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COMPREHENSIVE RICE RESEARCH
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PROJECT TITLE: Weed Control in Rice

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OBJECTIVES AND EXPERIMENTS CONDUCTED BY LOCATION TO ACCOMPLISH OBJECTIVES:

1. To test and screen herbicides for efficacy, safety and compatibility for tank mixtures or sequential treatments in order to develop, in integration with agronomic practices, weed control packages for the main rice production systems in California.

2. To continue searching and testing new compounds with potential for addressing critical weed control issues to establish their suitability and proper fit into the rice management systems of California. Encourage introduction of promising new chemicals to the California market.

3. To develop new alternatives to weed control through the exploration of agronomic opportunities, rice/weed competition to minimize herbicide costs and environmental impacts. To measure rice yield impact of specific weed species and develop a predictive approach.

4. To develop an understanding of herbicide resistance in weeds, provide diagnosis, test herbicides, and develop effective alternatives to manage this problem.

SUMMARY OF 2006 RESEARCH, BY OBJECTIVE:

OBJECTIVE 1. *To test and screen herbicides for efficacy, safety and compatibility for tank mixtures or sequential treatments in order to develop, in integration with agronomic practices, weed control packages for the main rice production systems in California.*

Herbicide test plots were located at two different sites at the RES (RES) in Butte County, and one off-station site in Glenn County. One of the sites has Londax (bensulfuron-methyl)-resistant smallflower umbrellasedge. The off-station site has resistant late watergrass as the main weed problem. The site in Glenn County was planted May 17, while planting at the Station occurred May 26 and June 1. Yield data is being presented this season for comparison between treatments. Very little lodging was experienced making the grain harvest more reliable. Fertility management was adjusted to prevent lodging and poor harvest conditions with the plot combine.

All sprayed herbicide applications were made with a CO_2-pressurized (30 psi) hand-held sprayer equipped with a ten foot boom and 8003 nozzles, calibrated to apply 20 gallons of spray volume per acre. Applications with solid formulations were performed by evenly broadcasting the product over the plots.

Shark (carfentrazone)

Shark has been tested for several years on station and at off station sites in growers' fields and has demonstrated efficacy for controlling sedges and broadleaves. Because of problems in the past with non-target injury (i.e.- drift onto prunes), emphasis has been oriented towards using this product either in a DDA (direct-dry application) or DSA (direct-stream application). After testing both the 1.2 mm and the new 0.6 mm extruded 40DF formulation in 2005, FMC Corporation decided to change the consumer formulation from 1.2 to 0.6 mm. The new formulation has the same percent active ingredient per weight of product, but has twice as many particles for greater distribution in the field. The dry application into the water allows reduced potential for non-target drift, and to cover large acreages effectively for early weed control. Shark is particularly important to California rice since resistance to Londax (bensulfuron) is widespread. Shark is an effective tool in California rice as it can be applied in combination with other into-water herbicides, and in sequential weed control operations. Timing of application is critical for best efficacy and reduction of crop injury. Very early applications of Shark caused severe rice establishment problems, while late applications may be less efficacious on the established sedges.

Shark (224 g ai/ha, 2-3 lsr) fb.[1] Super Wham (6726 g ai/ha, 1-3 Till) provided very good weed control and the highest grain yield in the continuous flood trial at Hamilton road (Table 1). Yield was greater than the Super Wham only treatment. Shark (224 g ai/ha, 2-3 lsr) applied same day as Granite GR (40 g ai/ha) also provided excellent weed control and high yield (Table 1). Combining Granite with Shark is a good management practice to protect Granite from ALS-resistance evolution in weeds. This treatment also had higher yield than the Granite GR only treatment. Cerano (673 g ai/ha, DOS) fb. Shark (224 g ai/ha, 2 lsr) had good broad-spectrum weed control and high yield in two experiments (Tables 3 & 11).

Prowl H_2O (pendimethalin)

Prowl is a selective herbicide for controlling annual grass (watergrass, barnyardgrass, sprangletop) and certain broadleaf weeds (smallflower umbrellasedge) as they germinate and emerge. As a meristematic inhibitor, it interferes with the plant's cellular division and early growth. Prowl H_2O has substituted Prowl EC on the supplemental label for drilled and dry seeded rice in California. Prowl H_2O is a new water based capsule suspension (CS) formulation. Wet/dry cycles cause the capsule wall to rupture and release the pendimethalin. Prowl H_2O needs to be applied to moist soil without any standing water. Flooding causes the chemical to degrade and loose efficacy; also volatility losses are more rapid when this herbicide is applied to wet soil surfaces. Prowl H_2O was tested in a drill seeded rice culture at the RES (Table 9). Prowl H_2O applied alone (1120 g ai/ha) as delayed pre emergent (DPRE) provided 58% watergrass/barnyardgrass control and 98% sprangletop control at 20 DAS but diminished to only 11% watergrass/barnyardgrass control and 68% sprangletop control by 60 DAS. Improved control of watergrass/barnyardgrass was achieved by following the Prowl H2O treatment with either Super Wham (6726 g ai/ha) or Regiment (12.5 g ai/ha) at 2-3 lsr. Prowl (1120 g ai/ha) applied alone at the 2-3 lsr did not provide control of watergrass/barnyardgrass or sprangletop. In both DPRE and 2-3 lsr there were emerged watergrass/barnyardgrass and sprangletop plants that are not controlled foliarly by this herbicide. Tank mixes of Prowl H_2O with Clincher (315 g ai/ha), or with Regiment (37 g ai/ha) plus Whip (32 g ai/ha) or with Super Wham (4484 g ai/ha) plus Whip (32 g ai/ha) improved the grass control and yield (Table 9). Super Wham, Regiment and Clincher in these tank mixes provide control of established grasses while Prowl prevents establishment of germinating grasses. Prowl generally works better in dry/drill seeded and aerobic conditions than in water saturated soils where it gets rapidly broken down. Thus in water seeded rice, Prowl works better when fields are drained and re-flood is slow or delayed.

IR-5878 WG (orthosulfamuron, water-dispersible granule)

Orthosulfamuron is an ALS inhibitor for broad-spectrum activity on susceptible watergrass and smallflower umbrellasedge. It has shown very little phytotoxicity to rice at all stages of growth. It does not appear to be efficacious on redstem. Testing has been done with a WG formulation for pinpoint applications and a GR for into the water treatments in continuously flooded rice culture.

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[1] Abbreviations: fb. = followed by; lsr = leaf stage of rice; Till = tillers.

Both formulations appear to very safe on rice. Londax-resistant smallflower umbrellasedge is usually resistant to this herbicide.

IR-5878 WG was tested in a standard pinpoint trial, and in another experiment as pinpoint application in a basin that had been previously treated with Cerano. The two pinpoint studies had IR-5878 applications at the 3-4 lsr timing (Tables 7 & 16). In the standard pinpoint study the best weed control and yields were achieved by tank mixes of IR5878 (74.5 g ai/ha) with Abolish (3363 g ai/ha) or with propanil (4484 g ai/ha), or the mixture of IR5878 (105 g ai/ha) with propanil (4484 g ai/ha). Additionally, a three way tank mix of IR5878 (74.5 g ai/ha) propanil (4484 g ai/ha) and Whip (31.5 g ai/ha) provided broad spectrum weed control and good yield; the low rate of Whip is intended for control of sprangletop, while maintaining safety to rice.

IR-5878 GR (granular formulation)

IR5878 GR was tested in a continuously flooded experiment (Table 4). Most herbicide combinations with IR5878 performed well with good weed control and yields. The best treatments were: Cerano (673 g ai/ha, DOS) fb. IR5878 GR (74.5 g ai/ha, 1-2 lsr) fb. Grandstand (158 g ai/ha, 1-3 Till); Cerano (673 g ai/ha, DOS) fb. IR5878 GR (74.5 g ai/ha, 1-2 lsr) fb. Propanil (6726 g ai/ha, 1-3 Till); tank mix of Bolero and IR5878 GR (4540 + 74.5 g ai/ha respectively, 1-2 lsr) fb. Propanil (6726 g ai/ha, 1-3 Till); and Cerano (673 g ai/ha, DOS) fb. IR5878 GR (74.5 g ai/ha, 3-4 lsr). This last treatment at the 3-4 lsr was the only one that provided substantial early bulrush control. This is likely an application timing issue. Bulrush was not reported at the earlier treatment timing of 1-2 leaf and was 2 leaf at the 3-4 leaf timing. Best control of bulrush by IR5878 GR appears to be when two to three leaves are present assuring most of the seed in the germination zone have germinated. This is substantiated by good control of bulrush between 1 and 3 leaves in the 2005 experiment. This suggests application timing being linked to bulrush growth stage if this is the dominant weed needing control.

Granite GR (penoxsulam, granular formulation) alone and in combinations

Granite GR is an ALS inhibiting post-flood, post-emergence herbicide for selective control of susceptible watergrass/barnyardgrass (not active on sprangletop), broadleaf and sedge weeds in California rice. The granular formulation, Granite GR, was first available commercially during the 2005 season. This product was applied into the water at 40 g ai/ha 7-14 days after seeding. It was tested alone and in combination with Bolero, Cerano, propanil, Clincher and Shark in a trial observing rice yield response to doubling herbicide rates (Table 2). Most treatments provided good to excellent weed control. Plants at the 3 leaf stage exhibited noticeable root stunting by Granite. This effect was short lived and the plants recovered. The best yielding Granite combination was Cerano (448 g ai/ha, 1-2 DAS) fb. Granite GR (40 g ai/ha, 2.5-3 lsr) fb. Clincher (315 g ai ha, 3-4 lsr) fb. Stam (6720 g ai/ha, 1-3 Till). Other good treatments were: Granite (40 g ai/ha, 7-14 DAS) fb. Shark (224 g ai/ha, 3-4 lsr) fb. Clincher (315 g ai/ha, 3-4 lsr) fb. Stam (6720 g ai/ha, 1-3 Till), Bolero (4480 g ai/ha, 7-12 DAS) fb. Granite GR (40 g ai/ha, 2 lsr) fb. Clincher (315 g ai/ha, 3-4 lsr) fb. Stam (6720 g ai/ha, 1-3 Till). In our regular continuously flooded trial the best Granite treatment combination was Shark applied same day as Granite GR (224 g ai/ha and 40 g ai/ha, respectively, 2-3 lsr). Other combinations with good weed control and yield are: Granite (40 g ai/ha, 2-3 lsr) fb. Stam (6726 g ai/ha, 1-3 Till) and Granite GR (40 g ai/ha, 2.5 lsr) fb. Clincher (315 g ai/ha, 1-3 Till).

Severe rice stunting occurs with early applications of Granite GR. This was evidenced by a treatment of Granite GR (40 g ai/ha, 1.5 lsr) fb. Clincher (315 g ai/ha, 1-3 Till). The weed control was excellent and the yield was lower but not significantly different from the top performers. Some stunting was observed when Granite followed Bolero, but in this experiment there were no significant adverse effects of doubling the Granite rate on rice yield.

Granite SC (penoxsulam) alone and in combinations

Granite SC is a fluid formulation of penoxsulam for foliar application. It was labeled for California in 2006, but was in limited supply. It was tested in a pinpoint flood system with flood water dropped for an application at the 3-4 lsr (Table 6). The highest yielding treatment in the trial with excellent weed control was Clincher (315 g ai/ha, 3-4 lsr) fb. a tank mix of Granite SC and Stam (35 g ai/ha and 6726 g ai/ha respectively, 30-35 DAS). Other combinations with good broad spectrum weed control and good yield were: a tank mix of Clincher and Granite SC (315 g ai/ha and 35 g ai/ha, 3-4 lsr) fb. Stam (6726 g ai/ha, 1-2 Till), Granite SC (35 g ai/ha, 3-4 lsr) fb. Stam (6726 g ai/ha, 1-2 Till), a tank mix of Clincher and Granite SC (315 g ai/ha and 35 g ai/ha respectively, 3-4 lsr), and a tank mix of Granite SC and Stam (35 g ai/ha and 6726 g ai/ha respectively, 3-4 lsr). Sprangletop control failed in absence of Clincher.

OBJECTIVE 2. *To continue searching and testing new compounds with potential for addressing critical weed control issues to establish their suitability and proper fit into the rice management systems of California. Encourage introduction of promising new chemicals to the California market.*

In recognizing the need for developing herbicides to meet the cultural needs of growers throughout the state, our herbicide testing system was designed around the various types of irrigation schemes that growers use. These include: Continuous flood, pin-point flood and dry/drill seeding with establishment flush irrigation.

Continuous flood system combinations

Continuous flood trials were conducted at the Hamilton road site at the RES and at one resistant site on cooperator grower’s land. Best yields in this system were obtained with herbicide programs providing at least 90% of broad-spectrum weed control during the first month after seeding rice (Figure 1). Sedges are relevant to yields, and poor sedge control impacted yields, as did weed control initiated by late post-emergence applications (1-3 Tiller stage of rice).

The Hamilton Road site has herbicide-susceptible weed species while the off station site has resistant late watergrass (“mimic”). In most cases, the applications were sequential comprising an initial application of Cerano, Granite GR, or Bolero/Abolish for watergrass control followed by an application of Shark, Londax, Super Wham, or Regiment at various timings (Table 1) to control broadleaves, sedges, and in some cases late-emerging watergrass plants or those missed by the early treatment. Granite GR is a newly available granular herbicide that was tested alongside other standard herbicides used by growers. At the RES, rice yields for most of the treatments were not statistically different. Statistically lowest yields were stand alone reference treatments to demonstrate the value of sequential applications and not expected to control all weed species.

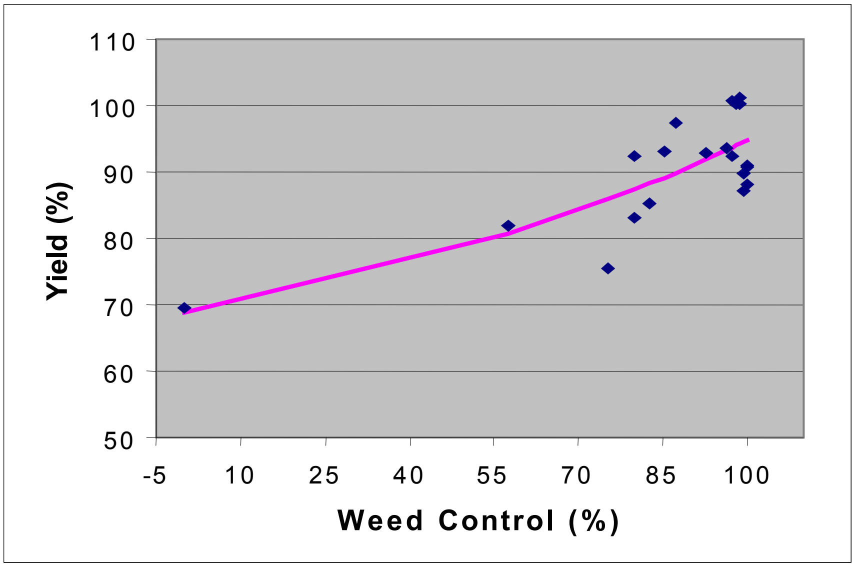

Figure 1. Rice yields (percent of the maximum yield) as affected by weed control efficacy expressed as percent of untreated plots (= 0% weed control) in water-seeded and continuously flooded rice. Weed control was evaluated one month after seeding rice.

The best treatments for weed control and yield are: Shark (224 g ai/ha, 2-3 lsr) fb. Super Wham (6726 g ai/ha, 1-3 Till); Abolish (4480 g ai/ha, as a pre-flood application on soil surface, PFS) fb. Super Wham (6726 g ai/ha, 1-3 Till); Granite GR (40 g ai/ha, 2-3 lsr) fb. Stam (6726 g ai/ha, 1-3 Till); Shark (224 g ai/ha) and Granite GR (40 g ai/ha) applied at 2-3 lsr; Bolero (4480 g ai/ha, 1-2 lsr) fb. Super Wham (6726 g ai/ha, 1-3 Till); Granite (40 g ai/ha, 2-3 lsr) fb. Clincher (315 g ai/ha, 1-3 Till); and Shark (224 g ai/ha, 2-3 lsr) followed by Clincher (315 g ai/ha, 1-3 Till). Good weed control and yield, but some stunting was observed when a PFS application of Abolish (4480 g ai/ha) was followed by 40 g ai/ha of Granite GR (2-3 lsr).

Cerano is a typical herbicide for this system providing broad-spectrum grass control applied from the day of rice seeding (DOS) up to the 1.5 lsr (or with watergrass not exceeding the 1.5 leaf stage). Excellent broad-spectrum weed control was obtained with Cerano (673 g ai/ha, DOS) followed by a foliar application of 6720 g ai/ha propanil at the 1-3 Till. If Cerano was instead followed by Regiment (37 g ai/ha; 1-3 Till), lower ricefield bulrush control and slight rice injury was observed, although yields were still acceptable. When Cerano was followed by 40 g ai/ha Granite GR, ricefield bulrush control was good, but herbicide symptoms on rice were more noticeable (Table 1).

The " mimic" site in Glenn County. At this resistant late watergrass site, three main treatment basins were set up. Each had one baseline into-the-water application of Cerano, Granite GR or Weco 632 SC (a new experimental chemical). All follow-up treatments were foliar sprays at the 4-5 lsr with water lowered (not drained) for weed foliage exposure (table 17). One of the best treatments was Weco 632 SC (800 g ai/ha, DOS) fb. Super Wham (6726 g ai/ha, 4-5 lsr). The Weco 632 SC provided near complete control of broadleaf and sedge weeds early on and weakened the watergrass.

The Super Wham controlled the recovering watergrass. Other good treatments were the base application of Cerano (673 g ai/ha, DOS) fb. Granite SC (40 g ai/ha, 4-5 lsr), Shark (112 g ai/ha, 4-5 lsr), Super Wham (6726 g ai/ha, 4-5 lsr) or Regiment (37 g ai/ha, 4-5 lsr). The Granite GR basin had less control of the resistant watergrass and, therefore, lower yields. Best results were obtained with Granite GR (40 g ai/ha, 2-3 lsr) fb. Super Wham (6720 g ai/ha, 4-5 lsr).

Cerano caused on average about 5% stand reduction. About 10% stand reduction was observed in the Weco 632 fb. Super Wham sequence. Rice appeared to recover in all cases.

Pin-point flood system combinations

Pin-point flood trials were conducted at the susceptible watergrass site at the RES and at the resistant watergrass site in Glenn County. Both trials were drained eight days prior to initial application and then re-flooded two days after application. Follow up applications of foliar herbicides requires lowering of water to achieve 70% weed exposure for effective coverage of weed foliage.

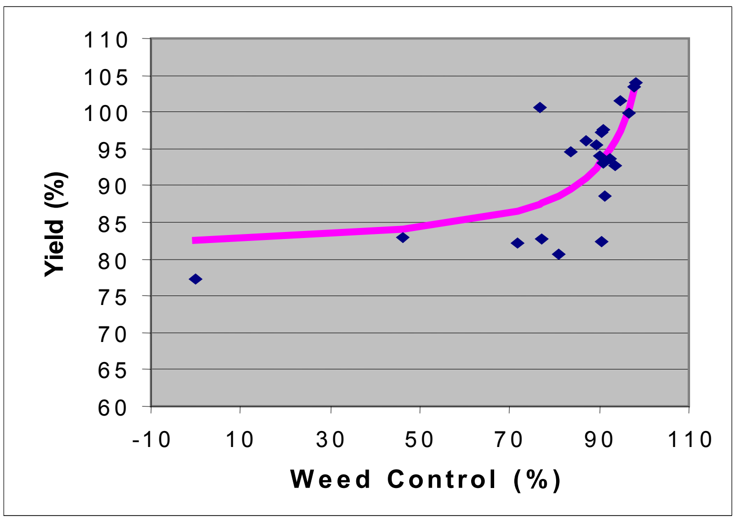

Figure 2. Rice yields (percent of the maximum yield) as affected by weed control efficacy expressed as percent of untreated plots (= 0% weed control) in water-seeded rice, where fields are temporarily drained to allow for weed foliage exposure to early foliar application of herbicides. Experiment seeded on June 1; weed control was evaluated on Aug 2.

Main weeds at the Hamilton road site and the resistant site were late watergrass, ricefield bulrush, smallflower umbrellasedge, sprangletop, and ducksalad. Weed interference is often tougher in a system where water is drained for even a brief period (note the steeper slope of the curve in Figure 2 compared to that in Figure 1), which encourages germination and growth of certain species. Thus smallflower umbrellasedge and sprangletop can pose additional problems in this system as compared to continuously flooded rice. Poor control of these weeds resulted in lower yields. Only broad-spectrum weed control approaching 95% ensured yields close to the maximum possible. Many of the treatments tested at the susceptible RES site had similar yields (Table 6). The following treatment combinations gave good weed control and yield: Clincher (315 g ai/ha, 3-4 lsr) fb. a tank mix of Stam and Granite SC (4484 and 35 g ai/ha respectively, 30-35 DAS); a tank mix of Clincher and Granite SC (315 and 35 g ai/ha respectively, 3-4 lsr) fb. Stam (6726 g ai/ha, 30-35 DAS); Granite SC (35 g ai/ha, 3-4 lsr) fb. Stam (6726 g ai/ha, 1-2 Till); Clincher (315 g ai/ha, 3-4 lsr) fb. Stam (6726 g ai/ha, 1-2 Till); a tank mix of Super Wham and Whip (6726 and 32 g ai/ha, 3-4 lsr); Super Wham tank mixed with Abolish (4480 + 4480 g ai/ha, 3-4 lsr). Clincher (315 g ai/ha, 3-4 lsr) fb. Regiment (37 g ai/ha, 1-2 Till) had good broad spectrum weed control except for being weak on smallflower umbrellasedge. Regiment (30 g ai/ha, 3-4 lsr) provided good watergrass control but was weak on smallflower umbrellasedge and missed sprangletop. Regiment (30 g ai/ha, 3-4 lsr) fb. Super Wham (6726 g ai/ha, 1-2 Till) provided good broad spectrum control except sprangletop. A tank mix of Regiment and Whip (30 + 32 g ai/ha, 3-4 lsr) gave excellent watergrass control and also sprangletop control but still missed smallflower umbrellasedge. Regiment (30 g ai/ha) tank mixed with MCPA (560 g ai/ha) controlled smallflower umbrellasedge but missed sprangletop. The tank mix of Regiment and Abolish (30 + 3360 g ai/ha respectively, 3-4 lsr) provided broad spectrum control but was not very effective on smallflower umbrellasedge or sprangletop. Granite, propanil (super Wham, Wham or stam) and Regiment do not control sprangletop, and unless Whip, Clincher or Abolish are part of the program, control of this weed will be poor.

The best broad-spectrum control and yields were obtained at the resistant site with the following combinations: Super Wham (6726 g ai/ha, 3-4 lsr) fb. Clincher (315 g ai/ha, 1 Till); Clincher (315 g ai/ha, 3-4 lsr) fb. Super Wham (6726 g ai/ha, 1 Till); Granite SC (35 g ai/ha, 3-4 lsr) fb. Stam (6726 g ai/ha, 1 Till); Regiment (44.5 g ai/ha, 3-4 lsr) fb. Super Wham (6726 g ai/ha, 1 Till); Super Wham (6726 g ai/ha, 1 Till); a tank mix of Regiment and Abolish (37 and 3360 g ai/ha, 3-4 lsr) fb. Super Wham (6726 g ai/ha, 1 Till), but the Super Wham treatment was likely skipped due to no control of bulrush. Control of resistant late watergrass in these programs was largely due to the presence of propanil (Super Wham, Wham or Stam) in the combination.

Drill seeded system

Rice seed was drilled into dry ground, then flush-irrigated for establishment. Additional flush irrigations were applied to insure good establishment. Standing water inhibits establishment of the rice that is drilled into the soil. The main weeds in this system were watergrass, ricefield bulrush, smallflower umbrellasedge and sprangletop. Our herbicide programs were successful in providing substantial control (80% or more) of sedges and broadleaf weeds, such that those remaining uncontrolled did not have consistent impact on yields (bunch of data points at the top right corner of Figure 3a. However, yields in this system were strongly driven by the efficacy of grass control, and top yields were attainable once about 95% control of grasses had been obtained (Figure 3b).

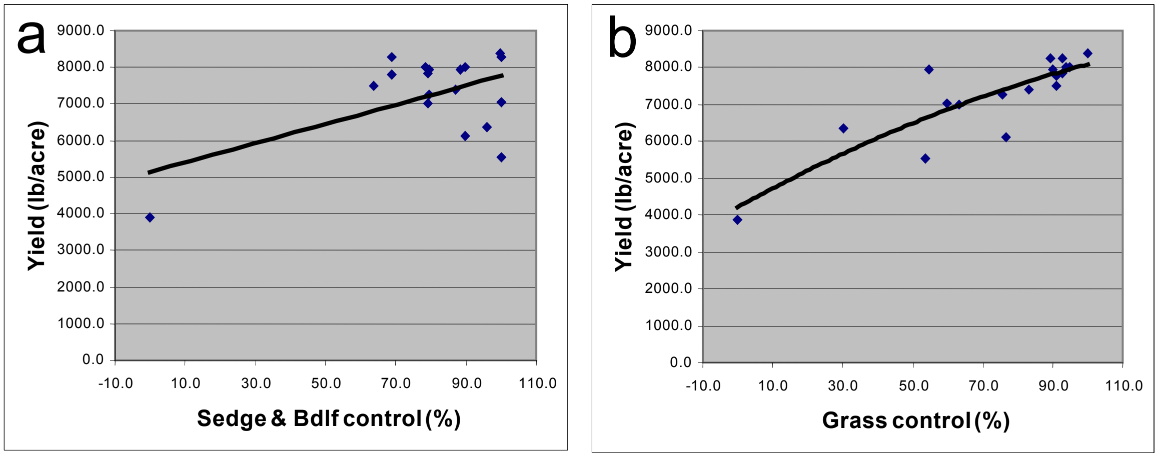

Figure 3. Rice yields (percent of the maximum yield) as affected by weed control efficacy expressed as percent of untreated plots (= 0% weed control) in drill-seeded rice; a) relationships between yields and sedge & broadleaf control under variable grass infestations; b) relationship between yields and grass weed control under variable sedge & broadleaf infestations. Experiment seeded on June 1; weed control was evaluated on Aug 2.

Herbicide timing included delayed pre-emergent (DPRE) after the first flush of irrigation, early post emergent (EPE) with rice at the 2-3 lsr, and post permanent flood (PPF) with rice at the 1-2 tiller stage. The best yielding treatment and best broad-spectrum weed control was achieved by a foliar application of Shark (168 g ai/ha, 3-4 lsr) fb. Clincher (315 g ai/ha, PPF). The early application of Shark was key to provide good control of smallflower umbrellasedge; a similar treatment (Clincher fb. Super Wham) failed to suppress this weed early in the season and yielded 1000lb/A less. Other good treatments were: Granite SC (35 g ai/ha, 2 lsr) fb. Clincher (315 g ai/ha, PPF); Abolish (4480 g ai/ha, DPRE) fb. Super Wham (6726 g ai/ha, 2-3 lsr); a tank mix of Prowl H_2O, Super Wham and Whip (1120, 4484 and 32 g ai/ha respectively, 2-3 lsr); Abolish (4480 g ai/ha, DPRE) fb. a tank mix of Regiment and Abolish (30 and 3360 g ai/ha respectively, 2-3 lsr); Prowl H_2O plus Regiment plus Whip (1120 + 37 + 32 g ai/ha, 2-3 lsr); Prowl H_2O plus Clincher (1120 + 315 g ai/ha respectively, 2-3 lsr); Prowl H_2O (1120 g ai/ha, DPRE) fb. Super Wham (6726 g ai/ha, PPF); Abolish (4480 g ai/ha, DPRE) fb. Regiment (12.5 g ai/ha, 2-3 lsr); Regiment plus Abolish (25 + 3360 g ai/ha respectively, 2-3 lsr) fb. Clincher (315 g ai/ha, PPF). Herbicides ensuring good control of all three sprangletop, smallflower umbrellasedge and *Echinochloa* are essential for this system.

OBJECTIVE 3. *To develop new alternatives to weed control through the exploration of agronomic and ecophysiological opportunities to minimize herbicide costs and environmental impacts. To measure rice yield impact of specific weed species and develop a predictive approach.*

Herbicide Resistance Weed Management Systems in Rice using Alternative Stand Establishment Techniques. The following alternative rice establishment systems have been developed and evaluated since 2004: 1) conventional water-seed rice, 2) conventional drill-seeded rice, 3) water-seeded rice after spring tillage and a stale seedbed, 4) water-seeded rice after a stale seedbed without spring tillage, and 5) drill-seeded rice after a stale seedbed without spring tillage. These systems have demonstrated their potential for manipulating the kinds of weed species that emerge with rice. Thus problematic weeds can be avoided or, alternatively, controlled by new herbicides for which they do not have resistance. Pendimethalin and glyphosate are not used in water-seeded rice, but can control weed biotypes resistant to herbicides used in conventional water-seeded rice. Again, as in 2004 and 2005, there were drastic differences in weed recruitment among systems, thus aquatic sedge and broadleaf weeds dominated the water-seeded systems, while the aerobic seedbeds of the drill-seeded systems favored grasses (*Echinochloa* spp. and sprangletop). In the two previous years, the stale seedbed technique (promotion of weed emergence with irrigation flushes, fb. pre-plant burn-down application of glyphosate at 1.2 lbs. a.e./a) had been extremely useful in depleting weed populations from the upper soil layer and, thus, markedly diminishing the amounts of weeds emerging with the crop. If this technique was fb. no or limited soil disturbance prior to seeding rice, very little weed control was needed thereafter. However, success with this technique depends on keeping seedbeds moist and allowing sufficient time for most weeds to emerge prior to glyphosate application. This year, however, there was not sufficient time and seedbed moisture for substantial weed emergence. Consequently, few weeds were present when the burn-down control was applied. The stale-seedbed technique reduced total weed infestation by 24% in the water-seeded systems compared to the conventional treatment. The concept of limiting soil disturbance to prevent weed recruitment contributed an additional 27% to weed reduction. Thus, the lowest weed infestation occurred where rice was water-seeded after a stale seedbed without spring tillage. Conventional drill-seeded systems typically result in heavy weed recruitment, and although using stale-seedbed and minimum soil disturbance reduced weed recruitment by 60%, there were still many weeds present in System 5:

Weed recruitment under different stand establishment systems (plants per square foot)

System	*Echinochloa*	Sptp.[1]	Bulrush	Smallflower	Ducksalad	Redstem
1. Water seed conventional	1 (2)[2]	0 (0)	19 (12)	26 (18)	6 (4)	12 (8)
2. Drill seeded, no till, stale	31 (16)	19 (8)	0 (0)	0 (0)	0 (0)	0 (0)
3. Water seeded, no till, stale	0 (0)	0 (0)	2 (1)	5 (2)	19 (11)	5 (3)
4. Water seeded, spring till, stale	0 (0)	0 (0)	1 (1)	32 (15)	7 (2)	8 (5)
5. Drill seeded conventional	97 (44)	27 (16)	0 (0)	2 (3)	0 (0)	0 (0)

[1] Sptp., bearded sprangletop; bulrush, ricefield bulrush; smallflower, smallflower umbrellasedge.
[2] Values in parentheses are standard errors of the mean.

Subsequently, the drill-seeded systems were treated with Clincher (13 oz/a) + propanil (4 lb a.i./a) + Prowl H_2O (2 pt/a) applied at the 3 lsr, and the water-seeded systems received propanil (6 qt/a) + Granite SC (2 oz/a) at the 4 lsr. The conventional water-seeded system required an additional 4 lb a.i. propanil/a. Weeds were thus controlled from all plots. Rice yields in previous years did not differ among these establishment systems. Therefore, the alternative rice establishment systems evaluated in this study may be used to effectively manipulate weed species recruitment and enable the use of herbicides that may control weed biotypes resistant to herbicides used in conventional water-seeded systems. Success in weed suppression is maximized if sufficient weed emergence is promoted prior to burn-down in the stale seedbed technique and with no spring tillage. Modeling of weed recruitment and growth is being evaluated to identify rotation options that may reduce the seed-banks of problematic weed species. Results from this research will be used to develop innovative integrated weed management programs for California rice by breaking weed life cycles through rotation of stand establishment methods, alternating herbicide modes of action, as well as effective crop interference.

Relating rice traits to competitiveness with watergrass and yield: a Path and QTL analysis. *Echinochloa phyllopogon* (STAPF) KOSS. Resistance to herbicides in the most important weeds threatens the sustainability of California rice. Weed-competitive rice cultivars could be a low-cost and safe non-chemical addition to an integrated weed management program. Tradeoffs between competitiveness and productivity and inconsistent trait expression under weedy and weed-free conditions could complicate the breeding of competitive rice cultivars. A two-year competition experiment was conducted in the greenhouse involving eight rice cultivars and two weed competition regimes (presence or absence of late watergrass) to examine the effects of rice weed-suppressive ability and tolerance to weed competition (weed tolerance) on rice yield. Competition reduced average rice yield from 32% to 48%, and watergrass biomass from 44% to 77%. Path analysis suggested that enhancing rice weed-suppressive ability and weed tolerance while minimizing possible productivity tradeoffs should promote early (12 d after seeding) growth and light-capture traits followed by moderate growth rates before heading and a vigorous grain filling period. Crop growth rate (CGR) after heading was a relevant determinant of yield (direct path: 0.82, $P < 0.01$) and correlated ($r = 0.30$, $P < 0.01$) with weed tolerance. Late biomass accumulation was negatively correlated with harvest index and CGR during ripening ($r = -0.46$, $P < 0.01$); thus, late-season competitiveness can lower productivity. Rice traits conferring competitiveness were correlated across weed competition regimes ($r = 0.36$ to 0.81, $P < 0.01$). However, significant cultivar by competition and cultivar by year interactions suggest that selection efficiency would be greater when traits are identified under competition and in different environments. This study relates to the phenotypic expression of traits for competitiveness. Breeding competitive cultivars will require additional knowledge on trait heritability, genetic correlations with competitiveness, and on the effects of the environment upon gene expression. Although competition studies should involve the entire life span of species, it is known that weed competition with rice is critical during early stages of crop growth. Following these findings, and given that watergrass competition with rice is critical during early stages of crop growth, a second study focused on the identification and interrelationships among traits for early vigor. A greenhouse experiment with watergrass and 21 rice genotypes grown in monoculture was conducted in 2000 and 2001. the experiment involved three destructive harvests for growth analysis at 12 DAS (4-5 leaf stage), 24 DAS (early tillering) and 36 DAS (mid to late tillering). The growth characteristics of watergrass and rice seedlings differed. At establishment, rice seedlings had greater values for most growth traits. However, watergrass had superior growth rates, and gradually became taller than the semidwarf genotypes used in these studies. Therefore, rice that emerges simultaneously with watergrass would not be able to overtop and shade this weed, making watergrass suppression through rice competition difficult unless watergrass emergence can be delayed and rice seedling vigor (early biomass accumulation) is enhanced. Clustering analysis found that seedling leaf area was a good discriminator between cultivar clusters differing in early vigor. Seedling height was not associated with the clustering of genotypes into high vigor groups. Early tillering was associated with fast growing genotypes, and was correlated with root biomass, total biomass and leaf area. These results suggest that rice early vigor, as a component of overall competitiveness, can be enhanced through selection for leafier, rapidly elongating, and highly tillered plants. A third study attempted the identification of quantitative-trait loci (QTL) associated with rice traits for early vigor and competitiveness against watergrass as identified in the two previous studies. A population of 137 F2 recombinant inbred lines derived from a cross between M-202 and IR50 were grown in the field in monoculture during 2003 and 2004. Phenotyping for seedling and vegetative vigor traits was performed at 20, 30 and 60 days after seeding (DAS). A genetic linkage map was generated using available molecular data for this population that had been obtained using 180 microsatellite markers showing polymorphism for the progenitors, Path analysis was used to clarify the relationships among diverse variables, including molecular markers, in hypothetical cause-effect models. We located about 40 putative genetic loci associated with rice traits related to plant vigor and competitiveness. Results from this research would be useful for using marker-aided selection to facilitate the identification of genotypes with superior vigor and competitiveness, and for combining these characteristics into a highly productive ideotype.

Red or Weedy Rice. Foci of red or weedy rice infestation had been detected in 2005. This season new detections were reported. In collaboration with the Rice Experiment Station and UC Cooperative Extension Farm Advisor Christopher Greer we proceeded to collect accessions from the few sites were these infestation had been reported. Seed was collected from individual plants from each population and tissue samples are being subjected to molecular analysis. A first selfed generation from each plant has been also obtained for further work. Plants will be grown next season for morphological and further molecular characterization. We aim at elucidating the distribution and diversity of these occurrences. Genetic studies will also reveal the extent of outcrossing into commercial rice that may have already occurred. This information will guide help industry design containment strategies. We are advising farmers on red rice identification and control.

OBJECTIVE 4. *To develop an understanding of herbicide resistance in weeds, provide diagnosis, test herbicides, and develop effective alternatives to manage this problem.*

Diagnostic and detection of herbicide resistance. We continue to screen potentially resistant grass samples (late watergrass, early watergrass and barnyardgrass) submitted by growers and PCAs against known susceptible and resistant lines. Testing this past season included Cerano, Regiment, Clincher, Bolero, Ordram, Granite and propanil applied at the standard field rate and ½ the standard rate. We implemented a new reporting method that we believe will help growers interpret their results. This includes a picture showing the individual treatment effects on their sample compared with the known susceptible and resistant lines. The percent control (i.e. control referred as percent of the mean of untreated plants for the same biotype) and standard error was labeled below each treatment. Response from growers was positive in that they liked seeing the effect on the grass along with the level of control. Various resistance patterns were observed in all submitted samples, which included barnyardgrass, early, and late watergrass accessions

Mechanisms and distribution of herbicide resistance in weeds of rice. We continued our work to characterize the dispersion of herbicide-resistant watergrass and to associate that dispersion to landscape, crop, and weed management variables. We use GPS, geostatistics and molecular markers for this work. Studies on gene flow, outcrossing, mechanisms of resistance and cross resistance in smallflower umbrellasedge, have been completed and are being analyzed. Studies on mechanisms of late watergrass (LWG) resistance to penoxsulam and clomazone are in progress. Dose-response experiments with thiobencarb and the cytochrome P4540 inhibitor ABT demonstrated that this herbicide may be the driver of resistance evolution in this species by selection for LWG biotypes capable to detoxify multiple herbicides. Work with penoxsulam and clomazone aim at corroborating this hypothesis. Penoxsulam is a new acetolactate synthase (ALS) inhibitor herbicide for use in rice. An LWG population presumed resistant (R) to penoxsulam was collected in CA rice fields. Whole-plant bioassays investigated LWG response to penoxsulam and the possible involvement of cyt P450 monooxygenases in LWG resistance to penoxsulam using the cyt P450 inhibitor malathion (previous studies had already shown cyt P450-mediated resistance to thiobencarb, bispyribac-sodium and bensulfuron-methyl in this population). The ratio (R/S) of the GR50 values of the resistant to susceptible plants was 9.8 for penoxsulam. Results suggest cyt P450 involvement in LWG resistance to penoxsulam. ALS activity assays demonstrated that resistance in R-LWG is not due to reduced ALS sensitivity. Low level of resistance to clomazone was found in dose response studies with three late watergrass biotypes collected in rice fields of the Sacramento Valley (Figure 4). This level of resistance corresponds to escapes seen in the field under conventional treatment in farms heavily infested with a resistant biotype of this weed. The dose-response studies were conducted under flooded conditions, with a four inch flood, and the weed at the one-leaf stage of growth. Fresh weight was harvested 20 days after treatment. Growth reduction (50%) values were significantly lower for the susceptible biotype compared to the resistant biotypes. Application of clomazone in combination with organophosphate insecticides (that are cytochrome P450 inhibitors) had protective and synergistic effects on LWG. Effects differed between R and S biotypes suggesting that an oxidative step is required for activation and toxicity of this herbicide, and that an enhanced metabolic ability may endow higher clomazone tolerance in the R biotype. Studies are under way to clarify the mechanism of resistance. Studies are under way to clarify the metabolic routes of herbicide degradation associated with resistance to these herbicides in LWG.

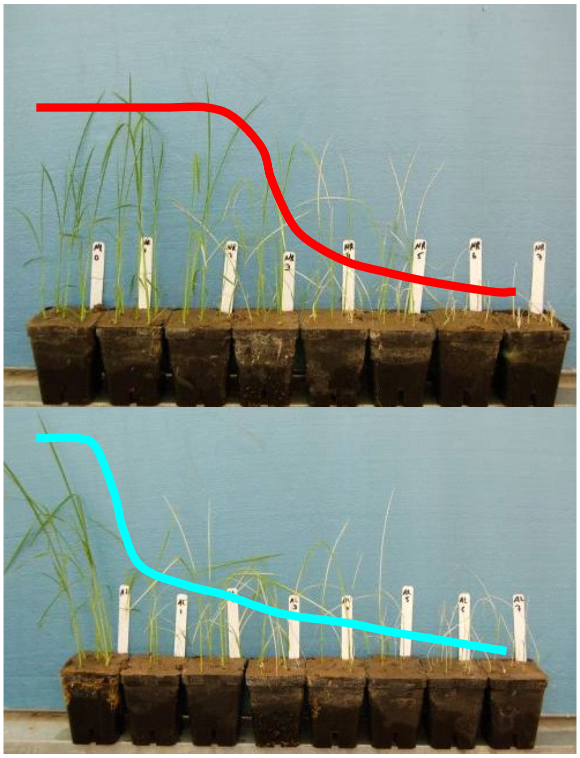

Figure 4. Response of herbicide-resistant (top) and -susceptible (bottom) late watergrass to increasing rates (from left to right) of Cerano.

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CONCISE GENERAL SUMMARY OF RELEVANT RESULTS OF THIS YEAR'S RESEARCH:

Our field program includes the testing of current and new herbicides, their mixtures and sequential combinations for the rice growing systems that currently prevail in California. We also have a strong emphasis towards the diversification and sustainability of weed management in rice, thus we continued work on a long-term field experiment with new alternative rice stand establishment systems in order to develop novel but feasible solutions for controlling herbicide-resistant weeds. Experiments were conducted on the Rice Experiment Station's (RES) and at a cooperating grower's field heavily infested with herbicide-resistant watergrass (" mimic").

Continuous flooded rice. Sprangletop and smallflower umbrellasedge are generally not a problem when a continuous flood is maintained. The combination of Cerano fb. propanil, Granite GR, or Regiment provided excellent broad-spectrum control at our susceptible[2] site. Combinations of Granite GR fb. either propanil or Clincher also provided broad-spectrum control at the susceptible site. Granite and Regiment should not be combined, since both have the same mode of action (ALS inhibitors) and this would encourage the evolution of resistance. Other excellent broad-spectrum combinations were: Bolero fb. propanil or Abolish (PFS[3]) fb. either propanil or Granite GR. Shark applied into-the-water at the same time as Granite GR or fb. propanil also provided excellent broad-spectrum control. Cerano causes mild to severe bleaching of rice but the crop usually grows out of it. Regiment and Granite GR may cause stunting and darkening of rice; some root growth stunting may also occur temporarily after application. The crop seems to recover from these effects, but Granite should not be applied earlier than at the 2 leaf stage.

Pinpoint flood management. Rice was water seeded and the water drained to expose weeds for early foliar herbicide treatments; our fields were then re-flooded. The drainage period generally allows weeds like sprangletop, barnyardgrass, and smallflower umbrellasedge to germinate in the

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[2] Susceptible refers to the absence of resistant weeds.
[3] PFS, pre-flood application onto the soil surface.

aerobic environment. Residual herbicides can be especially helpful when drain time is prolonged due to time needed to re-flood large fields. The best broad-spectrum treatments were: Granite SC fb. propanil; Clincher fb. propanil; a tank mix of Clincher and Granite SC fb. propanil ; Clincher fb. a tank mix of propanil and Granite SC; propanil tank mixed with Abolish, although slight injury to rice was noted initially. The Regiment + Abolish tank mixture applied at the 3-4 lsr continues to produce excellent watergrass control due to the synergistic nature of this mixture. This treatment also controlled sprangletop. Regiment alone provides excellent control of watergrass at this location. Six oz/a Whip tank mixed with 6qt propanil at the 3-4 lsr provided good weed control including sprangletop.

Drill-seeded rice. Rice M206 was drill seeded and flushed with water three times for establishment, then a final permanent flood (3-4 inches) was applied when rice was at the 5 leaf stage. The main weeds in this system were watergrass and sprangletop. The best treatment was foliar applied Shark fb. Clincher (PPF[4]), which provided the best broad-spectrum control. Abolish (DPRE[5]) fb. a tank mix of Regiment and Abolish provided 94% control of watergrass and 96% control of sprangletop. Abolish (DPRE) fb. Super Wham was also an excellent treatment, although watergrass control was weaker. Clincher fb. Super Wham controlled watergrass by 93% and sprangletop by 80%. Granite SC fb. Clincher was also an outstanding broad-spectrum treatment. Prowl H_2O alone applied as a delayed pre-emergent (DPRE) controlled 58% of the watergrass and 98% of the sprangletop initially, however, this control diminished over time. Control was improved when Prowl was fb. foliar-active herbicides like propanil or Regiment.

New herbicides. Granite SC worked very well as a foliar formulation of the same active ingredient used in Granite GR (penoxsulam). IR5878 GR and IR5878 WG are ALS inhibitors for broad-spectrum control, including activity on *Echinochloa* spp., with some residual effect. Control of Londax-resistant smallflower umbrellasedge was poor and required the mixture with Super Wham or Abolish. Other new experimental compounds have also been tested this season. To avoid resistance, ALS inhibitors should not be used together in a program.

Herbicide resistance herbicide programs: Experiments were conducted at a site heavily infested with herbicide-resistant late watergrass (“mimic”), which in addition to the usual resistance pattern to most grass herbicides, also escapes control by Cerano and Granite. In continuous flood, Cerano fb. propanil was the best broad-spectrum treatment. Granite GR fb. Regiment treatment is not recommended due to both being ALS inhibiting herbicides. In the pinpoint flood experiment Super Wham fb. Clincher was the best treatment for the second year controlling watergrass by 93% and sprangletop by 100%, but long-term control of bulrush was poor. It is likely that the bulrush continued to germinate after the propanil application. Regiment tank mixed with Abolish controlled watergrass by 88% and sprangletop by 89%. Regiment fb. Super Wham still provided 86% watergrass control two months after application, while Super Wham controlled “mimic” by 61% and suppressed most other weeds except sprangletop.

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[4] PPF, post permanent flood; postemergence application after permanent flood is established.

[5] DPRE, preemergence application after rice seeds have imbibed water 7days after initial irrigation flush; rice had not yet emerged and watergrass was at the 0.5 leaf stage).

Managing Herbicide Resistance using Alternative Rice Stand Establishment Techniques. The alternative rice establishment systems have been developed involving drill, water seeding, no-till options, and the use of the stale-seedbed technique (promotion of weed emergence with irrigation flushes, followed by pre-plant burn-down application of glyphosate). Again, as in 2004 and 2005, these systems demonstrated their potential for drastically altering the kinds of weed species that emerge with rice by breaking weed cycles and introducing new herbicides for which they do not have resistance (pendimethalin and glyphosate). Thus, aquatic sedge and broadleaf weeds dominated the water-seeded systems, while the aerobic seedbeds of the drill-seeded systems favored grasses (*Echinochloa* spp. and sprangletop). The stale seedbed technique has been extremely useful in depleting weed populations from the upper soil layer and, thus, markedly diminishing the amounts of weeds emerging with the crop. If this technique was followed by no or limited soil disturbance prior to seeding rice, very little weed control was needed thereafter. Success depends on keeping seedbeds moist and allowing sufficient time for most weeds to emerge prior to glyphosate application. This year, however, there was not sufficient time and seedbed moisture for substantial weed emergence. Consequently, few weeds were present when the burn-down control was applied. The stale-seedbed technique reduced total weed infestation by 24% in the water-seeded systems compared to the conventional treatment. Limiting soil disturbance to prevent weed recruitment contributed an additional 27% to weed reduction. Thus, the lowest weed infestation occurred where rice was water-seeded after a stale seedbed without spring tillage. Conventional drill-seeded rice is typically very weedy, and although using stale-seedbed and minimum soil disturbance reduced weed recruitment by 60%, there were still many weeds present. Subsequently, the drill-seeded systems were treated with herbicides at the 3 lsr, and the water-seeded systems at the 4 lsr. The conventional water-seeded system required an additional 4 lb a.i. propanil/a for complete weed control. Rice yields in previous years did not differ among these establishment systems. Therefore, the alternative rice establishment systems evaluated in this study may be used to effectively manipulate weed species recruitment and enable the use of herbicides that may control weed biotypes resistant to herbicides used in conventional water-seeded systems.

Other ongoing studies include assessing the distribution and identity of red rice detections, and the elucidation of mechanisms of resistance to Granite and Cerano. We continue to work with growers, the Rice Experiment Station, UC Cooperative Extension, and industry to bring options for sustainable weed management to California growers.