# 3 B.2 - ALTERNATIVE RICE STAND ESTABLISHMENT TECHNIQUES FOR MANAGING HERBICIDE RESISTANCE AND WEED RECRUITMENT

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Abstract: Five rice stand establishment systems have been evaluated yearly in northern California since 2004: 1) conventional water-seeded rice, 2) conventional drill-seeding, 3) water-seeding after spring tillage and a stale seedbed, 4) water-seeding after a stale seedbed without spring tillage, and 5) drill-seeding after a stale seedbed without spring tillage. Aquatic sedge and broadleaf weeds dominated the water-seeded systems, while the aerobic drill-seeded systems favored *Echinochloa* species and *Leptochloa fascicularis*. The stale seedbed technique (promotion of weed emergence with irrigation flushes, followed by pre-planting application of glyphosate) depleted weed populations from the upper soil layer and diminished weed emergence with the crop. If this technique was followed by no or limited soil disturbance prior to seeding rice, weed control required thereafter was minimal. In a fifth year, when drill-seeded plots with heavy *E. crus-galli* and *L. fascicularis* infestations were switched to water seeding after a stale seedbed without spring tillage, weeds were almost eliminated using only glyphosate.
Key Words: *Echinochloa*, *Leptochloa fascicularis*, glyphosate, stale seed-bed, drill-seeding.

## INTRODUCTION

Rice is produced on over 200,000 hectares in northern California's Sacramento Valley annually. Because of the prevalence of heavy flood-prone soils, rice in this region is grown as a water-seeded monoculture, perpetuating over many decades an un-rotated aquatic environment to which many serious weeds of rice have adapted. Since permanent flooding offers only partial control of weeds, water seeded rice culture has come to depend on repeated applications of post-emergent grass herbicides. The resultant high selection pressure has, in turn, led to the evolution of herbicide-resistant weeds, which have become one of the main problems threatening the long-term sustainability of California's rice-based systems (Fischer *et al.* 2000).

Minimum tillage with a stale seedbed offers new opportunities to control herbicide-resistant weeds in California rice fields. The approach entails preparing a stale seedbed before planting by flushing or flooding the field with water to induce weed-seed germination, and then killing the weeds. Usually broad spectrum herbicides like glyphosate are used. The soil is then left untilled to ensure that buried weed seeds are not brought to the surface to germinate. None of the weeds of rice has evolved resistance to glyphosate in California (Linquist *et al.* 2008). Stale seedbed systems are currently in use in the Mid-southern United States (Bond *et al.* 2005) and are also often used for the control of red rice in areas of South America and Europe (Fischer and Antigua 1997; Ferrero 2003). Minimum-till systems are not new to rice and are being evaluated in the southern United States (Watkins *et al.* 2004), Asia (Lal *et al.* 2004), South America (Salazar *et al.* 2002) and Europe (Martins and Fátima 2001).

A field experiment was established to assess the effectiveness of integrating cultural and chemical weed control practices to manage herbicide-resistant weeds by altering weed species recruitment and introducing new herbicides unique to specific rice establishment systems. To validate the experimental results, one of the stale seedbed treatments was implemented in a grower's field.

## MATERIALS AND METHODS

Five alternative rice establishment systems were developed and evaluated yearly 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 (Table 1). Plots were located at the California Rice Experiment Station (RES) near Biggs, CA (Lat: 39.4511613; Long: -121.71753) and were divided into four blocks, within which the five stand establishment systems were randomly arranged. Each treatment area measured 1821 $m^2$ and included a 455 $m^2$ weed recruitment section where no further herbicides were sprayed after seeding; the remainder of each treatment area received post-establishment selective herbicides as described in Table 1.

Continuously flooded plots had water applied and not drained throughout the duration of the season. Dry seeded rice (M-104) was drilled into the soil followed by flushes of water to establish the rice; subsequently a permanent flood was established. All sprayed herbicide applications were made with a CO2-pressurized (0.21 MPa) hand-held sprayer equipped with a ten foot boom and 8003 nozzles, calibrated for a spray volume of 187 L ha-1. Applications with solid formulations were performed by evenly broadcasting the product over the plots. Crop oil concentrate (1.25% v/v) was added to cyhalofop and propanil. Weed density was determined from ten 0.0929 m2 quadrates, randomly placed in the weed recruitment and post-emergent herbicide applied sections of each plot at approximately the time of rice canopy closure (20 to 30 DAP). Fertility management was adjusted to reduce the potential for lodging and to optimize harvest conditions with the plot combine. All data were analyzed using Statistical Analysis System (SAS version 9.1) software and a randomized complete block design.

In the fifth year of the study, treatments were rotated between plots to validate the potential of shifting aerobic and anaerobic stand establishment, and the value of implementing a stale seedbed with glyphosate to deplete fields from all kinds of herbicide resistant weeds. All drill seeding was replaced by water seeding and vice-versa to offset weed adaptations and all treatments, except a conventional water seeded control, were preceded by a stale-seedbed technique. Thus, only three of the original treatments were implemented this season: Water seeded conventional, water seeded stale seedbed and drill seeded stale seedbed. In addition, the two stale seedbed treatments were also no-till.

An alternative stand establishment technique was applied to a 40,000 $m^2$ check, at a private grower's field in Glenn County (Lat: 39.5654283; Long: -122.0683767) with a heavy herbicide-resistant *Echinochloa phyllopogon* (Stapf) Koss. infestation that has gone uncontrolled over the years in spite of multiple herbicide applications, causing heavy yield and economic losses. Resistance in this species was originally selected by the repeated use of thiocarbamate herbicides (molinate and thiobencarb); resistant biotypes are resistant to all grass herbicides available for use in rice in California, except propanil (Fischer et al. 2000). The spring-till stale seedbed method was used with a short season rice variety (M-104). The soil surface was kept saturated or under a shallow flood for ten days and thereafter the field was slowly drained; glyphosate was applied five days later. After two days, the field was re-flooded and seeded. A follow-up application of penoxsulam and cyhalofop-butyl was necessary for control of broadleaf weeds, sedges and a light *Leptochloa fascicularis* (Lam.) A. Gray presence that germinated after the re-flood.

## RESULTS AND DISCUSSION

Yearly data averaged from 2004 through 2007 shows drastic differences in weed recruitment among systems: aquatic sedge and broadleaf weeds dominated the water-seeded systems, while the aerobic seedbeds of the drill-seeded systems favored grasses (*Echinochloa* spp. and *L. fascicularis*). The stale seedbed technique was very useful in depleting weed populations from the upper soil layer, thereby 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. Conventional drill-seeded systems typically result in heavy weed recruitment, and although using stale-seedbed and minimum soil disturbance reduced weed recruitment by 40%), there were still many weeds present in the no-till drilled rice with a stale seedbed treatment.

In the water seeded conventional system the weed seedbank shifted over four years with reductions in *C. difformis*, *Ammania* spp., *H. limosa* and *L. fascicularis* and slight increases in *S. mucronatus* and *Echinochloa* spp. When switched to a no-till stale seedbed system, the early-season flush mainly recruited *Echinochloa* spp., *Ammania* spp. and *C. difformis*, which were subsequently killed by the glyphosate treatment. Drill seeding followed on that site in 2008 without any additional soil disturbance and weeds at canopy closure in the area that received no further herbicides were *Echinochloa* spp. and *L. fascicularis* (Figs. 4c, 5).

The water seeded spring tilled stale seedbed was dominated by *C. difformis*, *Ammania* spp.and *H. limosa*, though their seedbank populations decreased over four years along with *L. fascicularis*. *S. mucronatus* and *Echinochloa* spp. remained about the same. When switched to a water seeded conventional approach, there were very few weeds and the fields could have been taken to harvest without any further herbicide applications.

In the water seeded no-till stale seedbed, *C. difformis*, *Ammania* spp. and *H. limosa* dominated, though their populations were reduced, as was *L. fascicularis*. *S. mucronatus* and *Echinochloa* spp. remained about the same. Flushing for weed recruitment prior to glyphosate application encouraged *C. difformis*, *Ammania* spp., and *H. limosa* to germinate. These weeds were then killed by the glyphosate application. The drill seeding no-till stale seedbed treatment introduced in 2008 was accomplished without any further soil disturbance and had low weed pressure except for some patches of *L. fascicularis* visible in the area of the field that did not get any follow-up herbicides \. The original treatment was very successful. If the drill seeded no-till stale seedbed treatment is continued, *Echinochloa* spp. and *L. fascicularis* are likely to become problematic.

The conventional drill seeded system was dominated by *Echinochloa* and *L. fascicularis*, as is confirmed by the increase of *Echinochloa* spp. and *L. fascicularis* in the seedbank over four years of this treatment while *C. difformis*, *Ammania* spp. and *H. limosa* all decreased in number and *S. mucronatus* remained about the same. When switched to water seeded no-till stale seedbed, the pre-plant flushing of the soil encouraged germination of *Echinochloa* spp., *L. fascicularis* and *C. difformis*, which were subsequently killed by the glyphosate treatment. The resulting weed infestation at canopy closure was very low.

*Echinochloa* spp. and *L. fascicularis* dominated and increased in the soil the drill seeded no-till stale seedbed system, as is confirmed by the seedbank change from the beginning of the trial to just prior to changing the system. *C. difformis*, *Ammania* spp. and *H. limosa* decreased in numbers and *S. mucronatus* remained about the same. The stale seedbed treatment in spring 2008 recruited mainly *Echinochloa* spp. but also some *L. fascicularis*, *C. difformis*, and *Ammania*, which were then killed by the glyphosate application. This system was subsequently flooded and seeded without any further soil disturbance. Weed populations in the no-herbicide plot consisted of a few *Echinochloa* spp., *C. difformis*, and *Ammania* spp., suggesting that this treatment could have gone to harvest without any further herbicide applications, as confirmed by the photograph of the field.

Some of these results were confirmed in 2008 on a private grower's field with heavy multiple herbicide-resistant *E. phyllopogon* infestations. The spring tilled stale seedbed method was used and the glyphosate treatment controlled the resistant *E. phyllopogon*, *Leptochloa fascicularis*, broadleaves and sedges that were initially recruited by the flush/flood stale seedbed treatment. No new watergrass germinated in this field after the glyphosate applications. The weed infestation that emerged due to the early irrigation was substantial, as can be seen in the untreated control areas in figure 18, which illustrates the relevance of the stale-seedbed technique with glyphosate for controlling herbicide-resistant weeds.

## CONCLUSIONS

Consistently, the five systems produced comparable yields as when conventional weed control was applied to each treatment (Table 2). Alternating from aerobic rice to anaerobic rice establishment was successful in reducing weed infestations when this was combined with a stale seedbed (Figs. 4, 7, 10, 13 & 16) and yields were excellent and not different between areas with conventional weed control or when the only weed control treatment was glyphosate (Table 2). Again, this strongly demonstrates the potential for controlling resistant weeds and lowering herbicide use. The exception to this, was rotating out from conventional water-seeded rice into a drill-seeded-no-till treatment, where the stale seedbed technique was not able to fully eliminate the strong grass infestations associated with this system (Table 2). We advise against the use of drill seeding given the strong infestations that occur in this system and the opportunities for red rice infestations. In our experiments, drill seeding was helpful to diminish the pressure of aquatic weeds, but should only be used in conjunction with a stale seedbed technique and should be implemented either before or after water-seeded rice that involves the use of a stale seedbed treatment with glyphosate (Table 2). 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.

**Table 1.** Summary of rice stand establishment treatments.

| System | Flushing | Permanent Flooding | Herbicides | |
|---|---|---|---|---|
| | | | Pre-emergent | Post-emergent |
| Conventional water seeded | none | 10 d before planting (DBP) | None | propanil (6.7 kg a.i./ha at the 4-5 leaf rice stage (lrs). |
| Conventional drill-seeded | 1 and 7 DAP | 17 DAP | None | propanil, pendimethalin & cyhalofop-butyl (6.7 kg a.i./ha, 2.5 L/ha + 0.97 L/ha, respectively) at 3 lrs. |
| Water seeded/ stale seedbed | 30 and 18 DBP | at planting | glyphosate (1.6 kg a.e./ha) sulfate; 3 DBP | propanil (6.7 kg a.i./ha ) at the 4-5 lrs. |
| Water seeded/ stale seedbed/ no-till | 30 and 18 DBP | at planting | glyphosate (1.6 kg a.e./ha; 3 DBP | propanil (6.7 kg a.i./ha) at the 4-5 lrs. |
| Drill seeded/ stale seedbed/ no-till | 30 and 18 DBP & 1 and 7 DAP | 17 DAP | glyphosate (1.6 kg a.e./ha & 2% ammonium sulfate 3 DBP | propanil, pendimethalin & cyhalofop-butyl (6.7 kg a.i./ha, 2.5 L/ha + 0.97 L/ha, respectively) at the 3 lrs. |

**Table 2**. Paddy yields for five stand establishment systems implemented in a field experiment conducted at the RES[a] from 2004 to 2007

| | 2004 | | | 2005 | | | | 2006 | | | 2007 | | | | 2004-2007 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weed Control | Weedy | | Weed Control | Weedy | | | Weed Control | Weedy | | Weed Control | Weedy | | | Weed Control | Weedy | | |
| | lb/A (14% moisture) | | | | | | | | | | | | | | | | | |
| Water Seeded Conv | 9577 | 8202 | * | 8718 | 7516 | a | | 7923 | 4937 | * | 10751 | 9290 | abc | * | 9242 | 7486 | ab | * |
| Drill Seeded Conv. | 9658 | 6703 | * | 8974 | 2812 | c | * | 8140 | 2731 | * | 11388 | 6115 | d | * | 9540 | 4590 | d | * |
| Water spring seeded stale | 8437 | 8722 | * | 7834 | 8042 | a | | 7379 | 5308 | * | 10546 | 8506 | c | * | 8549 | 7644 | ab | |
| Water seeded no till stale | 9313 | 8415 | * | 8723 | 7061 | ab | | 7457 | 4062 | * | 10094 | 8945 | bc | | 8897 | 7121 | bc | * |
| Drill seeded no till stale | 9233 | 8303 | * | 8848 | 5101 | bc | | 8966 | 3326 | * | 11057 | 4182 | d | * | 9526 | 5228 | cd | * |

For each year and treatment, * indicates no differences (P>0.05) in yields of weed control and Weedy plots according to orthogonal contrasts tests; within columns, values followews the same letter are not different /NS, p>0.05) according Tukey's HSD test.

Table 3. Paddy yields of three stand establishment systems that were implemented in 2008 on plots where five alternative rice stand establishment systems were conducted during 2004-2007[a].

| Treatment 2004-2007 | Treatment 2008 | Weed Control | Weedy | |
|---|---|---|---|---|
| | | --- lb/A (14% moisture) --- | | |
| Water Seeded Conv | Drill seeded no till stale | 7310 | 6599 | b |
| Drill Seeded Conv. | Water seeded no till stale | 8175 | 8031 | a |
| Water spring seeded stale | Water Seeded Conv | 8180 | 8161 | a |
| Water seeded no till stale | Drill seeded no till stale | 7429 | 7832 | ab |
| Drill seeded no till stale | Water seeded no till stale | 8019 | 8176 | a |
| | | NS | | |

[a] For each treatment, Weed Control and Weedy plots were not different (P>0.05) according to orthogonal contrasts tests; within colums, values followed the same letter are not different (P>0.05) according to Tukey's HSD test; NS, means within a column are not different (P>0.05)

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