PROJECT NO. RP-1

COMPREHENSIVE RICE RESEARCH

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PROJECT TITLE: Weed Control in Rice

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OBJECTIVES OF PROPOSED RESEARCH:

1. To investigate the efficacy, timing and compatibility of new herbicides in water-seeded rice.

2. To assess the performance of new herbicides in combination with both new and existing herbicides, and to maintain the safe and effective uses of existing herbicides integrated with appropriate cultural practices.

3. To develop new alternatives to weed control through the exploration of agronomic opportunities, rice/weed competition, and weed stress biology 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 investigate the efficacy, timing and compatibility of new herbicides in water-seeded rice (including water management variations of water seeding).*

Herbicide test plots were located at two different sites at the Rice Experiment Station in Butte County and one off-station site in Glenn County. One of the Rice Experiment Station sites has Londax (bensulfuron-methyl)-resistant sedges. The off-station site has resistant late watergrass as the main weed problem. The site by Hamilton Rd. at the Rice Experiment Station was recently land leveled, which probably contributed to low weed pressure at that site this year. The resistant watergrass site was planted May 21 while planting at the Station occurred from May 11 to June 9.

All herbicide applications were made with a CO_2-pressurized (30 psi) hand-held sprayer equipped with a ten foot boom and 8002 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.

Cerano (clomazone) rate and timing studies

Cerano, (clomazone) a pigment synthesis inhibitor, is a grass herbicide that has been tested for seven seasons at the Rice Experiment Station (RES) and for two seasons at known resistant late watergrass sites in Glenn County. Cerano was applied this season in a 5MEG (microencapsulated extruded granule) form at 673 grams active ingredient per hectare (g ai/ha)[1] into 16- by 25-ft levee plots at the 0.5 leaf stage of rice (lsr).

Cerano has repeatedly demonstrated high efficacy on watergrass (*Echinochloa* spp.) and sprangletop (*Leptochloa fascicularis*) control (Table 4) when applied at 673 g ai/ha at the 0.5 lsr. In general, safety to rice and grass control decreases when Cerano is applied beyond the 1 to 1.5 lsr. This is the fourth season of experimentation with the 5MEG granular formulation and its symptoms to rice include leaf whitening/bleaching, stunting, and some stand reduction. Although a characteristic symptom of Cerano is bleaching of rice foliage, the extent of stunting and stand reduction provide a better estimation of injury to the crop. Damage to the crop can be reduced, and yield losses prevented, when flood water depth is not lower than 4 inches. This season, injury symptoms from Cerano were again very low at the RES and were also low at our off station site. It controlled susceptible late watergrass (*Echinochloa phyllopogon*) excellently at the above-mentioned rate and timing. Late watergrass control by Cerano was mediocre at the resistant site. Cerano in combination with other herbicides like Shark (carfentrazone) or Super Wham (propanil) gave very good broad-spectrum weed control at sites with susceptible watergrass (Tables 4, 10, 15 & 16). These other herbicides are necessary where ricefield bulrush (*Schoenoplectus mucronatus*), smallflower umbrella sedge (*Cyperus difformis*) and broadleaf weeds are problematic weeds. Cerano followed by Super Wham was one of the better combinations for broad-spectrum control at the resistant site (Table 1). Cerano followed by Londax (bensulfuron-methyl) performed well on ricefield bulrush where sedge and broadleaf weeds were susceptible to Londax (Table 4) and marginal where resistance to Londax is suspected (Table 1). Cerano

[1] Corresponding commercial product rates in U.S. units appear on the accompanying tables.

followed by Regiment (bispyribac-sodium) provided good watergrass control except for smallflower umbrellasedge at both watergrass-susceptible and -resistant sites (Tables 1 & 4). Sedge infestations can be more problematic when of Cerano injury to rice weakens the weed suppressive ability of the rice canopy.

The mechanism of action of clomazone differs from the rest of the available grass herbicides. Although good control of herbicide-resistant early watergrass (*E. oryzoides*) has been observed, certain herbicide-resistant late watergrass strains have shown significant tolerance to this herbicide. This was the case at the 2003 and 2004 resistant sites, and has been noted by pest control advisors in Glenn County.

Regiment (bispyribac-sodium) alone and in combinations

Regiment has been tested at the RES for several seasons and also in farmers' fields where resistant watergrass is problematic. Regiment is a post emergent herbicide that when used with a silicone surfactant it is effective on watergrass, ricefield bulrush, and demonstrates good activity on California arrowhead.

Combinations of Regiment and Abolish (thiobencarb) have demonstrated synergistic effects on watergrass (susceptible & resistant) control. We have been evaluating this tank-mix combination in a pin-point flood system for several years at the RES, where the field was fully drained two days prior to application to expose all the weed foliage to the herbicide spray, and the flood was brought back within 48 hours after spraying. This field season we applied Regiment at 5 and 10 g ai/ha in combinations with Abolish at 2240 g ai/ha, and at 25 and 37 g ai/ha in combination with Abolish at 3360 g ai/ha when rice was at the 4-5 lsr in a 10- by 20-ft staked plot experiment. These treatments were also duplicated on a resistant watergrass site at a cooperating grower's field.

Sequential applications involving Regiment were also tested at the RES in rice herbicide programs where water management strategies may require its use at differing rates and timings during the cropping season. In a continuously flooded system, Regiment was applied over 16x25-ft levee plots at 37 g ai/ha (+ Kinetic at 0.125% v/v) at the 1-3 tiller stage of rice growth following applications of: Cerano at 673 g ai/ha at the 0.5 lsr, Bolero (thiobencarb) at 4480 g ai/ha at the 1-2 lsr, or Sofit (pretilachlor + safener) at 444 or 642 g ai/ha as a pre flood surface application.

In a Pin-point Flood System, an application of Clincher at 315 g ai/ha with 1.25% v/v Crop Oil Concentrate (COC) was made at the 4-5 lsr and then followed by Regiment at 37 g ai/ha plus Kinetic at 0.125% v/v at the 2-3 tiller stage of rice (Table 5). In this system, Regiment was used for broadleaf and sedge control and clean-up of any missed watergrass from the initial Clincher application. Floodwater was drained 2 days prior to application for the initial spraying of Clincher and plots were re-flooded 1 day later. Regiment was applied with the water depth at 2-3 inches for a 70% weed foliage exposure.

Regiment plus Abolish performed well on susceptible watergrass (Table 5) and suppressed resistant watergrass and a broad-spectrum of weeds at the resistant site (Table 2). Best watergrass control was achieved with Regiment at 37 g ai/ha plus Abolish at 3360 g ai/ha.

Clincher (cyhalofop) rate, timing, mixtures and sequential combinations.

Clincher (cyhalofop-butyl) is a post-emergent ACCase inhibitor, to control watergrass and sprangletop. Clincher has been registered in California for the control of sprangletop (*Leptochloa fascicularis*) in soils where thiobencarb (Bolero, or Abolish) cannot be used due to the development of DPS (delayed phytotoxicity syndrome) to rice. Clincher is restricted to ground use only due to non-target activity on peach trees.

This is the seventh season of experimentation with Clincher at the RES and the second season tested off-station at a resistant late watergrass site. This season we tested Clincher at various rates and timings and in numerous combinations and sequential applications with other herbicides.

At the RES, Clincher was tested alone, in combination, and sequentially with other rice herbicides for weed control programs where water management may require its use at differing rates and timings.

In a pin-point flood system, Clincher was applied at the 4-5 lsr then followed by either Super Wham or Regiment at the 1-3 tiller stage. The Clincher followed by Super Wham treatment provided excellent broad-spectrum control at a susceptible watergrass site (Table 5). Clincher followed by Regiment was excellent on watergrass but provided poor control of smallflower umbrellasedge. Clincher was also tested following Super Wham and Regiment. Both of these combinations provided excellent broad-spectrum weed control. Clincher followed by Londax provided excellent broad-spectrum control at this susceptible weed site. Clincher followed by Super Wham provided very good broad-spectrum control at the resistant watergrass site (Table 2).

Clincher was used in combination and in mixtures with several other herbicides. In all cases, it controlled sprangletop and improved control of watergrass (Tables 4,8 & 13).

In a separate trial, Clincher was tested at various rates alone and in tank mix combinations with varying rates of Super Wham (Table 14). This trial is a continuation of work on the interaction of these two compounds in tank mix. All treatments were made at the 1-3 tiller stage of rice to 10x20 ft stake plots. Clincher alone generally provided good watergrass control at the higher label rates and complete control of sprangletop at relatively low rates. Super Wham had moderate activity on susceptible watergrass, ducksalad (*Heteranthera limosa*) and redstem (*Ammannia* spp.), and provided good control of ricefield bulrush and smallflower umbrellasedge. The effectiveness of Clincher on sprangletop was reduced in mixtures with the high rate (6720 g ai/ha) of Super Wham.

Clincher is a good post emergent herbicide for herbicide-susceptible watergrass and sprangletop. Because of its high level of safety to rice, Clincher can be effectively applied at 280 g ai/ha on rice at the 2 to 3 lsr, and at 315 g ai/ha with rice at the 5 lsr to mid-tiller stage, and at 350 g ai/ha from mid-tiller to just before panicle initiation. It can be successfully applied in sequential applications for broad-spectrum control. In previous years, we have observed that control of sprangletop by Clincher was antagonized by all rates of Super Wham in tank mixes, but antagonism was overcome at the high rates of Clincher. This did not appear to be the case for watergrass. In general, tank-mixing herbicides with Clincher reduces its ability to control grasses, therefore, sequential applications are more reliable. A practical approach for a pin-point flood system is to achieve early control of competitive grasses with Clincher applied at the 3-6 leaf stage of rice growth and following this application with SuperWham or Regiment to control sedges, broadleaves, and any missed watergrass plants.

Shark (carfentrazone)

Shark has been tested for several years on station and at off station sites in growers' fields and has demonstrated to be effective 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). In 2004, 224 g ai/ha Shark was evenly spread as a dry flowable granule over the plots at several growth stages, alone and following Cerano applied at the 0.5 lsr. This experiment had both an early and a late planting to get different weather conditions during establishment. Treatment of both Cerano and Shark at the 0.5 lsr caused greater (28%) stand reduction than any other treatment in the early planting. Best broad-spectrum control and yield occurred when Shark followed Cerano at the 2-4 lsr (Table 15). At the late planting experiment, the stand reduction for that timing was 10% (Table 16).

Shark also performed well on ricefield bulrush and smallflower umbrellasedge at all sites (Tables 1 and 4).

The dry application into the water allows to reduce the 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. We intend to continue our research with Shark to expand on application methods, combinations, and different formulations for increased application ease and efficacy.

Prowl (pendimethalin) EC and Prowl H_2O

Prowl is a selective herbicide for controlling annual grass (watergrass, barnyardgrass, sprangletop) and certain broadleaf weeds as they germinate and emerge. As a meristematic inhibitor, it interferes with the plant's cellular division and early growth. Prowl EC has had a supplemental label for drilled and dry seeded rice in California. A tank mix of Prowl and Super Wham applied at the 4-5 lsr provided good control of watergrass, ricefield bulrush and smallflower umbrellasedge (Table 5). When Prowl EC was applied alone at the 3-4 lsr in a pinpoint experiment, very good control of watergrass was achieved, but control of ricefield bulrush, smallflower and sprangletop was poor. The tank mix of either Prowl formulation with Super Wham applied at the 3-4 lsr controlled watergrass and sedges (Table 6). Applications of Prowl alone beyond the 5 lsr were not effective. In a dry/drill seeded trial, Prowl EC provided very good initial broad-spectrum control that diminished over time (Table 13). Follow-up treatments with Super Wham, Clincher and Regiment all provided excellent broad-spectrum control that was sustained longer than that of Prowl alone.

Prowl H_2O is a new water based capsule suspension (CS) formulation that was tested this year. Wet/dry cycles cause the capsule wall to rupture and release the pendimethalin. The H_2O formulation applied alone (3-4 lsr) was somewhat less active than Prowl EC (Table 6). In tank mixture with Super Wham, control with H_2O formulation was slightly greater than with the EC formulation for some weed species. At the resistant site, tank mixes of Prowl H_2O with Super Wham provided good broad-spectrum control and, in some cases, better than that of comparable treatments with Prowl EC (Table 3). This formulation is being considered for its potential to fit into flood-seeded rice culture in California.

IR-5878 WG

IR-5878 is an ALS inhibitor that was tested for a seventh season at the RES for broad-spectrum activity at a site with susceptible watergrass and Londax-resistant smallflower umbrellasedge. This season, we tested IR-5878 in 10x20-ft. plots with the water drained for an early (2 to 3 lsr) application, and in a separate trial drained for a late (5 to 6 lsr) application. IR-5878 was applied at 5 rates as a stand-alone treatment and at 75 g ai/ha in combination with Abolish (3360 and 4480 g ai/ha) or Super Wham (at 3360 g ai/ha). IR-5878 (2-3 lsr) was also tested with a sequential application of Clincher at 315 g ai/ha + COC at the 1-3 tiller stage. Floodwater was returned to normal depth within 2-days after application of IR-5878. Floodwater was dropped for 70% weed exposure prior to the Clincher applications at the 1-3 tiller stage.

When applied early (2-3 lsr), IR-5878 provided good watergrass control, had marginal effect on ricefield bulrush, and poor activity on smallflower umbrellasedge (suspected resistance to ALS-inhibitors) (Table 11). IR-5878 does not control bearded sprangletop. When applied in tank-mix with Super Wham, broad-spectrum control was experienced. Smallflower umbrellasedge, watergrass and sprangletop control was good in combination with Abolish, but the effect on ricefield bulrush was marginal (Table 11). Ricefield bulrush control was better when IR-5878 was applied later at the 5-6 lsr (Table 12). Broad-spectrum efficacy was good to excellent when this herbicide was followed by Clincher (Tables 11). Thus, IR-5878 is a good initial treatment for the early control of watergrass and sedges and then Clincher can be used to clean up any missed watergrass and to control sprangletop.

When applied late (5-6 lsr), IR-5878 provided good watergrass and ricefield bulrush control, moderate control of sprangletop and poor control of smallflower umbrellasedge and redstem (Table 12). Tank mixes with SuperWham improved smallflower and redstem control. IR-5878 followed by Clincher provided good control of watergrass, ricefield bulrush and sprangletop. This treatment had only marginal control of smallflower (suspected ALS-inhibitor-resistant) and poor control of redstem.

IR-5878 GR

This is the third season of experimentation with this granular formulation of IR-5878. This herbicide is being tested in a continuous flood system and applications were made into 16x25-ft flooded levee plots, in combination with Cerano. Cerano was applied at the standard rate of 673 g ai/ha and IR-5878 was applied at 17.5, 35 and 70 g ai/ha at the 0.5 lsr. Cerano was also applied by itself to determine the contribution of IR-5878.

Cerano alone provided excellent watergrass control and appeared to have activity on ducksalad. When IR-5878 was added, excellent control was achieved for ricefield bulrush and waterhyssop.

Sofit (pretilachlor + safener)

This is the third season we tested this broad-spectrum herbicide that is readily taken up by germinating weeds. It has a complex mode of action that differs from currently available herbicides for California rice. It has been mainly used in transplanted rice. We have been testing this compound in continuous flood, pinpoint flood and in a drill/dry seeded system.

In the continuously flooded system Sofit was applied at 444, 543 and 642 g ai/ha as a pre-flood application to dry soil. Applications were made over 16x25-ft. levee plots. Flood water was applied for aerial seeding on the day following the application. Additional plots had a follow up treatment of either Super Wham or Regiment at the 1-3 tiller stage of rice. Sofit provided excellent watergrass and broadleaf weed control at both the susceptible and resistant late watergrass sites (Tables 1 & 4), as well as good initial control of ricefield bulrush. This weed eventually became a severe problem due to a second flush that was likely stimulated by the thin stand in these treatments. The material applied at these rates caused severe stunting and stand reduction that persisted for several weeks. The follow up applications of Super Wham and Regiment prolonged the effect on watergrass control and provided good to excellent control of late emerging ricefield bulrush.

Sofit was tested in a pinpoint system at the resistant site (Table 2). Sofit was applied to the dry soil 3 days prior to flooding and six days prior to seeding rice. Follow-up treatments of either Super Wham or Regiment in tank mix with Sofit were applied at the 4-5 lsr. The pre-flood surface treatments caused severe stand reduction at these rates. The follow up tank mixes of Sofit and Super Wham or Regiment did not cause any further stand reduction, but the Regiment tank mix stunted rice. These treatments were marginally effective against watergrass, ricefield bulrush and redstem, but good against waterhyssop and smallflower umbrellasedge (Table 2).

Sofit was also tested as a treatment in a drill/dry seeded trial (Table 13). Seed was drilled into dry soil then flushed for establishment. Sofit was applied at two rates (450 and 650 g ai/ha) as a post flush-pre emergent (PFPE) treatment. The soil was still moist at the time of application. Each rate was tested alone and also with a sequential treatment of Super Wham, Clincher or Regiment. All Sofit rates and combinations provided excellent initial control of ricefield bulrush, smallflower umbrellasedge, redstem and sprangletop. Initial control of watergrass with the high rate of Sofit was 84%, suggesting that a higher rate may be needed. No injury on rice was recorded. Good to excellent watergrass control was achieved with

Sofit followed by Super Wham or Clincher. The best broad-spectrum long-term control was achieved with Sofit at 650 g ai/ha followed by Clincher at 315 g ai/ha. This treatment also had the best yield of the entire experiment. These results suggest good potential for using Sofit in drill-seeded rice.

Granite (penoxsulam, DE-638) alone and in combinations

Granite GR is an ALS inhibiting post-flood, post-emergence herbicide for selective control of susceptible grass (not active on sprangletop), broadleaf and sedge weeds in California rice. The granule formulation, Granite GR should be available for the 2005 season. This product was applied into the water at 40 g ai/ha 8-9 days after seeding. It was tested in combination with Bolero and as a follow-up for Cerano. In addition, it had follow-up treatments of Stam or Clincher. Granite GR by itself and in combination with other herbicides provided excellent broad-spectrum control of susceptible weeds with moderate stand reduction and stunting (Table 9).

Granite SC is a liquid formulation for foliar application. It may not be labeled here in the near future. It was tested in a pinpoint flood system with flood water dropped for an application at the 3-4 leaf stage of watergrass. It was applied alone, in tank mix with Clincher and with follow-up of Stam (propanil). Granite SC alone provided excellent control of watergrass, smallflower umbrellasedge, ricefield bulrush and ducksalad, while causing no stunting or stand reduction (Table 8). It did not control sprangletop. The tank mix of Granite SC + Clincher provided the best broad-spectrum control and the highest yield for the experiment. Certain ALS-inhibitor-resistant weed biotypes may be poorly controlled by this herbicide. This formulation was tested in 2003 at a resistant late watergrass site where it was applied at the 5-6 lsr in a pin-point flood trial. Under these conditions it did not control the resistant late watergrass sufficiently.

Buctril (bromoxynil)

Buctril is a selective post-emergence broadleaf herbicide used primarily in cereal grain crops. Being primarily a contact herbicide, thorough coverage of weed seedlings is essential for optimum control. Due to very low residual activity, subsequent flushes of weeds will not be controlled. Buctril was applied at 300 and 600 g ai/ha at the 3-4 lsr two days after flood water was lowered for weed exposure. This product was also tested at the 5-6 lsr at the above-mentioned rates and application conditions. Buctril performed best on ricefield bulrush at both application timings. It also had activity on smallflower umbrellasedge, with better control at the 3-4 lsr than at 5-6 lsr. It appeared to have little activity on ducksalad and as expected, no activity on grass weeds.

OBJECTIVE 2. *To assess the performance of new herbicides in combination with both new and existing herbicides, and to maintain the safe and effective uses of existing herbicides integrated with appropriate cultural practices.*

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 seeding with flush irrigation.

Continuous flood system combinations

This season's continuous flood systems trials continued the testing of many treatment options used by growers and that of a new chemical with potential for use in CA. In most cases the applications were sequential comprising an initial application of Cerano or Sofit for watergrass and sprangletop control followed by either an application of Shark, Londax, Super Wham, or Regiment to control broadleaves, sedges, and in some cases late-emerging watergrass plants or those missed by the early treatment. At the RES, Cerano was applied at 673 g ai/ha at the 0.5 lsr and then followed with either Shark at 224 g ai/ha at the 2-3 lsr as a direct dry application (DDA), Londax at 71 g ai/ha at the 2-3 lsr, a foliar application of Super Wham at 6727 g ai/ha (with COC at 1.25% v/v) at the 1-3 tiller stage of rice, Regiment at 37 g ai/ha (with Kinetic at 0.125% v/v) at the 1-3 tiller stage, Super Wham (6727 g ai/ha), or Grandstand at 280 g ai/ha at the 1-3 tiller stage. Sofit was applied as a pre flood surface treatment at three rates (444, 543 and 642 g ai/ha) alone and followed by either Super Wham at 6727 g ai/ha with COC at 1.25% v/v at the 1-3 tiller stage of rice, Regiment at 37 g ai/ha with Kinetic at 0.125% v/v at the 1-3 tiller stage, or Clincher at 315 g ai/ha with COC at 1.25% v/v at the 1-3 tiller stage of rice. Additionally, Bolero was applied at 4480 g ai/ha at the 1-2 lsr followed by either Super Wham at 6727 g ai/ha with COC at 1.25% v/v at the 1-3 tiller stage, Regiment at 37 g ai/ha with Kinetic at 0.125% v/v at the 1-3 tiller stage, or Regiment at 37 g ai/ha plus Grandstand at 280 g ai/ha with Kinetic at 0.125% v/v at the 1-3 tiller stage. Ordram at 4480 g ai/ha was tested with Londax at 71 g ai/ha at the 1-2 lsr. Ordram was also tested as a pre plant incorporated material at 4480 g ai/ha as either the 15G or 8E formulation followed by Cerano at 448 g ai/ha at the 0.5 lsr, then followed by Shark at 224 g ai/ha at the 2-3 lsr. Regiment at 10 g ai/ha plus Abolish at 2240 g ai/ha and Regiment at 25 g ai/ha plus Abolish at 3360 g ai/ha were also tested at the 1-3 tiller stage.

At the resistant watergrass site a similar study was performed. Several treatments not expected to perform at a resistant site were dropped from this experiment. An additional treatment of Regiment at 37 g ai/ha plus Abolish at 3360 g ai/ha was added to this experiment

Cerano followed by Shark, Londax, or Super Wham provided excellent broad-spectrum control at the susceptible watergrass site (Table 4). Cerano followed by Regiment provided excellent control except for smallflower umbrellasedge. Cerano followed by Grandstand also provided no control for smallflower and only poor control of ricefield bulrush. Sofit provided initial broad-spectrum control, but reduced rice stand leaving it open for later sedge growth, which is controlled with follow-up treatments of Super Wham or Regiment. Ordram followed by Londax as well as the triple sequence of Ordram/Cerano/Shark treatments provided excellent broad-spectrum control (Tables 1 and 4). The Regiment + Abolish mix and the sequential treatment of Bolero followed by Regiment + Grandstand also provided excellent control (Table 4).

At the resistant watergrass site, Cerano followed by Super Wham provided good watergrass and broad-spectrum control (Table 1). Cerano followed by Regiment controlled watergrass, but was poor on ricefield bulrush and failed to control smallflower umbrellasedge. Bolero followed by either Super Wham or Regiment provided good broad-spectrum control. Sofit alone controlled watergrass, smallflower umbrellasedge and ducksalad, but was poor on ricefield bulrush, California arrowhead and redstem. Ricefield bulrush control was improved when Sofit was followed by Super Wham or Regiment. All other treatments that worked well at the susceptible site failed to control watergrass sufficiently at the resistant site.

Pin-point flood system combinations

Pin-point flood trials were conducted at a susceptible watergrass site at the RES and at a resistant watergrass site in Glenn County. Both trials were drained 2-days prior application the at 4-5 lsr and then re-flooded 1-2-days after. The treatments are various combinations of the following herbicides: Regiment, Abolish, Clincher, Super Wham, Prowl, Shark or Sempra (Tables 2 and 5).

The best overall treatments at the susceptible watergrass site were: Regiment at 30 or 37 g ai/ha, Clincher followed by Londax, Regiment plus Sempra, Clincher followed by Regiment plus Grandstand and Regiment plus Shark (Table 5).

The best overall treatments at the resistant site were: Regiment at 37 or 44.5 g ai/ha, Super Wham at 6720 g ai/ha, Regiment followed by either Super Wham or Clincher. Sofit followed by Sofit + Regiment provided good control of smallflower umbrellasedge, and fair control of watergrass, ricefield bulrush and redstem (Table 2).

Dry seeded system

This season the seed was drilled into dry ground, then flushed-irrigated for establishment. The main weeds in this system were watergrass, ricefield bulrush and sprangletop. Herbicide timing included post flush – pre emergence (PFPE), 1-3 lsr, 3-4 lsr, 4-5 lsr, 5-6 lsr and post permanent flood (PPF). Sofit at 450 and 650 g ai/ha, Prowl at 1120 g ai/ha and Abolish at 4480 g ai/ha were tested at PFPE (Table 13). Combinations included Sofit (PFPE) followed by Super Wham, Clincher or Regiment at the 5-6 lsr. Sequential applications of Abolish at PFPE followed by Super Wham or Clincher at 5-6 lsr or Regiment at PPF were also tested. Tank mixes of Regiment and Abolish were tested at the 4-5 lsr with a follow-up treatment of Clincher at PPF. In the combinations of Super Wham followed by Clincher, Clincher followed by Super Wham, Shark followed by Clincher, Shark followed by Super Wham, and Shark followed by Regiment the first material was applied at the 5-6 lsr and the second application was made at post permanent flood (PPF).

The best broad-spectrum control and highest yield in this experiment was achieved with a sequential of Sofit at 650 g ai/ha applied PFPE followed by Clincher at 315 g ai/ha applied onto rice at the 5-6 lsr prior to permanent flood. Prowl provided good initial broad-spectrum control, including sprangletop, but watergrass and ricefield bulrush control diminished over time. Watergrass control was maintained when Prowl was followed sequentially by Super

Wham, Clincher or Regiment. Abolish (PFPE) followed by Clincher (5-6 lsr) provided excellent initial broad-spectrum control, but control of ricefield bulrush diminished over time.

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

Stand Establishment and Tillage Alternatives to Reduce Weed Seed Banks, Reduce Herbicide Use, and Manage Herbicide Resistance in Rice.

The conventional CA water seeding system for rice produces greater rice yields per acre than most other rice growing regions in the U.S., but continuous use of this system and the lack of integrated weed management options have contributed to selection and rapid expansion of herbicide resistant weed populations. The primary incentives for adopting alternative rice establishment systems will be to manage current herbicide resistant weed populations or minimize future selection for resistant biotypes. In 2004 we started a large field experiment at the RES based on results from preliminary studies in 2003. Alternative rice establishment systems were developed and evaluated for their potential to reduce weed species recruitment and facilitate the use of herbicides with alternative mechanisms of action, such as pendimethalin and glyphosate, which may control weed biotypes resistant to herbicides used in conventional water-seeded rice. Evaluated rice establishment systems included 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. A detailed description of each system was presented in the 2003 Annual Report. Each treatment was established in 0.5 acre (0.2 ha) plots that were replicated four times in a randomized complete block design. Total area for this study was approximately 15 acres (6 ha). Tillage was completed on April 26 in all plots except the no till treatments. Plots were seeded with M-202 rice at a rate of 170 kg ha^{-1} or 110 kg ha^{-1} in the water seeded or drill seeded plots, respectively, which are the rates that are generally used by CA growers. In each plot, a 1,399 square feet (130 m^2) area was designated as a weedy check where herbicides were not applied after rice planting. Specific management procedures for each system treatment occurred as follows:

1) *Conventional water seeding*: A permanent flood was established on May 14 and pre-soaked rice seed was applied by air on May 17. Clomazone (Cerano®, 0.7 kg ai ha^{-1}) was applied into the flooded plots at the 0.5 rice leaf stage. Metal barriers were placed in the plots to prevent herbicide drift in the water to the weedy check. Propanil (6.7 kg ai ha^{-1}) was applied at the 3 to 4 rice tiller stage to control broadleaf and sedge weed species.
2) *Conventional drill seeding*: Rice was drill-seeded on May 12 and flushed on May 13 and 24 to promote rice seedling growth. A mixture of pendimethalin (Prowl®, 1.1 kg ai ha^{-1}) and cyhalofop-butyl (Clincher®, 0.3 kg ai ha^{-1}) was applied on

May 26 (5 d after rice emergence). Pendimethalin was applied for residual control of watergrass (including resistant forms), barnyardgrass and sprangletop and cyhalofop-butyl was applied to control grass weeds that had already emerged. A permanent flood was applied on June 5.

3) *Water-seeded rice after a stale seedbed and spring tillage*: To apply the stale seedbed approach, weed emergence must be induced and so that weeds may be controlled with a non-selective herbicide prior to rice planting. Therefore, this treatment was flushed on May 14 and 26. On June 1, glyphosate (1.3 kg ae ha^{-1}) was applied as a burn-down treatment prior to rice planting. Plots were permanently flooded on June 2 and air seeded on June 4. Propanil (6.7 kg ai ha^{-1}) was applied at the 3 to 4 rice tiller stage to control broadleaf and sedge weed species.
4) *Water-seeded rice after a stale seedbed without spring tillage*: In the no till treatments, dense plant residue from winter weeds was burned to facilitate soil-seed contact when water seeding. Application of the stale seedbed, weed management, and rice planting was similar for this treatment as for treatment 3. No post-emergence herbicides were applied as few weeds emerged after the stale seedbed treatments.
5) *Drill-seeded rice after a stale seedbed without spring tillage*: Stale seedbed management was similar to that of treatments 3 and 4. Rice was drill-seeded June 3 and flushed on June 4 and 8 to keep the soil surface moist as some rice seed was not properly buried in the soil with the drill seeder. A mixture of pendimethalin (1.1 kg ai ha^{-1}) and cyhalofop-butyl (0.3 kg ai ha^{-1}) was applied on June 15 (6 d after rice emergence). Plots were then flushed 1 d later to incorporate the pendimethalin into the soil. The permanent flood was applied on June 23 (14 d after rice emergence).

Species compositions of weed communities were distinctly different among establishment systems as the water-seeded systems were dominated by sedge and broadleaf weed species but the drill-seeded systems were dominated by grass weed species (Figure 1). These results suggest that growers may be able to minimize recruitment of entire groups of weed species using water or drill seeding methods. Therefore, alternating between these rice establishment methods among years may effectively reduce selection pressure for resistance. In the drill-seeded systems, grass control from pendimethalin and cyhalofop-butyl was higher than 89%. Glyphosate used in the stale seedbed systems reduced weed populations by 85 to 100% in drill-seeded rice and by nearly 100% in the water-seeded systems. In the water-seeded/stale seedbed/no till system, a pre-plant application of glyphosate was the only herbicide application required for nearly 100% weed control over the growing season. Rice yields did not differ ($P > 0.01$) among these establishment systems. This was demonstrated from grain harvested by a plot combine in a 484 ft^2 (45 m^2) area or hand harvested shoot biomass in a 0.4 m^2 area in each plot (Fig. 2). 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.

Although the herbicide treatments used in this study effectively controlled weed communities in each rice establishment system, management techniques may be improved with a greater understanding of biological processes associated with weed recruitment and competitive ability in each rice establishment system. Specifically, improvements may be made to: 1) minimize the time required for weed recruitment in the stale seedbed systems, 2) maximize weed recruitment prior to rice planting, and 3) schedule the time of permanent flood application in drill-seeded rice to minimize growth and competitive ability of aquatic weed species. To accomplish these objectives, a model is being developed to assist in identifying potential management option for these systems that will be subject to field validation. Critical growth parameters such as seed germination rates, early-season leaf area growth, and weed competition were measured in the lab and field to calibrate a model that predicts the effects of flushing/flooding dates on weed recruitment and competitive ability. Validation of the germination models suggested they could accurately predict weed germination rates in flooded rice fields (Fig. 3).

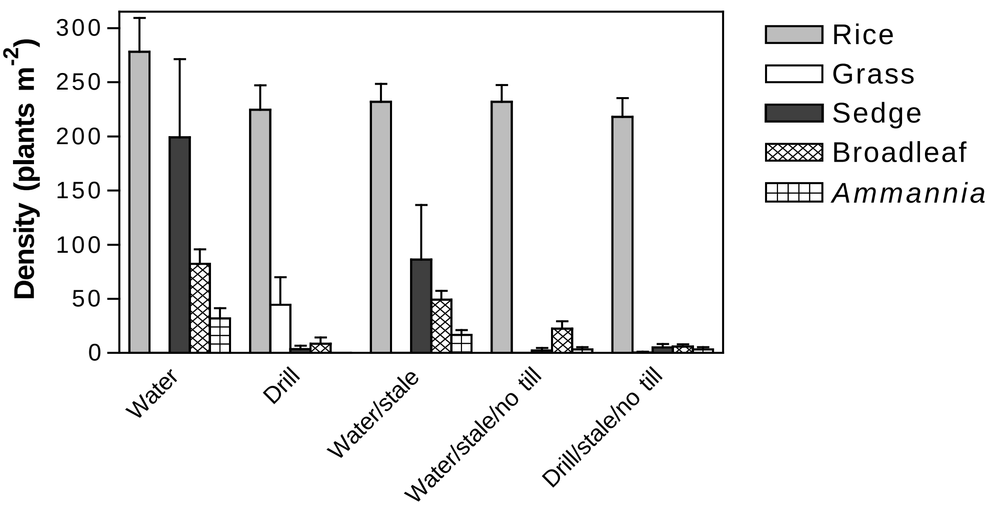

Figure 1. Density of rice and weed species at canopy closure in the water-seeded, drill-seeded, water-seeded/stale seedbed/spring till, water-seeded/stale seedbed/no till, or the drill-seeded/stale seedbed/no till systems. Error bars represent the 95% CI.

According to weed germination predictions, recruitment time required for 100% weed emergence could be reduced by approximately 5 d if flushing/flooding is completed after average daily air temperatures are above 15 C. If the soil is kept aerated and moist at this time, weed recruitment may be completed in 6 to 10 d for the grass weed species and *Cyperus difformis* or 17 d for *Scirpus mucronatus* and *Ammannia* spp. If 10 additional days are added for soil drying for a ground application of glyphosate and possibly drill seeding, rice may be planted by the end of May with little weed pressure after rice emergence In drill-seeded rice, delay of permanent flooding may delay recruitment of aquatic weed species. According to model predictions, yield loss of aquatic weed species could be reduced from 12% to approximately 1% if the permanent flood is applied 20 d after rice planting, provided the soil can hold sufficient moisture to support rice growth. Early flooding in drill-seeded rice may inhibit germination of some grass weed species, but on the other hand, grass emergence may be completed in only 7 to 10 days after rice planting and a residual soil-applied herbicide can prevent further grass emergence.

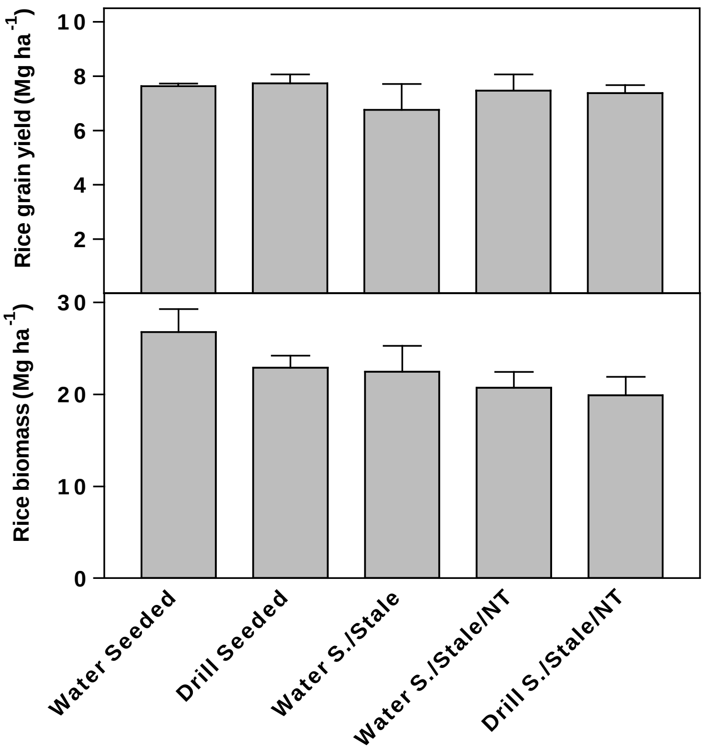

Figure 2. Rice grain and biomass yield in each establishment system. Error bars represent the 95% CI.

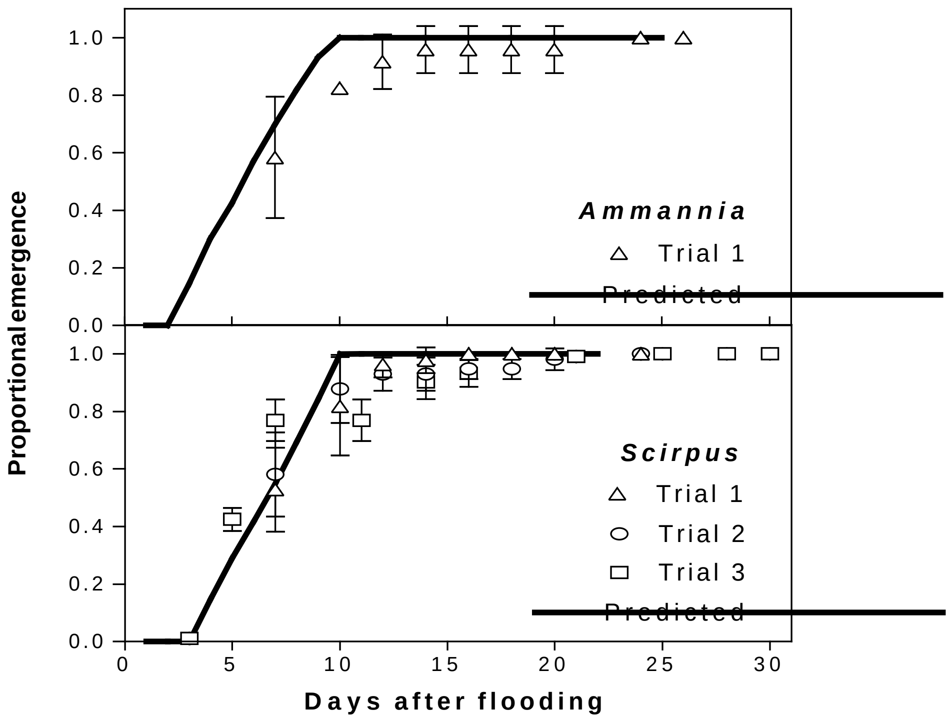

Figure 3. Field validation of model routines developed to predict the effect of temperature on weed emergence rates in flooded rice fields. Field observations were made from pots (10 cm by 10 cm) submerged under 10 cm of water in a rice field. Emerged seedlings were counted and removed from each pot every two days. Predicted emergence was estimated from hourly temperatures using variables defined in Table 1. Error bars represent the 95% CI.

This research provides rice growers the essential tools to control expanding populations of herbicide resistant weed biotypes. Various reasons determine that in many rice-growing areas water-seeded rice is grown continuously, without the potential benefits of crop rotation. Therefore, diversification of rice establishment methods may be the most practical short-term solution to manage herbicide resistance in CA rice. Results from this study demonstrate the efficacy of management techniques for alternative rice establishment systems that influence weed species recruitment and facilitate the use of herbicides with different mechanisms of action than herbicides used in conventional water-seeded rice. Additional funding for this project is provided by a UC IPM grant and a USDA IPM grant.

Enhancing rice cultivar weed suppressiveness.

We conducted a second season of experiments repeating those conducted in 2003. This project aims at delivering criteria for breeding competitive rice cultivars in order to delay the evolution of herbicide resistance, and reduce herbicide use. a). Competition experiment. A competition experiment was conducted at the Rice Experiment Station near Biggs, CA, in 2004. A total of 39 experimental lines of the population M-202/IR50 plus the two parents were studied. Cultivars were selected to support a complete factorial arrangement of three categories of heading time (early, 90-97 days after planting; intermediate, 99-105; and late 107-112) and three categories of plant height at maturity (short, 65-75 cm; intermediate, 78-90 cm; and tall, 92-110 cm). Each of the nine treatments was represented by at least two cultivars or a maximum of four. Plots size was 3.3 m^2, sub-plots were rice grown with and without watergrass competition. Each treatment was replicated four times. Sampling for growth analysis was conducted at 20 days after seeding (DAS) (to determine plant height and stand), 45 DAS, 75 DAS (to determine leaf area, tiller no., plant height, and total aboveground biomass) and at harvest to measure grain yield, yield components and harvest index. b). Phenotyping and QTL identification of competitiveness-related traits. A set of 138 recombinant inbred lines and parents from the M-202/IR50 population were planted with three replications. Stand, tiller number, plant height, leaf area, specific leaf area and total aerial biomass were measured at three intervals. Genetic studies from this experiment are in progress.

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

A study is being conducted to elucidate the bases for the current distribution of herbicide-resistant *Echinochloa* spp (early and late watergrass, and barnyardgrass) in California rice. Two-hundred and forty seed samples were collected in the fall of 2003 from throughout the rice growing region of the Sacramento Valley. Some grower-submitted samples were included in this group. All seed samples are being tested for resistance to Bolero, Ordram, Regiment, Clincher. Because it is known that herbicides tend to be over active in greenhouse conditions, all materials were applied at ½ the standard rate and the standard rate. Bolero was applied at 2240 and 4480 g ai/ha at the 1-2 leaf stage of grass (lsg). Ordram was applied at 2240 and 4480 g ai/ha at the 1-2 lsg. Regiment was applied at 20 and 40 g ai/ha at the 1-3 tiller stage. Clincher was applied at the rates of 63 and 126 g ai/a at the 1-3 tiller stage. Susceptible and resistant controls are included in the test.

Mechanisms and distribution of herbicide resistance in weeds of rice.

We have made substantial progress in the identification of the biochemical bases of herbicide-resistance in *Echinochloa* spp. Cytochrome P450 was identified as the mechanism conferring resistance to thiocarbamates and to ACCase-inhibiting herbicides. This mechanism of resistance is also responsible for the lower effectiveness of propanil. This knowledge has allowed for the identification of selective synergists to overcome resistance to bispyribac-sodium in late watergrass. Resistance was also identified towards clomazone. Cross-resistance patterns to different ALS-inhibiting herbicides (bensulfuron methyl, halosulfuron, penoxsulam, propoxycarbazone, bispyribac-sodium, and imazethapyr) have been characterized for a large collection of *Cyperus difformis* accessions gathered throughout the state, and the molecular bases of these resistances are being identified. This work is relevant for making decisions about the future scope and stewardship for ALS-inhibiting herbicides that are under development for use in CA rice. A large collection of early watergrass (*Echinochloa oryzoides*), late watergrass (*E. phyllopogon*) and barnyardgrass (*E. crus-galli*) has been gathered to study how herbicide resistance has evolved and propagated throughout CA rice fields. The flow of resistance genes will be assessed and related to geographical and field management patterns. Additional funding from UC IPM has been obtained and other grant proposals are being submitted to additional funding sources.

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9. Fischer, A.J., J.E. Hill, J. Williams, R.G. Mutters, K.D. Gibson, and T.C. Foin. Strategic concepts for herbicide-resistance management in California rice. Proceedings 30th Rice Technical working Group Meeting, Feb. 29-March 3, New Orleans, Louisiana.

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11. Gibson, K.D., A.J. Fischer, T.C. Foin, and J.E. Hill. 2003. Implications of delayed *Echinochloa* germination and duration of competition for integrated weed management in water-seeded rice. Weed Research. 42:351-358.

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

This year we continued to develop herbicide programs for water-seeded and drill seeded rice. Herbicide efficacy, including new compounds, tank-mix combinations and sequential applications continues to be a major emphasis of the program. We also tested new compounds, including an herbicide that is likely to be available next season, and another for controlling herbicide-resistant late watergrass. This work was conducted at the Rice Experiment Station and on a cooperating grower's property in Glenn County where highly resistant late watergrass exists. In addition, the program includes experiments that evaluate alternative crop establishment methods as a means of altering weed dynamics and diversifying herbicide options to manage herbicide-resistant weeds in rice. Research also addresses non-chemical options for weed management. Funding for our research program from the California Rice Research Board is expanded with additional funding from other grants.

Herbicide efficacy of currently registered and potential new herbicides has become a more crucial issue in recent years with the development of herbicide resistant weeds. Cerano, (clomazone) a pigment synthesis inhibitor, is a grass herbicide that has been tested for seven seasons at the Rice Experiment Station (RES) and two seasons at known resistant late watergrass sites in Glenn County, CA. Cerano has repeatedly demonstrated high efficacy on watergrass (*Echinochloa* spp.) and sprangletop (*Leptochloa fascicularis*) control, but has been less effective against herbicide-resistant watergrass. Very good broad-spectrum weed control was obtained with Cerano used in combination with either Shark (carfentrazone), or Super Wham (propanil); this last combination also provided good broad-spectrum control at the resistant site. Regiment (bispyribac-sodium) is a post emergent herbicide applied with a silicone surfactant. It is effective on watergrass, ricefield bulrush, and demonstrates good activity on California arrowhead. Regiment was tested in both continuous flood and pin-point (water drained for application) systems alone, in tank mixes, and in sequences. Regiment performed well in pin-point systems in sequence with Clincher (cyhalofop-butyl), and as a tank mix with Abolish; also as a follow-up treatment to Cerano, Bolero and Sofit in continuously flooded systems. Clincher (cyhalofop-butyl) is a post-emergent ACCase inhibitor that controls watergrass and sprangletop and is very safe on rice. Clincher appears to work best when applied as a sequential in pin-point systems. Very good broad-spectrum control was obtained when Clincher followed Super Wham at susceptible and resistant watergrass sites. Shark (carfentrazone) into-the–water was tested at different timings following Cerano in a continuously flooded system. Best broad-spectrum control, yield, and safety to rice occurred when Shark followed Cerano at the 2-4 leaf stage of rice. Prowl (pendimethalin) is a meristematic inhibitor that interferes with the plant's cellular division and early growth. The EC formulation is labeled for use in dry/drill-seeded rice in California, while the potential of the new H_2O (CS) formulation is being tested in water-seeded rice. At identical application rates, the EC formulation was generally more efficacious than the H_2O formulation. Tank mixes of Super Wham with both Prowl formulations improved grass control efficacy. IR-5878 is a sulfamoylurea (ALS inhibitor) that worked well in pin-point and continuously flooded systems, but provided poor control of ALS resistant sedge biotypes. Sofit (pretilachlor + safener) differs in mode of action with currently available rice herbicides for California. The pre-flood surface application provided excellent broad-spectrum control, but caused fairly severe stand reduction. Given the different mode of action and efficacy on resistant late watergrass, further research with this chemical is warranted. Granite GR (penoxsulam) is an ALS inhibiting post-flood herbicide for selective broad-spectrum control (not active on sprangletop and weak on resistant late watergrass). This formulation should be available for use in 2005. It performed well on susceptible weeds as a sequential following Cerano and Bolero, or followed by Stam (propanil) or Clincher. As with all ALS-inhibiting compounds, Granite will fail to control biotypes that are resistant to the mode of action of this compound.

Alternative rice establishment systems were developed and evaluated for their potential to shift and reduce weed species recruitment and facilitate the use of herbicides, such as pendimethalin and glyphosate, which have mechanisms of action capable of controlling weed biotypes resistant to herbicides used in conventional water-seeded rice. Evaluated rice establishment systems included 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. Species compositions of weed communities were distinctly different among establishment systems, as the water-seeded systems were dominated by sedge and broadleaf weed species but the drill-seeded systems were dominated by grass weed species. In the drill-seeded systems, grass control from pendimethalin and cyhalofop-butyl was > 89%. Glyphosate used in the stale seedbed systems reduced weed populations by 85 to 100% in drill-seeded rice and by nearly 100% in the water-seeded systems. In the water-seeded/stale seedbed/no till system, a pre-plant application of glyphosate onto emerged weeds was the only herbicide application required for nearly 100% weed control over the whole growing season. Rice yields 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.

In addition to the above studies, cross-resistance patterns to different ALS-inhibiting herbicides (bensulfuron methyl, halosulfuron, penoxsulam, propoxycarbazone, bispyribac-sodium, and imazethapyr) have been characterized for a large collection of smallflower umbrella sedge (*Cyperus difformis)* accessions gathered throughout the state, and the molecular bases of these resistances are being identified. This work is relevant for making decisions about the future scope and stewardship for ALS-inhibiting herbicides that are under development for use in CA rice. We also conducted a second season of experiments aiming at delivering criteria for breeding competitive rice cultivars in order to delay the evolution of herbicide resistance, and reduce herbicide use.