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Dear Mr. Hunter,

Please find attached a copy of the FINAL REPORT pertaining to:

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

Contract No.: 98-0278

Principal Investigator(s): Dr. Albert J. Fischer, Dr. James E. Hill

I wish to express our gratitude in your assistance in the completion of this project, and look forward to another productive year.

Regards,

Albert Fischer
Weed Ecophysiolopgist

DEPARTMENT OF PESTICIDE REGULATION
PEST MANAGEMENT GRANTS - APPLIED RESEARCH
RFP # 98-04

FINAL REPORT

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Contract No.: 98-0278

Principal Investigator(s): Dr. Albert J. Fischer, Dr. James E. Hill

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PREPARED FOR CALIFORNIA DEPARTMENT OF PESTICIDE REGULATION

DISCLAIMER

The statements and conclusions in this report are those of the contractor and not necessarily those of the California Department of Pesticide Regulation. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

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TABLE OF CONTENTS

	Page
List of figures	5
List of tables	5
Abstract	5
Executive summary	6
Report	7
Introduction	7
Materials and Methods	8
Results and Discussion	10
Summary and Conclusions	13
References	15
Appendices	16

List of Figures

Page

Figure 1. Field layout of experimental treatments 17

Figure 2. Percent watergrass control (visual evaluation) at two dates after herbicide application; molinate was considered as check (0% control). Watergrass in molinate plots was largely uncontrolled (80-90% cover).............. 18

List of Tables

Table 1. Early watergrass (*Echinochloa oryzoides*) densities during 1999 and final rice grain yield.. 19

Table 2. Evaluation of herbicide resistance (percent control) in early watergrass (*E. oryzoides*) plants from soil and panicle seed samples for each of the experimental main field treatments.. 19

Table 3. Herbicide performance on accessory demonstration plots.................. 20

Abstract

The first year of a medium-term study was initiated in 1999 on a cooperating farmer's rice field in Colusa Co., CA, to understand the role of herbicide management in delaying the development of resistance in a presumably herbicide-resistant early watergrass (*E. oryzoides*) population. Three general strategies are being tested: a) continuous use of herbicides with the same mechanism of action as reference checks (the thiocarbamate herbicide molinate and glufosinate in conjunction with glufosinate-resistant rice; b) rotation and tank mixes of herbicides with different mechanisms of; and c) use of glufosinate in conjunction with glufosinate-resistant rice in rotation with conventional herbicide treatments. Seed from soil samples and panicle collections were tested in the greenhouse for resistance to herbicides, showing multiple resistance to thiobencarb, fenoxaprop-ethyl and bispyribac-sodium (a herbicide not yet available in California). During this first season propanil and glufosinate controlled the resistant watergrass. However, seed rain at the end of the season was high. Grain yields, which followed inversely the levels of watergrass infestations (4 to 63 plants m^{-2}) were 4800 kg ha^{-1} for molinate, 9990 for propanil, and an average of 9060 for glufosinate. The sequence of treatments to be imposed in the successive years will seek to reduce the proportion of herbicide-resistant seeds in the soil. A portion of the plots, was used by a farm advisor to test short-term applied weed control alternatives. As from next year the experiment, as well as the farm advisor's plots, will be ready for demonstration and education purposes, which was already done to some extent this year, and treatments will also include straw management techniques and reduced tillage as non-chemical options.

EXECUTIVE SUMMARY

Because of an epidemic of herbicide resistance in watergrass (*Echinochloa phyllopogon*, and *E. oryzoides*) in California rice, the first year of a three- to four-year study was begun for understanding the role of herbicide management in delaying the development of resistance. The experiment was conducted during the 1999 season on a cooperating farmer's rice field in Colusa Co., CA. This field is heavily infested with early watergrass (*E. oryzoides*), with resistance to thiobencarb, bispyribac-sodium and fenoxaprop-ethyl. Research focuses 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. Three general strategies are being tested: a) continuous use of herbicides with the same mechanism of action as reference checks (the thiocarbamate herbicide molinate and the use of glufosinate in conjunction with a transgenic cultivar with resistance to this herbicide; b) rotation of herbicides with different mechanisms of action and the use of tank mixes of herbicides with different mechanisms of action; and c) use of glufosinate in conjunction with a transgenic cultivar with resistance to this herbicide in rotation with conventional herbicide treatments. Herbicides applied this year were molinate (4 lb ai ac^{-1}) in treatment 1, propanil (4 lb ai ac^{-1}) in treatment 2, glufosinate (0.36 lb ai ac^{-1}) to Liberty-Link transgenic rice in treatments 3 and 4. The dynamics of watergrass and herbicide-resistant watergrass seed in the soil was monitored, as well as the yearly recruitment of herbicide-resistant watergrasss cohorts. Seed from soil samples and panicle collections were tested in the greenhouse for resistance to herbicides, showing multiple resistance to thiobencarb, fenoxaprop-ethyl and bispyribac-sodium (a herbicide not yet available in California). Seed bank patterns of resistance will ultimately guide the selection of herbicides in the successive years. During this first season propanil and glufosinate (used with glufosinate-resistant rice) controlled the resistant watergrass. However, seed rain at the end of the season was high and dual applications and/or better water management will be required for increased watergrass suppression. Grain yields in herbicide-treated plots were 4800 kg ha^{-1} for molinate, 9990 for propanil, 9280 for glufosinate (treatment 3), and 8840 for glufosinate (treatment 4). Grain yields followed inversely the levels of watergrass infestations, which ranged from 63 to 4 plants m^{-2}. The sequence of treatments to be imposed in the successive years will illustrate herbicide management options to reduce the proportion of herbicide-resistant seeds in the soil, which is the ultimate goal in herbicide resistance management. A portion of the plots, unsuitable for seedbank assessments due to machinery transit, have been used by a farm advisor to test short-term applied weed control alternatives. As from next year the experiment, as well as the farm advisor's plots, will be ready for demonstration and education purposes, which was already done to some extent this year. The portfolio of treatments will be expanded next year to include straw management techniques and reduced tillage as non-chemical options.

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. 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. 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 for 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, along with complex herbicide combinations, 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 begun 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 1999 activity was to set up a medium-term field experiment 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, and the use of tank mixes wit herbicides with different mechanisms of action, and 2) the use of rice cultivars resistant to environmentally friendly, broad-spectrum herbicides. The ultimate success of the alternative strategies is assessed in terms of the reduction achieved in the levels of herbicide-resistant watergrass infestations in the soil seed reservoir. An additional goal was for the local farm advisor to use a section of the main plots to implement a demonstration trial on the use of new chemical tools for the control of herbicide-resistant watergrass. The first year of this field research 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

Experimental layout. A field experiment was initiated in the spring of 1999 on a commercial rice field using ½ acre levied plots. The experiment was mounted on Mr. Larry Maben's ranch, on Hwy 162, about 10 miles west from the Rice Experiment station near Biggs. Four long-term treatments were established and replicated four times within a randomized complete block design (Figure 1). Each plot had an area of 0.57 acres. The total area of the experiment was 11.3 acres. Levees are used for individual water control, rice and weed seed confinement, and to prevent cross contamination of herbicide treatments. The study was seeded on May 12, 1999. The treatments applied this season included: 1) the first year of a continuous use regime of glufosinate (Liberty®) with glufosinate-resistant Liberty Link M-202 rice; 2) the first herbicide (propanil) of an annual rotational regime of chemicals and tank mixes with different modes of action; 3) the first application of glufosinate for a sequence which will alternate the use of Liberty-Link rice with available grass herbicides and non-transgenic M-202 rice, 4) a conventional application of molinate as a check treatment. Data collected were subject to analysis of variance and correlation. Treatment means were separated using Fisher's protected LSD with $P = 0.05$.

Seedbank assessment. The study began by establishing the baseline infestation of watergrass and resistant-watergrass seed in the soil. Prior to flooding, 15-cm depth soil samples were taken at 128 marked sample points uniformly distributed throughout the trial area (8 per plot). Samples from each plot were bulked (7600 cm^3), mixed, subsampled (1900 cm^3), and placed in screen mesh bags. Soil was washed from the bags in a conventional washing machine, and apparently viable seed were individually picked from the residue with forceps. Thus watergrass seed from each plot sample was extracted and counted. Seed (duplicate subsamples) from each plot were germinated in trays (four replications) with sterile soil in the green house, and sprayed with commercial rates of propanil, molinate, thiobencarb, fenoxaprop-ethyl, bispyribac-sodium and glufosinate. Granular formulations of thiobencarb and molinate were applied at the 1.5 leaf stage of watergrass, and the other herbicides were applied at the 4-leaf stage. Plants were maintained under a 4-inch flood. Water was lowered for foliar applications and water depth restored 24 h after application. Treated plants were grown in the greenhouse under a 14-h photoperiod. Additional seed samples of known herbicide-susceptible watergrass accessions were used as susceptible checks to establish by comparison the level and proportion of resistance to these herbicides in the samples collected from each experimental plot. The percent control obtained with each herbicide treatment was scored visually 20 days after herbicide application and the number of surviving plants in each pot counted. The same procedure was followed with seed collected from watergrass panicles shortly before harvest

In successive years, this baseline seed count and characterization of resistance patterns will be used to monitor the effect of the different herbicide management strategies on the seedbank populations of herbicide-resistant watergrass. Changes in the level of resistance in the population will be established through dose-response tests of annually collected watergrass seed from panicles and soil samples. Also, at maturity watergrass panicles were collected from each plot, and panicle density and seed numbers estimated. Seed collected in this was tested for resistance as above. Soil samples taken after harvest will establish the amount of seed reinfestation allowed by each treatment.

Herbicide applications. Granular molinate (Ordram® 15 G) was broadcast into the water at a rate of 4 lb ai/A with a hand operated belly grinder on May 21, 9 days after seeding (DAS), at the 2 leaf stage of rice and 1.5 leaf stage of watergrass. All foliar applications were applied on June 8 (27 DAS) at the 2-3 tiller stage of rice and 2 tiller stage of watergrass under drained conditions. Propanil (SuperWham®) was applied at a rate of 4 lb ai/A with 1.25% v/v crop oil concentrate in a spray volume of 15 Gal/A using an ATV spray rig. Glufosinate (Liberty®) was applied at a rate of 0.36 lb ai/A in a mixture with 3 lb/A ammonium sulfate in a spray volume of 20 Gal/A using the cooperating grower's ground rig equipped with 11003 Turbo Tee Jet® drift guard nozzles on a 60 foot boom. Broadleaf weeds and sedges were controlled with an application of carfentrazone (Shark) at a rate of 0.1 lb ai/A over the entire experiment.

Watergrass plant density counts were taken within 1 m^2 quadrates placed at the soil core sampling sites, both prior to and after herbicide applications. On July 14 and July 29 percent watergrass control with respect to the molinate check (set at 0% control) was determined, from visual estimations of watergrass cover.
Yield harvest. A central area in each plot was harvested for yield. Transgenic rice seed was destroyed.

Late season watergrass control study-accessory demonstration plots. This grass herbicide trial was established as a sub-trial of an overall weed resistance study located in Glenn County, California. Part of the plots unsuitable for seedbank assessments due to machinery transit were used this year, and will continue to be used in the future, to develop short-term applied weed control alternatives in collaboration with farm advisors. Farm advisor Dr. Steven Scardacci conducted this year a series of herbicide comparisons using the first 50 x 55 feet of each plot. Treatments for this experiment appear on Table 3. Watergrass was not adequately controlled in the 4 basins treated early with molinate. In addition, several broadleaf weeds were not completely controlled by carfentrazone. Part of these basins were then used to study the performance of several grass herbicides applied late with and without additional broadleaf weed control. The herbicides tested were cyhalofop (Cincher ®) at 4 oz active ingredient acre^{-1} , propanil (SuperWham®) at 6 lb ai ac^{-1}, bispyribac-sodium (Regiment®) 15 and 18 g ai ac^{-1}, and fenoxaprop-ethyl (Whip®) at 0.2 lb ac^{-1}of the ester. An untreated control was included.
The grass herbicides were applied (as above) late (47 days after planting) to well established watergrass in about the 2-6-tiller stage. The watergrass was thought to be resistant, since the grower previously had problems controlling it with molinate, thiobencarb or fenoxaprop. Water management may have affected control as well. Treatments were arranged in a split-plot design with the grass herbicides in the main plots and broadleaf control in the subplots. Each treatment was replicated 4 times with individual plots being 10 x 20 ft in size.

Grass weed control was rated on several dates from June 28 to September 9 on a subjective 1-10 scale with 1 = no control and 10 = complete control. Broadleaf weed control was also rated on several dates on the same scale. Final grain yield was recorded.

Results and Discussion

Seedbank. The preplant soil samples yielded sufficient watergrass seed for resistance testing and indicated that an average seed density of 3,370 seeds m^{-2}.was distributed evenly throughout the trial area (Table 1). By 14 DAS a watergrass seedling density of about 117 plants/m^2 (3.5% of the preplant seedbank) was established in all plots (Table 1).

Herbicide resistance patterns in soil and panicle seed samples. The response to molinate, thiobencarb, propanil, bispyribac, glufosinate, and fenoxaprop of plants derived collected from the soil and from emerged watergrass panicles was highly correlated (r = 0.94; $P < 0.001$), and suggested resistance to thiobencarb, bispyribac and fenoxaprop-ethyl (Table 2). Survival counts followed the same trend (data not shown) as the data on % control. However, at the time of evaluation, all pots showed considerable watergrass regrowth from their underground unexposed growing point, including pots corresponding to the susceptible control. Thus a detection of susceptible plants within the resistant populations could not be done with acceptable accuracy. This suggests that in the future the evaluation of the evolution or decrease of resistance in the seed bank should preferably be evaluated through dose-response experiments involving sufficiently large seed samples.

Herbicide performance in the field plots. Watergrass cover reached 80 to 90% at 37 DAS (data not shown) in the molinate treated plots, demonstrating that its activity on the putative resistant strain of watergrass was very low. This was also indicated by the plant counts (Table 1), where the declining plant density over time later in the season could be attributed to intraspecific competition, as plants grew larger. The glufosinate (Liberty ®) treatments strongly suppressed watergrass growth (Figure 2), and appeared to have 100% control at 42 days after rice emergence (Table 1). However, the glufosinate/carfentrazone (Liberty®/Shark®) combined application proved to be very phytotoxic to rice this year. This injury weakened the competitive capacity of rice and allowed some watergrass to emerge above the rice later in the season and to produce some seed (Table 1). Thus the final average rating of control with this herbicide was about 70% (Figure 2). Propanil (SuperWham®) provided a level of watergrass control comparable to the glufosinate treatments (Figure 2) with less rice injury. Due to the fluctuating temperatures this season, second flush infestations of weeds were experienced throughout the northern valley and in this experiment; thus final weed control ratings were not as high as expected (Figure 2). Plant and panicle densities illustrate the second flush infestations and suggest the possible seed rain from each treatment (Table 1).

Given the results of the tests for herbicide susceptibility performed on plants derived from seeds from soil or emerged watergrass panicles, it is difficult to conclude that the poor control observed with molinate in the field plots can be entirely due to resistance. However, for a given dosage, herbicide effects in the greenhouse tend to be stronger than in the field, and it is thus possible that enhanced molinate activity could have masked some degree of tolerance to this herbicide. Given the level of resistance detected to thiobencarb, some level of resistance to molinate (also a thiocarbamate herbicide) can also be expected (Fischer et al., 2000). To clarify this issue additional dose-response experiments are being implemented. Water management in the farm and the newly established levies in the experiment did not allow to maintain a fully satisfactory flooding after molinate application. This should have affected the performance of the herbicide contributing to the poor control observed in the molinate-treated plots.

Rice yields in main field plots. Grain yields were inversely related to the levels of established weed infestation recorded at 84 DAS (Table 1). Except for the molinate plots, where weed control was poor, yield in the propanil- and glufosinate-treated plots was high and in most cases outyielding the farmer's fields.

Demonstrations. Implementing a large-scale experiment on a commercial field with a cooperating farmer was an experiment in itself, and this was the baseline year for multi-season work. Thus, real opportunities for using our plots for demonstration and extension purposes are expected to develop in the successive years. However, the differential effects of the herbicides in the initial watergrass control were evident and were shown to visitors by farm advisor Dr. Steven Scardacci. DPR scientist Dr. Nan Gorder and Butte Co. Ag also visited the site. Commissioner Mr. Richard Price who were positively impressed by the successful field work implementation. Mr. Larry Maben has participated in the design of the experiment, and has been in permanent contact with us throughout the implementation and evaluation of this year's work.

Late season watergrass control study in accessory demonstration plots. The mean grass weed control ratings are shown in Table 3. These results show that bispyribac (Regiment®) and propanil provided fairly good control of watergrass when applied late to 2-6 tiller watergrass. Propanil was very active within a few days of the application, but some grass regrowth occurred after a few weeks. In contrast, bispyribac took longer to control watergrass. Shortly after the applications, propanil had significantly better ratings than bispyribac, but the later ratings showed the 15-g rate of regiment to have the best control. Propanil- and bispyribac- treated plots had the highest yields being significantly higher than the untreated control (Table 3). Both of these herbicides provided relevant later season control of watergrass. The performance of these and the other treatments may be different at earlier application timings. Rice in the bispyribac-treated plots was significantly shorter compared to untreated plants. This was noted shortly after the herbicide applications and remained evident until harvest. This was the only phytotoxic effect noted for bispyribac. Lodging was severe in weedy plots.

The poor performance of cyhalofop (Clincher®) was expected given the resistance detected in the greenhouse tests to fenoxaprop, also an aryloxyphenoxy herbicide. Although resistance to bispyribac was detected in the greenhouse tests, its performance in the demonstration plots was better than expected. Recent reports from the manufacturer suggests that this herbicide may be more active on resistance watergrass when applied after plants have developed 1-2 tillers, rather than on younger 4-leaf plants as it was done in the greenhouse test. These aspects needs further study. Watergrass suppression in bispyribac-treated plots may have been enhanced by the competition of the well-developed rice plants, while plants in the green house tests are not subject to the competition of rice. However, the detection of resistance to this herbicide suggests that its continuous use has the potential for developing resistance in watergrass population. Resistance to pesticides usually develops as a result of the repeated use of chemicals with the same mechanism of action. Such repeated use exerts a selection force that favors the survival of resistance biotypes of a given species, which is otherwise normally susceptible to that pesticide. Bispyribac should preferably be used in combination with herbicides of a different mechanism of action and with additional weed suppressive cultural practices such as deep water. The use of this herbicide alone should be avoided in areas where resistance was detected. Recent studies with late watergrass (*Echinochloa phyllopogon*) have demonstrated that bispyribac-resistant biotypes of this species also exhibit cross-resistance to bensulfuron-methyl (Londax®) (A.J. Fischer, unpublished). Resistance to bispyribac, a herbicide not yet used in California rice, could have thus developed from the repeated use of bensulfuron. Resistance to bensulfuron in broadleaf and sedge species is widespread in California. The use of bispyribac should thus be avoided in areas where resistance to bensulfuron has already been detected.

Summary and Conclusions

The first year of a three- to four-year experiment to develop a system of sound and safe herbicide management strategies as part of an integrated herbicide-resistant watergrass control strategy was successfully implemented in the rice season of 1999. The experiment was conducted on the rice farm of Mr. Larry Maben in Colusa County, CA. The focus of this research is to assess the depletion of herbicide-resistant watergrass seeds from the soil seed reservoir. This is the ultimate goal in the successful management of herbicide resistance in weeds. Three general strategies are being tested: a) continuous use of herbicides with the same mechanism of action (molinate and continuous glufosinate checks); b) rotation or tank mixes of herbicides with different mechanisms of action; and c) use of transgenic cultivars with resistance to glufosinate in rotation with conventional herbicide treatments. Herbicides applied this year were molinate (4 lb ai ac^{-1}) in treatment 1, propanil (4 lb ai ac^{-1}) in treatment 2, glufosinate (0.36 lb ai ac^{-1}) to Liberty-Link transgenic rice in treatments 3 and 4. Seed bank testing for resistance will ultimately guide the selection of herbicides in the successive years. The dynamics of watergrass and herbicide-resistant watergrass seed in the soil is monitored. Also, collecting watergrass panicles monitors yearly recruitment of herbicide-resistance watergrasss cohorts. Seed bank patterns of resistance will ultimately guide the selection of herbicides in the successive years. Seed from soil samples and panicle collections were tested in the greenhouse for resistance to herbicides. Tests conducted in 1999 revealed multiple resistance to the herbicides thiobencarb, fenoxaprop-ethyl and bispyribac-sodium. This underscores the difficult situation of the rice industry where resistance to the few available herbicides will lead to widespread resistance in farmers' fields. In other studies, where seed samples collected from farmers, fields were similarly tested, the presence of widespread resistance in early and late watergrass to molinate, thiobencarb, bispyribac-sodium and fenoxaprop-ethyl has already been confirmed for a large number of rice farms in California (Fischer et al. 2000, and A. J. Fischer, unpublished). Thus, the relevance of the study we are reporting here can be fully appreciated.

Fortunately, for research purposes, this experiment presented a huge watergrass seed bank, a very severe infestation evenly distributed in all plots and within plots. Watergrass numbers and distribution were a concern before we started the experiment on this site. Soil sampling will be much easier than it would have been with a low density and uneven weed distribution. This infestation appears to be highly resistant to thiobencarb, fenoxaprop-ethyl and bispyribac. The watergrass population consists mostly of early watergrass (*E. oryzoides*). Multiple herbicide resistance has also been found in early and late watergrass in many other California rice fields (Fischer *et al.*, 2000; A. J. Fischer, unpublished), and the general concepts derived from this experiment would be applicable to both species.

Results so far demonstrated that propanil and glufosinate (used in conjunction with glufosinate-resistant rice) are chemical options to control multiple-resistant watergrass. For these treatments to be effective in the long term, seed rain reinfestations still need to be much lower. Thus, in years of prolonged watergrass emergence periods, such as 1999, more than one application per season will be required. This experiment allows testing the effects of such increased selection pressure on the development of resistance in watergrass populations. Thus, in view of the need for more than one herbicide application per season to eliminate the seed rain from survivors (potentially resistant plants that will reload the seedbank) and late emerging watergrass cohorts, two options need to be contemplated. One is the successive application of different chemicals (modes of action), the other is the use of different tank mixes with herbicides having different modes of action. Tank mixes offer, perhaps, the best option to delay the development of herbicide resistance when herbicides are used for weed control (Gressel and Segel, 1982). These options are depicted in the treatments intended for the following years of this research (Figure 1). However, water management should be further improved next year with higher and more impervious levees and a better draining system. Besides managing watergrass seed bank populations, the sequence of treatments to be imposed in the successive years of this experiment (Figure 1) will illustrate their effect in reducing the proportion of herbicide resistant seeds in the soil. This knowledge, together with existing information on the effects of water depth upon watergrass suppression (Hill, *et al.*, 1985) and information being developed in other experiments on the effects of straw management to reduce seed rain (Hair, et. al., 1999), will allow us to delineate rational and sustainable alternatives to manage herbicide-resistant watergrass in rice fields.

The implementation of this experiment has been the result of excellent cooperation between a cooperating farmer, UC researchers and farm advisors. This was the baseline year for multi-season work; thus, real opportunities for demonstration and extension are expected to develop in the successive years. Farm Advisor Dr. Steven Scardacci showed the treatment effects observed during 1999 to visitors. DPR scientist Dr. Nan Gorder and Butte Co. Ag also visited the site. Commissioner Mr. Richard Price who were positively impressed by the successful field work implementation. Mr Larry Maben participated in the design and implementation of the experiment, and has been always in permanent contact with us throughout this year's work. Demonstration plots were installed in a sub-area within the main field plots where new herbicides were tested for their effectiveness against herbicide resistant watergrass by the Colusa Co. Farm Advisor. On the next season the experiment, as well as secondary demonstration plots, will be ready for demonstration and education purposes.

Demonstrations. Implementing a large-scale experiment on a commercial field with a cooperating farmer was an experiment in itself, and this was the baseline year for multi-season work. Thus, real opportunities for using our plots for demonstration and extension purposes are expected to develop in the successive years. However, the differential effects of the herbicides in the initial watergrass control were evident and were shown to visitors by farm advisor Dr. Steven Scardacci. DPR scientist Dr. Nan Gorder and Butte Co. Ag also visited the site. Commissioner Mr. Richard Price who were positively impressed by the successful field work implementation. Mr Larry Maben has participated in the design of the experiment, and has been in permanent contact with us throughout the implementation and evaluation of this year's work.

Overall, we have made a successful beginning, and I expect an even more successful operation next season after this year's experience.

References

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APPENDICES

Plot No.	Treatment
1	1
2	2
3	3
4	4
5	4
6	1
7	3
8	2
9	2
10	3
11	1
12	4
13	2
14	4
15	1
16	3

Plot area = 0.57 ac.
Total experimental area = 11.3 ac

Treatments applied in 1999

1 Continuous use of molinate
2 Propanil
3 glufosinate with Liberty Link rice
4 glufosinate with Liberty Link rice

Treatments for 2000 and thereafter

1 continuous molinate
2 tank mix combinations (different modes of action)
3 herbicides with different modes of action applied sequentially each season
4 glufosinate with Liberty Link rice
[1] Two herbicide applications within one season may be needed for late-emerging

Figure 1. Field layout of experimental treatments.

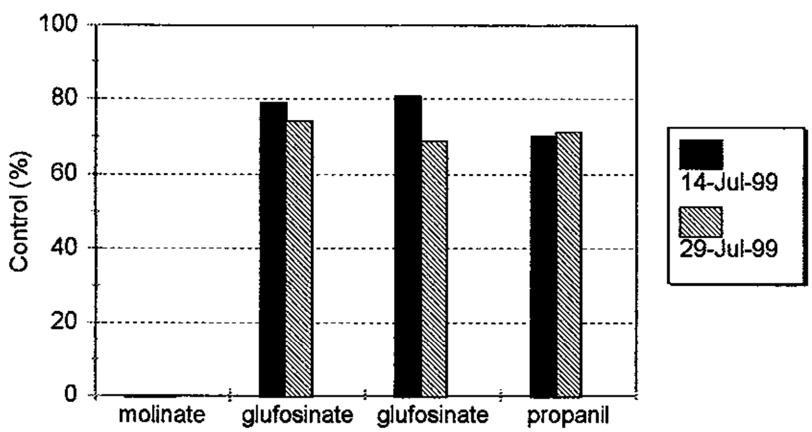

Figure 2. Percent watergrass control (visual evaluation) at two dates after herbicide application; molinate was considered as check (0% control). Watergrass in molinate plots was largely uncontrolled (80-90% cover).

Table 1. Early watergrass (*Echinochloa oryzoides*) densities during 1999 and final rice grain yield.

	Days after seeding rice									
	-18	14	21	37	42	63	84	123		
Treatment	Preplant Seed m^{-2}	Plants m^{-2}						Panicles m^{-2}	Predicted Seed rain [1/] $\#/m^{-2}$	Grain Yield kg ha^{-1}
1 Molinate	3328	114	101	143	75	71	63	508	127,000	4800
2 Propanil	3191	98	100	19	6	4	4	68	17,000	9990
3 Glufosinate	3537	118	126	19	0	3	8	96	24,000	8840
4 Glufosinate	3427	133	188	5	0	3	7	103	26,000	9280
LSD (0.05)	889	32	81	48	23	11	13	76	-	355

[1/] Assuming 250 seed/panicle.

Table 2. Evaluation of herbicide resistance (percent control) in early watergrass (*E. oryzoides*) plants from soil and panicle seed samples for each of the experimental main field treatments.

	Herbicide tested on plants from seed samples					
Field experiment treatment	molinate	thiobencarb	propanil	bispyribac	glufosinate	fenoxaprop
a) Soil seed samples				(%)		
1 Molinate	92[1]	13	55	34	69	58
2 Propanil	88	8	54	37	84	57
3 Glufosinate	66	18	42	34	81	52
4 Glufosinate	96	22	53	32	84	54
Control[2]	100	100	61	84	73	95
LSD (0.05)	---------- 23 ----------					
b) Panicle seed samples						
1 Molinate	91	30	63	38	94	74[3]
2 Propanil	90	32	64	35	94	73
3 Glufosinate	93	26	65	30	95	56
4 Glufosinate	91	34	62	37	90	56
Control	100	100	65	84	84	90
LSD (0.05)	---------- 17 ----------					19

[1] Each value is an average of four subsamples tested from each of four plots (replications) comprising each experimental main field treatment.
[2] Known herbicide susceptible early watergrass control plants.
[3] Values in this column are from an experiment conducted separately.

Table 3. Herbicide performance on accessory demonstration plots.

	Watergrass Weed Control Rating July 1	Watergrass Weed Control Rating July 22	Plant Height July 7	Plant Height Oct.16	Lodging (1-99) Oct 16	Grain Yield
	---------- (1-10)[1]	---------	(cm)	(cm)	(1-99)[2]	(kg ha^{-1})
Control	2.6	2.8	28.7	92.0	85.0	3426
Clincher 4 oz. ai/acre (cyhalofop)	3.9	2.8	28.8	90.9	79.4	3903
SuperWham 6 lb ai/acre (propanil)	7.4	6.6	27.8	87.9	23.8	7361
Regiment 15gms ai/acre (bispyribac sodium)	5.6	8.5	25.6	82.9	25.3	7174
Regiment 18gms ai/acre (bispyribac sodium)	5.5	6.9	25.8	81.9	23.1	6214
Whip 0.2 lbs. ai/acre (fenoxaprop)	3.9	4.5	26.6	88.6	43.1	4447
LSD (0.05)	1.69	2.28	2.1	7.2	25.5	1721

1 Visual scale, 1= no control, 10 = complete control.
2 Visual scale, 1= no lodging, 99 = plants lodged.