PROJECT NO. RP-3

COMPREHENSIVE RESEARCH ON RICE
ANNUAL REPORT

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PROJECT TITLE: Protection of rice from invertebrate pests.

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OBJECTIVES AND EXPERIMENTS CONDUCTED BY LOCATION TO ACCOMPLISH OBJECTIVES:

Objective 1: The recognition of physical and biological factors that result in fluctuation and movement of pest populations that cause economic injury to rice plants.

1.1) To determine seasonal trends (timing and magnitude) in the flight activity of the Rice Water Weevil (RWW) and armyworm.

1.2) To determine flight activity and infestation patterns of the RWW in relation to timing, cardinal direction and distance from field margin.

1.3) To determine the influence of daily weather conditions (temperature and wind speed) on springtime flight behavior of the RWW.

1.4) To determine the influence of habitat conditions (specifically, water-vegetation-soil relationships) on RWW flight behavior and physiology (as it relates to flight capability).

1.5) To compare the invertebrate populations occurring in paired fields of organic and conventionally grown rice to determine if certain cultural practices, commonly used in organic rice, limit pest populations and if so how they might be developed or exploited to control pests in other rice systems.

1.6) To determine the effect of temporary early season drainage on non-target invertebrates.

Objective 2: To determine the most effective control of rice invertebrate pests while maintaining environmental quality compatible with the needs of society.

2.1) Rice water weevil - chemical control.

2.1.1) To determine if Londax is directly toxic to some stage of the RWW (adults, eggs, or larvae) or reduces RWW oviposition.

2.1.2) To evaluate the effectiveness of an unknown ICI compound, at various rates and formulations, in controlling the RWW.

2.1.3) To evaluate the effectiveness of Dimilin for control of the RWW in large scale field tests.

2.1.4) To evaluate the effectiveness of the flowable formulation of carbofuran for control of the RWW.

2.1.5) To determine if carbofuran, in the absence of a weevil infestation, increases yield (functions as a possible plant growth stimulator).

2.1.6) To determine if nematodes, when used as a biological insecticide, are effective in controlling the RWW. Furthermore, to determine what nematode species, rates of application and water regimes at application are most effective.

2.2) Rice water weevil - genetic control.

2.2.1) Studies on the tolerance of rice to the weevil were made in the field at Biggs Rice Experiment Station (RES) with a standardized test that compared two susceptible commercial varieties to 28 lines developed for weevil tolerance.

2.2.2) A greenhouse experiment at UCD compared a tolerant and susceptible line when exposed to three levels of adult weevils on 14, 21, and 28 day old plants to provide information on the mechanism of tolerance and the influence of plant age at time of infestation on susceptibility.

2.2.3) A field experiment at Biggs RES compared tolerant and susceptible lines exposed to a natural infestation of the RWW to provide information on the mechanism of tolerance.

2.2.4) A pilot study compared tolerant, susceptible and lines noted for their superior seedling vigor to explore the possibility that seedling vigor and weevil tolerance are related.

2.3) Rice water weevil - cultural control.

2.3.1) To determine the effect of delayed planting on RWW infestation level, plant growth and yield.

2.3.2) To determine the effect of temporary early season drainage on RWW infestation and survival, plant growth and yield.

2.3.3) To determine the effect of drainage on specific life history stages (adults, eggs, first instars, and late instars) of the RWW.

2.3.4) To evaluate the influence of seeding rate and weevil damage on yield to determine if weevil losses can be mitigated with higher seeding rates along the margins of fields.

Objective 3: Determine the nature and extent of interactions among various invertebrates, pathogens and weed pests of rice.

3.1) To determine the interaction between root damage from RWW larvae and seedling pathogen invasion/development on rice survival and growth.

3.2) To determine the relationship between broadleaf weed control and weevil damage on rice growth and yield.

SUMMARY OF 1989 RESEARCH BY OBJECTIVE:

Objective 1:

1.1) Light trap collections for the rice water weevil are made annually to determine the levels and intervals of peak flight periods so as to interpret infestation magnitude and timing in research plots. The spring migratory flight of 1989 was extremely heavy. Approximately 15,159 adult weevils were captured in the light trap at Biggs RES. This level has been exceeded only twice (1969 & 1981) in the twenty-seven years these data have been taken. The spring migratory flight consisted of two peaks. The first peak was relatively small. It occurred between April 3-14, with an accumulation of about 100 day-degrees and a warming period of daytime temperatures up to 92°F. The end of this first peak was associated with cooler weather, with daytime temperatures dropping to 60°F.

The second peak was massive. Eighty-seven percent of the weevils collected in the light trap were captured during this second peak. It occurred between April 26 and May 8 with an accumulation of ca. 175-250 day-degrees. Ninety percent of the flight was completed at ca. 246 day-degrees which occurred on May 6, about two weeks earlier than last year.

The massive spring migratory flight of April 26-May 8 coincided with the flooding/planting of many paddies. As a result, many weevils probably found their way into paddies. Perhaps of greater importance, they arrived very early in the cropping cycle. The level and timing of this flight likely resulted in heavy weevil feeding pressure on small rice plants (which are most susceptible to weevil damage) in many fields and explains, at least in part, the high levels of weevil damage experienced by many growers this year. Fields flooded near the end or after the peak flight had passed would likely have lower infestations. This appeared to be true for fields at the Biggs RES (flooded between May 5-16) where many of the of the field experiments described in this report were located. This was unfortunate, as the success of many of the experiments depended on an adequate natural RWW infestation to properly evaluate control tactics. On the positive side, this demonstrated the effectiveness of delayed planting to reduce or avoid weevil infestation.

The light trap also catches armyworm adults. These are recorded to obtain background information that may relate to infestations in rice. Only sixty-four moths were collected between March 30 and June 28. This is about 20% of what was collected in a similar period in 1988. Peak flights occurred in mid to late June in both years.

1.2) Rice water weevil flight activity and infestation pattern in relation to the distance from the margin was further evaluated with sticky traps. Sixteen traps were placed in a 10 ac. field at the Biggs RES. Four traps were positioned along each side of the field at 0, 50, 100, and 150 feet from the margin. Leaf scar counts were taken around each trap to compare weevil density with flight activity. Adult weevils were collected from and around the sticky traps for dissection to determine the state of physiological transition from flight capable to reproductive status. The traps were placed in the paddy on May 3 and flooding was completed by May 5. They were checked every 2-3 days until no additional weevils were collected on three successive visits.

Very few weevils were captured on the sticky traps. This may be explained in part by the late flooding of the field (70% of the flight had been completed by flooding time) and the inherent inefficiency of sticky traps at capturing weevils. The low weevil catches on the sticky traps prevented many of the comparisons that were initially planned. Even so, some interesting observations were made. A total of twenty-six adult weevils were collected from the sticky traps between May 6-17. All of these weevils had developed flight muscles and contained no eggs. The first weevils collected from the paddy surface occurred on May 17 and coincided with the emergence of rice through the water surface. All of these paddy-collected weevils were found along the margins and all contained eggs. The fact that the first weevils collected in the paddy had eggs indicates they were present in the paddy area for at least a week (1989 greenhouse studies showed it takes ca. 6-10 days to produce eggs after flying is completed). These weevils may represent "local" individuals present on the levees throughout the winter or those that had flown in during an earlier flight period, waiting for the rice to emerge. Future studies will be conducted to differentiate between these two possibilities so that the relative contribution of local and distant weevil populations to a given infestation can be determined.

1.3) Water weevil flights were studied in relation to daily weather conditions. This information, in conjunction with day-degree data, should be useful in making more accurate prediction about weevil flights. Weevils were observed and collected with black lights at Biggs RES. The observation period began 1/2 hour before sunset and continued as long as weevils could be collected. This was repeated three evenings: May 4, 19 and 26.

As was found last year, greater weevil catches were associated with higher temperatures at sunset (TAS) and lower wind speeds. More than 1000 weevils were collected on 4 May when TAS was 80°F and winds ranged from 6 mph at sunset to 0 mph at 8:30 pm. It was noted that on this evening the weevils began to fly in mass around 8:30 pm, when the winds had calmed. In contrast, only 21 weevils were collected on May 19 when TAS was 70°F and wind speed was 7 mph. On 26 May 176 weevils were collected with TAS of 75°F and wind speed of 8 mph. Some of the differences in the number of weevils collected may be attributed, in part, to seasonal flight dynamics rather than daily environmental conditions. Even so, the data suggest that weather plays an important and somewhat predictable role in influencing the occurrence and magnitude of weevil flights. In general, major flights seem to occur when TAS is greater than 70°F and winds are below 8 mph.

1.4) A greenhouse experiment was conducted to determine the influence of habitat on RWW flight behavior and physiology (as it relates to spring flight capability). This information will help researchers interpret seasonal flight behavior such as field selection by the weevils and may have important implications for experimental control tactics such as delayed planting and early season drainage.

The tendency of the weevil to fly out of confinement chambers with differing water-vegetation-soil conditions was evaluated. The five treatments were dry soil, moist soil, flooded soil, moist soil with rice, and flooded soil with rice. As expected, the dry-soil treatment showed the highest level of departure with 75% of the weevils leaving within 24 hours. In contrast, the flooded-soil-with-rice treatment ranked lowest with 23% emigration.

A second experiment compared the rate of flight muscle degeneration and reproductive maturation of flight capable weevils that were collected with black lights at the Biggs RES. These weevils were then confined on each of the five habitats mentioned earlier for six days. At the end of this period, dissections were made to determine flight muscle, ovary condition, and egg development.

After six days the weevils in the two treatments with rice (moist soil with rice and flooded soil with rice) showed signs of flight muscle degeneration with muscle volumes of 0.017 and 0.022 mm^3 respectively compared to a range of 0.037 to 0.049 mm^3 for the weevils in the other treatments. The trend for reproductive development was somewhat different. The weevils in the moist-soil only treatment had smaller ovaries and fewer eggs than the weevils in the other treatments. Ovary volume was 0.027 mm^3 compared to a range of 0.047 to 0.062 mm^3 for the others while the number of eggs in these weevils average 0.33 per individual compared to a range of 4.5 to 6.5 for the weevils in the other treatments. In summary, it appeared that flight muscle degeneration was associated with the presence of rice while the flooded condition and/or rice appeared to trigger a more rapid reproductive response. The linkage of flight muscle degeneration and reproductive development may not be as tightly linked as once thought, given the condition of the weevils in the flooded-soil treatment which had both developed flight muscles and eggs. All of the weevils in the dry-soil treatment died and desiccated, precluding intended measurements. This apparent vulnerability might possibly be exploited by means of early season drainage discussed later in this report.

1.5) The impact of organic rice culture on pest and beneficial invertebrates was determined by sampling in two adjacent fields. One field was water-seeded and grown conventionally, while the other was drill-seeded and grown organically. Populations and/or damage were monitored for various invertebrate pests and beneficial organisms (e.g. predators).

Feeding scars produced by the RWW were counted in three checks of each field on two different dates. On 14 June, before the organic field was permanently flooded, 6.7% of the plants sampled in the conventional field and 5.8% of those in the organic field were scarred. On 21 June, after the organic field was permanently flooded, 2.4% and 8.4% of the plants were scarred in the respective conventional and organic fields. Unfortunately the low weevil infestation precluded a meaningful comparison of weevil abundance and damage. Sampling of aquatic invertebrates with minnow traps showed that predators were more abundant in the organic than in the conventional field which was also true in the 1988 comparison.

1.6) Studies to determine the effect of drainage on non-target invertebrates were conducted. Three minnow traps were placed in previously drained and continuously flooded fields on a biweekly basis throughout the growing season. No significant differences in the numbers of any particular species were found between drained and flooded plots except for the beetle, *Hydrophilus triangularis*. Total numbers of this beetle were significantly less in a field drained 27 May than in a paired, continuously flooded field.

Objective 2:

2.1) Rice water weevil - chemical control.

2.1.1) The effect of Londax on the RWW was evaluated in response to observations in 1988 in which Londax treated plots contained fewer RWW larvae and showed lower levels of damage than plots treated with other broadleaf herbicides, despite higher adult infestation levels in the Londax treated plots. A greenhouse experiment was conducted to determine if Londax is directly toxic to some stage of the RWW (adults, eggs, or larvae) or reduces RWW oviposition.

Pre or postoviposition applications of Londax at 0.1 oz. (AI)/ac. were applied to one-liter plastic pots that contained two rice plants exposed to a controlled infestation of adult weevils. Various combinations of rice foliage and/or water were treated at selected intervals to determine possible effects on the adult, or immature stages including eggs. It appeared that Londax was not directly toxic to any stage of the RWW. No adult mortality was observed and no significant differences existed among the treatments in any of the characteristics measured (weevil abundance or plant growth measurements). Similar results were obtained in a related field experiment presented later in this report.

2.1.2) An experimental ICI compound (belonging to the synthetic pyrethroid class of insecticides) and a standard, Trebon, were evaluated for control of the RWW in a replicated field experiment at Biggs RES. Plots consisted of rice enclosed by aluminum rings that encompassed ca. 8 ft^2. Fifty adult weevils collected from a nearby paddy were added to each ring about 3 hours before the chemical treatments were applied.

Leaf scar counts of twenty plants for adult feeding on the two newest taken 2 days post treatment averaged 6.8 to 10.0 scars for the treated and 17.3 scars for the untreated. Seven day post treatment counts showed the treated averaged 0.3 to 1.0 scars compared to 19.8 in the untreated. The final sample at 13 days post treatment showed 0.0 to 0.3 scars in the treated compared to 18.3 in the untreated. There were no significant differences in scarring by adults between the different chemicals, formulations or rates of applications but they were all significantly less than the untreated. Ten cores were taken from each ring at 27-29 days post treatment. The immatures recovered from the roots were counted and plant growth characteristics measured. The average number of immatures per core ranged from 0.2 to 1.2 in the treated plots compared to 9.7 in the untreated.. As was the case for the leaf scar counts, there were no significant differences between chemicals, formulations or rates but they were all significantly less than the untreated. Of the seven plant growth characteristics measured, only root length and wet root weight were significantly different, such that treated was greater than untreated but no differences existed among the treated plots. Other growth characteristics, including yield, showed a general trend for improved growth of treated over untreated.

Based on the low scar counts, these compounds seem to be very effective adulticides. However, because of this, the time of application would be a critical factor. This limitation may explain, at least in part, why these compounds do not produce the yield increases that were associated with carbofuran in other experiments, both this and in previous years.

2.1.3) Dimilin was evaluated for control of the RWW in large scale field plots. Adjacent paddies, ca. 2 ac., received applications of carbofuran or Dimilin at four separate locations in the Sacramento Valley. Carbofuran was applied at 0.5 lbs. (AI)/ac. preplant-incorporated. Dimilin was applied by air at 0.25 lbs. (AI)/ac. in 10 gallons water per acre ca. 5 days after 50% of the rice had emerged through the water surface. Pre-treatment adult feeding scar counts were taken 1-3 days before the Dimilin was applied. Post-treatment scar counts were taken approximately one week after the Dimilin application. Ten cores (4" diameter), with one plant per core, were removed from four areas in each plot. Soil was washed from the plant roots and the number of immature rice water weevils were recorded and plant growth characteristics measured.

Unfortunately, three of the four test locations had very light to almost non-existent infestations, presumably because they were planted late (after 5 May), near the end of weevil flight. In the one location planted early, where the infestation level was adequate, the pattern of infestation was such that valid comparisons could not be made between treatments. The effectiveness of commercial applications of Dimilin on large scale plots remains undetermined.

2.1.4) A field test to determine the effectiveness of the flowable formulation of carbofuran in controlling the RWW was conducted at the Biggs RES. Preplant treatments of both the 4F and 5G formulations of carbofuran were applied at 0.5 lbs. (AI)/ac. to 10 by 10' plots. Ten cores were removed from each plot to determine the number of immature rice water weevils and measure plant growth characteristics. Yields were determined by harvesting 0.5 m^2 samples from within each plot.

Although the weevil infestation in the plots was lower than expected, and no significant differences were found in the number of immatures or in any of the plant growth characteristics, trends existed that seem to indicate that flowable formulation was effective. The plots treated with 4F carbofuran averaged the lowest number of immatures (4.7/core compared to 6.0 for the granular formulation and 6.7 for the untreated control) and the highest yields (1.296 Kg/m^2 compared to 1.214 Kg/m^2 for the granular formulation and 1.180 Kg/m^2 for the untreated control).

2.1.5) A field experiment to determine if carbofuran increased yield in the absence of a weevil infestation (i.e, functions as a plant growth stimulant) was conducted at the Biggs RES. Twelve paired rice plots, enclosed within aluminum rings, were placed in paddies that were on flooded on May 17. This was well after the peak weevil flight had passed so the plots contained very few weevils. Plots were randomly assigned one of two treatments: untreated control or carbofuran 5G at 2.0 lbs. (AI)/ac. Half of the carbofuran was applied preplant and the other half applied ca. 3-4 weeks postflood. Scar counts taken 7 days after 50% of the plants had emerged through the surface of the water showed that no RWW's were feeding in the plots.

Carbofuran did not appear to stimulate rice plant growth or significantly increase yield. The carbofuran treated plots yielded an average of 0.648 kg compared to 0.620 kg for the untreated control. However, this difference was not significant with a P-value was 0.409.

2.1.6) A greenhouse experiment was conducted to determine if nematodes, when used as a biological insecticide, are effective in controlling the RWW. And furthermore, to compare effectiveness of different nematode species, rates and water regimes at application time. Two nematode species (*Steinernema carpocapsae* and *Heterohabditis* spp. HP-88) were applied at two rates (40 and 80/cm^2) in association with three water management regimes { 1) nematodes applied directly into the water, 2) the water was drained and the nematodes were applied to the soil with reflooding after four days, 3) same as previous except reflooding after 8 days}. The nematodes were added to one-liter plastic pots that contained two rice plants that had been exposed to a controlled infestation of RWW adults for oviposition. Soil was washed from the roots at ca. 3 weeks post application and the number of RWW immatures recorded and plant growth characteristics taken .

No control was realized with either nematode species or any rate when applied directly to the water. When applied to the soil, *S. carpocapsae* consistently out-performed *Heterohabditis* spp. at a given application regime and rate, although not significantly so in all cases. The level of control improved with the higher rate and longer interval before reflooding with *Heterohabditis* but not with *S. carpocapsae*. The level of control obtained with *S. carpocapsae* (40 nematodes/cm^2), when applied to the soil with reflooding after 4 days, was impressive. This treatment showed an average of 2.8 RWW immatures per container compared to 23.3 for the control. When applied to the soil with reflooding after 8 days the above mentioned nematode treatment averaged 1.5 RWW per container compared to 11.3 for the control. The difference in the number of RWW immatures in the two controls may reflect the adverse effect of extended drainage on the survival of RWW larvae.

2.2) Rice water weevil - genetic control.

Weevil control through the development of one or more tolerant rice cultivars is the major goal of this objective. Differences in plant reaction to water weevil attack is believed to be primarily in the form of tolerance of the plants to larvae. With the cooperation of the plant breeders at Biggs RES, efforts have concentrated on incorporating several sources of tolerance into lines having suitable agronomic qualities. The mechanism(s) of this tolerance is being investigated in the field and greenhouse.

2.2.1) A standard field test for tolerance (see previous annual reports) compared 30 cultivars under treated (carbofuran) and untreated conditions under a natural weevil infestation. The test included 8 high ranking lines from previous standard tests (one line tested since 1985, one since 1986, two since 1987 and 4 lines carried over from 1988. 20 lines showing the most promise in the plant breeders tests in 1988 were selected for evaluation in this standard test for the first time in 1989. M-202 and M-9 were used as susceptible lines for comparison. The extent of adult weevil feeding scars indicated a below normal natural infestation. Even so, some early to mid-season weevil injury was observed in the untreated plots of M-202 and M-9 and carbofuran provided adequate control of weevils for comparisons with untreated plots.

A major difference between this and last years test was the presence of moderate broadleaf weed competition in 1989. In 1988 Londax was used and gave excellent season-long broadleaf weed control. This appeared to increase the ability of the rice to recover from early season weevil injury. This tended to mask the differences in tolerance (differences of the treated and untreated) making the selection process less clear. For example, the average percent difference in yield between treated and untreated susceptible varieties ranged form 1.2 to 4.5% in 1988. These values typically range from 20 to 60%, depending on infestation level and other variables. To avoid any possible masking of tolerance differences in 1989, MCPA was used for broadleaf weed control. This appeared to be a good decision as yield differences of 17-28% were obtained between treated and untreated susceptible varieties despite a very light weevil infestation.

A combined evaluation of visual growth, seven plant growth characteristics and yield ranked the best ten cultivars in the following order: 1) 89-W-24, 2) 89-W-12, 3) 86-W-03, 4) 89-W-10, 5) 88-W-11, 6) 89-W-16, 7) 88-W-22, 8) 88-W-20, 9) 89-W-25, 10) 85-W-02. Five of eight lines evaluated in the standard tests of previous years maintained high levels of tolerance while three were replaced by newly developed lines with gradual improvement in agronomic qualities. The yield reduction between treated and untreated for the top seven lines ranged from 1.9 to 5.3% compared to 17.1 to 28.1% for the susceptible lines.

2.2.2) A standard greenhouse test to determine the mechanism of tolerance was conducted at UC Davis. The tolerant line 85-W-02 was compared to the susceptible M-9 under different levels and time of infestations of RWW adults. Plants of different age (14, 21, and 28 days old) were exposed to 0, 1, 2, or 3 RWW adults for a total of four days over a period of six days. It was decided that adults should be used rather than larvae, as was done in previous years, because of the problem of low larvae recovery when larvae are added directly.

As was found in last years experiment, the smaller the plant at infestation the greater the susceptibility. Both the tolerant 85-W-02 and susceptible M-9 were greatly affected by a combination of adult and larvae weevil feeding at the earliest infestation (14 days). There were a significant reductions in all plant growth characteristics at all three infestation levels but not between tolerant and susceptible line at any level. The number of larvae recovered were very low for all treatments averaging a range of 0.0 to 2.0 per container. This suggests that stunted plants with highly damaged root systems (low root masses) are not able to support even modest larval populations. It is presumed that the larvae starve.

The plants infested at 21 days show some interesting differences. The tolerant out performed the susceptible line in all plant growth characteristics within a given infestation level. However, the average number of larvae recovered in the treatments where weevils were added did not differ significantly between tolerant or susceptible or among infestation levels even though initial infestation levels varied considerably.

The plants infested at 28 days generally showed similar trends as those infested at 21 days with the exception that fewer larvae were recovered from the tolerant plants within a given infestation level, suggesting possible delayed antibiosis. An indication of antibiosis was also observed in a 1988 field test although absent in many similar experiments conducted over a number of years. If antibiosis is functioning it is likely to be very subtle and highly variable. These statements are based on preliminary analysis of the data. More elaborate multivariate analyses are planned that may provide additional clues as to nature of the tolerance/resistance observed in selected lines.

2.2.3) A test similar to the standard test for tolerance was conducted at Biggs RES. The tolerant lines 85-W-02 and 86-W-03 were compared to the susceptible M-202. Plant samples and larval counts were made in paired treated (carbofuran) and untreated units at 40, 65, and 100 days after planting. The purpose of the test was to see if some difference in plant growth throughout the season could be found to provide information on the mechanism of tolerance that would aid in the plant selection process.

Some significant differences between selected pairs (treated and untreated) of tolerant and susceptible lines existed at both the 40 and 65 day samples despite a below normal weevil infestation. Plant recovery proceeded such that plant height was the only characteristic that was significantly different at 100 days. Yield data showed no significant differences between treated and untreated for any of the lines. However significant differences in yield did exist among the lines. The tolerant line 86-W-03 had the highest yields with an average of 1.207 kg for the treated and 1.227 kg for the untreated. The tolerant line 85-W-02 ranked second with average yields of 0.971 kg for the treated and 0.944 kg for the untreated. M-202 had the lowest yields with an average of 0.698 kg for the treated and 0.666 kg for the untreated. These results are somewhat surprising in that the tolerant lines outperformed M-202 in absolute yield in the absence of a moderate RWW infestation. Based on previous experience and the performance of these same lines in the standard field test for tolerance, it appears as if some unknown factor was functioning that contributed to these unique and unlikely results.

2.2.4) A pilot study to compare tolerant (85-W 02 and 86-W-03), susceptible (M-9 and M-202) and superior seedling-vigor lines (IL and R10641-23) with respect to RWW tolerance was conducted at the Biggs RES. Lines were planted in rows 4 ft. long. Seedling vigor performance, as determined from visual ranking, was taken ca. three weeks postflood. Cores were taken ca. five weeks postflood to record the number of RWW immatures and measure plant growth characteristics.

The lines noted for their superior seedling vigor ranked highest in the early season visual evaluation yet they appeared to be most susceptible to weevil damage, as they were greatly stunted by mid season when weevil damage was fully expressed. The tolerant lines showed intermediate seedling vigor. The susceptible lines showed the lowest seedling vigor (partly a reflection of early season weevil damage). Somewhat unexpectedly, there were no significant differences among the different rice lines in the number of larvae recovered. Yields could not be compared because of substantial bird damage to the early maturing seedling-vigor lines. The seedling-vigor lines may prove useful in future mechanism of tolerance experiments.

2.3) **Rice water weevil - cultural control.**

2.3.1) As eluded to earlier, the relationship of weevil flights to flooding dates, planting dates, and plant age may present opportunities to avoid or reduce the potential for water weevil injury. If flooding and planting dates cannot be manipulated than the knowledge of when maximum injury is expected can be used to apply control strategies. Weevil flight is dependent upon accumulation of heat units (for the development of their flight muscles) and suitable evening temperatures and wind conditions to allow for flight. The feasibility of monitoring the variables affecting flight so as to predict it's completion thereby avoiding or limiting the weevil infestations through delayed planting was tested at the Biggs RES. Nine paddies incorporating three flooding/planting dates were used.

Initial plans were to compare the weevil infestations and yields of an early planting, a intermediate planting and a late planting (around 100, 200 and 300 day-degrees, respectively) In actuality first paddies were not ready to flood/plant until 246 day-degree units had accumulated on May 7. By this time 90% of the flight had been completed. The second flooding/planting was made at 279 day-degrees had accumulated on 11 May with 95.5% of the flight completed. The third flooding/planting occurred at 387 day degrees on 29 May with 99.8% of the flight completed. No carbofuran was used and preflood Ordram and postflood MCPA and Ordram were applied. Three hundred plants per replication were examined for adult feeding scars for each planting time at about 7 days after 50% of the plants had emerged through the water surface. Ten plant cores were removed from each replication about 5 weeks post planting. Plots were harvested by combine and yields obtained.

Scar counts on the two newest unfurled leaves for the first, second and third plantings were 19.3, 15.7 and 22.2% respectively. The lack of a sufficient gradient in infestation level among the planting dates prevented the intended comparisons. Unfortunately the first planting was not early enough as the flight was 90% completed by this time. Presumably an earlier planting would allow for the "capture" of a greater number of weevils and provide a "control" with which to measure the effectiveness of delayed planting.

2.3.2) Water by its absence, through non-replacement or rapid removal, may be detrimental to a stage of the water weevil life cycle by direct mortality or by affecting its behavior pattern. A Field experiment was conducted at the Biggs RES to evaluate the effect of early season drainage on the RWW..

Nine plots (20 by 150') were drained for 10-12 days beginning ca. 14 days after planting. These were compared to paired plots that were continuously flooded with respect to scar counts, the number of immatures, plant growth and yield.

A predrain scar count showed the paddies to be continuously flooded with an average of 19.1% of the plants scarred compared to 26.8% in the paddies to be drained. These values indicated a light infestation, approaching the economic level. At the end of the drain period the soil was hard, dry and cracked and the rice plants showed signs of wilting. Scar counts taken immediately after reflooding showed 50.2% of the plants scarred in the continuously flooded paddies compared to 10.4 in the drained paddies. The low scar counts in the drained paddies may reflect lower adult levels from weevil departure and/or mortality and/or reduced feeding behavior during the drain period. Cores taken from each paddy at ca. 5 weeks postflood showed the drained treatment averaged 0.2 immatures per core compared to 5.5 for the continuous flood. The drained treatment averaged 10,398 kg/ha (± 1506 SD), nearly the same as the previous year, while the continuous flood averaged 11,096 kg/ha (± 1438 SD) an 11% increase over last year. This increase in the flooded may reflect the reduced weevil infestations in 1989. Predrain scar counts averaged 40-50% in 1988, about twice that of 1989. Drainage appears to control weevils but also depress yield. However, from the 1988 experiment, it appears that there is a level of weevil infestation where the benefit of drainage in terms of weevil control exceeds the yield loss incurred from drainage. The availability of other weevil controls and long term weed management need to be considered.

2.3.3) Studies to determine the effect of drainage on specific life history stages (adults, eggs, first instars, and late instars) of the rice water weevil were conducted. Plants exposed to RWW adults in the greenhouse for oviposition were transplanted into the field and subjected to flooded or variable intervals of the drainage (0 to 12 days). Statistical comparison of egg and first instar survival between flooded and drained plots could not be performed because of block and day effects between various treatment factors within plots. However, large numbers of immature weevils per plant were recovered for both drained and flooded treatments in each experiment. This suggests that reduction of weevil numbers by field drainage does not stem from its effects eggs in the plant or first-instar larvae. No statistically significant difference was found in the survival of late larval instars of the weevil between flooded and drained plots.

Adult weevils caged on plants in the drained treatment plot laid significantly fewer eggs and made significantly fewer feeding scars per plant than adults in the continuously flooded plot. These results add support to the hypothesis stated earlier that drainage may have it's greatest effect on the adult stage of the weevil. If this is true then early season drainage for weevil control might be modified with respect to initiation and duration of drain to possibly increase effectiveness against the weevil, reduce stress to the rice and increase compatibility with other cultural practices.

2.3.4) The interaction of seeding rate and weevil damage on yield was investigated in an experiment at Biggs RES. It is known that weevil damage to rice reduces the number of tillers produced per plant. The feasibility of compensating for this by artificially increasing the number of tillers through increasing planting rate was evaluated. Seeding rates of 75, 150, and 225 lbs/ac of M-202 in carbofuran treated and untreated plots (20' by 20') were established and replicated four times.

No significant differences in yield existed among seeding rates although higher yields were associated with the higher seeding rates among the untreated plots. The treated plots yielded and average of 0.267 lbs./ft^2 which was significantly greater than the untreated at 0.247 lbs./ft^2. The percent differences in yield between treated and untreated for the 75, 150. 225 lbs./ac. seeding rates were 11.6, 10.4, and 7.2% respectively. It is likely that more dramatic differences might have been expressed had the infestation level been greater.

Objective 3

3.1) The interaction between weevil feeding by the larvae on the roots and seedling pathogen invasion/development on rice survival and growth was evaluated in a greenhouse experiment conducted at UC Davis. The intent was to compare rice seedling survival and growth when exposed to: the "natural" occurring microbial fauna in the soil (unsterilized soil), a known seedling pathogen (pathogen added to sterilized soil) and pathogen free environment (sterilized soil); both with and without larvae feeding on the roots.

The dominant effect, which masked any other effects that might have been present, was wether or not the soil was sterilized. Plants in the unsterilized soil were much more vigorous than those in treatments where the soil had been sterilized, irrespective of other factors. It is now evident that a treatment where the pathogen was added to unsterilized should have been included.

3.2) The relationship between broadleaf weed control and weevil damage on yield was evaluated in a field test at Biggs RES. It was previously observed that plots treated with Londax showed lower levels of damage than plots treated with other broadleaf herbicides. To test this, paired rings (treated and untreated for the RWW) were placed in paddies where Londax, MCPA, or no broadleaf herbicide had been applied. Fifty adult RWW's were added to each ring. Ten cores were taken from each ring ca. five weeks post flood to determine the number of RWW immatures and measure plant growth characteristics. All the plants within the rings were harvested to obtain yield.

The carbofuran did an excellent job in this test as significantly fewer weevils were found in the carbofuran treated plots which average between 0.0 to 1.0 immature per core compared to a range of 8.5 to 10.6 in the untreated. However, no differences existed in RWW abundance among the herbicide treatments. These data support the results of a greenhouse experiment, reported earlier, in which no toxicity of Londax to the weevil was detected. Londax treated plots shower significantly greater plant growth than the MCPA treated plots in two of seven plant growth characteristics but was not different from the control. These samples were taken ca. 1 week after the MCPA was applied and presumably reflects injury to rice, which is associated with MCPA. Yield data showed Londax to be an excellent herbicide. In the plots where weevils were control the Londax treatment yielded 19 and 16% more than the MCPA treatment and control respectively. This difference in yield increased to 26 and 40% more than the MCPA treatment and control respectively when weevil damage was added. Viewed another way, the percent difference in yield between plots treated and untreated for the RWW was 19.8% for Londax, 26.9% for MCPA, and 42.0% for the control. This experiment clearly shows that yield losses from the weevil are reduced when Londax is used. In fact, the average yield in the Londax plots without carbofuran (0.526 kg) did not differ significantly from the MCPA (0.531 kg) or control (0.550 kg) plots where weevils were controlled with carbofuran. It appears that the rice was better able to recover from weevil damage when relieved of early season broadleaf weed competition and/or herbicide injury as is the case when Londax is used. In addition, weed problems usually associated with weevil damage (i.e., thin stands) were avoided in the Londax treated plots.

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CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

Rice Water Weevil (RWW) flight activity began later, ended earlier and was much heavier than in most years. The magnitude of the 1989 flight, as determined by light trap, has been exceeded only twice. Two peaks were detected. The first was relatively small. It occurred between April 3-14, with an accumulation of about 100 day-degrees. The second peak was massive, representing about 87% of the total flight. It occurred between April 26 and May 8 with an accumulation of ca. 175-250 day-degrees. Paddies flooded before or during this second flight period may have been "invaded" by a large number of flying adults, resulting in high infestation levels early in the season when the rice is small and most susceptible to weevil feeding. Fields at the Biggs RES, flooded after this second peak flight period, generally had low weevil infestations. This was a problem for researchers who rely on adequate natural infestations to evaluate experimental control methods. Delayed planting would appear to be a viable control alternative in years like 1989, when flight activity drops off sharply relatively early in the season.

Weevil flight is not governed by day-degree accumulation alone, but is also dependent on suitable evening temperatures and wind conditions. Observations of evening flight between May 4-26 indicate that major flights are associated with temperatures-at-sunset near 80°F and little or no wind. The integration of this information into day-degree accumulation models will increase the proficiency of researchers to forecast peak weevil flights thereby enhancing the capability to avoid or reduce weevil infestations through delayed planting.

The influence of habitat on RWW flight behavior and physiology (as it relates to flight capability) was investigated in a greenhouse experiment. The tendency of the weevil to fly out of confinement chambers with differing water-vegetation-soil conditions was evaluated. Dry soil showed the highest level of departure with 75% of the weevils leaving within 24 hours. Flooded soil with rice ranked lowest with 23% departure. Flight muscle degeneration was associated with the presence of rice while the flooded condition and/or rice appeared to trigger a more rapid reproductive response. All of the weevils subjected to dry soil conditions died, indicating that adults were susceptible to desiccation. This apparent vulnerability might be exploited by some form of early season drainage discussed later.

The impact of organic rice culture on pest and beneficial invertebrates was investigated. Weevil infestations were very low in both the organic and conventional fields sampled. Predators were more abundant in the organic field, which was also true in a 1988 comparison.

An ICI compound (belonging to the synthetic pyrethroid class of insecticides) seemed to be very effective at controlling RWW adults and significantly reduced the number of larvae found feeding on the roots but failed to produce significant yield differences.

Dimilin was evaluated for control of the RWW in large scale field plots. Because of an inadequate weevil infestations, the evaluation was not conclusive. The ability of Dimilin to control the weevil under commercial growing conditions remains undetermined.

A field test to determine the effectiveness of the flowable formulation of carbofuran in controlling the RWW was conducted at the Biggs RES. Although not significantly different, the plots treated with the flowable carbofuran averaged the lowest number of immatures and the highest yields. These differences might have been significant had the weevil infestation level been higher.

A field experiment showed that carbofuran, when applied at 2.0 lbs. (AI)/ac., did not increase yield of M-202 in the absence of a weevil infestation (i.e., did not function as a plant growth stimulant).

The nematode species, *Steinernema carpocapsae* and *Heterohabditis* spp. HP-88, when applied to drained soil as a biological insecticide under greenhouse conditions, reduced the number of RWW larvae by approximately 87 and 45%, respectively. No control was realized when the nematodes were applied directly to the water.

A standard field test for tolerance compared 30 lines under treated (carbofuran) and untreated conditions under a natural weevil infestation. A combined evaluation of using visual ranking of growth, and measurement of seven plant growth characteristics and yield, ranked the best ten cultivars in the following order: 1) 89-W-24, 2) 89-W-12, 3) 86-W-03, 4) 89-W-10, 5) 88-W-11, 6) 89-W-16, 7) 88-W-22, 8) 88-W-20, 9) 89-W-25, 10) 85-W-02. The yield reduction between treated and untreated for the top seven lines ranged from 1.9 to 5.3% compared to 17.1 to 28.1% for the susceptible lines.

A standard greenhouse test to determine the mechanism of tolerance was conducted at UC Davis. The tolerant line 85-W-02 was compared to the susceptible M-9 under different levels and times of infestations with RWW adults. As was found last year, smaller plants show greater susceptibility. Both the tolerant and susceptible lines were greatly affected by weevil feeding at the earliest infestation (14 days). The number of larvae recovered was very low for all treatments, averaging a range of 0.0 to 2.0 per container. This suggests that plants with highly damaged root systems (low root masses) are not able to support even modest larval population levels. It is presumed that the larvae starve. The plants infested at 21 days show some interesting differences. The tolerant line out-performed the susceptible in all plant growth characteristics within a given infestation level. The plants infested at 28 days generally showed similar trends as those infested at 21 days with the exception that fewer larvae were recovered from the tolerant plants within a given infestation level, suggesting possible delayed (induced) antibiosis.

A pilot study to compare tolerant (85-W-02 and 86-W-03), susceptible (M-9 and M-202) and superior seedling-vigor lines (IL and R10641-23) with respect to RWW tolerance was conducted at Biggs RES. The lines noted for their superior seedling vigor ranked highest in the early season visual evaluation yet they appeared to be the most susceptible to the weevil, as they were greatly stunted by mid-season when weevil damage was fully expressed.

The effect of early season drainage (10-12 days beginning ca. 14 days after planting) on the RWW was evaluated in a field test at Biggs RES. At the end of the drain period the soil was hard, dry and cracked and the rice plants showed signs of wilting. Scar counts taken immediately after reflooding showed 10.4% of the plants scarred in the drained paddies compared to 50.2% in the paddies that were continuously flooded . The low scar counts in the drained paddies may reflect some combination of adult weevil departure, mortality, or reduced feeding behavior during the drain period. At five weeks after planting the drained treatment averaged 0.2 immatures per core compared to 5.5 for the continuous flood. The drained treatment yielded an averaged of 10,398 kg/ha {about 93 sacks/acre}, nearly the same as the previous year, while the continuous flood averaged 11,096 kg/ha {about 99 sacks/acre}, an 11% increase over last year. This increase in the flooded may reflect the lower weevil infestations in 1989. Predrain scar counts averaged 40-50% in 1988, about twice that of 1989. Drainage, appears to control weevils but also depresses yield. However, from the 1988 experiment, it appeared that there is a level of weevil infestation where the benefit of drainage, in terms of weevil control, exceeds the yield loss incurred from drainage when other means of weevil control are not available.

The effect of drainage on specific life history stages of the weevil showed that adults laid significantly fewer eggs and made significantly fewer feeding scars per plant during the drain treatment than adults in the continuously flooded plot.

The interaction of seeding rate and weevil damage on yield was investigated in an experiment at Biggs RES. M-202 was seeded at 75, 150, and 225 lbs./ac. in carbofuran treated and untreated plots. The percent differences in yield between treated and untreated for the 75, 150, and 225 lbs./ac. seeding rates were 11.6, 10.4, and 7.2% respectively. It appears that yield losses from the weevil are reduced somewhat at higher seeding rates.

The interaction between weevil feeding by the larvae on the roots and seedling disease was evaluated in a greenhouse experiment conducted at UC Davis. Plants grown in unsterilized soil were much more vigorous than those in treatments where the soil had been sterilized, irrespective of all other factors tested.

The relationship between broadleaf weed control and weevil damage on yield was evaluated in a field experiment at Biggs RES. Previously it was observed that plots treated with Londax showed lower levels of weevil damage than plots treated with other broadleaf herbicides. The experimental results clearly support this observation. In the plots where weevils were controlled, the Londax treatment yielded 19 and 16% more than the MCPA treatment and control respectively. This difference in yield increased to 26 and 40% more than the MCPA treatment and control respectively when weevil damage was added. In fact, the Londax without carbofuran plots yielded (0.526 kg) nearly that of the MCPA (0.531 kg) or control (0.550 kg) plots where weevils were controlled with carbofuran. It appeared that the rice was better able to recover from weevil damage when relieved of early season broadleaf weed competition and herbicide injury as is the case when Londax is used. In addition, weed problems usually associated with weevil damage (i.e., thin stands) were avoided in the Londax treated plots. Based on the results of field and greenhouse experiments, Londax did not appear to be directly toxic to any stage of the RWW.