ANNUAL REPORT
COMPREHENSIVE RICE RESEARCH
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PROJECT TITLE: Weed Control in Rice

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OBJECTIVES OF PROPOSED RESEARCH:

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.

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 Rice Experiment Station (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 3, while planting at the Station occurred May 18 and May 23. Yield data is being presented this season for comparison between treatments. Very little lodging was experienced last season and again this season partially due to using M-205 and M-206 at the station trials. This made grain harvest of small plots more reliable. Fertility management was adjusted to additionally reduce the potential for lodging and poor harvest conditions with the plot combine.

Continuously flooded experiments have water applied and not drained throughout the duration of the season, while pinpoint experiments have flood water at time of seeding then water drained for foliar applications of herbicides at specific stages of rice growth. Dry seeded experiments were drilled into the soil followed by flushes of water to establish the rice then permanent flood was established. 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). FMC Corporation changed the consumer formulation of Shark from 1.2 to 0.6 mm granule. The new formulation is named Shark H_2O. 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 have 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) or Clincher (315 g ai/ha, 1-3 Till) provided very good weed control and high grain yield in the continuous flood trial at Hamilton road (Table 1). However, control of ricefield bulrush and smallflower umbrellasedge was better in mixture with propanil. Shark (224 g ai/ha, 2-3 lsr) applied same day as Granite GR (40 g ai/ha) provided excellent weed control and one of the highest yields in the trial (Table 1). Combining Granite with Shark is a good management practice to protect Granite from ALS-resistance evolution in weeds. 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 2 & 12).

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 8). Prowl H_2O applied alone (1120 g ai/ha) as delayed pre-emergent (DPRE) provided 80% watergrass/barnyardgrass control and 100% sprangletop control at 20 DAS but diminished to 58% watergrass/barnyardgrass control and 93% sprangletop control by 60 DAS. Improved control of watergrass/barnyardgrass was achieved by following the Prowl H2O treatment with Super Wham (6726 g ai/ha) at 2-3 lsr. Since it does not have post-emergence activity, Prowl (1120 g ai/ha) applied alone at the 2-3 lsr did not provide control of watergrass/barnyardgrass and poor control of 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 late season grass control and yield (Table 8). Super Wham, Regiment and Clincher in these tank mixes provide control of established grasses while Prowl prevents establishment of germinating grasses; Super Wham and Regiment do not control sprangletop. 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.

Strada WG (orthosulfamuron, water-dispersible granule)

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

Orthosulfamuron is an ALS inhibitor for broad-spectrum activity on susceptible watergrass and smallflower umbrellasedge, and other sedges and broadleaf weeds. It has shown very little phytotoxicity to rice at all stages of growth. Testing has been done with a WG formulation for pinpoint applications and a GR for into the water treatments in continuously flooded rice culture. Both formulations appear to very safe on rice. Londax-resistant smallflower umbrellasedge is usually resistant to this herbicide.

Strada 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 Strada WG applications at the 3-4 lsr timing (Tables 6 & 11). In the standard pinpoint study the best weed control and yields were achieved by tank mixes of Strada WG (74.5 g ai/ha) with propanil (4484 g ai/ha) or followed by propanil, or the mixture of Strada (74.5 g ai/ha) with Shark H2O (28 g ai/ha) fb. propanil (4484 g ai/ha), however, neither of these combinations controls sprangletop. Additionally, a three way tank mix of Strada WG (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. The Whip did not control sprangletop to a desired level, nor did a triple mixture of Strada plus Super Wham plus Whip applied at an earlier stage. This suggests possible antagonism to Whip by tank mixing with Strada.

Strada GR (granular formulation)

Strada GR was tested in a continuously flooded experiment (Table 3). Most herbicide combinations with Strada GR performed well with good weed control and yields. The best treatments were: Cerano (673 g ai/ha, DOS) fb. Strada GR (74.5 g ai/ha, 1-2 lsr) fb. Propanil (6726 g ai/ha, 1-3 Till); Cerano (448 g ai/ha, DOS) fb. Strada GR (74.5 g ai/ha, 1-2 lsr) fb. Propanil (6726 g ai/ha, 1-3 Till); same day applications of Bolero ultramax and Strada GR (4540 + 74.5 g ai/ha respectively, 1-2 lsr) fb. Propanil (6726 g ai/ha, 1-3 Till). All these combinations provided better bullrush control and better yield than Cerano (673 g ai/ha, DOS) fb. Propanil (6726 g ai/ha, 1-3 Till). Best control of bulrush by Strada GR appears to be when one 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 and 2006 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 4). Most treatments provided good to excellent weed control. Rice plants at the 3 leaf stage exhibited noticeable root stunting by Granite at suggested field rate. This effect was short lived and the plants recovered. The doubled rate of Granite caused greater stunting of rice while doubled rate of Cerano caused greater visible crop injury. The best yielding Granite combination was Bolero ultramax (4480 g ai/ha, 2 lsr) 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: Cerano (448 g ai/ha, 1-2 DAS) fb. Granite (40 g ai/ha, 7-14 DAS) fb. Clincher (315 g ai/ha, 3-4 lsr) plus Stam (6720 g ai/ha, 1-3 Till), Granite GR (80 g ai/ha, 2 lsr) fb. Clincher (315 g ai/ha, 3-4 lsr) fb. Stam (6720 g ai/ha, 1-3 Till), and 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), same as 2006. 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), Granite GR (40 g ai/ha, 2.5 lsr) fb. Clincher (315 g ai/ha, 1-3 Till) and Cerano (673 g ai/ha, DOS) fb. Granite GR (40 g ai/ha, 2.5 lsr). Severe rice stunting occurs with early applications of Granite GR.

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 and was in good supply in 2007. It was tested in a pinpoint flood system with flood water dropped for an application at the 3-4 lsr (Tables 5 and 7). High yielding treatments that included Granite SC were: Clincher tank mixed with Granite SC (280 g ai/ha and 35 g ai/ha respectively, 3-4 lsr) fb. Stam (6726 g ai/ha, 1-2 Till), a tank mix of Granite SC and Stam (35 g ai/ha and 6726 g ai/ha respectively, 3-4 lsr) fb. Clincher (315 g ai/ha, 1-2 Till.) (Table 5), and Granite SC (35 g ai/ha, 3-4 lsr) as the only herbicide (Tables 5 and 7). When Granite is applied alone at 35g/ha it performed equally well within the timing range of 2-4 leaf stage rice. Sprangletop control failed in the absence of Clincher.

Herbicide programs and combinations

The first month after seeding corresponds to the “critical” period of competition between weeds and rice. Best yields were obtained when herbicide programs provided at least 90% of broad-spectrum weed control during this period (Figure 1). In our experiments at RES watergrass and ricefield bulrush control was essential in water seeded rice. Sprangletop control was extremely important in drill seeded rice. The magnitude of the regression slopes in Figure 1 relates to the relative effects of weeds in each system. As observed in previous years, weed infestations in drill seeded rice tend to cause the more severe yield losses, followed by those in a pinpoint water seeded system (Figure 1b and c). The continuous flooded system is more suppressive of weed competition with rice (Figure 1a). The treatments tested this year have been mostly those that have provided consistently good results in previous years. Therefore, there are none or few points corresponding to intermediate and low levels of weed control in the plots of Figure 1.

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 continuously flooded rice, pinpoint flooded rice and drill-seeded rice.
Weed control was evaluated one month

a) <u>Continuous flood system combinations</u>

Continuous flood trials were conducted at the Hamilton road site at the RES and at one resistant site on a cooperator grower's land.

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 recently 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.

The best treatments for weed control and yield were: Bolero ultramax (4480 g ai/ha, 1-2 lsr) fb. Propanil (6726 g ai/ha, 1-3 Till); Shark (224 g ai/ha, 2-3 lsr) followed by Clincher (315 g ai/ha, 1-3 Till); Shark (224 g ai/ha, 2-3 lsr) fb. Super Wham (6726 g ai/ha, 1-3 Till); Shark (224 g ai/ha) and Granite GR (40 g ai/ha) applied at 2-3 lsr; Granite GR (40 g ai/ha, 2-3 lsr) fb. Clincher (315 g ai/ha, 1-3 Till); Cerano (673 g ai/ha, DOS) fb. Granite GR (40 g ai/ha, 2-3 lsr); Propanil (6726 g ai/ha, 1-3 Till); Granite GR (40 g ai/ha, 2-3 lsr) fb. Propanil (6726 g ai/ha, 1-3 Till); Abolish (4480 g ai/ha, as a pre-flood application on soil surface, PFS) fb. Propanil (6726 g ai/ha, 1-3 Till).

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 Granite GR (40 g ai/ha, 2-3 lsr). While this treatment had injury from the Cerano and stunting from the Granite it still was one of the better treatments for yield. If Cerano was instead followed by Propanil (6726 g ai/ha, 1-3 Till) or Regiment (37 g ai/ha; 1-3 Till), lower ricefield bulrush and smallflower control was observed, and slightly lower yields
(Table 1).

The " mimic" site in Glenn County. At this resistant late watergrass site, two main treatment basins were set up. Each had one baseline into-the-water application of Cerano or Granite GR. All follow-up treatments were foliar sprays at the 4-5 lsr with water lowered (not drained) for weed foliage exposure (Table 15). The best weed control and yield were achieved with the sequence of Cerano (673 g ai/ha, DOS) fb. propanil (6726 g ai/ha, 4-5 lsr). 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) or Regiment (44.5 g ai/ha, 4-5 lsr). Best results in the Granite basin were obtained with Granite GR (40 g ai/ha, 2-3 lsr) fb. Super Wham (6720 g ai/ha, 4-5 lsr). Granite GR (40 g ai/ha, 2-3 lsr) fb. Regiment (44.5 g ai/ha, 4-5 lsr) provided good weed suppression, however, we strongly discourage this treatment because it is the use of two herbicides with the same mode of action (ALS inhibitor), which will seriously accelerate resistance problems in a broad-spectrum of weeds.

Cerano caused, on average, about 5% stand reduction and bleaching while Granite GR causes stunting of rice. Rice appeared to recover in all cases and produces good yields.

b) 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.

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 1b compared to that in Figure 1a), 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 90-95% ensured yields close to the maximum possible. Most of the treatments tested at the susceptible RES site had statistically similar yields (Table 5). The following treatment combinations gave good weed control and yield: Regiment (30 g ai/ha, 3-4 lsr) provided good watergrass control but was weak on smallflower umbrellasedge and missed sprangletop; Clincher tank mixed with Granite SC (280 g ai/ha plus 35 g ai/ha respectively, 3-4 lsr) fb. Propanil (6726 g ai/ha, 1-2 Till) did not control sprangletop possibly due to later emergence of this weed; Granite SC tank mixed with Propanil (35 g ai/ha plus 6726 g ai/ha respectively, 3-4 lsr) fb. Clincher (315 g ai/ha, 1-2 Till) controlled sprangletop in this case likely due to later timing of Clincher; Propanil plus Abolish (4484 g ai/ha plus 4484 g ai/ha respectively, 3-4 lsr) provided good broad-spectrum control; Regiment (30 g ai/ha, 3-4 lsr) fb. Propanil (6726 g ai/ha, 1-2 Till) did not control sprangletop or monochoria; Regiment tank mixed with Abolish (30 g ai/ha plus 3360 g ai/ha respectively, 3-4 lsr) did not control monochoria and was weak on sprangletop. Adequate timing of herbicide application vs. sprangletop emergence was critical in this experiment.

The " mimic" site in Glenn County. Control of sprangletop and smallflower in addition to "mimic", was critical at this site. The best broad-spectrum control and yields were obtained at the resistant site with the following combinations: Clincher (315 g ai/ha, 3-4 lsr) fb. Propanil (6726 g ai/ha, 1 Till); a tank mix of Clincher and Granite SC (315 g ai/ha plus 35 g ai/ha, respectively, 3-4 lsr) fb. Propanil (6726 g ai/ha, 1 Till); Granite SC (35 g ai/ha, 3-4 lsr) fb. Propanil (6726 g ai/ha, 1 Till); Propanil (6726 g ai/ha, 1 Till); Regiment (44.5 g ai/ha, 3-4 lsr) fb. Propanil (4484 g ai/ha, 1 Till), although sprangletop control was poor in these last three treatments; a tank mix of Regiment and Abolish (37 and 3360 g ai/ha, 3-4 lsr) fb. Propanil (6726 g ai/ha, 1 Till). Control of resistant late watergrass in these programs was largely due to the presence of propanil (Super Wham, Wham or Stam) in the combination.

c) 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

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 3-4 leaf stage (Table 8). Early control of watergrass and sprangletop that lasted through the season generally led to the highest yields in this trial. There was no statistical difference between any of the treatments in this experiment. The best yielding treatment was achieved with a tank mix of Regiment and Abolish (25 g ai/ha plus 3360 g ai/ha respectively, 2-3 lsr) followed by Clincher (315 g ai/ha, PPF). Other high yielding treatments were: Granite tank mixed with Clincher (35 g ai/ha plus 280 g ai/ha respectively, 2-3 lsr) fb. Propanil (6726 g ai/ha, PPF); a tank mix of Granite SC, Prowl H_2O and Clincher (35 g ai/ha, 1120 g ai/ha, and 315 g ai/ha respectively, 2-3 lsr); Clincher (280 g ai/ha, 3-4 lsr) fb. Propanil (6726 g ai/ha, PPF); a tank mix of Prowl H_2O, Regiment and Whip (1120 g ai/ha, 37 g ai/ha and 32 g ai/ha respectively, 2-3 lsr);; Abolish (4480 g ai/ha, DPRE) fb. Regiment (12.5 g ai/ha, 2-3 lsr); Prowl H_2O (1120 g ai/ha, DPRE) fb. Propanil (6726 g ai/ha, 2-3 lsr). Good yields were obtained with Abolish (4480 g ai/ha, DPRE) fb. a tank mix of Regiment and Abolish (30 g ai/ha plus 3360 g ai/ha respectively, 2-3 lsr); Abolish (4480 g ai/ha, DPRE) fb. Regiment (12.5 g ai/ha, 2-3 lsr), however these early Regiment applications cause significant early injury to rice (Table 8). Pre-emergent or early use of Prowl ensured consistency of sprangletop control.

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.

Preliminary experiments were conducted with some new compounds. Promising results were obtained in certain cases and we anticipate continued work with some of them to establish their fit in a rice program (Tables 9, 13, and 14).

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.*

Managing Herbicide Resistance using Alternative Rice Stand Establishment Techniques.

Justification: Integrating cultural and chemical weed control practices may decrease weed management costs through the reduction of herbicide resistant weed populations, delayed evolution of herbicide resistance, and timely reduction of weed seed banks. Alternative cultural rice establishment techniques such as drill seeding, stale seedbed, or no-till may be used to manipulate weed species recruitment and expand herbicide options for the control of herbicide-resistant weeds. In drill-seeded rice, pendimethalin (Prowl) may be used for soil residual control of many grass species. In stale seedbed systems, weeds that emerge prior to rice planting may be controlled with non-selective herbicides such as glyphosate (Roundup) for which resistance has not evolved in weeds of rice. These herbicides provide alternative mechanisms of action, may be less expensive, and may be more environmentally benign than some of the herbicides used in conventional water-seeded rice systems. No till alternatives discourage weed recruitment and favor seedbank depletion through seed decay. Therefore, a large field experiment was established at the Rice Experiment Station to assess the effectiveness in managing herbicide-resistant weeds by altering weed species recruitment and introducing new herbicides unique to specific rice establishment systems.

RICE ESTABLISHMENT TREATMENTS IN 2007

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. Following is a list of these treatments with a summary of crop establishment practices and herbicides used.

CONVENTIONAL WATER-SEEDED:

Conventional Water seeded:

Crop establishment:

- Spring tillage
- Permanent flood: May 22
- Water seeded: May 31

Herbicides:

- Propanil + Granite SC (6 lb a.i./a + 2 oz/a, respectively) at the 4-5 leaf rice stage (June 27).

CONVENTIONAL DRILL-SEEDED:

Crop establishment:

- Spring tillage
- Drill-seeded May 30
- Flushed for establishment May 31, additional flush June 6
- Permanent flood: June 16

Herbicides:

- Propanil, Prowl, and Clincher (6 lb a.i./a + 2.1 pt/a, 13.3 oz/a, respectively) at the 3 leaf rice stage (June 7).

WATER-SEEDED / STALE SEEDBED:

Crop establishment:

- Spring tillage

- Flushed for weed recruitment May 1 and May 13
- Water seeded June 1

Herbicides:

- Pre-flood: Roundup Weather Max (glyphosate) 1.4 lbs a.e./acre plus 2% ammonium sulfate May 29.
- Post emergence: Propanil + Granite SC (6 lb a.i./a + 2 oz/a, respectively) at the 4-5 leaf rice stage (June 27).

WATER-SEEDED / STALE SEEDBED / NO TILL:

Crop establishment:

- Flushed for weed recruitment May 1 and May 13
- Water seeded June 1

Herbicides:

- Pre-flood: Roundup Weather Max (glyphosate) 1.4 lbs a.e./acre plus 2% ammonium sulfate May 29.
- Post emergence: Propanil + Granite SC (6 lb a.i./a + 2 oz/a, respectively) at the 4-5 leaf rice stage (June 27).

DRILL-SEEDED / STALE SEEDBED / NO TILL:

Crop establishment:

- Flushed for weed recruitment May 1 and May 13
- Drill-seeded May 30
- Flushed for establishment May 31, additional flush June 6
- Permanent flood: June 16

Herbicides:

- Pre-plant: Roundup Weather Max (glyphosate) 1.4 lbs a.e./acre plus 2% ammonium sulfate May 29.
- Propanil, Prowl, and Clincher (6 lb a.i./a + 2.1 pt/a, 13.3 oz/a, respectively) at the 3 leaf rice stage (June 7).

Note: Crop oil concentrate (1.25% v/v) was added to applications of Clincher and Propanil. Ammonium sulfate (2% by weight) was added to applications of Roundup.

RESULTS SUMMARY

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. Data averaged across four years show 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) (Figure 2). 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 very 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 (to prevent new weed recruitment) prior to water-seeding rice, very little weed control was needed thereafter. Thus, the stale-seedbed technique reduced weed recruitment in water-seeded rice by about 40%, and by 70% if spring tillage was eliminated (no-till) (Figure 3). Conventional drill-seeded systems typically result in heavy weed recruitment, and although using stale-seedbed and minimum soil disturbance reduced weed recruitment by 40% (Figure 3), there were still many weeds present in System 5 (no-till drilled rice with a stale seedbed treatment).

Success with the stale-seedbed technique depends on the patterns of weed emergence and, very importantly, upon being able to keep the seedbeds moist and to allow sufficient time for most weeds to emerge prior to glyphosate application. These techniques were successful in suppressing the earlier emerging weeds, particularly *Echinochloa* spp. and smallflower umbrellasedge in dry and water-seeded rice, respectively (Figure 3), since substantial weed emergence was achieved prior glyphosate application, which resulted in very limited weed emergence thereafter (Figures 4a and 4b). However, aquatic weeds have delayed emergence respect to rice and other weeds and little emergence had occurred by the time glyphosate was applied, thus a substantial proportion of these weeds emerged later in the season in water-seeded rice (Figure 4b and c). To control these weeds using a stale seedbed technique a longer period of very moist conditions would be required to promote substantial emergence and thus deplete the top layer of soil of germinable weeds. In dry-seeded rice a delayed emergence of sprangletop with respect to *Echinochloa* spp. was also observed Figure 4a). The patterns of weed infestation over time illustrate how although the mostly grass weed infestations in the no-till drill-seed rice increased over time, the system was successful in reducing recruitment of these grasses every time the stale seedbed technique was adequately timed such that glyphosate could be applied once most weeds had emerged (Figure 5a). In water-seeded rice, the stale-seedbed technique was successful in reducing recruitment of the mostly smallflower composed infestations, essentially also because substantial weed emergence was achieved prior to seeding rice (Figure 5b), which could be eliminated with glyphosate to reduce subsequent weed emergence. Weed dynamics in the no-till systems was different. Although substantial amounts of weeds are eliminated with the glyphosate application, a significant proportion of sprangletop (in no-till drill-seeded rice) and of the aquatics redstem and ducksalad occurs late in the season (Figure 4c) and infestations by these weeds have gradually increased over time (Figure 5c). Being able to expose weeds to the action of glyphosate (or other non-selective herbicide for which resistance has not evolved) is an essential aspect of implementing alternative stand establishment techniques in order to control herbicide-resistant weeds.

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 (lb a.i./a) + Granite SC (2 oz/a) at the 4-5 lsr. 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 if spring tillage is avoided to prevent stirring up new weeds from the soil. 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.

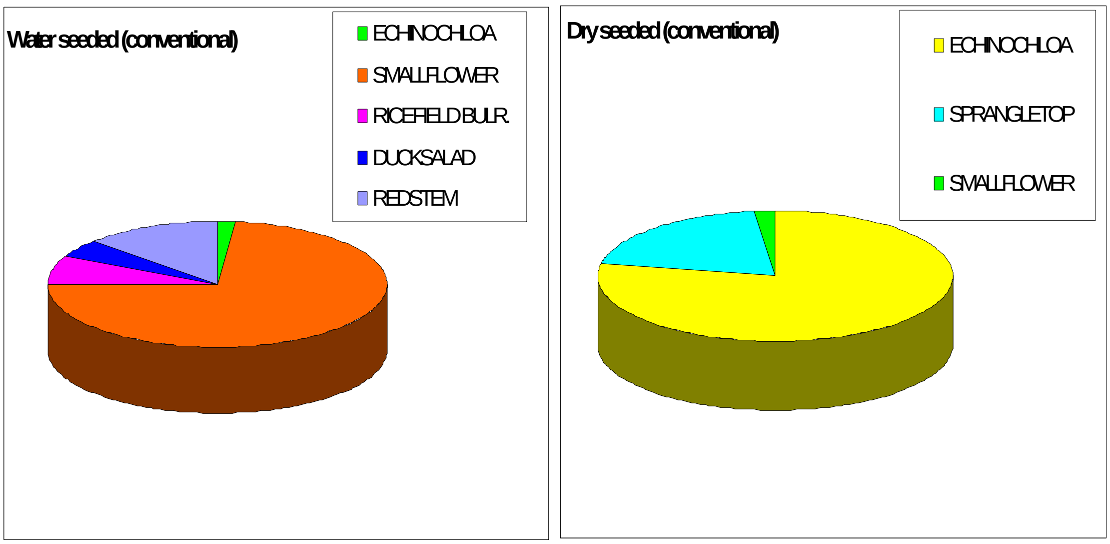

Figure 2. Proportional weed species recruitment in conventionally water-seeded and drill-seeded rice determined 35-40 days after rice emergence in plots where conventional herbicides have not been applied. Data are averages across four years of experiments.

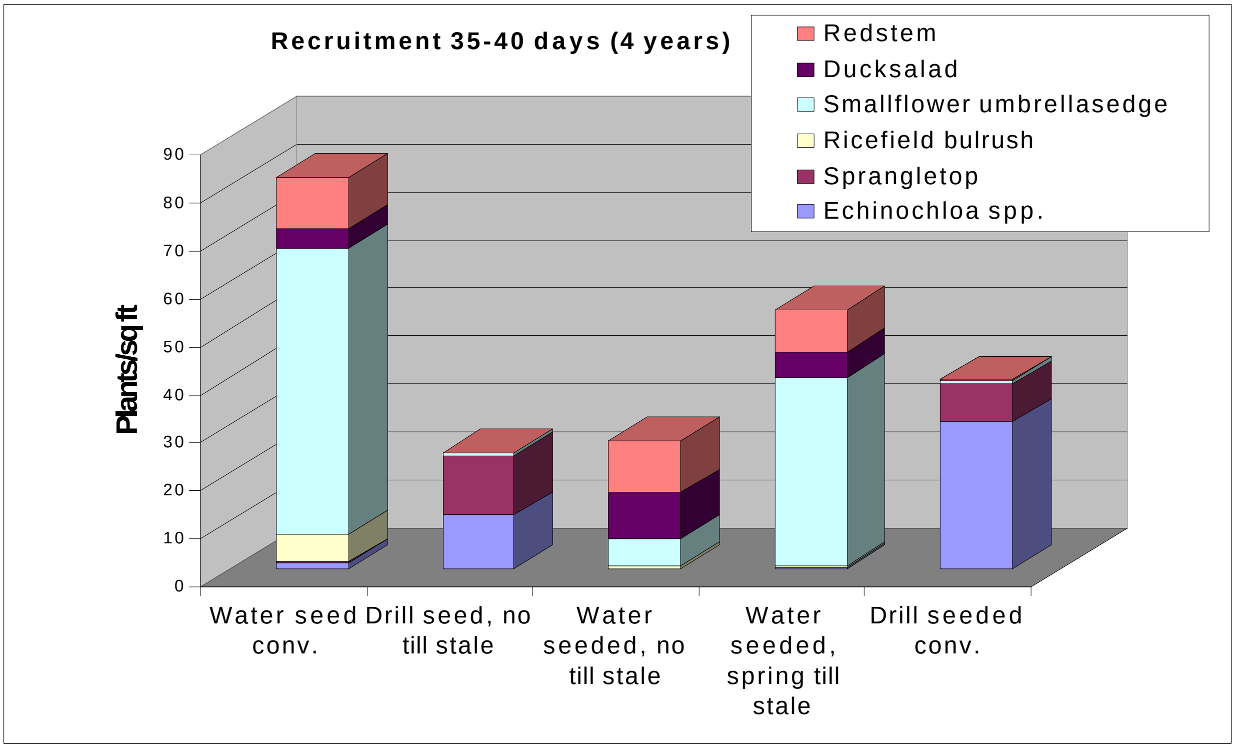

Figure 3. Effect of alternative rice establishment systems on weed species that emerge with rice in plots where conventional herbicides have not been applied (except for glyphosate in the stale-seedbed treatments). Data are averages of four years.

Figure 4. Weed emergence by major species prior glyphosate application in stale-seedbed treatments and the weed infestation present at rice canopy closure (35-40 days after rice emergence) for three alternative rice establishment systems. Data are averages of four years.

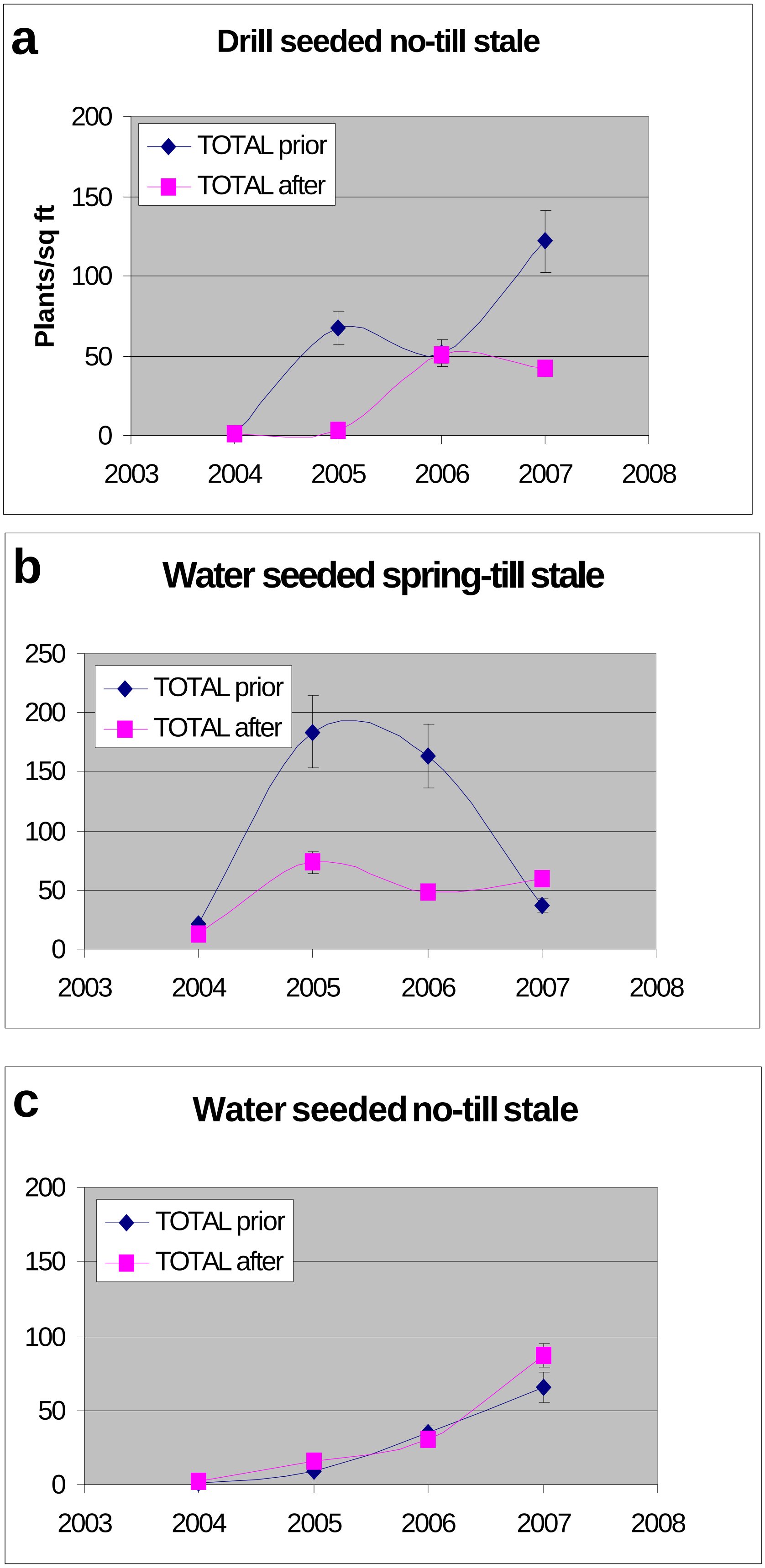

Figure 5. Total weed emergence prior and after (35-40 d after rice emergence) glyphosate application in stale-seedbed treatments determined yearly for three alternative rice establishment systems.

CALIFORNIA WEEDY (RED) RICE

Weedy rice is a serious problem in commercial rice fields because it belongs to the same species as rice (*O. sativa* L.), and is thus difficult to control selectively with the herbicides currently available for use in this crop. Red rice is a **weedy rice** that has kernels with a red pericarp (bran). It is highly tillered, competitive, and shatters its seed easily. This weedy rice is a major problem in the southern US states, and world-wide where rice is grown. Red rice is not yet a problem in California. However, red rice has been identified in a few Colusa and Glenn County rice fields since 2003 (Greer 2006). Red rice can have a serious economic impact by reducing yields and quality, and by increasing weed management costs. Dealing with this problem requires adequate identification of this weed, scouting, and the implementation of a red rice management program (Greer, 2006). The objectives of this study were:

1. To use DNA markers for characterizing California red rice accessions and for comparing them with weedy and commercial rice from a southern US location.
2. To morphologically characterize seed from weedy rice samples collected in California rice fields and compare them to cultivated rice seed.

The following studies were conducted:

Seed Morphology. Seeds from the UC Davis weedy rice collection were used. This collection consists of 104 lines derived from accessions collected in Colusa and Glenn Counties. Also included in this comparison, were two field collected unidentified red- bran rice types.

DNA Study. Phyllogenetic relationships among all the accessions was assayed by DNA polymorphisms of simple sequence repeats (SSRs) using 16 primers pairs selected from the data base of rice microsatellite markers. Also included in this analysis were three weedy rice accessions collected in rice fields from Missouri (New Madrid County) and the southern US rice cultivar Cheniere.

Results and Discussion

Seed Morphology. Seed characteristics of the weedy rice from California are variable across the different accessions collected, but differ from those of commercial rice varieties. In general, it is straw-hulled and medium-type grain, but has long awns, is pubescent, and the kernels have a red pericarp (Figure 6).

DNA Study.
California weedy rice (Cluster 3 in Fig. 7) may be more related to straw-hulled red rice from the southern US (Clusters 1 and 2) than to a commercial rice variety and a black-hulled red rice accession from Missouri (Clusters 7 and 4, respectively). It also appeared to be genetically distant from other non-weedy red bran rice types (Cluster 5 and 6) found in California.

DNA Cluster	Lemma and palea color	Bran color	Awn	Pubescence	Paddy grain length (mm)	Paddy grain width (mm)	Weight 10 grains (mg)
Red bran rice 1	Brown, tawny	Purple	Absent or short	Yes	8.76-9.02	3.25-3.31	0.28-0.29
Red bran rice 2	Brown furrows	Purple Brown	Absent or short	Yes	7.68-8.30	3.12-3.49	0.21-0.32
Glenn County	Straw	Purple Brown	Long 21-85 mm	Yes	7.46-8.9	2.9-3.42	0.21-0.31
(cv Cheniere)	Straw	White	Absent or short	No	Long	-	-
M-104 M-205 M-206 M- 202	Straw	White	Absent or short	No	7.82-8.56	3.00-3.20	0.28-0.31

Figure 6. Morphological kernel characteristics of selected samples

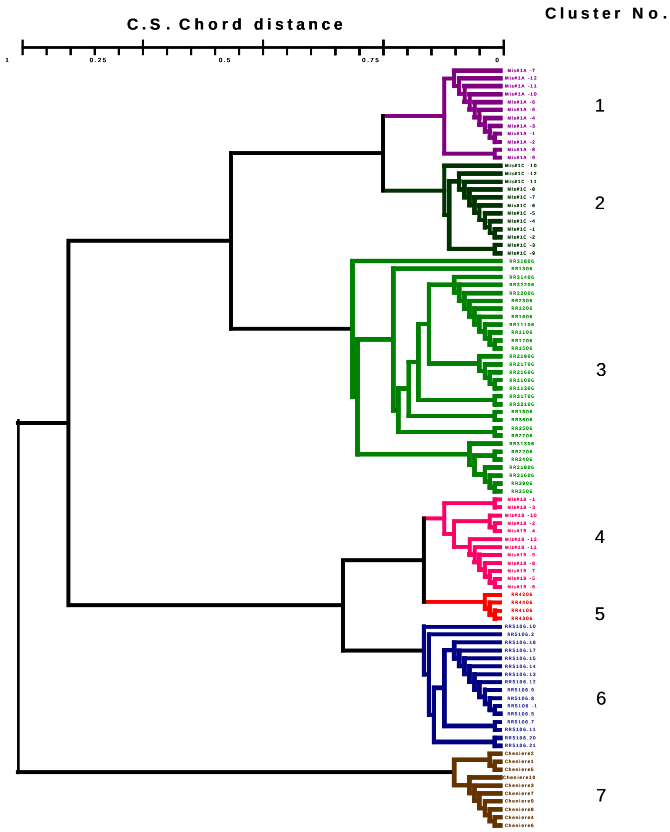

Figure 7. Phyllogenetic relationships based on DNA microsatellite polymorphism.

TRAITS FOR FIELD IDENTIFICATION OF *MONOCHORIA VAGINALIS* AND BIOTYPES OF *HETERANTHERA LIMOSA* AT DIFFERENT GROWTH STAGES.

It has recently been noted that there is a widespread misconception/misidentification of one of the predominant weeds in California rice. Ducksalad (*Heteranthera limosa*) has been a common weed in California rice for many decades. The 1976 Rice Field Day booklet notes ducksalad first recorded in Glenn County in 1948. It also notes a marked spread of the weed during the early 1970's. From anecdotal evidence this ducksalad was the white flowered biotype. A blue flowered biotype was noted around 1989 in Butte County by then Butte County farm advisor Carl Wick (Bill Brandon, personal communication). It was found on the Rice Experiment Station at this same time (Bill Brandon, personal communication). At present, ducksalad in California is classified as *Heteranthera limosa* (S.) Willd.by DiTomaso in Aquatic and Riparian Weeds of the West. *Heteranthera rotundifolia* (Kunth) Griseb. is listed as a synonym for this species, although certain authors consider it a closely related species with some characteristics that resemble those of the blue flowered biotype, which appears to be more aggressive than the white flowered biotype. This blue flowered biotype of ducksalad has been called Monochoria by growers across the Sacramento Valley. A survey of ducksalad/monochoria populations is warranted to clear up this misidentification. The blue flowered ducksalad has largely displaced the white flowered biotype in most fields where it has been introduced. The displacement appears to happen within a few years after initial infestation. Ducksalad produces copious amounts of seed that is very small. It is likely spread by tillage equipment, harvest equipment, wildlife and water. Young ducksalad leaves form on long petioles and are elliptic to lanceolate in shape with rounded tips. Later leaves also form on long petioles, are ovate to elliptic with rounded tips. The blue flowered biotype appears to be more likely than the white flowered biotype to develop creeping stems with roots developing at each node. Both biotypes of ducksalad are early season annuals that bloom June through July and begin to die back once seed is set in late July. Ducksalad flowers form on a single long stalk and are very prominent. The flowers open above the water. Additionally, there may be a third ducksalad type on the west side of the Sacramento Valley with leaves that are round with a deep scallop at the point of attachment to the petiole. Multiple flowers (2-8) form on a spike and are light purple.

Early monochoria leaves are longer and narrower than ducksalad and come to a more defined point. The early leaves often float on the water surface. Later leaves are heart shaped and come to a more distinct point. Monochoria leaves are more waxy and often darker green than ducksalad. Monochoria flowers form as a cluster on a short stalk, are often under water and also often open under water. The flowers are blue, but are generally not noticeable due to position under the canopy of leaves. Flower formation begins mid to late July.

Organic rice growers have expressed concern over the spread of the blue flowered biotype of ducksalad due to the more aggressive creeping stem behavior. This creates a dense mat of plants that is more difficult to kill with the field dry down method of control. This creeping behavior also tends to pull the rice down at early stages of growth.

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. The past two seasons we have reported results of testing by including 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 and PCA's continues to be positive. They comment that they like seeing the effect on the grass along with the level of control by the different herbicides. Various resistance patterns were observed in all submitted samples, which included barnyardgrass, early, and late watergrass accessions.

Penoxsulam Faces Metabolic Resistance in California's Late Watergrass

Penoxsulam is a new acetolactate synthase (ALS) inhibitor herbicide for control of annual grasses, sedges, and broadleaf weeds in rice. A late watergrass (LWG, *Echinochloa phyllopogon*) population presumed resistant (R) to penoxsulam was found in rice growing areas of California. Whole-plant bioassays were conducted to study LWG response to penoxsulam and to detect 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. Pre-treatment with thiobencarb antagonized penoxsulam. Results suggest cyt P450 involvement in LWG resistance to penoxsulam. ALS activity was assayed on leaf extracts from R and susceptible (S) plants for a range of penoxsulam concentrations. These assays demonstrated that resistance in R-LWG is not due to reduced ALS sensitivity. Studies are under way to clarify the metabolic routes of penoxsulam degradation in R and E *E. phyllopogon*.

Clomazone Resistance in Late Watergrass (*Echinochloa phyllopogon*)

Late watergrass (*Echinochloa phyllopogon*) is a major weed of rice in California, and several populations showed resistance to multiple herbicides of differing modes of action. 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. This level of resistance corresponds to escapes seen in the 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. Clomazone rates were: 0, 1/4X, 1/2X, X, 2X and 4X; X is the field rate = 673 g ha^{-1}; a commercial formulation of clomazone (CERANO) was used. Growth reduction (50%) values were significantly lower for the susceptible biotype compared to the resistant biotypes. Application of clomazone in combination with disulfoton or oxydemeton reduced clomazone toxicity to resistant late watergrass biotypes, suggesting that an oxidative step is required for activation and toxicity of this herbicide. Studies are under way to clarify the mechanism of resistance.

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

Our field and lab program seeks to assist California rice growers in their critical weed control issues of preventing and managing herbicide-resistant weeds, achieve economic and timely broad-spectrum control and comply with personal and environmental safety requirements. Thus we test in the field at the RES, and in a cooperator's field heavily infested with mimic, herbicides, their mixtures and sequential combinations for the rice growing systems that currently prevail in California. 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. We have worked on the molecular and morphological characterization of red rice plants recently found in CA rice fields, both of plants, and our lab work emphasizes the elucidation of mechanisms of herbicide resistance in weeds of rice and the means by which resistance spreads among fields. This year we have also included morphological studies allowing to distinguish ducksalad (*Heteranthera limosa*) from monochoria (*Monochoria vaginalis*) and research activities to elucidate this weed's emergence patterns.

Advantages of the Continuous Flooded rice system include the suppression of watergrass by deep water, which is particularly relevant when there is resistant watergrass, and the elimination of Sprangletop as a problem provided a uniform 4-inch water depth can be maintained. We had heavy early and late watergrass infestations, but also ricefield bulrush and the complex of ducksalad/monochoria were present. Granular formulations applied early into-the-water are excellent non-drift tools for this system. Thus sequences with Cerano followed by (fb.) either Granite GR, Regiment, or propanil gave excellent broad-spectrum control. Some stunting and dark green color of rice could be noticed after the Granite GR treatment. Also, one could start with Granite GR applied into the water followed by either propanil (also protects Granite from the evolution of resistance to ALS inhibitors) or Clincher. Shark (also protects Granite from ALS-resistance) followed by Granite GR improved ricefield bulrush control and provided good broad-leaf and sedge control. Finally, a classical and very effective treatment was the new granular Bolero ultramax formulation followed by propanil. Rice yields for these treatments were in the range of 8900-9700 pounds per acre of paddy rice (14% moisture).

The Pinpoint System in California rice requires draining at the 2-4 leaf stage to expose weed foliage to foliar herbicides. However, this exposure of the soil surface to air is also favors the establishment of weeds like sprangletop, barnyardgrass and smallflower. For this reason it is important that fields are rapidly re-flooded beginning 48 hours after application. Follow-up applications can be made at 1-2 tiller stage after lowered (drainin-not needed) to expose 70% of weed foliage to the spray. The best broad-spectrum treatments were: Clincher fb. propanil; propanil + Abolish; sequences including Granite SC in tank mix with either Clincher or propanil fb. propanil or Clincher, respectively. Granite SC applied at 3-4 lsr was is an excellent broad-spectrum herbicide but needs a complement of Clincher to control sprangletop. Regiment applied between the 4 leaf and 1-2 tiller stage of rice is a good watergrass herbicide with activity on ricefield bulrush, although sprangletop and smallflower will escape control.
Strada is a new broad-spectrum ALS inhibiting herbicide. There will be a granular formulation suited for into-the-water applications. We had promising results with Strada GR following an early application of Cerano, or Strada (1-2 lsr) followed by propanil. Combining Strada with herbicides with another mode of action is important to protect this herbicide from ALS resistance.

"Mimic" (herbicide-resistant late watergrass) is resistant to all available herbicides for grass control, except propanil. In a continuously flooded system Granite GR (2-3 lsr) applied into-the-water followed by propanil or by Regiment at the 4-5 lsr controlled all weeds present (mimic, ricefield bulrush and ducksalad). Combinations of Cerano followed by propanil or by Regiment at the 4-5 lsr were also very good treatmens in this system. Yields of treatments with good weed control ranged between 7600-10000 Lb/acre paddy rice (14%). In a pinpoint experiment, a single application of propanil (6 lb ai.i/a; at the 1tiller stage of rice) gave total control of resistant late watergrass, smallflower umbrellasedge and ducksalad, which were the main weeds present in this experiment. Clincher followed by propanil, Regiment (0.79 oz/a; 3-4 lsr) followed by propanil, or a tank mix of Regiment plus Abolish followed by propanil were also excellent treatments.

Our Drill-Seeded rice (M206) was flushed with water three times for establishment (May 18, June 5, and June 10), then a final permanent flood (3-4 inches) was applied when rice was at the 5 leaf stage (June 20). The main weeds in this system were watergrass and sprangletop. Residual herbicides (Prowl H_2O and Abolish) applied in delayed pre-emergence (DPRE, this is right after the germination flush before rice emerges) were particularly suited to this system to provide weed control until permanent flood can be installed. These early treatments can be followed up by propanil at the 2-3 lsr. Other good treatments for this system were: Regiment plus Abolish followed by Clincher (PPF, post permanent flood); and Clincher (3-4 lsr with sprangletop at the 3 leaf stage) followed by propanil (PPF).

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). As in 2004, 2005 and 2006, these systems demonstrated their potential for good yields while drastically altering the kinds of weed species that emerge with rice, and for allowing to introduce new herbicides for which resistance does not occur in those weeds (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. The lowest weed infestation occurred where rice was water-seeded after a stale seedbed without spring tillage. Therefore, alternative rice establishment systems may be used to effectively manipulate weed species recruitment and enable the use of herbicides that may control herbicide-resistant weed biotypes.

Weedy rice is a serious problem in commercial rice fields because it belongs to the same species as rice (*O. sativa* L.), and is thus difficult to control selectively with the herbicides currently available for use in this crop. Red rice is a weedy rice that has kernels with a red pericarp (bran). It is highly tillered, competitive, and shatters its seed easily. Red rice can have a serious economic impact by reducing yields and quality, and by increasing weed management costs. This weedy rice is a major problem in the southern US states, and world-wide where rice is grown. Red rice is not yet a problem in California, although it has been identified in a few Colusa and Glenn County rice fields since 2003. Dealing with this problem requires adequate identification of this weed, scouting, and the implementation of a red rice management program. Seed characteristics of the weedy rice from California are variable across the different accessions collected, but differ from those of commercial rice varieties. In general, it is straw-hulled and medium-type grain, but has long awns, is pubescent, and the kernels have a red pericarp. California weedy rice may be more related to straw-hulled red rice from the southern US than to a commercial rice variety and a black-hulled red rice accession from Missouri. It also appeared to be genetically distant from other non-weedy red bran rice types found in California.

Studies on herbicide resistance mechanismsms demonstrated that “mimic” is also resistant to penoxsulam (Granite), and recent research results suggest this is mediated by cyt P450 detoxification. This mimic population studied has already been identified as having P450-mediated resistance to Regiment and Londax. Studies are underway to further characterize the mechanism of resistance to this herbicide. Low levels of resistance to clomazone (Cerano) were found in dose response studies with three late watergrass ("mimic") biotypes collected in rice fields of the Sacramento Valley. This level of resistance corresponds to escapes seen in the biotype of this weed. Studies are under way to clarify the mechanism of resistance.