining resistant population will then set seed.

Eventually, the population becomes mostly resistant individuals.

At this point the herbicide is no longer effective.

## Herbicide Susceptibility Chart

| Herbicide: Grouped by Mode of Action | Barnyardgrass | Early Watergrass | Late Watergrass | Sprangletop | Smallflower | Ricefield bulrush | CA arrowhead | Ducksalad | Redstem | Monochoria |
|---|---|---|---|---|---|---|---|---|---|---|
| **ALS Inhibitor** | | | | | | | | | | |
| Londax | ℝ | ℝ | ℝ | | R | R | R | ● | R | |
| Granite | r | r | ℝ | | R | R | R | ● | R | ● |
| Regiment | ℝ | ℝ | ℝ | | | R | R | ○ | ○ | ○ |
| **ACCase** | | | | | | | | | | |
| Whip | ℝ | ℝ | ℝ | ● | | | | | | |
| Clincher | ℝ | ℝ | ℝ | ● | | | | | | |
| **Lipid Inhibitor** | | | | | | | | | | |
| Ordram | ℝ | ℝ | ℝ | | | | | | | |
| Bolero/Abolish | ℝ | ℝ | ℝ | ● | ● | | | | | |
| **PSII Inhibitor** | | | | | | | | | | |
| Stam/Wham | ● | ● | ● | | R | R | ○ | ○ | ○ | ○ |
| **Pigment Inhibitor** | | | | | | | | | | |
| Cerano | r | r | ℝ | R | | | | | | |
| **Auxin Mimic** | | | | | | | | | | |
| Grandstand | | | | | | ● | | | ● | |
| **Protox Inhibitor** | | | | | | | | | | |
| Shark | | | | | ● | ● | ● | ○ | ○ | ○ |

**Legend**

Type resistance: **R** - TS; ℝ - EMD

● control **R**, ℝ - resistant, poor control

○ suppression r - **moderately** resistant, may escape

Use the colors in the chart to group by Mode of Action (MOA) and type of resistance. This is complicated by the fact that we have both Target Site (TS) resistance for the ALS and Enhanced Metabolic Degradation (EMD) resistance across groups of herbicides—EMD being particularly important for the "grass" herbicides. Avoid the same MOA twice in the same year or in consecutive seasons.

| | *Year 1* | *Year 2* | *Year 3* |
|---|---|---|---|
| **TS (broadleaf and sedges) R** | | | |
| **No!** | Londax | Granite | Regiment |
| **Yes!** | Londax | Abolish | SuperWham |
| **EMD (grasses) ℝ** | | | |
| **No!** | Clincher | Ordram | Granite |

**Yes!** **Any order of EMD resistant herbicides should be followed by propanil in the same season or rotated with propanil to protect against resistance.**

The weed susceptibility chart on the left lists different rice herbicides grouped by color by their MOA. Herbicides with the same color have the same MOA. Herbicides with the "white R" exhibit EMD resistance across several MOAs. On the top is a list of the principal rice weeds. An effective tank mix or sequential program will include herbicides that have different MOAs as well as herbicides that do not have EMD resistance. Some may be tank mixed or applied sequentially. The application timing varies so a good program with different MOAs can be used to prevent or control escapes. The choices are more limited for some of the broadleaf weeds such as Redstem, with only two MOAs available. A successful weed resistance management program has to consider these factors both within a single season as well as over multiple cropping years. The same MOA or herbicide with EMD resistance used successively in a single season or in back-to-back cropping seasons should be avoided.

### Herbicides are key tools that need to be protected, particularly the ALS inhibitors

- ❑ Resistance evolution is driven by your weed control decisions
- ❑ Resistance management requires keeping records of past herbicide use and planning of herbicide use in future years
- ❑ Dealing with resistance will require intensive management and higher costs

## How to delay the Evolution of Resistance?

1. Cultural practices

- Use of weed-free certified crop see
- Control all weeds that escape to prevent seed return to the field by cutting, roguing, or spraying weed patches with a non-selective herbicide
- Avoid spreading resistant weeds: clean equipment, harvest resistant fields last, etc
- Alternate rice stand establishment systems to shift natural infestations and discourage the prevalence of specific resistance weeds (Use **stale-seedbed technique** whenever possible)
- Practice crop rotation whenever feasible
- Maintain adequate water depth for weed suppression

2. Herbicide use

- Avoid using the same MOAs sequentially within the same or consecutive seasons. Control escaped weeds with sequential applications of alternate MOA herbicides
- Use tank mixtures of two herbicides that are equally effective on the same weed and, if possible, with similar residual activity
- With different residual activity, apply the tank mixtures when most weeds have emerged, and maintain adaquate water depth
- Don't use the same tank mixture repeatedly
- Practice the stale seed-bed technique whenever possible prior to seeding the crop
- Do not use ALS inhibitors or ACCase inhibitors as the sole means of control
- Keep yearly records of herbicide use within each fiel

## GRASSES:

### Barnyardgrass & Watergrass

***Barnyardgrass and watergrass can easily be distinguished by the absence of a ligule around the collar region, or the region where the leaf blade encloses the stem, as compared to the presence of a membranous ligule with rice.***

Left: Barnyardgrass and watergrass – no ligule
Right: Rice – membranous ligule present

### Barnyardgrass
**(*Echinochola crus-galli)***

Seedling

Tillering plant

Seedhead

### Early Watergrass
**(*E. oryzoides)***

Seedhead

### Late Watergrass
**(*E. phyllopogon)***

Seedhead

# GRASSES:

### Bearded Sprangletop
**(*Leptochloa fascicularis*)**


Ligule


Seedling


Tillering


Mature plant


Flowering structures

# SEDGES:

### Ricefield Bulrush
**(*Schoenoplectus mucronatus*)**


Seedling: Side-view


Seedling:  Above-view


Flowering

**Smallflower Umbrella Sedge**
***(Cyperus difformis)***


Seedling


3-4 leaf stage


Flowering sedge


Close-up: flowering structures

## BROADLEAVES:

### California and Gregg's Arrowheads

**Seedling:** ***California and Gregg's arrowheads have similar seedling as shown to the left. They can not be distinguished until they have put on their first true leaf***.

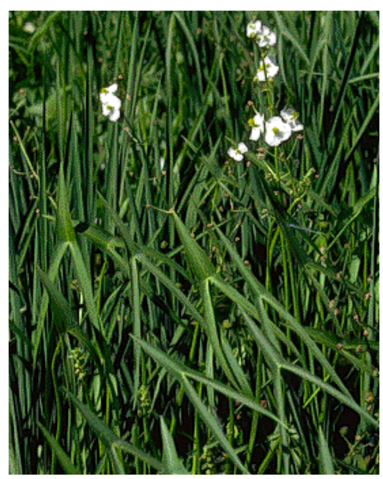
### California Arrowhead
***(Sagittaria montevidensis)***


Leaf


Flowering plant

### Gregg's Arrowhead
***(S. longiloba)***


Leaf

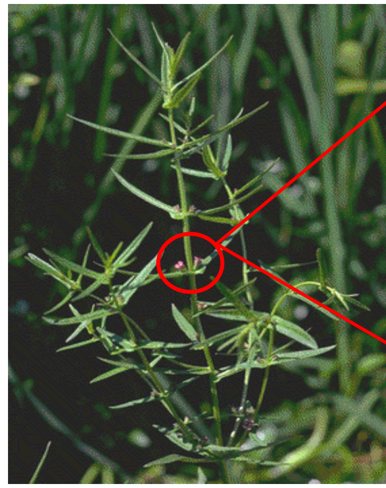

Flowering plant

## Redstem

**(*Ammannia* species)**

Emerging seedling

Seedling



Flowering redstem

Flowering structures

## Ducksalad

**(*Heteranthera limosa*)**

Emerging seedling

Mature plants in flower. The flowers may also be blue

Ducksalad infestation

## Waterhyssop

**(*Bacopa rotundifolia*)**

Seedling

Mature plants

Flowering plants

## Common Waterplantain
**(*Alisma plantago-aquatic)***


Seedling


Flowering plant

## Monochoria
**(*Monochoria vaginalis)***


Young plants


Flowering plant


Note flower cluster

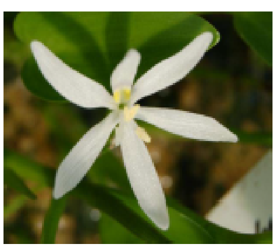
## Ducksalad species found in Sacramento Valley rice fields

### White-flowered
*Heteranthera limosa*
(Sw.) Willd.


Adult plant


Seedling


Leaves with rounded tips

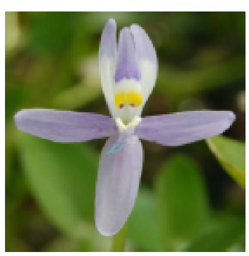

Single white flower

### Blue-flowered
*Heteranthera rotundifolia*
(Kunth) Griseb.


Adult plant


Seedling


Leaves with rounded tips

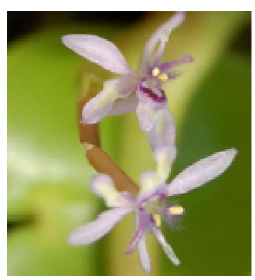

Single blue flower

### Bouquet mudplantain
*Heteranthera multiflora*
(Griseb.) Horn


Immature and adult leaves


Seedling


Adult Leaves with deep lobes at petiole attachment

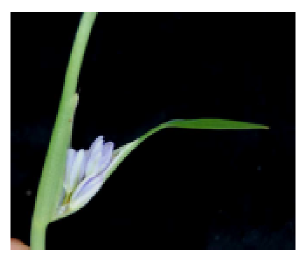

Multiple blue-purple flowers

### Monochoria
*Monochoria vaginalis*
*(Burm. F.) Kunth*


Adult plant


Monochoria seedling


Leaves with  pointed tips


Cluster of blue flowers

James Eckert, University of California, Department of Plant Science, Davis, CA

# RED RICE

Red rice plant fully headed

Long panicle that shatters easily

Straw colored pubescent hulls with long awns

Red rice seed with long awns

Red colored bran


Solitary red rice plant at mid-season


Red rice leaf collars


Patch of red rice next to levee prior to heading


Red rice ligule & auricles

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