WEEDS

Introduction

Weed populations have always been dynamic and the continuous use of almost any management practice alone 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 of rice weed control.

The Weeds: Species, Recordkeeping and Resistance

Proper identification of weed species is essential to successful weed management in rice. Weed identification is particularly important because many of the rice 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.

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.

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

Group	Common Name	Scientific Name	Weed Type
Grasses	Barnyardgrass	*Echinochloa crus-galli*	annual
	Watergrass (early)	*Echinochloa oryzoides*	annual
	Watergrass (late)	*Echinochloa phyllopogon*	annual
	Sprangletop, bearded	*Leptochloa fusca ssp. fascicularis*	annual
	Sprangletop, Mexican	*Leptochloa fusca ssp. uninervia*	annual
	Weedy Rice	*Oryza sativa*	annual
Sedges	Smallflower Umbrella Sedge	*Cyperus difformis*	annual
	Bulrush, Ricefield	*Schoenoplectus mucronatus*	annual
	Bulrush, River	*Schoenoplectus fluviatilis*	perennial
	Cattails	*Typha spp.*	perennial
Broadleaf	California Arrowhead	*Sagittaria montevidensis*	annual
	Gregg's Arrowhead	*Sagittaria longiloba*	perennial
	Ducksalad	*Heteranthera limosa*	annual
	Marshweed	*Limnophilia spp.*	perennial
	Pickerelweed	*Monochoria vaginalis*	annual
	Pondweed, American	*Potamogeton nodosus*	perennial
	Redstems	*Ammannia spp.*	annual
	Common Waterplantain	*Alsima triviale*	perennial
	Waterhyssop	*Bacopa spp.*	annual
	Winged Primrose Willow	*Ludwigia decurrens*	annual

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 Weed Science Program 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 percentages 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 weedy (red) rice or noxious weed seeds and have eliminated red rice from California. 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 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 control them more effectively.

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

Table 2. Waterholding requirements, pre-harvest intervals (PHI) and restricted entry intervals (REI) for rice herbicides (by trad name and active ingridient). Note: Rice herbicides waterholding requirements, pre-harvest intervals (PHI) and restricted entry intervals (REI) from product labels. Please read and follow label directions and contact your county agricultural commissioner for label interpretations and permit conditions.

COMMON TRADE NAME	ACTIVE INGREDIENT	WATERHOLD TIME	PRE-HARVEST INTERVAL (PHI)	RESTRICTED ENTERY INTERVAL (REI)
Solution Water Soluble	2,4-D	0-days	60-days	48 hours
Londax®	Bensulfuron-methyl	7-days static	80-days	24 hours
Butte®	Benzobicyclon + Halosulfuron	20-days	82-days	12-hours
Shark®	Carfentrazone-ethyl	5-days static 30-days release: less close system	60-days	12-hours
Cerano® MEG	Clomazone	14-days	120-days	12-hours
Clincher® CA	Cyhalofop-butyl	0-day	60-days	12-hours
Loyant® CA	Florpyrauxifen-benzyl	0	60-days	12-hours
Sandea®, Sempra®	Halosulfuron-methyl	0-days	69-days	12-hours
Strada®	Orthosulfamuron	0-days	90-days	12-hours
Granite® SC & GR	Penoxsulam	0-days	60-days	12-hours
Stam® 80 EDF SuperWham!®	Propanil	7-days: Less closed system	60 days	24-hours
Abolish® 8EC Bolero® UltraMax League® MVP	Thiobencarb	See appendix 1	See appendix 1	7-days
Grandstand® CA	Triclopyr TEA	20-days: less closed system	60-days	48-hours

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 man- dated water holding regulations (Table 2) 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 tomato, safflower, cereal crops, or sunflower, 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, and bulrush, 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 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 3).

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 to provide enough foliage 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 California rice 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

Table 3. The common and trade names of current herbicides for rice in California.

Common	Trade Names
Bensulfuron	Londax
Benzobicyclon + halosulfuron	Butte
Bispyribac	Regiment
Carfentrazone	Shark
Clomazone	Cerano
Cyhalofop	Clincher
Florpyrauxifen	Loyant
Halosulfuron	Sempra, Sandea
Orthosulfamuron	Strada
Pendimethalin	Prowl
Penoxsulam	Granite
Propanil	Stam, SuperWham!
Thiobencarb	Abolish, Bolero
Thiobencarb + imazosulfuron	League MVP
Triclopyr	Grandstand

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) work 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 complement 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 4 provides additional information on the behavior of current and future herbicides respectively.

Table 4. Behavior of currently used herbicides(lsr = rice leaf stage; mt = mid-tillering; ** = both foliar & soil activity)

1. Foliar Activity. Herbicides that must be directly sprayed on the plant to be effective are said to be foliar active and often require fields to be drained before they are applied so the weeds are adequately exposed to the spray.
2. Applied in Water. Herbicides that are formulated as granules (e.g., Bolero Ultramax) are active through the soil and do not require field draining. Herbicides marked with an asterisk (*) are formulated as a spray for foliar contact but are also adsorbed to the soil when sprayed into the water so that plants take them up through the roots as well.
3. Translocation Index. The translocation index provides a measure of how much the herbicide moves within the plant: numbers above 7 indicate highly mobile, numbers below 4 mean little movement. This index is important for water management when applying an herbicide. For example, if a foliar-applied herbicide is translocated in the plant, it may not be necessary to completely drain the field. If it is used in combination with a foliar herbicide that does not translocate (i.e., a contact herbicide), weed control would be compromised by not having the field drained fully to expose the weeds.
4. Timing Window. Application timing is important to minimize rice injury and optimize weed control. Timing is stated in relation to the rice crop development: lsr=leaf stage of rice and mt = mid-tillering. Because several herbicides also work best when timed to the weed's stage of development, the timing window may be further reduced.
5. Residual Activity. Residual activity is the length of time that the herbicide remains active in the soil and is generally determined by the amount and strength of soil adsorption and by the rate of degradation of the herbicide. Residual activity is important in herbicides that are applied early in the season because it helps to prevent reinfestation by subsequent germination of a new flush of weeds before the rice canopy is large enough to shade them out.
6. Mode of Action. Weeds are resistant to the

mode of action that kills them, not to the herbicide per se; consequently, once the weeds become resistant to a particular mode of action, all other herbicides with similar modes of action will likely fail to control the weed. To distinguish between herbicide modes of action, group numbers, assigned by the Weed Science Society of America (WSSA), are listed. Weeds with the same group number have the same mode of action. Although weeds may exhibit multiple resistance (resistance across many groups), mode-of-action numbers are useful in planning mixtures or sequences of herbicides. For more information, see http://wssa.net

7. Weed Resistance. In fields where herbicide resistance has been identified, it is critically important to implement the herbicide resistance management strategies outlined below.
8. No resistance has been confirmed for benzobicyclon, but there is resistance to halosulfuron.

Foliar or Soil Activity

Most of the newer herbicides are active only as foliar sprays. However, Abolish, Bolero, Cerano, Butte, Granite, and Londax have soil activity. Generally, when the product is formulated and used as a granule such as Bolero, Butte or Granite, 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 and Loyant 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 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 4 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 labels for Grandstand and Loyant, 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 ap-

Table 4. Behavior of currently used herbicides(lsr = rice leaf stage; mt = mid-tillering; ** = both foliar & soil activity)

Herbicide	Foliar activity [1]	Applied in water [2]	Translocation index [3]	Timing window [4]	Residual (days) [5]	Mode of action [6]	Weed resistance[7]
Bensulfuron (Londax)	Yes	Yes *	4	0–5 lsr	35–40	2	Yes
Benzobicyclon/ Halosulfuron (Butte)	Yes	Yes	4	0–5 lsr	30	27/2	see comment [8]
Bispyribac (Regiment)	Yes	No	4	5 lsr–mt	0	2	Yes
Carfentrazone (Shark)	Yes	Yes *	2	4 lsr–mt	5–8	14	No
Clomazone (Cerano)	No	Yes	6	0–1 lsr	5 (water)	13	Limited
Cyhalofop-butyl (Clincher)	Yes	No	4	2 lsr–mt	0	1	Yes
Florpyrauxifen (Loyant)	Yes	No	8	2 lsr to 60 days before harvest	0	4	No
Halosulfuron (Sandea)	Yes	Yes *	4	0–5 lsr	30	2	Yes
Orthosulfamuron (Strada)	Yes	Yes *	4	2–4 lsr	12–24	2	Yes
Pendimethalin (Prowl)	No	No	0	soil cracking	5 (water) 20 (dry soil)	3	No
Penoxsulam (Granite)	Yes	Yes	4	2 lsr–mt	0	2	Yes
Propanil (Stam, SuperWham)	Yes	No	3	3 lsr–mt	0	7	Yes
Thiobencarb (Abolish)	Yes	Yes *	3	1–2 lsr	20–25	8	Yes
Thiobencarb (Bolero)	No	Yes	3	1–2 lsr	20–25	8	Yes
Thiobencarb/ imazosulfuron (League MVP)	No	Yes	3	1–2 lsr	20–25	8/2	Yes
Triclopyr (Grandstand)	Yes	No	8	5 lsr–mt	0	4	No

1 Foliar Activity. Herbicides that must be directly sprayed on the plant to be effective are said to be foliar active and often require fields to be drained before they are applied so the weeds are adequately exposed to the spray.
2 Applied in Water. Herbicides that are formulated as granules (e.g., Bolero Ultramax) are active through the soil and do not require field draining. Herbicides marked with an asterisk (*) are formulated as a spray for foliar contact but are also adsorbed to the soil when sprayed into the water so that plants take them up through the roots as well.
3 Translocation Index. The translocation index provides a measure of how much the herbicide moves within the plant: numbers above 7 indicate highly mobile, numbers below 4 mean little movement. This index is important for water management when applying an herbicide. For example, if a foliar-applied herbicide is translocated in the plant, it may not be necessary to completely drain the field. If it is used in combination with a foliar herbicide that does not translocate (i.e., a contact herbicide), weed control would be compromised by not having the field drained fully to expose the weeds.

4 Timing Window. Application timing is important to minimize rice injury and optimize weed control. Timing is stated in relation to the rice crop development: lsr=leaf stage of rice and mt = mid-tillering. Because several herbicides also work best when timed to the weed's stage of development, the timing window may be further reduced.
5 Residual Activity. Residual activity is the length of time that the herbicide remains active in the soil and is generally determined by the amount and strength of soil adsorption and by the rate of degradation of the herbicide. Residual activity is important in herbicides that are applied early in the season because it helps to prevent reinfestation by subsequent germination of a new flush of weeds before the rice canopy is large enough to shade them out.
6 Mode of Action. Weeds are resistant to the mode of action that kills them, not to the herbicide per se; consequently, once the weeds become resistant to a particular mode of action, all other herbicides with similar modes of action will likely fail to control the weed. To distinguish between herbicide modes of action, group numbers, assigned by the Weed Science Society of America (WSSA), are listed. Weeds with the same group number have the same mode of action. Although weeds may exhibit multiple resistance (resistance across many groups), mode-of-action numbers are useful in planning mixtures or sequences of herbicides. For more information, see http://wssa.net
7 Weed Resistance. In fields where herbicide resistance has been identified, it is critically important to implement the herbicide resistance management strategies outlined below.
8 No resistance has been confirmed for benzobicyclon, but there is resistance to halosulfuron.

plication 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 re-infestation 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. Carfentrazone, 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.

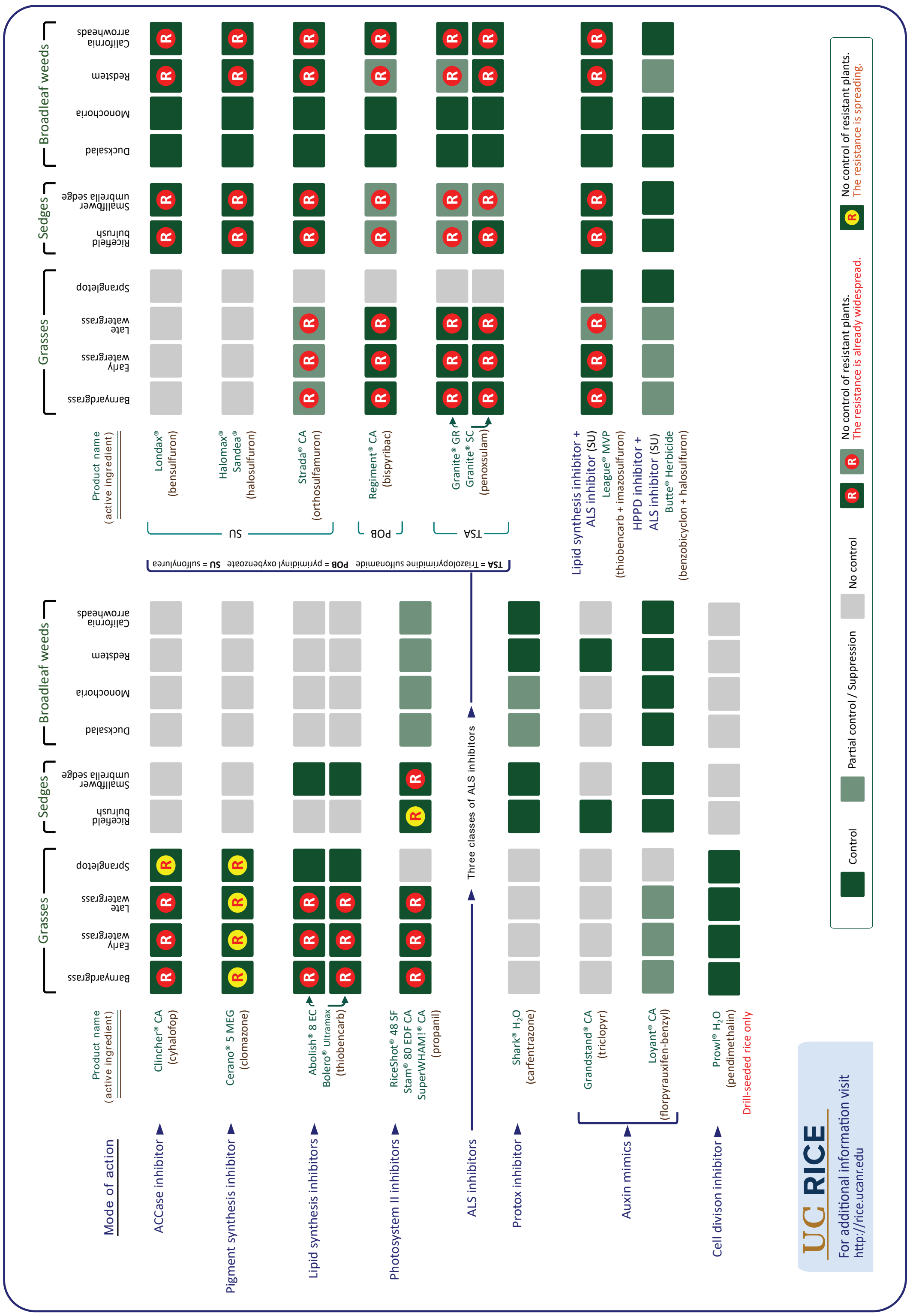
Mechanisms of Action

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 5 shows the current rice herbicides grouped by mechanism of action. Thus, it would not be a good idea to use Granite where resistance to Regiment 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.

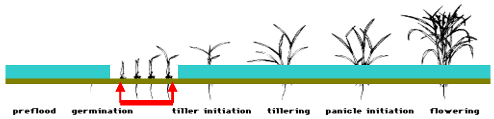
Table 5. Herbicides mechanism of action

Group	Active Ingredient	Mechanism of Action
Thiocarbamates	thiobencarb (Abolish, Bolero)	VLCFA (Very long chain fatty acids)
Aryloxyphenoxy-propionates	cyhalofop-butyl (Clincher)	ACCase inhibitors
Amide	propanil (SuperWham, Stam)	Photosystem II inhibitor
Sulfonylurea	bensulfuron (Londax) halosulfuron (Sempra) Orthosulfamuron (Strada) Imazosulfuron (component of League)	ALS inhibitor
Phrimidinyl-thiobenzoates	bispyribac (Regiment)	ALS inhibitor
Triazolopyrimidines	penoxsulam (Granite)	ALS inhibitor
Dinitroaniline	pendimethalin (Prowl)	Tublin inhibitor (mitosis.)
Isoxazolidinone	clomazone (Command)	Carotenoid biosynthesis
Pyridine-carboxylates	florpyrauxifen-benzyl (Loyant)	PPO inhibitor
Pyridyloxy-carboxylates	triclopyr (Grandstand)	Synthetic Auxin
Unclassified	benzobicyclon (Butte)	HPPD inhibitor

CALIFORNIA RICE WEED HERBICIDE SUSCEPTIBILITY CHART



Abolish
(Pin-point Flood)

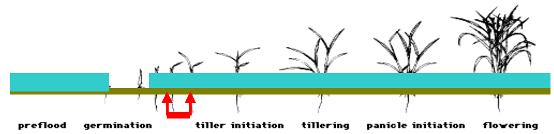


Emrg. shoot, 1st. lf.	Yes
Appl'd in water	No
Translocated	Little
Timing	1-3 lsr
Resistance	Yes

Application timing

1.0 to 3.0 lsr (4 lb ai/ac)

Bolero
(Leathers' Method)

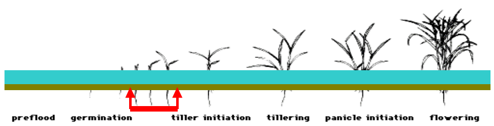


Emerg. shoot	Yes
Appl'd in water	Yes
Translocated	Little
Timing	2 lsr
Resistance	Yes

Application timing

2.0 lsr (4.0 lb ai/ac)

Bolero
(Permanent Flood)

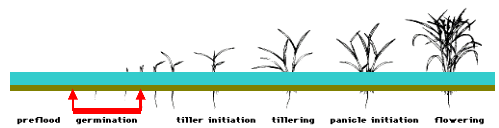


Emerg. shoot	Yes
Appl'd in water	Yes
Translocated	Little
Timing	1-2 lsr
Resistance	Yes

Application timing

1.0 to 2.0 lsr (4 lb ai/ac)

Cerano
(Permanent Flood)

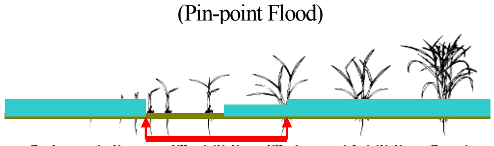


Roots, emerg. Shoots	Yes
Appl'd in water	Yes
Translocated	Yes
Timing	preseed-lsr
Resistance	Yes

Application timing

Preseed to 1.0 lsr (0.6 lb ai/ac)

Clincher
(Pin-point Flood)

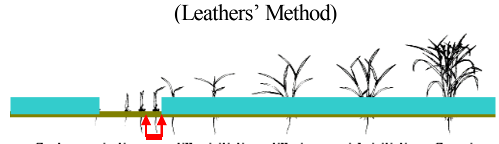


Foliar	Yes
Appl'd in water	No
Translocated	Yes
Timing	2 lsr-midtil
Resistance	Yes

Application timing

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

Clincher
(Leathers' Method)

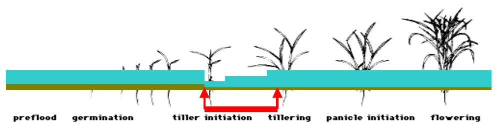


Foliar	Yes
Appl'd in water	No
Translocated	Yes
Timing	2 lsr
Resistance	Yes

Application timing

2.0 lsr (0.25 lb ai/ac)

Grandstand
(Pin-point Flood)

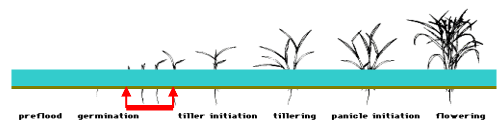


Foliar	Yes
Appl'd in water	No
Translocated	Yes
Timing	1 till-maxtil
Resistance	No

Application timing

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

Londax, Sandea
(Permanent Flood)

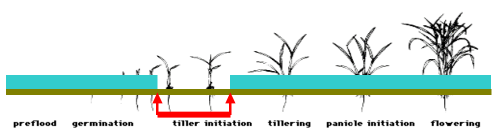


Foliar and roots	Yes
Appl'd in water	Yes
Translocated	Yes, moderate
Timing	0-5 lsr
Resistance	Yes

Application timing

1.0 to 3.0 lsr (0.06 lb ai/ac)

Londax, Sandea
(Pin-point Flood)

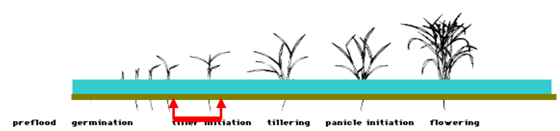


Foliar and roots	Yes
Appl'd in water	Yes
Translocated	Yes, moderate
Timing	0-5 lsr
Resistance	Yes

Application timing

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

Granite GR
(Continuous Flood)

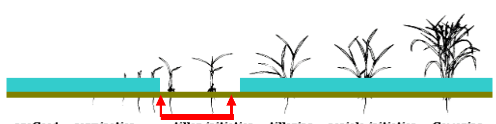


Foliar and roots	Yes
Appl'd in water	Yes
Translocated	Yes, moderate
Timing	2-3 lsr
Resistance	Yes

Application timing

2-3 lsr (0.04 lb ai/ac)

Granite SC
(Pin-point Flood)

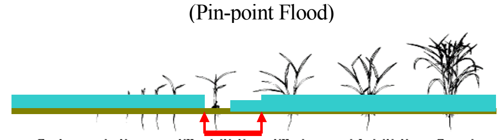


Foliar and roots	Yes
Appl'd in water	No
Translocated	Yes, moderate
Timing	2 lsr to 1 Till
Resistance	Yes

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

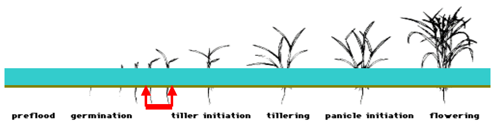
Application timing

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)



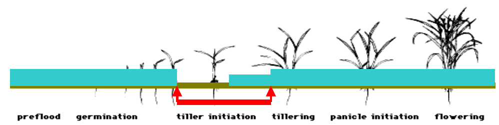
Foliar	Yes
Appl'd in water	Yes
Translocated	No
Timing	2-3 lsr
Resistance	No

Application timing

2.0 to 3.0 lsr (0.20 lb ai/ac)

propanil

(Pin-point Flood)



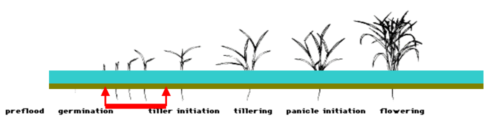
Foliar	Yes
Appl'd in water	No
Translocated	No
Timing	3 lsr-midtil
Resistance	No

Application timing

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

Butte

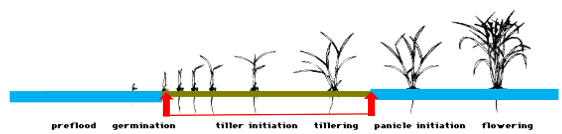
(Permanent Flood)



Roots, emerg. Shoots	Yes
Appl'd in water	Yes
Translocated	Yes
Timing	preseed-lsr
Resistance	No

Day of seeding to 2
to 9 lb product), at 1
inches water depth

Loyant



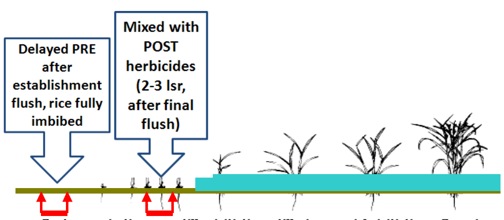
FoliarAppl'd	Yes
in water	No
Translocated	Yes
Timing	2 lsr
Resistance	No

Application timing

2.0 lsr to 60 days before harvest (0.035 lb ai/ac)

Prowl

(Dry-seeded)

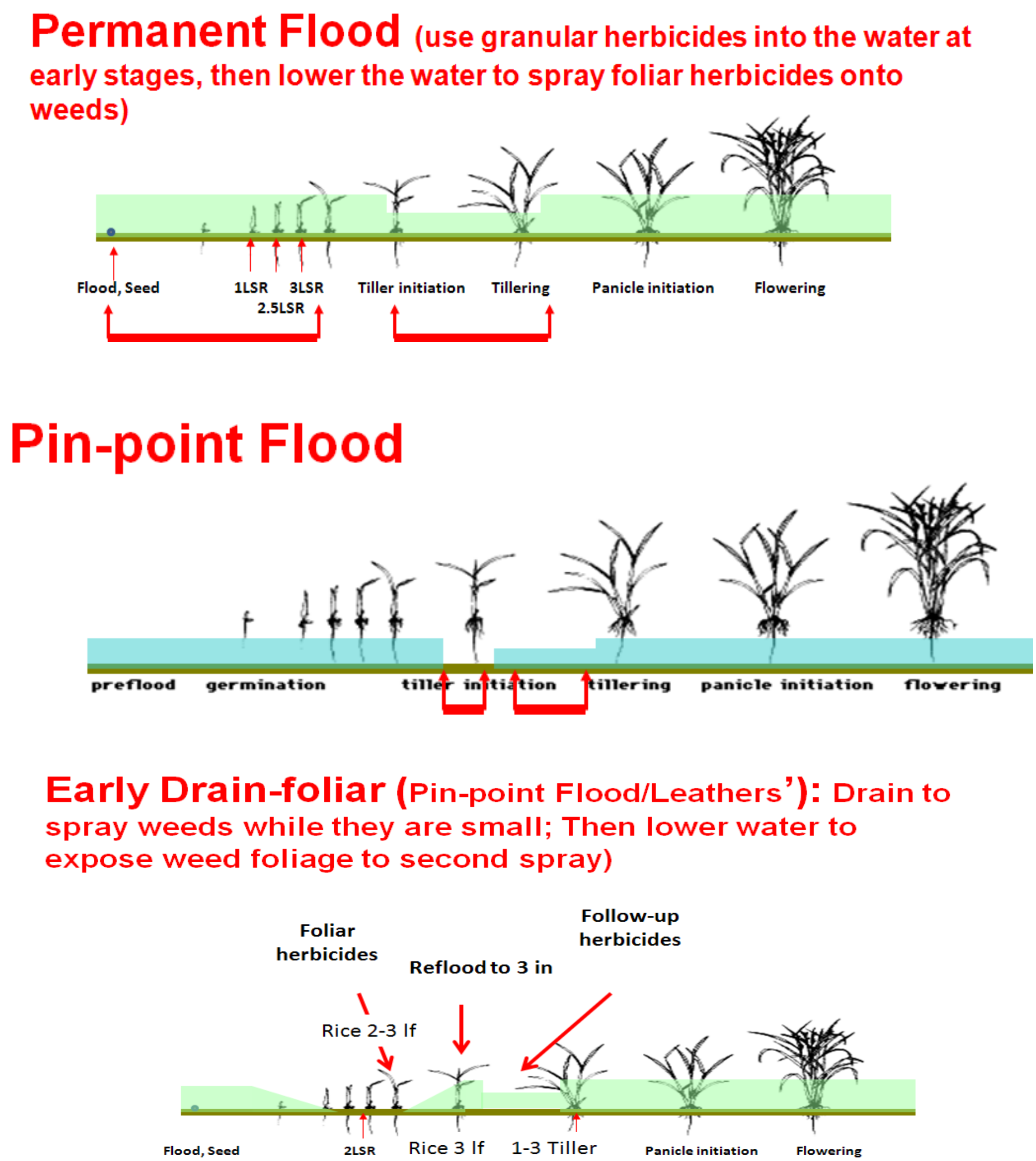


Foliar	No
Appl'd in water	No
Translocated	No
Timing	Delayed PRE or 2-3 lsr (as PRE)
Resistance	No

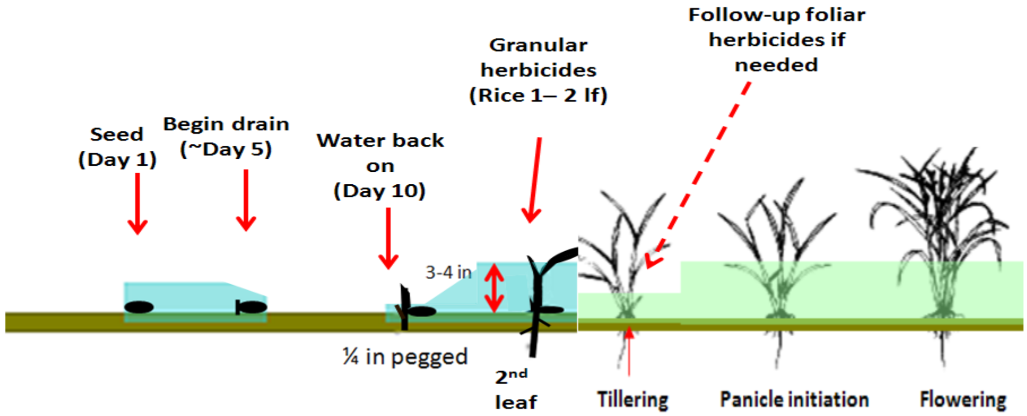
Application timing

DPRE (1 lb ai/ac)

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



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)

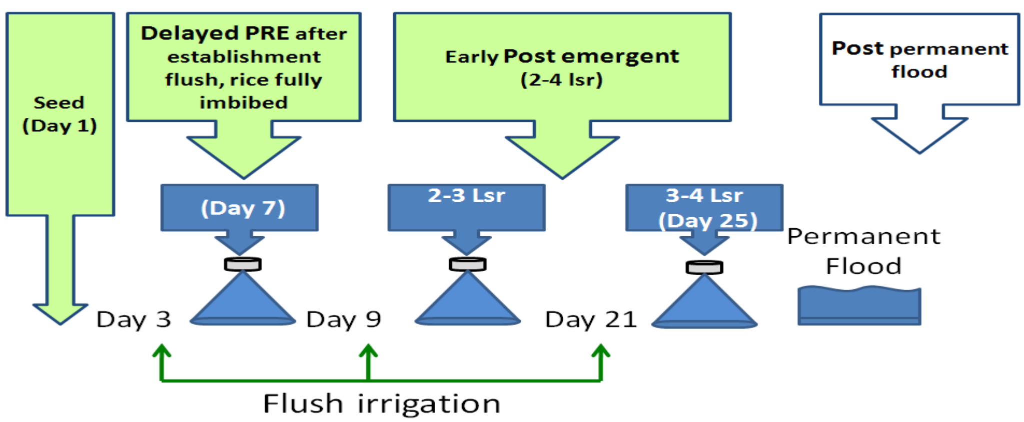


Figure 1b (continued). Major herbicide-based weed control systems for rice in California.

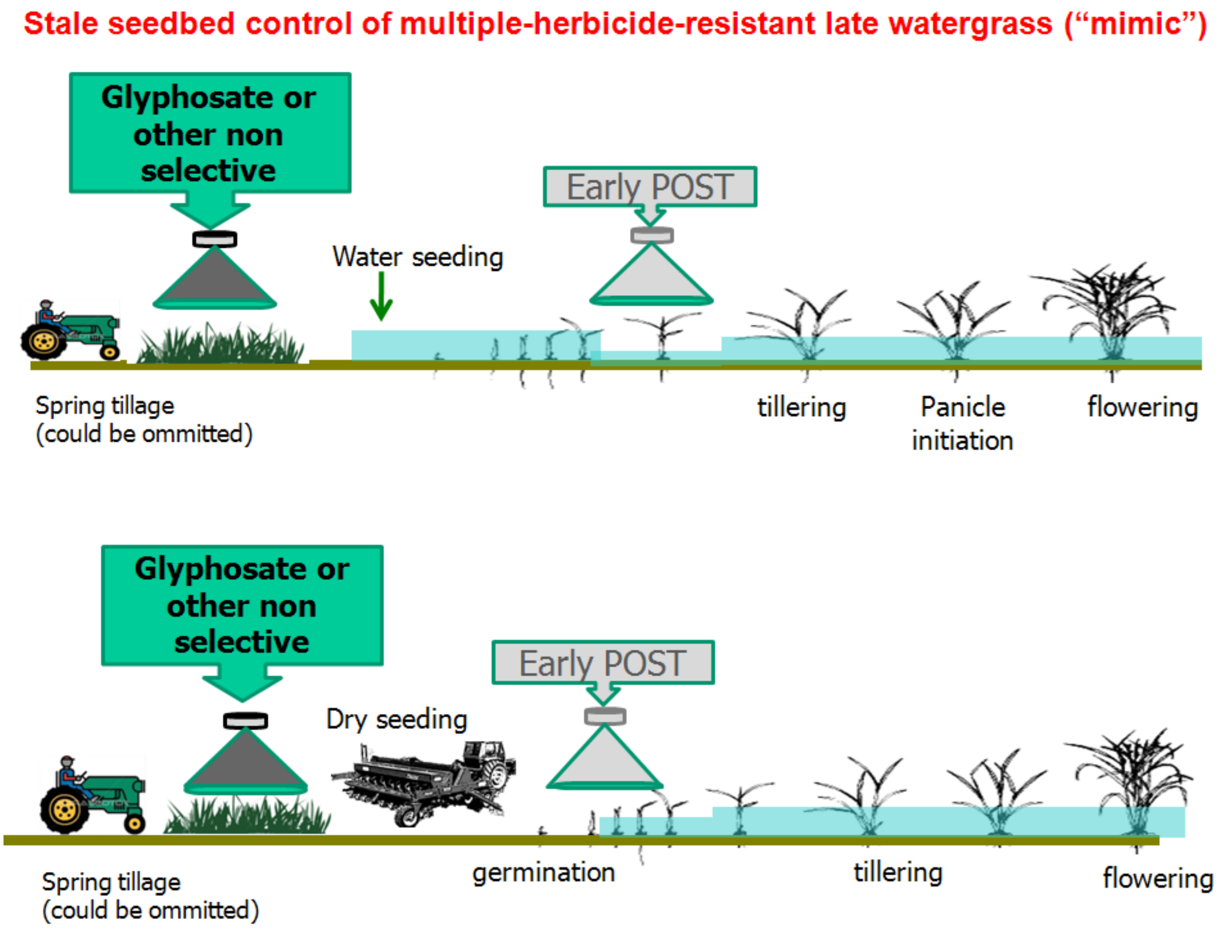


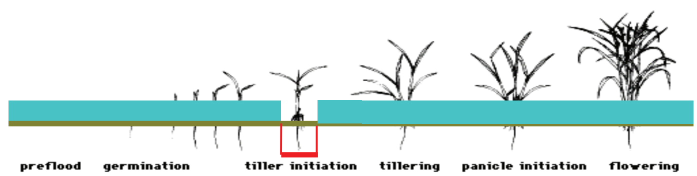
Figure 2. Weed susceptibility, application timing and water management regimes for tank-mixed herbicides in California rice

	Barnyardgrass	Watergrass	Sprangletop	Smallflower Umbrella	Ricefield Bullrush	CA Arrowhead	Gregg's arrowhead	Ducksalad	Redstem	Monochoria
Stam or Superwham	+	+	-	+	+	±	-	±	±	±
Abolish	+ / R	+ / R	+	+	-	-	-	-	-	-

+ Control
- No Control
± Suppresion
R Resistant

Propanil + Abolish

(Pin-Point Flood)



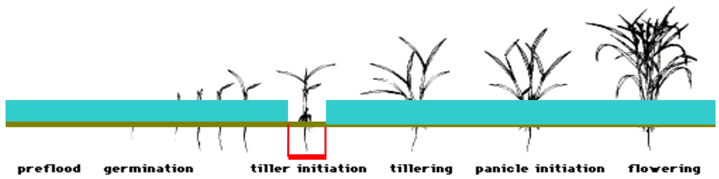
2-3 lsr (3 lb ai/ac + 3.0 lb ai/ac)

	Barnyardgrass	Watergrass	Sprangletop	Smallflower Umbrella	Ricefield Bullrush	CA Arrowhead	Gregg's arrowhead	Ducksalad	Redstem	Monochoria
Regiment	+ / R	+ / R	-	-	+ / R	+ / R	-	±	-	±
Abolish	+ / R	+ / R	+	+	-	-	-	-	-	-
Shark	-	-	-	+	+	+	-	±	±	±
Whip	+ / R	+ / R	+	-	-	-	-	-	-	-

+ Control
- No Control
± Suppresion
R Resistant

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

Regiment + Abolish
(Pin-Point Flood)

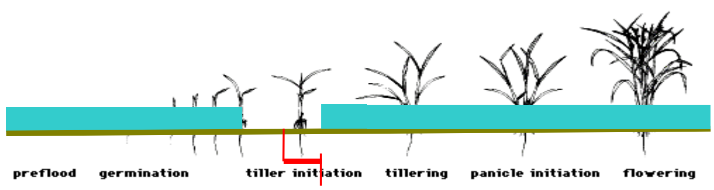


Synergistic mixture intended only for late water grass

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

Can also be effective on smallflower and bulrush

Regiment + Shark
(Pin-Point Flood)



Broad-spectrum

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

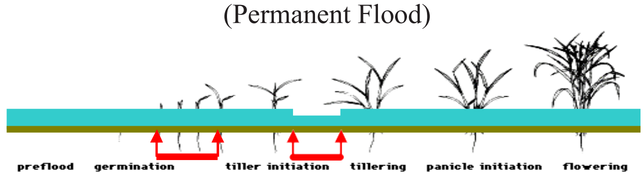
Figure 3. Weed susceptibility, application timing and water management regimes for herbicide sequences with Regiment.

	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	+	+	-	+	+	±	-	±	±	±

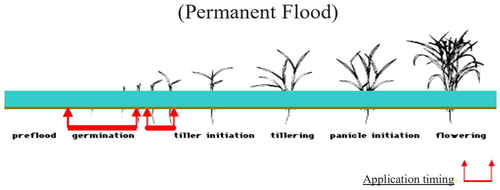
+ control
- no control
± suppression
R resistant

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)



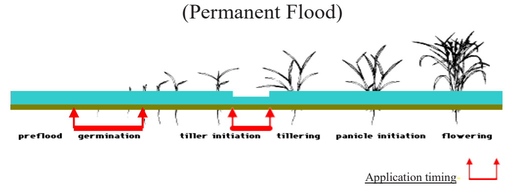
Preseed to 1.0 lsr (0.6 lb ai/ac)

Fb.

2-3 lsr (0.06 lb ai/ac)

Cerano fb. Regiment

(Permanent Flood)

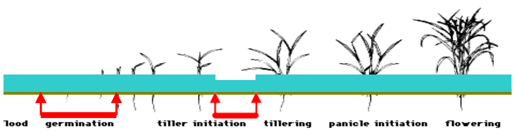


Preseed to 1.0 lsr (0.6 lb ai/ac)

Fb.

2-3 Tiller (15 g ai/ac)

Cerano fb. propanil
(Permanent Flood)



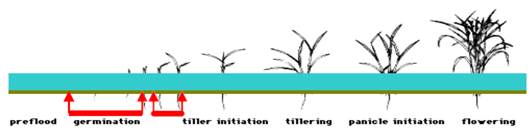
Application timing-

Preseed to 1.0 lsr (0.6 lb ai/ac)

Fb.

1-3 til (6 lb ai/ac)

Cerano fb. Shark
(Permanent Flood)



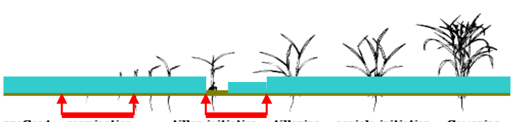
Application timing

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)

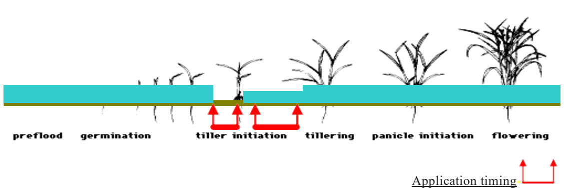
Figure 5. Weed susceptibility, application timing and water management regimes for herbicide sequences with Clincher in California rice.

	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)



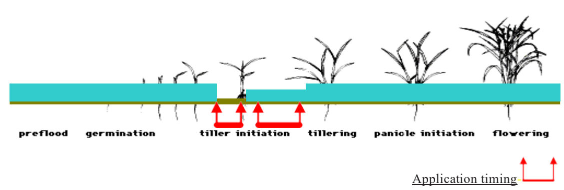
3.0 to 6.0 lsr (0.25-0.28 lb ai/ac)

Fb.

2-3 til (0.06 lb ai/ac)

Clincher fb. Regiment

(Pin-point Flood)

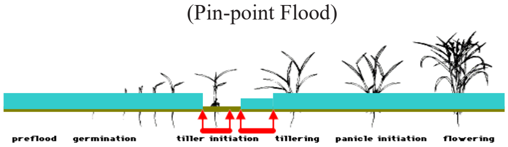


3.0 to 6.0 lsr (0.25-0.28 lb ai/ac)

Fb.

2-3 til (15 g ai/ac)

propanil fb. Clincher
(Pin-point Flood)



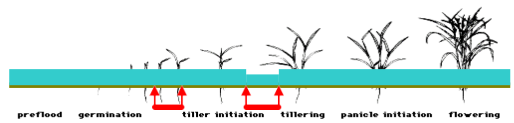
Application timing

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

<u>**Fb**</u>**.**

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

Shark fb. Clincher
(Pin-point Flood)



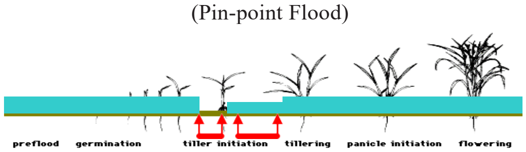
Application timing

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

<u>**Fb**</u>**.**

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

Clincher fb. propanil
(Pin-point Flood)



Application timing

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

<u>**Fb**</u>**.**

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

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

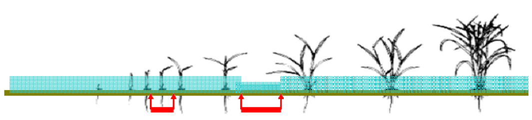
\- no control

± suppression

R resistant, poor control

Granite (GR) fb Propanil

(Permanent Flood)



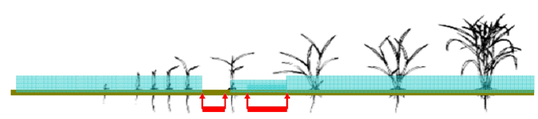
Application timing-

•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)

HERBICIDE RESISTANCE STEWARDSHIP IN RICE

June 2018

What is Weed Resistance?

- The ability of a weed biotype to survive treatment with a given herbicide to which the weed species is normally susceptible
- 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) **Non-Target Site** 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:

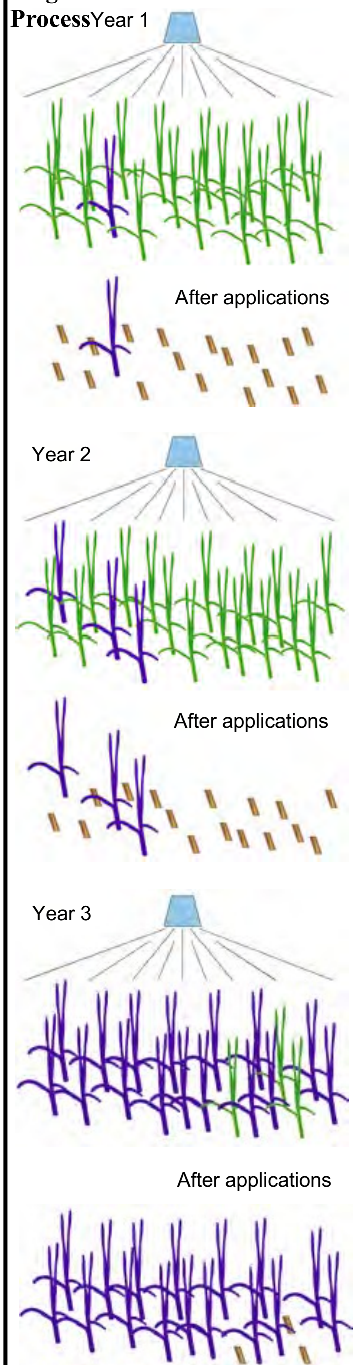
- There are healthy looking plants alongside dead plants of the same species after treatment
- One susceptible species is poorly controlled, while other adjacent susceptible species are well controlled
- The species was previously well controlled by the same herbicide and rate but a gradual decline in 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 that have annual growth habit and produce lots of seeds with little dormancy
- 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

Stages of Herbicide Resistance Evolutionary Process



Weed Identification Pictures

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

Bearded Sprangletop
(Leptochloa fusca ssp. fascicularis)


Ligule


Seedling


Tillering


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

Broadleaveves

California and Gregg's Arrowheads

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.

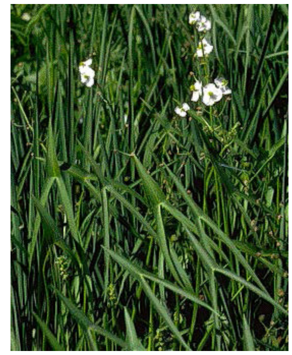
California Arrowhead
(Sagittaria montevidensis)


Leaf

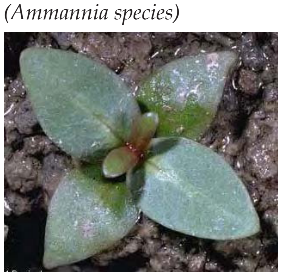

Flowering Plant

Gregg's Arrowhead
(S. longiloba)

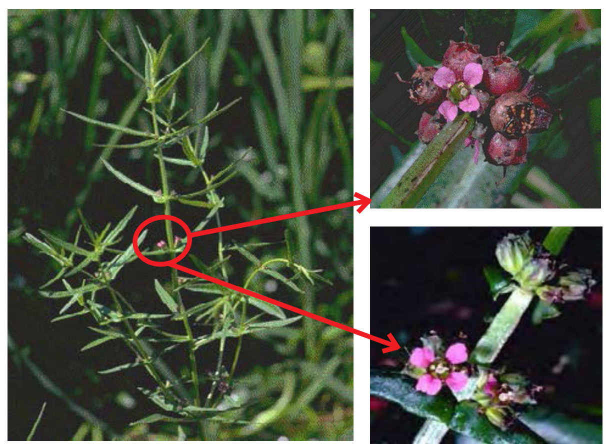

Leaf


Flowering Plant

Redstem
(Ammannia species)


Emerging seedling


Seedling


Flowering redstem

Flowering structures

Waterhyssop
(Bacopa rotundifolia)


Seedling


Mature Plants


Flowering Plant

Ducksalad
(Heteranthera limosa)


Emerging seedling


Mature plants in flower. The flowers may also be blue.

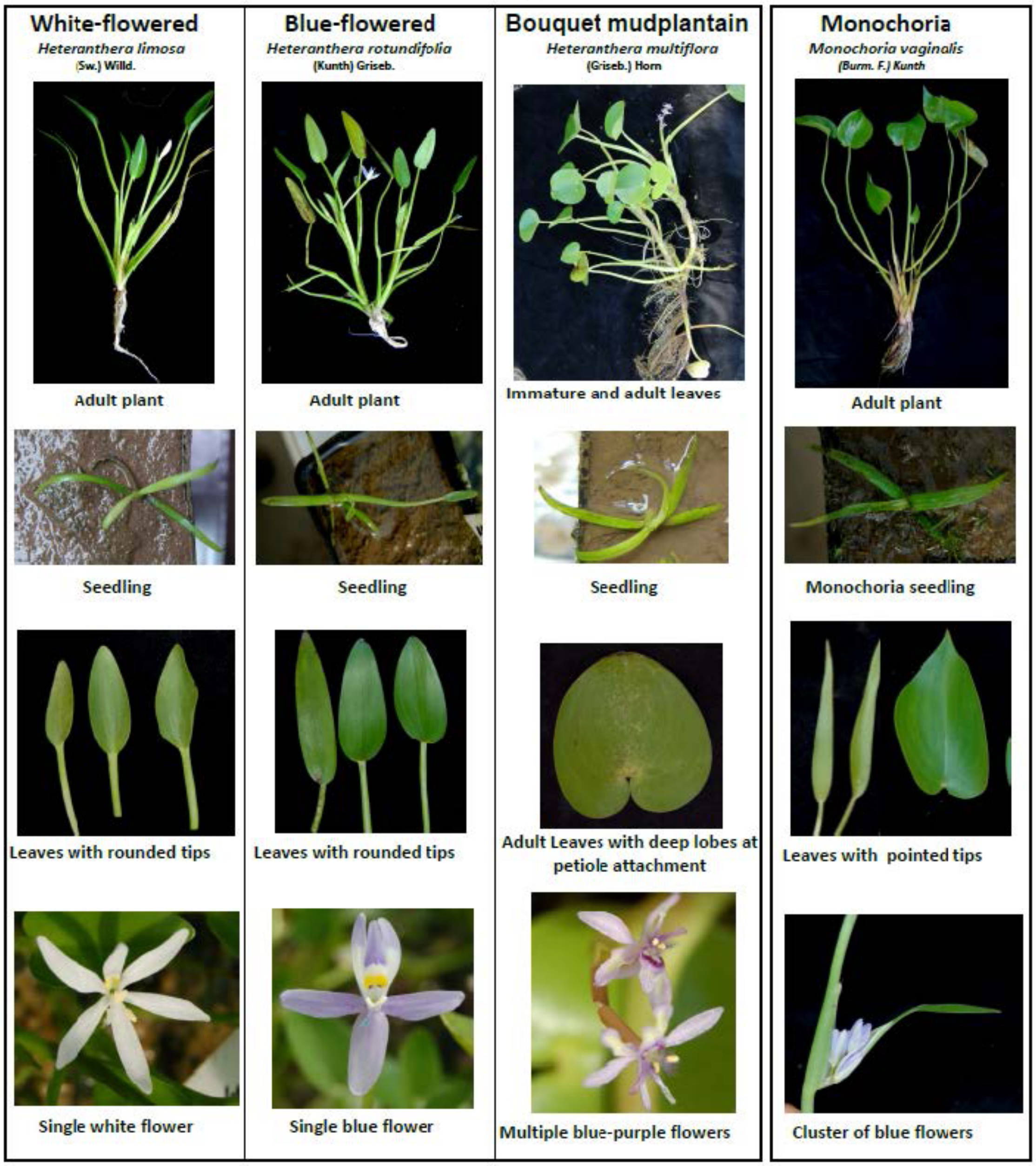

Ducksalad infestation

Common Waterplantain
(Alisma plantago-aquatic)


Seedling

Monochoria
(Monochoria vaginalis)

Ducksalad species found in Sacramento Valley rice fields



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

Weedy or "Red" Rice

Type 1:

- Short grain
- No color on nodes

Seeds:

- Awnless
- Straw-hulled seed
- High shattering
- High dormancy

Type 2:

- Medium grain
- No color on nodes

Seeds:

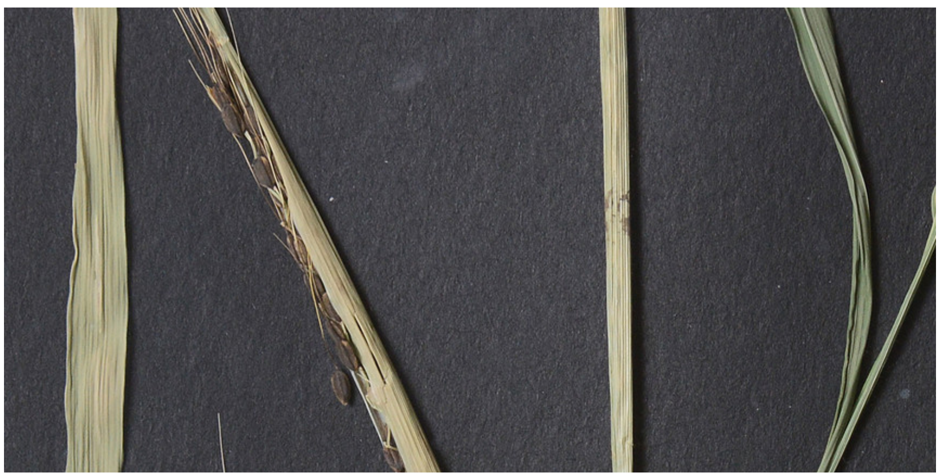
- Awnless
- Bronze-hulled seed
- High shattering
- Low dormancy

Type 3:

- Medium grain
- No color on nodes

Seeds:

- Awned
- Straw-hulled seed
- High shattering
- High dormancy



Type 4:

- Medium grain
- No color on nodes

Seeds:

- Awned
- Black-hulled seed
- High shattering
- High dormancy

Type 5:

- Medium grain
- Purple bands on nodes

Seeds:

- Awnless
- Straw-hulled seed
- High shattering
- Low dormancy

All California weedy rice types have the following characteristics:

- Red pericarped (red-branned)
- Light green leaves
- Pubescent (fuzzy) leaves
- Taller in height than Calrose varieties

Solitary weedy rice plant at mid-season

Weedy rice leaf collars

Patch of weedy rice next to levee prior to heading

Weedy rice ligule & auricles

Appendix 1.

Rice Pesticides Water Management Requirements Summary

Water must be held for the indicated number of 24-hour periods on the treated field, or within the containment area specified below before release into State waters.		Thiobencarb		Thiobencarb Plus Imazosulfuron	
		Bolero® UltraMax	**Abolish® 8 EC**	**League® MVP**	**Malathion**
		Hold	Hold	Hold	Hold
NORTH SAC VALLEY	Single treated fields.	30	19	30	4 (b)
	Release into tailwater recovery system or ponded onto fallow land or contained in other systems appropriate for preventing discharge.	19	19	19	
	System controlled by one permittee, then water may be discharged into the system in manner consistent with product labeling.	14	14	14	
	System includes drainage from more than one permittee, then water must be retained on site.	6	6	6	
	Water on fields within bounds of areas that discharge negligible amounts of drainage onto perennial streams. Commissioner must evaluate such sites and verify the hydrologic isolation of the fields.	6	6	6	
	CAC may authorize emergency release of tailwater.	19	19	19	
SOUTH SAC & SJ VALLEY (a)	All water on treated fields must be retained on the treated fields.	19	19	19	4 (b)
	Release into tailwater recovery system or ponded onto fallow land or contained in other systems appropriate for preventing discharge.	19	19	19	
	System controlled by one permittee, then water may be discharged in manner consistent with product labeling.	14	14	14	
	System includes drainage from more than one permittee, then water must be retained on site.	6	6	6	
	Water on fields within bounds of areas that discharge negligible amounts of drainage onto perennial streams. Commissioner must evaluate such sites and verify the hydrologic isolation of the fields.	6	6	6	
	CAC may authorize emergency release of tailwater.	19	19	19	

(a)- South Sacramento & San Joaquin Valley defined as: South of the line by Roads E10 and 116 in Yolo County and the American River in Sacramento County

(b) Volunteer hold.