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Project Title: Managing Watergrass (*Echinochloa* spp.) Resistance To Rice Herbicides in an Aquatic Environment: Research and Demonstration in Affected Farms

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ABSTRACT

California rice is being subjected to an epidemic of herbicide resistance in watergrass (*Echinochloa* phyllopogon and *E. oryzoides*) populations. Watergrasses are the major weeds of rice and the development of herbicide resistance not only deprives farmers of essential tools for weed control, but also results in increased herbicide rates and frequency of application. This problem has, thus, serious economical and environmental implications. This study was implemented in a conventional rice grower's field in Glenn Co. where lack of watergrass control with molinate, thiobencarb, and fenoxaprop has been repeatedly observed. The objective of the 2001 activity was to conduct the third and

final year of a medium-term field experiment (Main Trial) initiated under this grant in 1999 to evaluate in a systems approach key management options for reducing herbicide selection pressure towards resistance, namely: 1) annual rotation to herbicides with different mechanisms of action or tank mixtures and sequential applications of herbicides with different mechanisms of action, and 2) the use of transgenic rice cultivars resistant to environmentally friendly broad-spectrum herbicides, and 3) reducing seed survival with appropriate straw management practices by initiating a comparison of the seed survival rate under a) straw cover (straw chopped), b) straw burn, and c) straw incorporated (all three treatments were followed by winter flooding) post-harvest management practices which are expected to affect the soil re-infestation with herbicide-resistant seed. This year's activities also involved continuing the tracking of treatment effects on seed bank populations, using the research site as a field demonstration site by conducting a field day in collaboration with UC Cooperative Extension personnel, and making the site available for researchers interested in concurrent issues. The Main Trial and two additional separate experiments were conducted on this site in 2001. Te Main Trial and straw management trials were sampled, planted, treated and evaluated, and a herbicide screening trial was conducted, which tested various herbicides alone and in combination for in-season control of this thiocarbamate resistant early watergrass population. Also during this period, work was completed on the extraction and examination of watergrass seed taken from the fall 2000 and spring 2001 soil samples from the main and straw trials. Results from seedbank monitoring in the Main Trial show that under the three alternative herbicide strategies, new seed rain in 2000 was severely limited, weed pressure in 2001 was greatly reduced, and this resistant population of watergrass was being brought under control. In contrast, continuous molinate treatments have failed to limit reseeding sufficiently (8 times higher new seed rain in 2000) and seedbank densities remain high. Extremely good control obtained this year with the alternative herbicide treatments and continued poor control with molinate is expected to widen this difference even further. First results from the straw trial indicate that winter survival of new seed where straw was incorporated was about 3 times the survival rate where straw was burned or chopped - 66%, 20%, and 23%, respectively. The survival of old seed was not affected by straw treatment. When straw cannot be burned, chopping and flooding appears to be a preferable alternative to incorporation for limiting the survival of resistant watergrass seed. Other fundamental population dynamics parameters such as seedling emergence (highly variable), summer survival (highly depth dependent), and recruitment (highly density dependent) have also been measured. These data are contributing greatly to the development of a more comprehensive model of watergrass dynamics that suggests how other alternative cultural practices and whole systems could potentially increase control, reduce expense, and/or decrease herbicide use. Preliminary results comparing dose-responses to thiobencarb for an initial (1999) and a final (2002) population of water suggest that an intensive strategy involving sequential applications of herbicides with different modes of action reduced the average level of resistance in the emerged watergrass population. However it appears that substantial resistance still persists in those plots, thus, the continuation of an integrated approach to watergrass control appears to be absolutely necessary.

EXECUTIVE SUMMARY

Because of an epidemic of herbicide resistance in watergrass (*Echinochloa phyllopogon*, and *E. oryzoides*) in California rice, a three-year study was conducted to understand the role of herbicide management in delaying the development of resistance, and to introduce concepts for the integrated management of herbicide-resistant watergrass. The experiments were conducted during 1999, 2000 and 2001 on a cooperating farmer's rice field in Colusa Co., CA. This field is heavily infested with early watergrass (*E. oryzoides*), with resistance to molinate, thiobencarb, bispyribac-sodium and fenoxaprop-ethyl. Research focused on developing and demonstrating knowledge on rational herbicide use strategies for resistance management, which is essential for the implementation of sustainable integrated watergrass management strategies, and assessed the contribution of postharvest straw management techniques to reduce the watergrass soil seed-bank. Watergrasses are the major weeds of rice and the development of herbicide resistance not only deprives farmers of essential tools for weed control, but also results in increased herbicide rates and frequency of application. This problem has, thus, serious economical and environmental implications.

The objective of the 2001 activity was to conduct the third and final year of a field experiment initiated under this grant in 1999 to evaluate in a systems approach key management options for reducing herbicide selection pressure towards resistance, namely: 1) annual rotation to herbicides with different mechanisms of action or tank mixtures and sequential applications of herbicides with different mechanisms of action, 2) the use of transgenic rice cultivars resistant to environmentally friendly broad-spectrum herbicides, and 3) reducing seed survival with appropriate straw management practices by initiating a comparison of the seed survival rate under straw cover, straw removal, and straw incorporated post-harvest management practices which are expected to affect the soil re-infestation with herbicide-resistant seed. This year's activities also involved continuing the tracking of treatment effects on seed bank populations, using the research site as a field demonstration site by conducting a field day in collaboration with UC Cooperative Extension personnel, and making the site available for researchers interested in concurrent issues.

This experiment was implemented in a conventional rice grower's field in Glenn Co. where lack of watergrass control with molinate, thiobencarb, and fenoxaprop has been repeatedly observed. In this third year of the project the herbicide trial was planted, treated and evaluated, seedbank populations were also evaluated in an expanded site area that had been prepared in 2000 for the application of straw management treatments after harvest, part of a demonstration area was utilized to test tank mixed combinations of herbicides on this resistant watergrass population. Several important results were obtained this season: In the main trial the alternative herbicide strategies employed in the second season of the project (2000) were confirmed to have severely limited watergrass reseeding. Post- harvest seed density was decreased by 96% over 2 years. This supports the view that *Echinochloa spp.* have an extremely dynamic seed-bank susceptible to

being rather quickly depleted, and that the prevention of reseeding with effective herbicides that provide 99% control, is key to that strategy. In this year the herbicides glufosinate and bispyrabac continued to demonstrate the high degree of control required on this thiocarbamate-resistant population. Clomazone also demonstrated the potential for extremely high efficacy. Propanil, presently being used by growers, appears to be somewhat less effective, requiring multiple applications or combination with other herbicides to reduce reseeding sufficiently, especially when the soil seedbank has been built up to levels on the order of several thousand watergrass seed per square meter. In contrast to these effective herbicides, a strategy of continuous molinate use has failed to bring this resistant population under control. Similarly we have found that thiobencarb, fenoxaprop, and cyhalofop cannot be expected to adequately control this population. This project has also demonstrated that herbicide chemistry alone does not determine the degree of weed control; herbicides must be matched with optimum water management, rice stand establishment and canopy competition. There is a need for further studies to integrate alternative herbicide strategies with alternative cultural practices to improve the overall efficacy of whole systems.

Year round tracking of watergrass weed and seed densities has proven to be a successful means not only for evaluating herbicide use strategies over years, but also for evaluating the effects of straw management practices (1. burn, 2. chop, and 3. chop and incorporate; all three followed by winter flooding) were repeated this year. on the winter survival of watergrass seed. We can now conclude that the increasing frequency of failure to control watergrass that growers are experiencing is essentially due to increasing levels of thiocarbamate resistance resulting from repeated herbicide use exacerbated by a build-up in seed density due to fall burial when straw is incorporated. First results from this straw trial indicate that survival of new seed where straw was incorporated (66%) was 3 times the survival rate where straw was burned or chopped (20 and 23 %, respectively). When straw cannot be burned, chopping and flooding appears to be a preferable alternative to incorporation. Other fundamental population dynamics parameters such as seedling emergence (highly variable), summer survival (highly depth dependent), and recruitment (highly density dependent) have also been measured and discussed.

After completing three years of experiments, the concepts for the integrated management of herbicide-resistant watergrass evaluated in this project have led to the general conclusion that appropriate cultural practices work together with effective herbicides to suppress resistant watergrass populations. The integration of plant and seed density data provided a suitable framework for detailed tracking of the populations during three years. This enabled a comprehensive evaluation of both chemical and cultural components of an overall management strategy. Further, the data generated here are contributing greatly to the development of a more comprehensive model of watergrass dynamics that suggests how other alternative cultural practices and whole systems could potentially increase control, reduce expense, and/or decrease herbicide use. New practical integrated strategies are suggested by our data, such as pre-irrigation and no-till, in which herbicide use is complemented by other cultural weed control options. These should be the subject of further studies. Preliminary results comparing dose-responses to thiobencarb for an initial (1999) and a final (2002) population of water suggest that the Intensive combinations strategy involving two applications per season of single and tank-mix applications of herbicides with different modes of action has reduced the average level of resistance in the emerged watergrass population. However it appears that substantial resistance still persists. This would imply that reducing the overall infestation, although a major step, is not an indication of eradication of resistance from a field after three years of this strategy. Returning to the sole use of thiocarbamates in such fields would again allow resistant plants to produce large amounts of seed, which will quite rapidly reverse the progress achieved. The continuation of an integrated approach to watergrass control in those fields appears to be absolutely necessary.

In cooperation with UC Cooperative Extension, results from these experiments have been presented in field days, growers meetings, and scientific conferences from 1999 to 2002.

REPORT

Introduction

Pest management in rice is exceedingly complicated by the flooded nature of rice culture and by the lack of rotation to other crops due to the poorly drained nature of the heavy clay rice soils. Herbicides, which are still the main tool for weed control in rice, are applied into an aquatic environment, raising concerns about water quality and aquatic organism health. Ground applications are difficult and slow on flooded fields, thus most herbicides are applied by air. Herbicide drift has often resulted in injury to neighboring crops, such as walnuts, fruit trees and cotton. Concerns about crop safety and environmental health in California have restricted the availability of herbicides for rice compared to other crops.

Continuous rice, the limited opportunities for cultural control, and the few available chemical tools have resulted in the repeated use of herbicides with the same mechanism of action for the control of watergrass (*Echinochloa phyllopogon*, and *E. oryzoides*), which are the worst weeds of California rice. The herbicides available for watergrass control in rice (propanil, molinate, thiobencarb, and fenoxaprop) represent only three different mechanisms of action. The frequent application of herbicides with the same mechanism of action has exerted significant selection pressure on watergrass populations in favor of herbicide-resistant watergrass biotypes (Fischer et al. 2000). Herbicide resistance is not new to California rice. In fact, resistance to bensulfuron (Londax) in broadleaf weeds and sedges has reached epidemic proportions in the recent past. Most rice farmers in California cannot use this herbicide any longer; substitute herbicides have offered only partial help. In 1999 a new herbicide introduced to replace bensulfuron has resulted in severe drift injury to prune trees. Recent data also indicates that watergrass exhibits cross- and multiple resistance to existing and new, still unregistered, herbicides (Fischer et al. 2000, 2000b). In many cases watergrass accessions collected from rice fields have tested resistant to three of the four available herbicides. The exception was propanil; this has prompted increased use of this herbicide, which requires very judicious use to prevent damage to fruit trees from spray drift. Due to proximity to fruit trees and cotton the use of this herbicide is restricted for many areas of California rice. Herbicide resistance thus severely reduces farmers' options for weed control. Weed control failure due to resistance usually leads to increased dosages and number of applications that compromise water and environmental quality, the cost of weed control, the safety to rice and neighboring crops, and the economic viability of California's rice industry. Herbicide resistance in watergrass has reached epidemic proportions, but we are at a window where development and demonstration of resistance management strategies may have significant long-term results in delaying the development of resistance, and avoiding futile herbicide overuse.

Because of this new resistance epidemic in California rice, the University of California at Davis has undertaken a medium-term study to examine the effects of new methodologies in reducing infestations by herbicide-resistant watergrass. Since herbicide use is the driving force of this process, and herbicides are an essential tool for weed control as well as an environmental concern, it is of paramount importance that we understand the role of herbicide management in delaying the development of resistance. Scientifically validated knowledge in this area is woefully lacking. This research thus focuses on developing and demonstrating knowledge on herbicide use strategies, including the use of herbicide-resistant rice cultivars, for resistance management. This knowledge is essential to allow for the successful implementation of integrated management strategies, where herbicide use is complemented by other non-chemical weed control options.

The objective of the 2001 activity was to conduct the third and final year of field experiments initiated under this grant in 1999 to evaluate in a systems approach key management options for reducing herbicide selection pressure towards resistance, namely: 1) annual rotation to herbicides with different mechanisms of action or tank mixtures and sequential applications of herbicides with different mechanisms of action, and 2) the use of transgenic rice cultivars resistant to environmentally friendly broad-spectrum herbicides, and 3) reducing seed survival with appropriate straw management practices by initiating a comparison of the seed survival rate under straw cover, straw removal, and straw incorporated post-harvest management practices which are expected to affect the soil re-infestation with herbicide-resistant seed. This year's activities also involved continuing the tracking of treatment effects on seed bank populations, using the research site as a field demonstration site by conducting a field day in collaboration with UC Cooperative Extension personnel, and making the site available for researchers interested in concurrent issues.

This research project was implemented in a conventional rice grower's field in Glenn Co. near the Princeton/Norman Road area of the northern Sacramento valley where lack of watergrass control with molinate, thiobencarb, and fenoxaprop has been repeatedly observed.

Materials and Methods

Three separate trials were conducted on the Maben Farms site in 2001 (Figure 1).

1. The **Main Trial** consisted of large plots to test herbicide management strategies for their efficacy in bringing a resistant watergrass population under control and for delaying the development of herbicide resistance in watergrass.
2. The **Straw Management Trial** investigated the effect of non-chemical cultural practices on reducing the soil reservoir of watergrass seed.
3. The **Herbicide Screening Trial** tested various herbicides alone and in combinations for in-season control of herbicide-resistant watergrass.

Spring 2001 soil sampling for watergrass seed. The trial area was drained Feb. 28. On 4/3 the straw trial was sampled using a stratified random pattern, 4 cores/plot divided into 0 - 2" and 2 - 5" depths, just as was done for the fall 2000 samples. Each 4" diameter core sampled a surface area of 0.0071 m^2. Emerged watergrass seedlings were counted in a 1 m^2 quadrat placed at each core position. After seedbed preparation, preplant samples were taken from the straw plots on 5/1 (4 cores/plot) and from the main plots on 4/30 (8 cores/plot). Each of these cores consisted of the entire column of dry tilled soil down to the depth of the plow pan (average depth 5.8")

Seedbed preparation and fertilization. The entire area was chiseled on 4/5 and disked on 4/13. The levees enclosing the main plots were built up with a ridger on 4/10 by a local custom operator. The plots of the herbicide trial were planed on 4/18 with a small implement borrowed from the Rice Experiment Station. Seedbed preparation was interrupted by rain on 4/20. The area outside the main plots was reworked with a second pass with the disk and planed on 4/27. On 4/29 the straw trial area received 120 lb N/ac as aqua ammonia. On 4/30 the main trial and the herbicide screening trial received 600 lb/ac of ammonium sulfate (126 lb N/ac) by air. This fertilizer was incorporated with a chisel on 5/1. The entire trial area received a "starter" application of 150 lb/ac ammonium sulfate (32 lbN/ac) prior to flood. Flooding of the entire area began on 5/7.

Rice planting. In the main plots presoaked seed was broadcast into the flood water by hand on 5/11. The variety M202 at a rate of 150 lb/ac was seeded in the plots receiving treatments 1, 2, and 3. The Liberty-Link variety used for treatment 4 (glufosinate herbicide) was seeded at a rate of 200 lb/ac because poor germination was anticipated. The straw trial area was seeded with M204 on 5/12.

Herbicide applications. In 2001 the herbicide strategy treatments applied in the main trial were as follows: <u>1. Continuous molinate</u>: Ordram 15 G was applied by hand with a belly grinder at a rate of 4 lb ai/ac at 1 leaf stage rice (lsr) 5 days after seeding (DAS) followed by (fb) MCPA at a rate of 1 pt/ac 28 DAS at the 2 tiller stage (2T). <u>2. Intensive combinations:</u> Command 5G (clomazone) applied by hand, 0.6 lb ai/ac at 1 lsr 5 DAS, fb a tank mix of Regiment (bispyribac-sodium) 12 g ai/ha and Superwham (propanil) 6 lb ai/ac. <u>3.Annual rotations:</u> Command 5G (clomazone) applied by hand, 0.6 lb ai/ac at 1 lsr 5 DAS fb MCPA at a rate of 1 pt/ac. <u>4. Continuous glufosinate:</u> Liberty 1.67SL at 500 g ai/ha. All of the spray applications were applied by the grower 28 DAS, 2T stage, with his ground rig equipped with a 60 ft boom using 15 gallons of water per acre (GPA). The straw trial area received one application of Superwham at 6 lb ai/ac, 27 DAS, 2T stage, also applied by the grower. The herbicide screening trial was treated with the various herbicides at the timings listed (Table 3). These applications were made to the 10 ft x 20 ft staked plots by backpack sprayer with a 5 ft boom.

Other applications. The insecticide Warrior was applied by air at the four leaf stage of rice for control of water weevil. One application of the fungicide Quadris was applied by air at boot split stage for control of blast.

Watergrass plant density and other field data collected. Water depth was monitored every 2 days in each trial area and in each of the main plots. At 21 DAS emerged watergrass density was determined by counting the number of plants inside a 1 ft^2 quadrat placed 4 times in each plot. Rice seedling vigor was rated at this time on a 1-10 scale. AT 27 DAS rice stand was estimated using the 1 ft^2 quadrat placed twice in each plot. The continued growth of watergrass and the emergence of *Cyperus difformis* (CYPDI) and *Monochoria vaginalis* were noted. At 40, 61 and 82 DAS the density of watergrass plants visible above the rice canopy were estimated. A final evaluation of watergrass infestation in each plot was made in September (116 DAS) by estimating the density of watergrass panicles. A collection of mature seed from the watergrass panicles in each plot was made at that time.

Extraction and evaluation of watergrass seed from 2000 post-harvest and spring 2001 soil samples. Apparently viable watergrass seed were extracted as described previously (Final Report, 2000) from five sets of soil samples. These samples were taken from each plot of the (1) main and (2) straw trials in fall 2000, (3) an early spring sampling of the straw trial, and (4),(5) preplant 2001 samples taken from both trials. Although the differences between new and old seed are less distinct in the spring than in the fall, new and old seed extracted from the early spring and preplant samples of 2001 were counted separately.

Rice harvest. Grain yield in the Main Trial was obtained on 10/9/01 by harvesting one 20 ft wide swath 350 ft long down the middle of each plot with the grower's harvester. This combine sample was weighed in a weigh wagon borrowed from UC Davis small grains program and samples were taken for moisture determination. The small plots of the Herbicide Screening trial were harvested with the small plot harvester borrowed from the Rice Experiment Station. Individual plot grain yield was not determined for the Straw Management Trial.

Post-harvest 2001 soil sampling and extraction of seed. Beginning the day after harvest, final samples were taken from the plots of the Main Trial in a stratified random pattern, taking 32 cores/plot, each divided into 0 - 2" and 2 - 5" depths. Since each 4" diameter core sampled a surface area of 0.0071 m^2, the total sampled area of each plot was 0.227 m^2. This is four times the volume of soil sampled previously and was judged necessary in order to accurately measure the anticipated very low seed densities. Seed were extracted from these samples as previously described, numbers of new and old seed from upper and lower soil layers were recorded separately and the densities calculated. Plots of the Straw Trial were sampled similarly in a stratified random pattern taking 16 cores/plot.

Application of treatments to plots of Straw Management Trial. The three straw treatments applied after rice harvest in 2000 (See Final Report for 2000, Agreement No. # 99-0221, prepared on March 1, 2001): (1) burn, (2) chop, and (3) chop and incorporate were repeated this year. Rice stubble in the entire straw trial area was chopped after harvest. A water truck was used to wet the straw around the plots to be burned in order to contain the burn. An excellent burn estimated to remove greater than 95% of the straw was obtained. In contrast to the previous fall when, due to rain, incorporated plots were only chiseled one pass, good weather in fall 2001 allowed three passes with a disk which incorporated the straw in those plots very well. The entire area was then flooded for the winter. A final sampling in March, 2002 will be necessary to determine seed survival during the second winter of this trial and evaluate the effect of these treatments.

Final tests for differences in evolution of resistance. Watergrass seed collected from the panicles of plants in the third year are presently (February, 2002) being compared with original seed from the initial seedbank in 1999 and with a susceptible accession of watergrass in a dose-response test that will measure the degree or proportion of thiocarbamate resistance. The objective is to learn how the different herbicide use strategies may have affected the evolution of resistance in this population. Another test will screen the seed collected in the third year from the plots that received continuous glufosinate treaments to determine whether this treatment has caused a detectable amount of glufosinate resistance to evolve. The results of these tests, along with final results from the straw management trial, will be reported in a supplement to this report.

Results and Discussion

a. Research, Main Trial

Correction to 2000 final report. In the final report of 2000 a preplant seed density averaging 460 seed/m^2 was reported (Table 2, p. 26). A critical review of the sampling and processing procedures followed at that time leads us to question this result. We must therefore declare that preplant seed density in the Main Trial in 2000 was not determined. This also means that the estimate of 95% decline in seed density during the first winter, and the estimates that 21 to 30 % of the preplant seedbank emerged as watergrass seedlings in 2000 cannot be substantiated with reliable data. Reports and discussion of these results elsewhere in the 2000 report should be disregarded (see Abstract, p. 6, Executive Summary, p. 7, Results and Discussion, p. 16 and 17, Summary and Conclusions p. 20, and footnotes 1 and 2 of Table 2, p. 26). This error in no way compromises our conclusions discussed below regarding the impact of herbicide use strategies on the watergrass population.

Fall 2000 seedbank assessment. The density of new watergrass seed recovered from the surface of the main trial was significantly higher (by about 8 times) in the continuous molinate plots than from the plots where the alternative herbicide strategies were employed (Table 1). Moreover, the ratio of new to old seed was 1.5 under continuous molinate treatments but only 0.25 under the alternative herbicide use strategies. These results confirm the success of the alternative treatments used in 2000 (2 applications were necessary) to severely limit reseeding and thus begin to deplete the seedbank. At the same time, it is clear that the continuous molinate treatment has failed to limit reseeding sufficiently, even though a split application at a higher rate (5 lb ai/ac) was used in conjunction with deep water to give 94% control in 2000 (Final Report, 2000). Old seed were recovered mainly from the lower 3 to 5" soil layer (87% of the total, data not shown). The total density of old seed, however, was not significantly different by treatment (Table 1).

Spring 2001 seedbank assessment, winter seed survival, and seedling emergence. The density of new watergrass seed recovered from preplant samples taken from the main trial was still significantly higher (about 5 times) from the continuous molinate plots than from the plots where the alternative herbicide strategies were employed (Table 1). Under the chop and flood winter straw treatment applied to the whole trial, winter survival of new seed was 32% (Table 1). Winter survival of old seed was about 64% with no difference by herbicide treatment (Table 1). Calculated as a proportion of the total preplant seedbank (new plus old seed) emergence of watergrass seedlings was 2.8% in both the molinate and glufosinate treatments (Table 1). No emergence was detected in those plots treated with clomazone. The lower density of emerged seedlings in the molinate and glufosinate plots (28 and 18 per m^2) than in the previous year indicates that the 2 herbicide applications used in 2000 and the deep water in the molinate treated plots had limited reseeding to a level that reduced weed pressure in the subsequent year. However, increasing herbicide rates is not an advisable practice, since it will increase selection pressure in favor of herbicide-resistant individuals and, thus, hasten the evolution of resistance in field populations of the weed.

Performance of herbicide applications in the Main Trial. Under the continuous molinate treatment mature watergrass plant density at 82 DAS was 13 plants/m^2 and plant survival was 46% (54% control), which indicated a failure of control by molinate due to resistance (Table 1). In 2000 we were able to improve control with molinate by using a continuous deep flood of about 5 to 6" water depth. We were not able to manage water as effectively this year because of a broken pump that allowed water to drop to a low of 2.2" seven days after treatment (Figure 2). This illustrates the practical difficulties that growers face in managing water with increasingly limited and irregular supplies. Evaluation of rice soon after treatment indicated a normal stand of 20 plants/m^2 but some injury at 21 DAS relative to the glufosinate treatment which was untreated at that time (Table 1).

The continuous glufosinate treatment resulted in a mature watergrass plant density of 0.27 plants/m^2 and plant survival of 1.5% (98.5% control) - significantly better than the molinate treatment (Table 1). This represents quite good control with only one application this year when compared to the 95% control obtained in 1999, or to the 2 applications used in 2000. Performance this year appeared to be aided by the exceptionally high stand establishment (290 plants/m^2, Table 1) due to the higher seeding rate, which seemed to provide stronger rice competition. Another factor could have been the lower ratio of new to old watergrass seed due to the success of this treatment in preventing reseeding in the previous year. Overall, the use of glufosinate on transgenic Liberty-Link rice has demonstrated its potential as a viable strategy for the control of thiocarbamate-resistant watergrass.

Both a rotational strategy and the intensive strategy included the early application of clomazone and in both there was no observable emergence of watergrass at 21 DAS. Mature plant density at 82 DAS however was significantly less under the intensive strategy than the rotational strategy (0.0008 and 0.008 plants/m^2 respectively, Table 1). This greater control by a factor of ten was due to the added effect of the foliar application of propanil and bispyrabac under the intensive strategy. This extremely low density of mature watergrass plants represents only about 2 plants per 0.57 acre plot. Since the preplant seed density in these plots was about the same as in the glufosinate plots, a plant survival value was calculated assuming that the same density of 18 plants/m^2 would have emerged there had it not been treated with clomazone. This calculation resulted in extremely low watergrass survival (0.004% and 0.04%, Table 1) and corresponding extremely efficacious control (99.996% and 99.96%) for the intensive and rotational strategies, respectively.

This remarkably good performance of clomazone however, was obtained with significantly greater early rice injury and stand depletion than with molinate (Table 1). By midseason the rice appeared to have largely recovered from this early injury (see rice height at 40 DAS, Table 1). Further studies with clomazone should investigate its efficacy and safety under various water management regimes.

Although the alternative herbicide strategies succeeded extremely well this year in controlling this population of thiocarbamate resistant watergrass, it is worth noting that the continuous molinate treatment followed by MCPA controlled *Cyperus difformis* significantly better (Table 1).

2001 Rice Grain Yield and Moisture. (see Table 2) It seems quite clear that yield was significantly lower in the molinate treated plots because of largely uncontrolled watergrass competition. It is less clear why the intensive combination treatment yielded significantly higher than the other two alternative treatments. Watergrass competition is unlikely to have a detectable effect on yield at such low densities (Table 1) (Hill et al, 1985). Also unexplained are the distinct significant differences in grain moisture among the different herbicide treatments. Early ratings of rice injury and density appear not to explain these differences. In particular, there is no evidence that indicates the early injury and stand reduction caused by the clomazone treatments had any effect on yield. It is possible that *Cyperus difformis* played a role here. Also since one replicate yielded significantly more and had higher moisture we may speculate that perhaps water management played a role as well. We may conclude from this that when the dominant factor of watergrass competition is removed by extremely effective herbicides, only then do other secondary factors determine yield differences.

Final seedbank assessment. Loss of control by molinate in 2001 caused a tremendous amount of reseeding in those plots. The density of new seed on the soil surface after harvest was measured at 9770 seed/m^2 (Table 2) – about 10 times the density of preplant seed in 2001. In contrast, the alternative treatments were extremely effective in limiting reseeding; only 25-29 new seed/m^2 and 190 new seed/m^2 for the clomazone and glufosinate treatments respectively (Table 2). Final old seed density averaged about 350 seed/m^2 in the plots of the alternative treatments and 570 seed/m^2 in the molinate treated plots. Only 4% of these old seed were in the upper 2" soil layer, 96% were below 2" deep in the soil. This confirms results from the first two years of this project and indicates the extent to which upper soil layers may be severely depleted of seed.

Final tests for differences in evolution of resistance. The dose-response testing to asses if the herbicide strategies, besides reducing the soil seed-bank, have also affected the proportion of resistant vs. susceptible individuals in the watergrass population are currently under way in the greenhouse at the Rice Experiment Station at Biggs. Preliminary results suggest that the Intensive combinations strategy involving two applications per season of single and tank-mix applications of herbicides with different modes of action has reduced the average level of resistance in the emerged watergrass population. However it appears that substantial resistance still persists.

Results and conclusions from the entire three-year Main Trial. Table 3 provides an overview of watergrass densities and herbicde efficacy throughout the three years of this project. In the first year single applications of propanil and glufosinate (on Liberty-Link rice) each provided 95% control contrasted with 31% by molinate. Nevertheless, seed density increased from a preplant value of 3,400 seed/m^2 uniformly distributed in all plots, to about 9,500 seed/m^2 after harvest in the plots receiving alternative herbicide strategies. In the second year 2 applications of all alternative treatments provided greater than 99% control and severely limited reseeding. These highly effective alternative treatments then caused a decrease in watergrass seedling density before treatment in 2001 of 81% in one year. Post-harvest seed density decreased 96% over 2 years.

Average density of emerged watergrass seedlings was about 3% of the preplant seedbank. Average summer seed survival in soil was about 45% but highly depth dependent: ~ 10% in the top 5 cm of soil and ~80% below 5 cm. Recruitment was typically about 1000 new seed per mature watergrass plant, but ranged from ~300 at very high watergrass densities to several thousand at very low densities.

Watergrass has an extremely dynamic seedbank susceptible to being quickly depleted. Control of reseeding with effective herbicides that achieve 99% control is essential. For severe infestations two applications may be necessary. Overall, glufosinate, bispyrabac, and clomazone demonstrated the high degree of efficacy required to control this resistant population. Propanil was slightly less effective. In contrast, molinate failed to control this resistant population. Preliminary results comparing dose-responses to thiobencarb for an initial (1999) and a final (2002) population of water suggest that the Intensive combinations strategy has reduced the average level of resistance in the emerged watergrass population. However it appears that substantial resistance still persists. This would imply that reducing the overall infestation, although a major step, is not an indication of eradication of resistance from a field after three years of this strategy. Returning to the sole use of thiocarbamates in such field would again allow resistant plants to produce large amounts of seed, which will quite rapidly reverse the progress achieved. The continuation of an integrated approach to watergrass control in those fields appears to be absolutely necessary.

b. Research, Herbicide Screening Trial

The results of this trial (Table 4) should be interpreted keeping in mind the variation in water depths that occurred in the trial area (Figure 2). In particular, note that due to a broken pump, water depth reached a low of 1.2" at 12 DAS which was just a few days after the early applications of Ordram (molinate), Bolero (thiobencarb), and Command (clomazone). Although poor watergrass control with Ordram and Bolero was expected because of resistance, low water undoubtedly contributed. It is instructive to contrast the poor control with clomazone in this (stake) trial with the very good control obtained in the main trial. The difference appears to be due to the fact that the drop in water level in the main trial occurred about 2 days later relative to treatment date and did not drop to as low a level (2.2", Figure 2). This sensitivity of clomazone to slight differences in water management is further evidence of the need for exploring the potential for using clomazone under different water management regimes as suggested above.

Among the foliar sprays applied at the 1-3 tiller stage, the application that is presently most widely used by growers, Super Wham at 6 lb ai/ac, gave 83% control of watergrass and 100% control of CYPDI (Table 4). Clincher alone was not effective (which confirms previous results), probably because this population is already resistant to ACCase inhibitors. When Clincher was mixed with SuperWham at 4 lb ai/ac however, control was improved to 90%. As in previous years Regiment gave excellent control of watergrass (100%) but used alone does not control CYPDI. Control of CYPDI was 100% with a mixture of Super Wham and Regiment, but watergrass control dropped to 82%; this antagonistic effect was also observed in other trials conducted at the Rice Experiment Station near Biggs, CA. Thiobencarb can control CYPDI but when used early in the granular form (Bolero), lowering of water for the later foliar application of Regiment can release CYPDI. When used in the liquid form (Abolish) as a tank mix with Regiment, it may be too late for good CYPDI control. There is a great need to explore the interactions of water management with herbicide, rate, and timing especially when sequential applications are involved.

c. Research, Straw Management Trial

Initial seedbank in fall 2000. The three straw treatments applied after rice harvest in 2000 (See Final Report for 2000, Agreement No. # 99-0221, prepared on March 1, 2001): (1) burn, (2) chop, and (3) chop and incorporate were repeated this year. The density of new seed in the straw management trial was quite variable (rep 3 significantly higher) and roughly matched the observed pattern of panicle density before harvest. Old seed was more uniformly distributed over the trial area. Only 6% of the total old seed was recovered from the upper 2" soil layer; 94% was from the lower layer (2 to 5" deep. Data not shown). This result (and a similar ratio from the main plots reported above) confirms the observation made last year regarding the depletion of the upper layer of soil and which was used to explain and demonstrate the practical potential of no-till seeding when watergrass reseeding is prevented. Overall, the density of new seed on the soil surface ($720/m^2$) equaled the density of underground old seed ($750/m^2$) (Table 5) and provided a suitable population for evaluating the effect of the straw management practices.

Preplant seedbank in spring 2001. The density of new watergrass seed recovered from preplant samples taken from the straw trial was significantly higher (about 3 times) from the plots where straw was incorporated with chisel than from the plots where straw was either burned or chopped only (Table 5). Straw treatment had no significant effect on the density of old seed. This indicates that the mechanisms of seedbank depletion over the winter period (thought to be predation and early spring germination) act only on those new seed on the soil surface in the fall. Winter survival of new seed was calculated to be 20% where straw was burned, 23% where chopped, and 66% where straw was incorporated (Table 2). These values are consistent with results of previous studies (Hair, et al, 2000, and Hair, 1996). Winter survival of old seed (44%, Table 2) was not significantly different by straw treatment. Comparison of samples taken in early spring just prior to tillage with those taken preplant suggest that the decline in old seed density occurred mostly after spring tillage (Data not shown).

Emergence and survival of watergrass plants during summer 2001. Emergence of watergrass seedlings was 24% of the total preplant seedbank (Table 2) in contrast to 2.8% in the main plots reported above. Other seedbank researchers have also noted large variation in this parameter (Forcella, 1992). The reason for this difference is not known but we may speculate that slight differences in water depth (see Figure 2) or the proportion of new and old seed in the preplant seedbank may play a role. This variation by a factor of ten in a key component of the watergrass population dynamics model we are building may represent an important new control point for non- chemical manipulation. It deserves further study in future research trials.

The significantly greater density of new watergrass seed where straw was incorporated manifested itself after emergence as only a slightly greater density of watergrass plants (Table 5). Herbicidal control (one application of propanil) was quite effective in limiting watergrass survival to only 1.6% (98.4% control, Table 5). Control of *Cyperus difformis* was also extremely good in the straw trial. It appears that water management and timing was optimum for best control with propanil. Application was made with 2" of water still in the field and quickly followed by reflooding to 7 to 8" depth (Figure 2). Final watergrass panicle density in September 2001 (4.1 per m^2) was about half that of September 2000 (7.7 per m^2) before treatments were applied (Table 5) and so the density of new seed on the surface of the soil after harvest was expected to be correspondingly less. Since this is the population affected by straw treatments, it was decided to sample more intensively in the fall of 2001in order to obtain sufficient seed for proper evaluation. The results of this second winter of the straw management trial will be reported in a supplementary report after spring 2002 samples can be analyzed.

d. Demonstration and Extension

A tour and discussion of these issues was held at the field site on August 14, 2001. As was the case last year, over thirty growers, PCAs, and other interested people attended. The turnout and discussions indicated that the problems associated with thiocarbamate resistance in watergrass continue to cause great concern among growers.

A poster entitled "Using watergrass population dynamics to study herbicide resistance and straw management effects" was presented at Rice Field Day on August 29, 2001 held at the Rice Experiment Station in Biggs, CA. Results from the first two years of this project provided the principal source material for that poster.

The overall results of the entire three year project contained in this final report will be presented in another poster at the 29th Rice Technical Working Group Meeting, Feb 24-27, 2002 in Lilttle Rock, Arkansas.

Summary and Conclusions

In the main trial the alternative herbicide strategies employed in the second season of the project (2000) were confirmed to have severely limited watergrass reseeding. Post-harvest seed density was decreased 96% over 2 years. This supports the view that *Echinochloa spp.* have an extremely dynamic seedbank susceptible to being rather quickly depleted, and that the prevention of reseeding with effective herbicides that provide 99% control, is key to that strategy. In this year the herbicides glufosinate and bispyrabac continued to demonstrate the high degree of control required on this thiocarbamate-resistant population. Clomazone also demonstrated the potential for extremely high efficacy. Propanil, presently being used by growers, appears to be somewhat less effective, requiring multiple applications or combination with other herbicides to reduce reseeding sufficiently, especially when the soil seedbank has been built up to levels on the order of several thousand watergrass seed per square meter. In contrast to these effective herbicides, a strategy of continuous molinate use has failed to bring this resistant population under control. Similarly we have found that thiobencarb, fenoxaprop, and cyhalofop cannot be expected to adequately control this population. This project has also demonstrated that herbicide chemistry alone does not determine the degree of weed control; herbicides must be matched with optimum water management, rice stand establishment and canopy competition. There is a need for further studies to integrate alternative herbicide strategies with alternative cultural practices to improve the overall efficacy of whole systems.

Year round tracking of watergrass weed and seed densities has proven to be a successful means not only for evaluating herbicide use strategies over years, but also for evaluating the effects of straw management practices on the winter survival of watergrass seed. We can now conclude that the increasing frequency of failure to control watergrass that growers are experiencing is essentially due to increasing levels of thiocarbamate resistance due to repeated herbicide use exacerbated by a build-up in seed density due to fall burial when straw is incorporated. First results from this straw trial indicate that survival of new seed where straw was incorporated (66%) was 3 times the survival rate where straw was burned or chopped (20 and 23 %, respectively). When straw cannot be burned, chopping and flooding appears to be a preferable alternative to incorporation. Other fundamental population dynamics parameters such as seedling emergence (highly variable), summer survival (highly depth dependent), and recruitment (highly density dependent) have also been measured and discussed. These data are contributing greatly to the development of a more comprehensive model of watergrass dynamics that suggests how other alternative cultural practices and whole systems could potentially increase control, reduce expense, and/or decrease herbicide use. These should be the subjects of further studies.

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Appendices

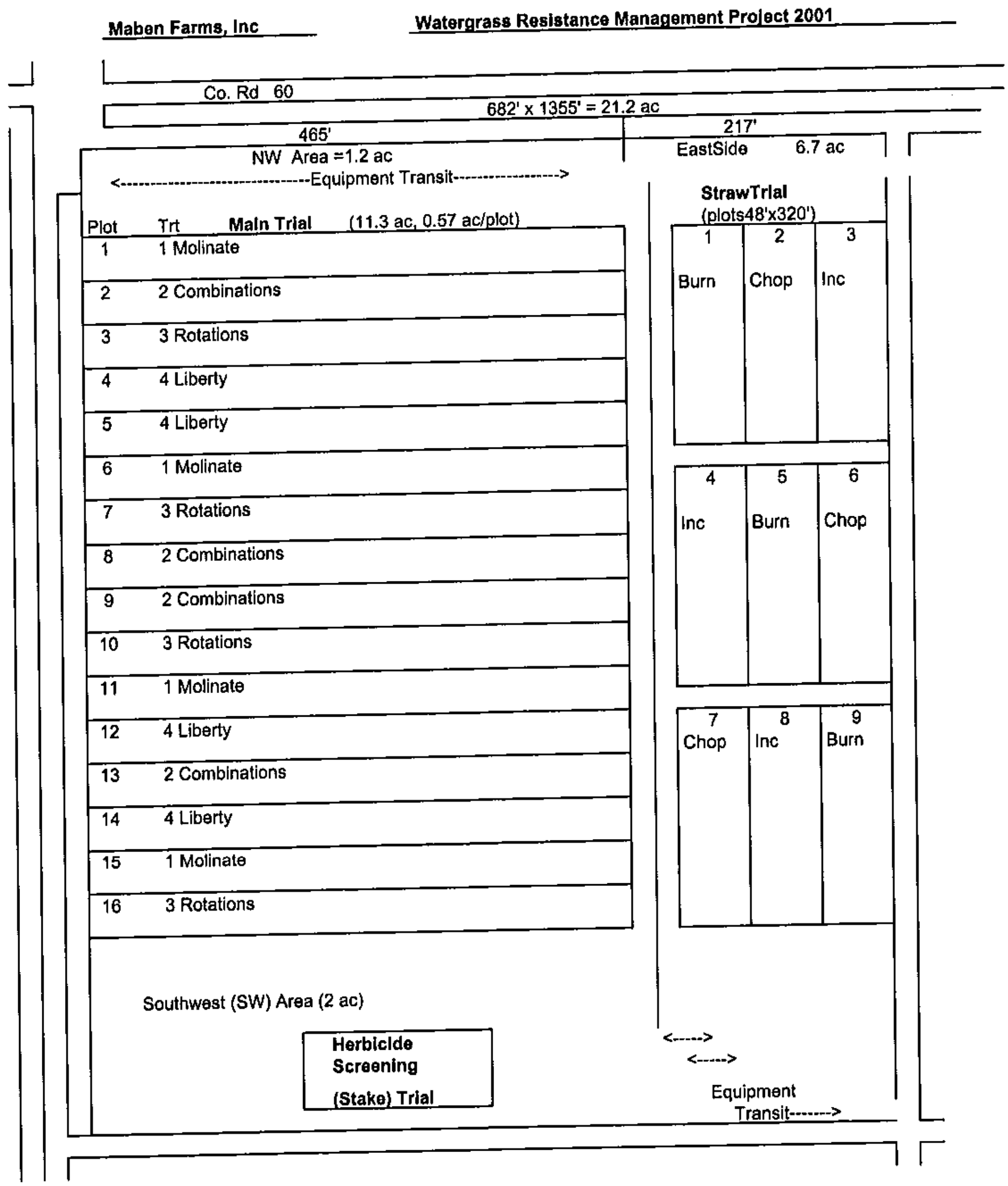

Figure 1. Field layout of trials at Maben Farms during 2001

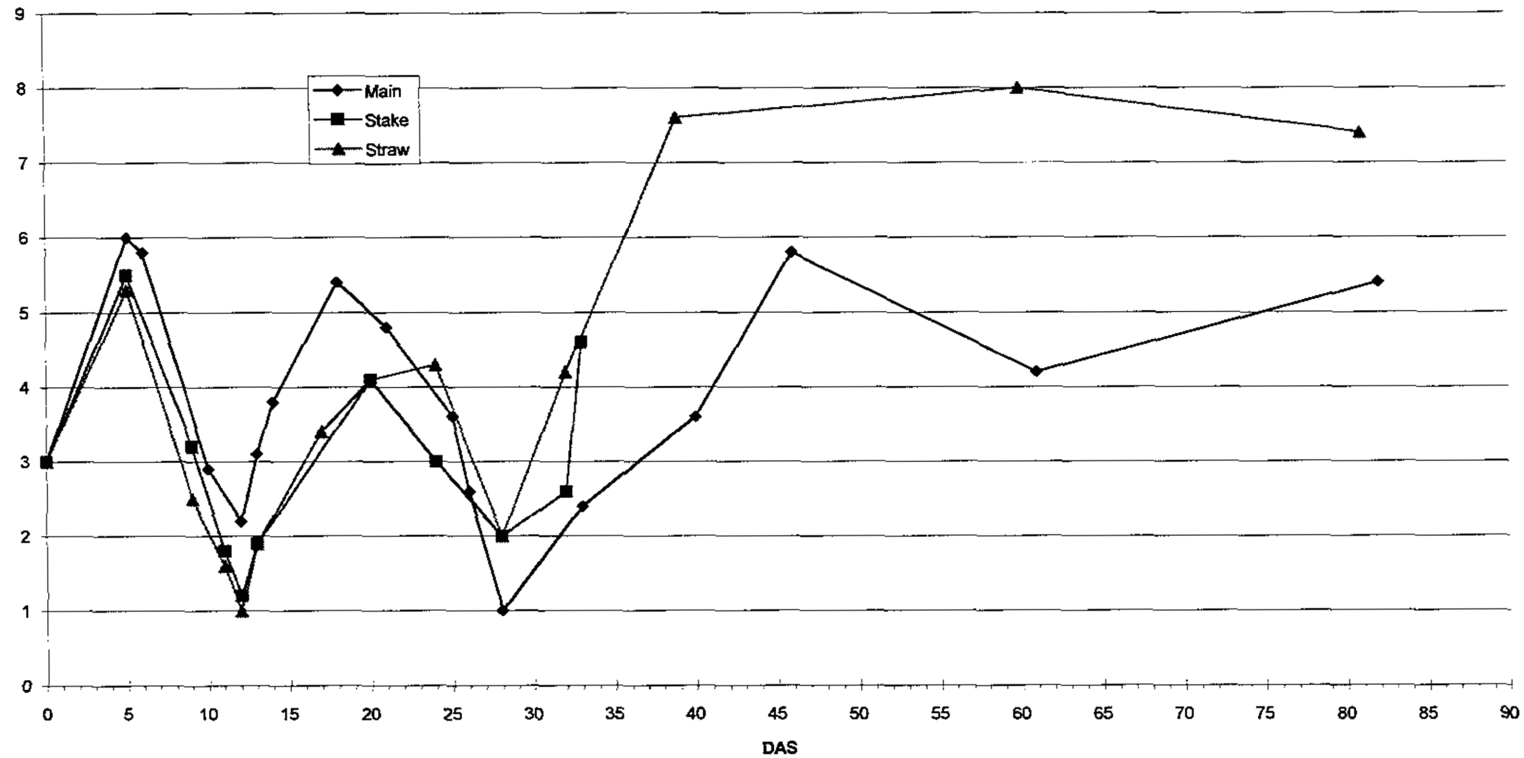

Figure 2. Water depths by days after seeding (DAS) in the three trials at Maben Farms in 2001
(Low water depths at 12 DAS caused by broken pump. At 28 DAS water lowered for foliar herbicide application)

Table 1. Early watergrass *(Echinochloa oryzoides)* densities and survival and rice evaluation under different herbicide strategies in the Main Trial during 10/00 to 0/01.

Herbicide Strategy	Seed Density New	Seed Density Old	Seed Density Total	Seed Density New	Seed Density Old	Seed Density Total	Early Watergrass Plant Density				WG Plant Survival	Panicle Density	CYPDI Density	Rice Evaluation Injury	Rice Evaluation Density	Rice Evaluation Height
	(#/m2)			(#/m2)			(#/m2)				(%)	(#/m2)	(#/m2)	1-10	#/ft2	inch
Date/DAS:	10/00			5/01			21	40	61	82	2001	9/01	9/01	21	27	40
1. Continuous Molinate	1680 a	1110	2790 a	460 a	550	1010 a	28	25	25	13 a	46 a	40 a	.003 a	8.75 b	20.00 b	15.5 b
2. Intensive Combinations	140 b	750	890 b	100 b	580	680 ab	0	0	.0008	.0008 d	.004 d	.008 d	1.4 b	7.25 c	16.75 c	16.6 ab
3. Annual Rotations	380 b	700	1070 b	140 b	570	710 ab	0	.03	.002	.008 c	.04 c	.16 c	8.5 b	6.25 d	12.75 d	15.9 b
4. Continuous Glufosinate	80 b	970	1050 b	40 b	560	600 b	18	.005	.06	.27 b	1.5 b	.48 b	4.8 b	9.78 a	27.25 a	17.3 a
Grand Mean	570	880	1450	180	560	750	-	-	-	-	-	-	-	8.0	19.2	16.3
Prob > F	.0003	.23	.0002	.0002	.99	.10	.37	-	-	<.0001	<.0001	<.0001	.0005	.0001	.0001	.06
CV (%)	*	33	26	45	35	29	61	-	-	*	*	*	*	7.1	12.0	5.0

1/ Means in same column followed by different letter significantly different. Means separation by protected LSD test at .001 level except rice variables and total WG seed density 5/01 at 0.05 level. Asterisk for CV value indicates variable Log transformed for analysis to obtain homogeneous variance.

2/ At 10/00 all new seed on surface. Old seed 13% in upper 2" soil layer, 87% in 2-5" layer. Data not shown.

3/ Under chop and flood straw treatment, winter survival of new seed 180/570 = 32%; old seed 560/880 = 64%.

4/ Watergrass emergence in molinate plots 28/1010 = 2.8%; in glufosinate plots 18/600 = 2.7%. No emergence in plots treated with clomozone.

5/ 2001 treatments: 1. Molinate: Ordram 15G 4 lb ai/ac 1 lsr 5 das fb MCPA 1 pt/ac 2 tlr 28 das. 2. Combinations: Command 0.6 lb/ac 0.5 lsr fb Regiment 12 g/ac and SW 6 qt/ac, 2 tlr, 28 das 3. Rotations Command 0.6 lb/ac 0.5 lsr fb MCPA 1 pt/ac 2 tlr 28 das. 4. Glufosinate: Liberty 500 ga ai/ha 2 tlr.

6/ Plant survival calculated from densities at 82 DAS relative to seedling density at 21 DAS. "Seedling density" for treatments 2 and 3 assumed 18/m2.

Table 2. Early watergrass *(Echinochloa oryzoides)* final seed density and rice yield under different herbicide strategies in the Main Trial October, 2001.

Herbicide Strategy	Final Seed Density New	Old	Total	Rice Moisture at Harvest	Rice Grain Yield @ 14%
		(#/m2)		(%)	(lb/ac)
1. Continuous Molinate	9770 a	520 a	10,300 a	18.6 a	7570 c
2. Intensive Combinations	25 c	280 b	300 c	15.4 d	9150 a
3. Annual Rotations	29 c	390 b	420 bc	17.4 b	8700 b
4. Continuous Glufosinate	190 b	370 b	570 b	16.5 c	8700 b
Grand Mean	-	390	-	17.0	8530
Prob > F	<.0001	.03	<.0001	<.0001	.006
CV (%)	*	24	*	2.4	5.5

1/ Means in same column followed by different letter significantly different. Means separation by protected LSD test at .05 level. Asterisk for CV value indicates variable Log transformed for analysis to obtain homogeneous variance.

2/ New seed on soil surface. Old seed 4% in upper 2" soil layer, 96% in 2-5" layer.

3/ 2001 treatments:

1. Molinate: Ordram 15G 4 lb ai/ac 1 lsr 5 das fb MCPA 1 pt/ac 2 tlr 28 das.
2. Combinations: Command .6 lb/ac .5 lsr fb Regiment 12 g/ac/SW 6 lb/ac 2 tlr
3. Rotations: Command 0.6 lb/ac 0.5 lsr fb MCPA 1 pt/ac 2 tlr 28 das.
4. Glufosinate: Liberty 500 ga ai/ha 2 tlr.

Table 3. Early watergrass *(Echinochloa oryzoides)* densities and survival and rice yields under different herbicide strategies in the Main Trial during 1999, 2000, and 2001.

Herbicide Strategy	Preplant Seed New	Preplant Seed Old	Emerged Seedlings	Mature Plants	Plant Survival	Percent Control	Rice Yield	Seed New	Seed Old
			(#/m ²)		(%)		(lb/ac)	(#/m²)	
1999 (spray 27DAS, 1-2 tlr)									
1. CONTINUOUS MOLINATE				63 a	69 a	31	4800 c	22,050	
(Ordram 4lb/ac 1 lsr, 9das)									
2. INTENSIVE COMBINATIONS	Mean		Mean	4 b	5 b	95	9990 a	5,850	Mean
(SW 4 lb/ac)	3400		122						1370
3. ROTATE MODE OF ACTION				8 b	6 b	94	8840 b	9,960	
(Liberty0.36 lb/ac+3 lb/acAS)									
4. CONTINUOUS GLUFOSINATE				7 b	5 b	95	9280 b	8,580	
(Liberty500g/ha+3 lb/acAS)									
2000 *(spray 28das 4lsr & 54das,late tlr)*									
1. CONTINUOUS MOLINATE				6 a	6 a	94	7860 c	1680 a	
(Ord 3 at12das fb 2 lb/ac 20das)									
2. INTENSIVE COMBINATIONS	No		Mean	0.1 c	0.1 c	99.9	8910 ab	140 b	Mean
(Ab4/Reg15 fb Clin210/SW6)	Data		97						880
3. ROTATE MODE OF ACTION				0.8 b	0.8 b	99.2	9260 a	380 b	
(SW 4 lb/ac fb SW 6 lb/ac)									
4. CONTINUOUS GLUFOSINATE				0.01 c	0.01 c	99.99	8310 bc	80 b	
(Liberty350 fb Lib 500 g ai/ha)									
2001 (spray 28das 1-3tlr)	New	Old							
1. CONTINUOUS MOLINATE	460 a		28	13 a	46 a	54	7570 c	9770 a	520 a
(Ord 4 lb/ac 1 lsr5das fb MCPA 1 pt/ac)									
2. INTENSIVE COMBINATIONS	100 b	Mean	0	0.0008 d	0.004 d	99.996	9150 a	25 c	280 b
(Com0.6lb/ac fb Reg12g/ac/SW6)		560							
3. ROTATE MODE OF ACTION	140 b		0	0.008 c	0.04 c	99.96	8700 b	29 c	390 b
(Com0.6lb/ac fb MCPA 1pt/ac)									
4. CONTINUOUS GLUFOSINATE	40 b		18	0.3 b	1.5 b	98.3	8700 b	190 b	370 b
(Liberty 500 g ai/ha)									

1/ Means in same column followed by different letter significantly different. Means separation by protected LSD test at 0.05 significance level.

2/ Percent control = (100 - plant survival) by definition. Means separation same as for plant survival.

3/ Fall 1999, straw burned and winter flooded. Fall 2000, straw chopped and winter flooded.

Table 4. Weed control and rice yield in Herbicide Screening Trial during 2001

Treatment	Rate	Timing	Rice Injury 14 DAT	Weed Control (%) ECHOR 42 DAT	CYPDI 42 DAT	SAGMO 28 DAT	Rice Yield @ 14% (lb/acre)
Untreated	--	--	0	41	11	8	4790
Ordram	4.0 lb ai/A	1.0 lsr	5	21	0	0	4220
Bolero	4.0 lb ai/A	1.0 lsr	8	21	40	0	5220
Command	0.6 lb ai/A	0.5 lsr	9	54	0	0	5370
Abolish	4.0 lb ai/A	1-3 Til	1	18	0	25	4840
Clincher + C.O.C.	113 g ai/A + 1.25% v/v	1-3 Til	0	66	0	0	6190
Super Wham + C.O.C.	6.0 lb ai/A + 1.25% v/v	1-3 Til	5	83	100	100	6770
Duet + C.O.C.	6.0 lb ai/A + 1.25% v/v	1-3 Til	4	76	100	100	6810
Super Wham + Abolish	4.0 lb ai/A + 4.0 lb ai/A	1-3 Til	5	70	100	100	6860
Super Wham + Clincher + C.O.C.	4.0 lb ai/A + 85 g ai/A + 1 .25% v/v	1-3 Til	3	90	100	100	6840
Regiment + Kinetic	12 g ai/A + 0.125% v/v	1-3 Til	6	100	35	100	6770
Regiment + Kinetic	15 g ai/A + 0.125% v/v	1-3 Til	10	100	68	100	6750
Regiment + Abolish	12 g ai/A + 4.0 lb ai/A	1-3 Til	5	98	74	100	7000
Bolero fb.4 Regiment + Kinetic	4.0 lb ai/A fb. 12 g ai/A + 0.125% v/v	1.0 lsr fb. 1-3 Til	9	90	88	75	5650
Regiment + Super Wham + Kinetic	12 g ai/A + 4.0 lb ai/A + 0.125% v/v	1-3 Til	5	82	100	100	6620

1/ ECHOR (Early Watergrass), CYPDI (Smallflower Umbrellasedge), SAGMO (California Arrowhead).
2/ DAT (days after treatment), lsr (leaf stage rice), Til (Tillers of rice), fb (followed by), C.O.C. (crop oil concentrate).
3/ Untreated weed control values represent % cover by respective weeds.
4/ LSD (0.05) = 1150 for grain yield.

Table 5. Early watergrass *(Echinochloa oryzoides)* densities and survival in the Straw Management Trial during 9/00 to 9/01.

Straw Treatments	Panicle Density	WG Seed Density			WG Seed Density			Seed Survival			Watergrass Plant Density			WG Plant Survival	Panicle Density
		New	Old	Total	New	Old	Total	New	Old	Total					
Date/DAS:	9/00	10/00			5/01			Winter 2000-01			20	60	81	81	9/01
	(#/m2)	(#/m2)			(#/m2)						(#/m2)			(%)	(#/m2)
1. Burn	6.0	270	890	1170	140 b	330	480 b	.20 b	.44	.32 b	100	2.2 b	1.3	1.5	3.3
2. Chop	9.4	1200	560	1760	170 b	260	430 b	.23 b	.35	.29 b	120	2.3 b	1.9	1.6	4.0
3. Incorporate	7.7	680	800	1580	480 a	390	870 a	.66 a	.52	.59 a	220	3.7 a	2.7	1.7	5.0
Grand Mean	7.7	720	750	1470	260	330	590	.31	.44	.40	142	2.7	2.0	1.6	4.1
AOV P value	.25	.48	.27	.73	.12	.53	.08	.11	.53	.08	.22	.12	.12	.93	.22
CV (%)	27	120	29	61	63	40	32	64	39	33	52	27	31	50	25
Orth. Contrast	-	-	-	-	.05	-	.03	.05	-	.03	.10	.05	.07	-	.13

1/ Means in same column followed by different letter significantly different at the 0.05 level by orthogonal contrast comparing treatment #3 with the group of treatments #1 and #2.

2/ After 10/00 samples taken all plots chopped, then trt#1 burned, trt#3 one pass with chisel, then all plots winter flooded.

3/ At 10/00 about 6% of old seed 10/00 were in top 2" layer; 94% in 2-5" layer. Data not shown.

4/ Emergence of WG seedlings 5/01 = 142/590 = 24%. Same in all treatments.

5/ Herbicide application at 28 DAS 2 tiller stage, SuperWham +COC 6 lb ai/ac +1.25% v/v.

6/ Plant survival calculated from densities at 81 DAS relative to seedling density at 20 DAS.