PROJECT NO. RP-3

ANNUAL REPORT
COMPREHENSIVE RESEARCH ON RICE

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PROJECT TITLE: Rice protection from invertebrate pests.

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OBJECTIVES AND EXPERIMENTS CONDUCTED BY LOCATION:

Objective 1: To determine the most effective control of rice invertebrate pests while maintaining environmental quality compatible with the needs of society.

1.1) Rice water weevil chemical control - Comparison of the efficacy of experimental materials versus registered standards for controlling rice water weevil in ring plots.

1.2) Effects of application method on effectiveness of registered and experimental insecticides for rice water weevil control.

1.2.a) evaluation of the efficacy of insecticides applied pre-flood, early post-flood, and at the 3-leaf stage for controlling rice water weevil in ring plots.
1.2.b) evaluation of experimental insecticides as a rescue treatment in rice for rice water weevil control

1.3) Efficacy of Coragen for Rice Water Weevil with a natural infestation in replicated field plots.

1.4) Evaluation of a biological insecticide for Rice Water Weevil in greenhouse and field studies.

1.5) Evaluation of the influence of applications of registered and experimental insecticides on populations of non-target invertebrates in rice.

1.6) Rice Water Weevil susceptibility to pyrethroid insecticides

1.7) Tadpole shrimp control – Evaluation of control with registered and experimental insecticides.
1.8) Impact of winter flooding on rice water weevil populations.

Objective 2: To evaluate the physical and biological factors that result in fluctuation and movement of populations of the rice water weevil so as to better time control options such as insecticide applications.

2.1) Evaluation of the movement of Rice Water Weevil (RWW) populations that result in economic injury to rice plants. Monitor seasonal trends (timing and magnitude) in the flight activity of the RWW.

2.2) Quantify the relative susceptibility of commonly grown rice varieties to RWW infestation and the yield response of these varieties to RWW infestation.
- 2.2.a) Studies with controlled populations of Rice Water Weevil
- 2.2.b) Studies with naturally-occurring populations of Rice Water Weevil

2.3) Study the impact of seeding rate and rice variety on the yield response to Rice Water Weevil damage.

Objective 3: Conduct appropriate monitoring, exploratory research, and educational activities on emerging and new exotic rice invertebrate pests.

3.1). Investigate possible insect-related causes for rice seed damage.

SUMMARY OF 2013 RESEARCH BY OBJECTIVE:

Objective 1:

1.1 - 1.2) Chemical Control of Rice Water Weevil - Ring Plots

1.1, 1.2) Research for subobjectives 1.1 and 1.2 was conducted within one plot area and the results and discussion for this study will be considered together. The data will be reported in its entirety for ease of comparison across treatments and the conclusion from each sub-objective will be reported. Each treatment was replicated four times. Twenty-one treatments (a total of seven different active ingredients) were established in ring plots to accomplish this research. Plots were in a replicated field study at the Rice Experiment Station (RES) near Biggs, CA. Treatment details are listed in Table 1.

Methods:

Testing was conducted with 'M-202' in 10.7 sq. ft aluminum rings. The plots were flooded on 28 May and seeded on 29 May. A seeding rate of 100 lbs./A was used. Prior to seeding, seed was soaked for 2 hrs. in 5% Clorox Ultra solution (for Bakanae control), followed by 22 hrs. in water, drained, and held for 24 hrs. The application timings were as follows:

27 May, pre-flood (PF) applications
10 June, early post-flood applications
17 June, 3-leaf stage treatments
26 June, 5-6 leaf stage application (rescue timing)

Granular treatments were sprinkled into the rings and liquid treatments were applied with a

CO_2 pressurized sprayer at 15 GPA. The natural rice water weevil infestation was supplemented with 8 adults placed into each ring on 8 June followed by 6 more RWW adults added on 20 June. The standard production practices were used. Cerano® was applied on 5 June and nitrogen was top-dressed in July. The following sample dates and methods were used for this study:

Sample Dates:

Emergence/ Seedling Vigor/Stand Rating: 16 June
Adult Leaf Scar Counts: 21 June and 26 June
Larval Counts: 10 July and 23 July
Rice Yield: 16 October

Sample Method:

Emergence/ Seedling Vigor/Stand Rating:
stands rated on a 1-5 scale with:
5=very good stand (>150 plants)
3=good stand (~100 plants)
1=very poor stand (<20 plants)
Adult Leaf Scar Counts: percentage of plants with adult feeding scars on either of the two newest leaves (50 plants per ring)
Larval Counts: 44 in^3 soil core containing at least one rice plant processed by washing/ flotation method (5 cores per ring per date)
Rice Yield: entire plots were hand-cut and grain recovered with a 'Vogel' mini-thresher and yields were corrected to 14% moisture.
Data Analysis: ANOVA of transformed data and least significant differences test ($\rho < 0.05$). Raw data reported herein.

Plot Design:

Randomized Complete Block

Results:

Rice Emergence/Stand Rating

Stand ratings ranged from an average of 2.6 to 3.0. There were slight differences among treatments in terms of seedling vigor and emergence but these were not significant (Table 2). A stand rating of 3.0 is approximately 100 seedlings per ring which is the preferred density. The spring establishment period was good which facilitated obtaining a viable stand. None of the preflood or early post-flood insecticide treatments affected germination or early establishment.

Adult Leaf Scar Counts

RWW adult feeding scars were counted twice at 5 days apart. The average of these two dates is shown in Table 2. Rice plant leaf scarring ranged from 5.3 to 16.3% across the treatments. Research in California has shown that a damaging level of RWW larvae is associated with a RWW feeding scar incidence of ~20%. These data would optimally be an evaluation of the activity of preflood and early post-flood insecticide treatments; the data were also collected after 3-leaf treatments were applied but some feeding damage occurred between the time of infestation of the rings with RWW and 3-leaf applications. Feeding damage was highest in the untreated, Dimilin, MAR-12 (3 rates), and Belay (5-6 leaf stage) treatments. These entries were either without insecticides, not effective on RWW adults, or not applied yet at the time of scarring evaluation. Several entries showed good activity on RWW adults and feeding damage including Warrior (all timings), Belay (early post-flood and 3-leaf timings), Mustang (3-leaf), Declare (3-leaf), and Coragen (3-leaf). If the leaf scarring is reduced, the insecticide most likely has toxicity to adults. This is particularly important and interesting when evaluating preflood and soil-applied treatments. If the leaf scarring is not reduced but the larval population is reduced, then the insecticide acts by directly killing larvae.

Larval Counts

RWW larval counts were made twice during the season (Table 3). The larvae are hidden and the speed of development depends on temperature. Thus when sampling for the larvae we are never sure how developed (large) they are. The two sample dates helps to insure that at least one of the sample dates coincides with the population peak as well as so we can look at residual control from products. Sometimes a product initially reduces the larval population but does not provide long-term, residual control. In 2013, RWW populations were about average. The threshold for damage is ~1 RWW per core so I strive to have at least that number. Populations in the untreated averaged 1.1 RWW per core sample in 2013. On the first coring date, all the treatments except MAR-12 (all three rates) and Coragen at the 5-6 leaf stage significantly reduced RWW populations compared with the untreated, i.e., sixteen of the treatments did so. In the second coring date, only ten of the treatments significantly reduced numbers of RWW larvae relative to the untreated. Populations in the untreated declined by about 50% from the first to second core sample thus this compression of the data resulted in fewer statistical differences. Overall, Warrior applied at the early post-flood timing zeroed the population and Warrior (3-leaf), Belay (early post-flood and 3-leaf), Declare (all three treatments), and Coragen (6.1 fl. oz. preflood) resulted in an average of only 0.1 RWW larva.

Rice Yield

Grain moisture at harvest (percentage), grain yields (lbs. per A at 14% moisture standard), and biomass (tons per A [straw + grain weight] at harvest) data are shown in Table 4. Moisture values ranged from 10.5 to 13.7% (Table 4). While there were some significant differences, they did not appear to be related to the treatment or to the amount of RWW damage. For instance the percentage moisture from untreated plots was intermediate with 12 other treatments with higher values and 8 with lower values. Rice grain yields ranged from ~2615 to 5930 lbs./A. The yield in the untreated plots was intermediate but nearer to the highest than the lowest yield at ~4795 lbs./A. Statistically, the yield in the untreated did not differ from any of the other yields. Overall, the yield in the Belay early post-flood treatment was significantly higher than that in the Mustang preflood and MAR-12 (8 and 16 lbs./A) treatments. The yield in the Warrior 3-leaf stage treatment was in second place and the only other one over 5000 lbs./A. For overall biomass (straw and grain), similar trends were seen. The biomass was greatest in the Warrior 3-leaf treatment and also high in the Belay preflood and early post-flood treatments. Weights less than 5 t/A were in Dimilin, Belay (5-6 leaf), Mustang (preflood), Coragen (2-3 leaf and 5-6 leaf), and MAR-12 (8 and 16 lbs./A).

In summary, two pyrethroid products continue to provide excellent RWW control. Warrior continues to effectively control RWW larvae via preflood and 2-3 leaf postflood application; Declare, which is a newly available pyrethroid, appears to provide as good of RWW control as

Warrior. The activity of Mustang, which has traditionally been equal to the other pyrethroids, now appears to be slightly less effective. This same observation was made in 2012. Belay, which is registered for the 2014 use-season provided very good RWW control with a 2-3 leaf stage timing. The preflood application of Belay was less effective. It appears the optimal timing with Belay is the 3-leaf stage. Coragen with a preflood timing provided excellent RWW control; this material is still in the experimental stage. The 3-leaf timing of Coragen was less effective although still provided ~60-70% control. Dimilin (3-leaf stage) performance was less than desired. The rescue timings of Coragen and Belay showed a moderate to good level of RWW control (better with Belay than Coragen) and may have a fit in certain situations.

1.3) Efficacy of Coragen for Rice Water Weevil with a natural infestation in replicated field plots.

Coragen is a potentially new RWW product (still experimental) that comes from a different class of chemistry than other insecticides registered in rice. It is available in southern rice as a seed treatment, but the seed treatment method of application has not worked well in the California water-seeded system. We have been examining this product using various methods of application, timings, and formulations. In ring plots, it has worked well with a preflood (soil-applied) method of application. Of course, the industry has experience with preflood insecticides for RWW with the use of Furadan for many years in the 1980-90’s.

Testing insecticides in ring plots is a way to effectively utilize resources (space and people) as many products can be compared and evaluated. But it does introduce some artificial aspects into the testing in that the RWW adults are introduced into the rings in clutches to lay eggs and to start the infestation. Testing of products in large open plots or in grower fields has advantages in determining efficacy. However, this is difficult to do before a tolerance for the active ingredient is granted (due to the need for crop destruct); the other consideration is that RWW infestations tend to be erratic and spotty so some locations will not have adequate pressure. The mobile nature of insects such as RWW means that fairly large plots must be used which potentially adds to the cost.

Coragen was examined in 600 sq. ft. plots at the Rice Experiment Station in 2011 with very good results. This study was repeated in 2012 and the results were more erratic. The research was continued in 2013.

Methods:

The treatments as shown in Table 5 were evaluated. All treatments were applied preflood. Three rates of Coragen were tested (0.08, 0.01, and 0.12 lbs. AI/A), with Warrior II and Belay as standards, and an untreated. Each treatment was replicated four times. The plots were 25 by 25 ft. with a 5 foot untreated buffer separating all plots. Rynaxapyr, the active ingredient in Coragen, does not move once applied to the soil thus the integrity of those treatments was maintained even though no barrier/levees were used. Warrior was treated similarly as it binds to organic matter. Belay is perhaps more prone to move in the water (it is systemic in plants) thus metal barriers were constructed around these plots and kept in place for the first 6 weeks of the study.

Leaf scarring, RWW population levels, and grain yields were evaluated. Methods used were as described in subobjectives 1.1 and 1.2 except that the grain yields were collected with the small plot harvester from a 7.25 x 25 ft. long strip and yields were corrected to 14% moisture.

The details are as follows:

27 May- preflood applications (trt. 1-5)
28 May - flooding
29 May – seeding
21 June and 26 June - adult leaf scar counts
11 July and 24 July - larval counts
13 October - rice yield

Results:

Stand establishment was generally good in this study (Table 6). RWW induced leaf scarring was evaluated twice; the numbers were fairly low (<20%) and there were no significant differences among the treatments (Table 6). RWW larval populations were moderate in this plot. On the first sample date, only the low rate of Coragen and Warrior provided a significant level of control compared with the untreated (Table 7). The Coragen treatment showed about 75% control with Warrior in the 95% range. The other two rates of Coragen reduced RWW populations by ~50%. Populations declined in all treatments in the second core sample probably indicative of RWW maturity and pupation (the population was beginning to cycle-out). As such there were no significant differences. But populations in the Coragen treatments, especially the two high rates, appeared to decline more than the untreated indicating an increased level of control. For instance, the RWW level in the untreated declined ~60% whereas in the 7.7 and 9.2 fl. oz. Coragen treatments it declined by ~70% and ~90%, respectively. Rice yields were similar among all treatments in this study (Table 8). There was a trend for lower yields in the two least effective treatments (Belay and untreated) but these differences were not significant. The Coragen treatments and Warrior were the highest yielding.

Overall, the results with Coragen were somewhat positive. From these data, it appears the product is effective but just very slow to effectively control RWW. The data from the later core sample show some positive results but from the first core sample the results are less conclusive. The yield results were consistently positive. Warrior (preflood) was more effective than Coragen and Belay (preflood) was less effective. This reinforces previous conclusions that Belay should be used at the 2-3 leaf stage as not preflood as done here (used this way so there could be a direct comparison to Coragen).

1.4) Evaluation of a biological insecticide for Rice Water Weevil in greenhouse studies.

Reduced risk, biorational, and bioinsecticides insecticides are the emphasis of the agrichemical companies today (along with biotechnology options). The definitions of these three terms are somewhat vague but generally represent more “natural” and a reduced level of environmental concern moving from reduced risk to bioinsecticide. Companies that have concentrated on traditional synthetic insecticides are now placing emphasis on these materials as shown by Bayer’s recent acquisition Agraquest. Microorganisms and by-products from microorganisms can have insecticidal properties. If appropriate, microbe products can be applied directly to crops, the by-product isolated and applied to crops (either as isolated or a synthetic version of the by-product), or some portion of the microbe can be inserted into crop plants and these process affords protection of the crop. *Bacillus thuringiensis,* a bacterium that is a commonly used insecticide, and spinosad, an insecticide that originated from a microorganism (and now there are synthetic variations of this compound with improved efficacies), are examples of this.

There are numerous types of *Bacillus thuringiensis,* both different strains and subspecies. These have different characteristics including what insect types and species they kill. The commonly-used *Bacillus thuringiensis* kills the larval stage of Lepidoptera – butterflies and moths such as armyworms. But other subspecies kill mosquito larvae and beetle larvae. In the late 1990's, my lab evaluated a biological insecticide for RWW and it proved very effective. The organism was *Bacillus thuringiensis* subspecies *tenebrionis* sold under the trade name of Novador®. In 2011, we started research on a related organism (*Bacillus thuringiensis* spp. *galleriae)* in greenhouse studies against RWW. This subspecies of *Bt* had not previously been tested against RWW. This product is being developed and has been tested against other soil-borne weevil/beetle pests of turf and forests. Registrations of this product for agricultural crops are pending. We continued these studies in 2013.

Methods:

Greenhouse: One of the challenges with bioinsecticides is stability – when mixing with water for application, after application on the leaf surface, and shelf-life in the container. *Bt* products are very susceptible to breakdown with UV light. Formulation development can help with this limitation. We tested new formulations of *Bt. galleriae* on RWW larvae in 2013. In addition to the *Bt. galleriae*, additional products were tested as standards for comparison. The experiment was in a randomized complete design with 14 treatments in 5 blocks. The treatments as shown in Table 9 were compared. Each product was applied preflood and post-flood to determine the best timing of application for the product. In the greenhouse, five rice plants were grown in small pots with "rice field soil" from the Rice Experiment Station. Each pot was enclosed in a 24 inch tall cylindrical mylar plastic cage to prevent RWW adults from escaping. Pots were infested with RWW at the 2-3 leaf stage. Post-flood applications were applied 3 days after weevil infestation. Weevil adults were subsequently removed 24 hours after post-flood applications. Pots were destructively sampled for RWW larvae 10 days after weevil removal.

Field: The same treatments were evaluated in a ring study at the Rice Experiment Station. Methods used were as described in subobjectives 1.1 and 1.2.

Results:

Greenhouse: Results are shown in Fig. 1. There was a significant difference between Warrior and the control ($P<0.05$). However, there were no significant differences between treatments ($P > 0.05$) across timing of application. The *Bt. galleriae* treatments, especially the high rate of the WDG formulation, showed activity although not as good as Warrior.

Field: Data analyses not complete yet; frozen samples are still being processed.

1.5) Evaluation of the influence of applications of registered and experiential insecticides on populations of non-target invertebrates in rice.

Mosquitoes and rice production have an obvious association. The egg, larval and pupal stages of mosquitoes are aquatic. Given the dry summer conditions in the area, one of the key aquatic ecosystems in the Sacramento Valley is rice fields. Several species of mosquitoes have evolved to use this aquatic system in their lifecycle. Correspondingly, several species of invertebrates have evolved as important predators of aquatic mosquito stages (tadpole shrimp is actually a predator of mosquitoes in some systems). A healthy system will have a balance of predators that feed on available prey items such as mosquito larvae. This will help to keep populations in check. Helping to keep mosquito populations to a minimum has several advantages including being a "good neighbor" and being able to enjoy a more favorable lifestyle. However, mosquitoes also transmit diseases as evidenced by the outbreak of West Nile Virus in recent years. There are numerous other mosquito-borne diseases that could become issues especially if climate change continues as some predict and this results in higher temperatures in northern California. In addition, mosquitoes, as are crop pests, are often introduced to new areas. Recently *Aedes aegypti*, the yellow fever mosquito, has been introduced into California (first in Madera and Clovis in June, followed by Fresno and the Bay Area city of San Mateo in August). Besides yellow fever, this species transmits dengue and several other viruses to animals. This species prefers to breed in containers.

While obviously the goal is to cost-effectively produce rice, utilizing good IPM practices can help accomplish this while also having several other advantages. Using insecticides that have favorable attributes, such as low risk to natural enemies/non-targets is one way to facilitate a high level of natural control of mosquitoes within the flooded rice system. This concept appears to fit the rice industry ideally as sustainability and environmental stewardship have been stressed by the industry and have created a viable and valuable niche for rice. The environmental aspects of rice production are well-documented and heavily promoted over the last several years. These attributes are key during the winter for migratory waterfowl habitat but also critical during the production season. Best Management Practices have been developed and endorsed by groups such as the California Rice Commission http://www.calrice.org/Environment/Sustainability.htm). While crop protection tools are a necessary component of rice production, well-designed integrated pest management programs have been developed to minimize the use of these products, i.e., to use them only when necessary and when an economic advantage is predicted. Another facet of integrated pest management is to use products with the least environmental consequences, so called reduced risk products, when possible. This study was designed to evaluate the environmental fit of insecticides used in rice production. The criteria were the effects on populations of non-target invertebrate organisms as well as the control of key invertebrate pests. Populations of mosquitoes were monitored.

Methods:

Each plot was ~0.04 A and each treatment was replicated three times. Methods used were as described in subobjectives 1.1 and 1.2 except that the grain yields were collected with the small plot harvester from a 7.25 x 25 ft. long strip and yields were corrected to 14% moisture.

The details are as follows:
18 May – preflood applications
19 May - flooding
20 May – seeding
10 June – 3-leaf stage applications
5 July and 18 July – RWW larval counts
26 July – applied armyworm timing application

13 October - rice yield

Sample Methods:

Floating barrier traps – a collection method for swimming organisms, used for the first 4 to 6 weeks after seeding, 2 traps per plot with collection made weekly

Quadrant samples – confines a 0.55-ft^2 area with animals collected with an aquarium net, collections made weekly, four areas sampled per plot

Mosquito dip samples - used to estimate populations of mosquito larvae, 25 dips in each of five locations per plot, data were collected weekly in July, August, and September

As new insecticides are being proposed for inclusion into rice pest management programs (such as Belay, Declare, and Coragen), the fit of these into the overall system needs to be determined. Specifically, effects of insecticides on populations of aquatic non-target invertebrates in rice were evaluated in this study. Collecting the samples during the growing season is laborious but separating out, counting, and indentifying the specimens during the off-season is the largest effort for this project. Therefore, the studies are always “in progress”. The treatments used the last 4 years are listed in Table 10. The treatment list changes annually so experimental products that could potentially have a fit in rice can be evaluated. Data from 2012 will be discussed in detail. The procedures followed are similar for each year and the exact procedures and dates used in 2013 are given above.

Results:

Non-Target Populations – This study attempts to sample all aquatic animals that are present in the plots. There is no attempt to separate these into beneficials (predators), seed and plant feeders (pests) or those that have neither positive nor negative effects. The data were divided into aquatic insects and other aquatic animals (non-insect invertebrates). The exact numbers vary with year; in some years one species will flourish because of the conditions present. This can skew the numbers and make graphs difficult to interpret. Therefore, the data are shown as a ratio using the populations in the untreated plots as the benchmark. A value of “1” means the numbers in the untreated plots and the treatment in question were equal; less than one means more were present in the untreated plots and greater than one means more were present in the treated plot. Data from the quadrant samples will be shown and discussed; mosquito data will also be discussed.

Preflood applications:

Two preflood insecticides (Warrior II and Coragen), along with an untreated, were evaluated in 2012.

Quadrant samples: *Aquatic Insects* - Warrior and Coragen had no effects on populations of aquatic insects from 22 to 50 DAT (days after treatment/flooding); populations were generally very low during the early dates (Fig. 2). From 57 through 78 DAT, Warrior reduced numbers of insects with the percentage reduction peaking at 64 DAT at 92%. Coragen had some substantial effects as well at 71 and 78 DAT. Later samples (85+ DAT) generally showed no impacts from Warrior or Coragen on aquatic insects. *Other Aquatic Invertebrates* – Results with populations of other aquatic organisms (non-insects) differed from those on aquatic insects (Fig. 3). Neither Warrior nor Coragen caused any severe, long-term reductions in populations. In most cases the treated plots had more organisms than the untreated plots. The primary reduction was from Warrior at 64 DAT.

3-Leaf stage applications:

Three insecticides were evaluated at the 3-leaf stage application timing – Warrior, Declare, and Belay.

Quadrant samples: *Aquatic Insects* - For the 3-leaf stage applications, Declare had the most severe impacts with reductions in number of aquatic insects in 11 of the 13 sample dates (Fig. 4). The reductions were 75% or more for 6 of the first 7 weeks after application. Comparable results were seen with Warrior (reductions in 11 of the 13 samples) but the magnitude of the reductions was not as severe as with Declare. Belay was "easier" on populations of aquatic insects; there were reductions on some of the initial dates after application but they were not over long periods. *Other Aquatic Invertebrates* – Declare and Warrior also had the most negative effects of the three insecticides on populations of other aquatic invertebrates (Fig. 5). With these organisms, the impacts of Warrior were more severe than those of Declare. There were consistent reductions of up to 50% for the first 5 weeks after application. Belay had more detrimental effects on this group of organisms than with aquatic insects. From 7 to 28 DAT, Belay reduced numbers by 74%; later dates, however, showed no impacts.

Armyworm timing:

A late July application of Warrior was evaluated as an example product that could be applied for armyworm management.

Quadrant samples: *Aquatic Insects* – The mid-season Warrior application generally had moderate, at most, effects on populations of aquatic insects (Fig. 6). The greatest reduction compared with the untreated plots was an average of 71% reduction in samples collected at 18 and 25 DAT. *Other Aquatic Invertebrates* – Populations of these organisms were not impacted as much as were aquatic insects by the mid-season Warrior application (Fig. 7).

Larval Mosquito Populations - Mosquitoes were very rare in these plots until mid-Aug. to early Sept. There were no obvious trends in levels with insecticide treatments.

Pest Populations – The data on pest populations are summarized from the 2013 study. RWW was the only pest present in any significant numbers. Stand emergence/early-season establishment was outstanding as shown by the high stand rating values (Table 11). Feeding damage on plants by RWW adults was minimal with a high of 5.3% of the seedling fed upon (Table 11). There were no differences among treatments for scarred plants. RWW larval populations were low (Table 12). On the first sample date, there were no significant differences in larval numbers but Warrior applied in July numerically had the high numbers (this treatment had not been applied yet at this time). In the mid-July sampling, the untreated plots had significantly more RWW larvae than the Warrior (preflood and 3-leaf), Coragen (3-leaf), and Belay (3-leaf) treatments.

Grain Yield – Grain yields at 14% moisture were over 8000 lbs./A for all treatments and there was 400 lbs./A difference among the entries (Table 13).

In summary, the preflood treatments had low initial effects (for the first 2 months after application) on populations of non-target organisms. These treatments included Warrior and the experimental, Coragen. Conversely, the insecticides applied at the 3-leaf stage were very detrimental to these populations. Declare had the most severe impacts on aquatic insects with reductions >75% for 6 of the first 7 weeks after application. Comparable results were seen with Warrior although the reductions were not as severe as with Declare. Belay was "easier" on populations of aquatic insects. Declare and Warrior also had the most negative effects of the three insecticides on populations of other aquatic invertebrates at this timing. Warrior applied in July (armyworm timing) generally had low to moderate effects on non-target organisms.

1.6) Rice water weevil susceptibility to pyrethroid insecticides.

Pyrethroid insecticides have been used for rice water weevil control in California rice since 1999. In most years, greater than 95% of all insecticide applications in rice include a pyrethroid insecticide. However, less than 50% of the rice acreage receives any insecticides and many fields are only border-treated, i.e., about two swatches around the perimeter of the checks. In recent years, there have been complaints that in some cases pyrethroid applications are not adequately controlling RWW. Insects with frequent exposure to a single mode of insecticide action have the propensity to develop insecticide resistance. Use of different modes of action, if available, are needed to reduce this selection pressure and this delays the development of resistance.

Methods:

In 1999, the susceptibility of RWW to a pyrethroid, lambda-cyhalothrin was used as a representative, was quantified. This was before any significant exposure of RWW to this class of chemistry. The method used was a Petri-dish bioassay. The inside surfaces of a 2 inch diameter Petri dish were coated with a range (five) of doses of lambda-cyhalothrin dissolved in ethanol. After drying, five RWW adults were placed into each dish (with four dishes per dose) and held for 6 hours. After this period, the mortality was assessed. The dosage that kills 50% of the RWW is the criteria for comparison. This same method was used in 2013 and the results compared with those from 1999.

Results:

The LD_{50} value in 1999 for lambda-cyhalothrin was 4.5 ppm. In 2013, the LD_{50} values for lambda-cyhalothrin were 0.95 and 0.1 ppm (Fig. 8). The RWW adults were collected from two separate rice fields in Butte Co. in May. Therefore, these data suggest that RWW from these locations are still susceptible to lambda-cyhalothrin. Additional sites should be assayed to further investigate this area.

1.7) Tadpole shrimp control – Evaluation of control with registered and experimental insecticides.

The last few years, tadpole shrimp has emerged as a significant pest of rice. Talking with long-time rice growers, they compared it to the early 1990's when fields had to be treated (with methyl parathion at the time) to get a stand. Tadpole shrimp eggs can lay in dry soil for ~10 years and still be viable; they hatch as soon as they are exposed to water. When this happends, the seed does not have a chance to germinate and root down before being attacked by the tadpole shrimp (unless environmental conditions are ideal). Tadpole shrimp management used to rely on copper sulfate (Bluestone). The usage of copper sulfate is ~25% the usage in 2000; the product does not work as well as previously and cost and availability problems are also an issue. Growers have been relying on pyrethroid treatments and they are effective in the short-term but perhaps do not provide the residual control. Thus tadpole shrimp levels continue to build-up although after the initial rice establishment period they are not damaging to the crop. Thus, there is the need for alternative management methods.

Methods:

A field study was conducted on tadpole shrimp control in 2013 in ring plots (standard 10.7 square feet aluminum rings). To facilitate finding the shrimp (dead or alive in the rings), a subplot of a 56 quart plastic storage bin was placed within the ring. The bins had 3 inch diameter screen inserts cut in each side to allow for water flow. This study evaluated registered and experimental products. Treatments evaluated are listed in Table 14. Four replicates in a randomized complete block design were used.

The key dates were as follows:

18 May, pre-flood (PF) applications
19 May, flooding
20 May, seeding (‘M-202’)
3 June, tadpole shrimp were collected from a neighboring field and introduced into rings – 4 shrimp were placed into each of the metal rings and plastic bins; rice was in the ~1-2 leaf stage
5 June, post-flood applications

Sample Dates:

7 June – live and dead tadpole shrimp, floating seedlings in both structures
13 June and 20 June - counts of established seedlings in both structures
13 June and 20 June - RWW adult leaf scar counts
5 July - RWW larval counts
10 November - rice yield

Sample Method:

Established Seedling Counts: Seedlings counted in aluminum ring and plastic bin
Tadpole Shrimp Mortality/Seedling Damage: floating (dead) tadpole shrimp and floating (dislodged) rice seedlings were counted
RWW Adult Leaf Scar Counts: percentage of plants with adult feeding scars on either of the two newest leaves (50 plants per both structures per date)
RWW Larval Counts: 44 in^3 soil core containing at least one rice plant processed by washing/ flotation method (5 cores per plot – only one sample date)
Rice Yield: entire plots were hand-cut and grain recovered with a Vogel mini-thresher and yields were corrected to 14% moisture.

Results:

Tadpole shrimp (TPS) that were dead/floating as well as those alive were counted from the plastic bin enclosure as well as from the larger ring (Table 15). There was 100% mortality in all three Warrior treatments, both Coragen treatments, Dimilin, and the early post-flood Belay treatment. This applied to both the TPS in the metal ring and in the plastic bin. The Belay preflood treatment had partial control of TPS - ~38% control in both structures. The number of dislodged seedlings was minimal in all treatments on this date. Seedling counts were made on 13 June and 20 June. There were minimal differences among the treatments. On these dates (24 and 30 days after seeding), the seedlings were pegged down and already firmly established (Table 16).

RWW damage and larval populations were sampled in this study but this pest was extremely rare in this plot. Only a trace of RWW larvae was found in these plots – 5 of the 40 rings had any RWW. Given the low levels, data will not be reported.

Grain yields, as measured, were low because ~40% of the ring was taken up by the plastic bin and not harvestable. The yields ranged from 2920 to 4120 lbs./A. Yield was highest in the treatment without the TPS infestation and this was significantly higher than the yield in the Warrior preflood, Belay (both treatments) and Coragen (preflood) (Table 17). The yields in the other treatments were intermediate.

In summary, Warrior with all application methods provided excellent TPS control. The experimental product Coragen also showed excellent TPS control. Belay was effective with a post-flood application but less so when applied preflood. As with RWW, the preflood method is not conducive effective pest control for Belay.

1.8) Impact of winter flooding on rice water weevil populations

Studies conducted in the late 1990's showed that winter flooding significantly reduced populations of RWW larvae the following spring. The mechanism that is involved in this effect was never determined but is now being investigated. If this could be determined, it could perhaps be developed into a more usable management method.

Methods:

The experiment was carried out in a lathehouse on the UC Davis campus. Each bin (~1 x 1.5 x 0.5 ft.) was filled with 5 in. of rice paddy soil. Four treatments with eight replications were used: 1.) 4-month long flood, 2.) rice straw, 3.) combination straw and flood, and 4.) a control. After the simulated winter flood, all bins were dried for two weeks and then all bins were flooded to a 5 in. depth. Rice 'M-202' was planted in each bin. Four RWW were placed in small cages in each bin in late June. A rhizon gas sampler was placed in each bin for the collection of soil porewater to measure methane production. Bins were sampled twice for RWW larvae starting four weeks following infestation in July. Gas samples were taken five times in June and July. In August, 1 gram of rice leaf material was collected from each bin and sent to the UC Davis Analytical laboratory for analysis of arsenic and silicon content.

Results:

There were significant differences between the control and the flood, straw, and combination treatments with methane production in the straw treatment being significantly higher than in the flood and combination treatment. There were no significant differences in the amount of plant Arsenic and Silicon between treatments. The flood treatments showed the same trend as previous field studies with RWW suppression by winter flooding. The interaction of straw and flood effect was significant but it is unclear how the interaction is manifesting. The other data have not been summarized and analyzed yet.

Summary – Objective 1 (Management of key invertebrate pests of rice)

Rice Water Weevil

1.) The pyrethroids still have good activity on RWW. Warrior was very active on weevil through a preflood, early post-flood, and 3-leaf stage application. Only the Warrior® II product was tested and I assume the generic products of lambda-cyhalothrin preform equally well (but have no data on this). The protection of yield and control of RWW larvae were consistent for Warrior across all studies (~4-5) in 2013. Declare® (gamma-cyhalothrin) preformed equally well against RWW in the ring study in 2013 via a preflood and 3-leaf stage application. Mustang (zeta-cypermethrin) provided a lower level of RWW control than the other two pyrethroids. Mustang was particularly weak with the preflood application, which is not recommended for this product.

2.) In recent years, there have been complaints that in some cases the pyrethroid insecticide application is not adequately controlling RWW. A laboratory bioassay on field-collected RWW adults was conducted and there was no evidence of resistance development.

3.) Belay was evaluated preflood, early post-flood, 3-leaf stage, and the 5-6 leaf stage as a rescue treatment in the ring study. The preflood application was moderately effective, but less so than the post-flood applications. The early post-flood and 3-leaf stage applications were very effective. The rescue application showed good activity and may have utility in some situations. In an open field study, the preflood application was largely ineffective reinforcing the need to apply this product into the water.

4.) Dimilin was not highly active on RWW and appears to have largely fallen out of the rice market.

5.) Coragen was applied preflood with 2 rates and post-flood with 2 rates in the ring study and 3 rates in the open plot study. The preflood applications in the ring study were effective; the post-flood applications were not very effective which reinforces previous results. In the open field study, the results with Coragen were somewhat positive. From these data, it appears the product is effective but just very slow to effectively control RWW. The data from the later core sample timing show some positive results but from the first core sample the results are less conclusive. The yield results were positive.

6.) *Bacillus thuringiensis* spp. *galleriae* in greenhouse studies showed potential for RWW control. The high rate of the WDG formulation showed activity although not as good as Warrior.

Tadpole shrimp

Warrior with all application methods provided excellent TPS control. The experimental product Coragen also showed excellent TPS control. Belay was effective with a post-flood application but less so when applied preflood. As with RWW, the preflood method is not conducive effective pest control for Belay.

Rice System

The preflood treatments, Warrior and Coragen, had minimal effects on populations of aquatic non-targets for the first 2 months after application. Conversely, the insecticides applied at the 3-leaf stage were very detrimental to these populations. Declare had the most severe impacts on aquatic insects with reductions >75% for 6 of the first 7 weeks after application. Comparable results were seen with Warrior although the reductions were not as severe as with Declare. Belay was “easier” on populations of aquatic insects. Declare and Warrior also had the most negative effects of the three insecticides on populations of other aquatic invertebrates at this timing.

Warrior applied in July (armyworm timing) generally had low to moderate effects on non-target organisms.

Objective 2:

To evaluate the physical and biological factors that result in fluctuation and movement of populations of the rice water weevil so as to better time control options such as insecticide applications.

2.1) Evaluation of the movement of RWW populations that result in economic injury to rice plants. Monitor seasonal trends (timing and magnitude) in the flight activity of the RWW.

The RWW was first found in California in 1958 although it may have been here for a few years prior to that. Soon after the discovery, UC scientists started studying the biology of this pest. One aspect of the biology examined was the flight of the adults in the spring as this was important as adults expanded the infestation and moved to additional rice fields. The insect is in a diapause state during the late fall, winter, and early spring and hidden in the soil, under debris, etc. for protection during the winter. This is not something the adults do by choice but instead it is genetically programmed into the adults triggered by some (unknown) environmental factor. As they break out of this diapause (and the exact environmental conditions needed to do this have never been determined despite several attempts to do so), they feed briefly on grasses to develop the flight muscles, and fly and land on levees, particularly those with weed growth. On the levees, they feed on grassy weeds during warm days, lose the flight muscles (and ability to fly), develop their eggs, and become ready to move into fields once flooded. The flight appears to be more on a local scale than long-range flight as happened several years ago nearer the time of this pest moving into California. The long range flight is no longer needed by RWW since it has fully invaded the rice production area. The flight monitoring allows us to assess the flight level and the peak flight timing(s). It is also interesting to compare RWW populations and flight trends over years, to draw some correlations with populations in the field, and to form some predictions about the future.

Methods:

A light trap is located at the Rice Experiment Station. This has an 18 watt black light bulb and this unit readily attracts night-active insects. When in flight, the insects hit metal baffles and fall into a collection bucket. The nightly capture is collected every morning from mid-March to mid-June and stored in a freezer until counted. The samples are transported to my lab at UC-Davis and the RWW adults are removed and counted. This sounds simple but on some nights more than 2-3 gallons of insects are collected and the RWW adults are very small (~ 1/8 inch long) and nondescript.

Results:

Flight only occurs during specific nights; evenings (6-11 pm) with warm temperatures (70-80^{0}F) and calm winds (<5 MPH) are optimal. In 2013, RWW spring flight was unusually prolonged. There were peaks in flight ~April 10, April 26-30, May 8-14, and May 14 (Fig. 9). Some RWW were captured on 20 separate nights in 2013. Flight was low to moderate in 2013 with a total of 832 RWW captured. This is ~1/5 the number of RWW captured in 2012 but more than twice the number from 2011. The total captures over the last 15 years are shown in Fig. 10.

2.2) Quantify the relative susceptibility of commonly grown rice varieties to RWW infestation and the yield response of these varieties to RWW infestation.

Well-designed integrated pest management programs should incorporate several different tactics of pest control such as cultural control measures (associated with the way the crop is grown), biological controls (predators and parasitoids), regulatory control (border stations, etc.), mechanical methods (row covers, etc.), plant-based approaches (host plant resistance, induced resistance), and chemical controls (insecticides). For the key pests of rice, rice water weevil and tadpole shrimp, insecticides are clearly the most developed approach. For biological approaches, the RWW is not accessible to predators and parasitoids for much of its life and not much is known about TPS in this regard. Cultural methods have been studied and are important management tools for these pests but clearly still do not reduce populations to noneconomic levels. The use of insecticides continues to be a challenge in the aquatic rice agroecosystem. While more environmentally-friendly insecticides, i.e., reduced risk, are being developed, detection methods, research approaches, and the scrutiny placed on these materials in the environment are constantly being elevated to a higher level. Using insecticides in the environment will be a continual process of discovery and refinement of active ingredients which has been successfully done over the last 30 years. The honey bee issue is becoming increasingly important and one may say this does not impact rice but the registration of Belay was challenged by this issue. Other IPM tactics are needed to supplement insecticides in rice IPM.

Host plant resistance for RWW has been extensively studied with low to moderate success. The “silver bullet”, i.e., a rice genotype that the insect will not damage, has not been found. However, another approach to host plant resistance is using it to provide partial control as part of an integrated program. Examining the commercial rice cultivars to see if there are any differences in the ability of key invertebrate pests to feed upon and damage these plants is one method to facilitate this goal. As new varieties are developed and production practices improve, the rice plants are more vigorous, i.e., higher yielding, and this may influence the pest interactions and responses. There may also be differences in the ability of a pest such as RWW to infest and survive on some cultivars. So instead of host plant resistance that provides 90% control (a worthy goal), a factor which reduces pest levels (or damage) by 40-50% may be in place and may be effective enough in the California rice system (especially when coupled with another moderately effective method) to adequately control this pest. Therefore, we have been examining the response of commonly-grown California rice cultivars to RWW in terms of 1.) severity of infestation and 2.) yield loss upon infestation. Two studies were done in 2013.

2.2.a) Varietal Susceptibility to RWW – Ring Study with Controlled Populations

<u>Methods:</u>

In the first study, four varieties, M-202, S-102, L-206, and PI experimental line, were grown in 10.7 sq. ft. aluminum rings and infested with RWW adults as detailed in subobjectives 1.1 and 1.2. These varieties were selected to represent a range of genotypes (grain types) within California rice. The infested rings were infested with adults to insure that a population was present; examining yield loss was the primary goal. The methods described in subobjectives 1.1 and 1.2 for assessing adult scarring, larval populations, and yields were also used herein. Within each variety, there were two treatments 1.) uninfested rings that were also treated with Dermacor seed treatment at 2.5 fl. oz. per 100 lbs. seed and Warrior II at 1.28 fl. oz. per acre applied preflood to make sure no damage occurred and 2.) the natural rice water weevil infestation which was supplemented with 8 adults placed into each ring on 8 June followed by 6 more RWW adults added on 20 June. This was done to insure that some rings had no RWW and others had as high of population as possible. RWW leaf scarring was counted on 21 and 26 June, RWW larvae were sampled on 11 and 24 July, and yield data were collected on 16 Oct.

Results:

Leaf scarring from RWW adults was at moderate levels (Table 18). The treated, uninfested rings averaged 3% scarred plants and the infested rings averaged ~11% scarred plants. Within the infested rings, there were significantly more scarred plants in M-202 than the PI line and L-206. The results with RWW larvae were as we expected (Table 18). The treated rings had essentially no RWW infestation (generally <0.05 RWW per core sample) and the infested treatments had high RWW populations. For the infested rings, L-206 consistently had the highest infestation and S-102 had the lowest infestation. RWW populations in M-202 and the PI line were intermediate. In the uninfested, treated rings, M-202 yielded significantly more than L-206 and the PI line. Overall, yields were moderate peaking at ~5600 lbs./A. (Table 19). Yields in the infested treatments were all less than 3800 lbs./A, however yields for M-202 were still numerically the highest and statistically higher than S-102. In order to compare all cultivars for the impact of RWW, yields were standardized by looking at loss from RWW, loss from 1 RWW larva, and percentage yield loss from 1 RWW larva. S-102 suffered the greatest yield loss from RWW in spite of the lowest average population of RWW. This caused the standardization to loss per 1 RWW larva to go “off the scale” (Table 19). M-202 was also severely impacted by the RWW infestation as shown by the calculated ~3600 lbs. grain yield loss from the standard 1 RWW per core sample infestation (64% of the potential yield). L-206, although having a high level of RWW, suffered lower yield losses. The loss was ~1400 lbs. per 1 RWW larva (32%). The PI line, suffered a low yield loss (~500 lbs./A per 1 RWW larva), this amounted to 14.04% due the low yield potential of this unimproved line. This is a line that some work had been done by the RES plant breeders several years ago in terms of resistance of RWW. It appears that there is a level of resistance but the yield potential and agronomic traits are not up to commercial standards.

2.2.b) Varietal Susceptibility to RWW – Small Plot Study with Natural Populations

Methods:

The rice varieties as shown in Table 20 were grown in small plots measuring 16 x 13 ft. with four blocks. The second factor examined was RWW population – either present at naturally-occurring levels or controlled with insecticides (Warrior II at 2.56 fl. oz./A [applied preflood on 27 May] + Dermacor 2.5 fl. oz./100 lbs. seed [applied at seeding on 29 May]). The methods described in Obj. 1.3 for assessing adult scarring, larval populations, and yields were also used herein. The varieties were selected to represent the range of genetic material in California cultivars as well as to include most of the commonly grown entries. One experimental line was included that was developed to include some resistance to RWW albeit the line is agronomically not refined.

Sample Dates:

<u>21 June and 26 June</u> - RWW adult leaf scar counts

9 July and 22 July - RWW larval counts
13 October - rice yield

Results:

This plot had a very low RWW infestation and thus no meaningful data were collected on RWW. Leaf scarring averaged only 2.4% and RWW larval counts were ~0.03 RWW per core sample (Table 21). The three basins to the north had moderate to high levels of RWW but they did not infest the two basins used for this study. I have seen that previously with RWW; it can be a fickle insect.

Yield data will be shown across RWW treatments as RWW due to the low levels had no impact on yield (Table 21). Percentage moisture values ranged from 18.3 (L-206) to 23.9% (M-205). Grain yields ranged from ~7400 lbs./A (M-206) to a low of 5230 lbs./A (M-205).

2.3) Study the impact of seeding rate and rice variety on the yield response to Rice Water Weevil feeding.

A study was started in 2011 and continued in 2013 based on some of our findings from the varietal susceptibility to RWW efforts in recent years. In summary, yield losses from RWW had been much higher in M-202 than in M-206 even though the larval infestation results were the inverse. It appears that M-206 may offer a level of resistance / tolerance to RWW at least compared with the very susceptible M-202. Most of the previous work with yield losses and RWW has been conducted at the RES with M-202 (or even older varieties) and with a 100 lbs./A seeding rate. Obviously, newer varieties are commonly utilized now and growers often use higher than 100 lbs./A seeding rates. These factors likely influence the response to RWW feeding and based on our observations these factors may reduce the yield impacts.

Methods:

The following study was set-up in 2011 to explore these relationships. Identical treatments and set-up were used in 2012 and 2013. Two rice varieties, M-202 and M-206, and four seeding rates, 50, 100, 150 and 200 lbs./A were used. These were planted in 10 by 20 foot plots with six replication/bocks. RWW infestation was approached in two ways. First, one-half the plots were treated Warrior II at 2.56 fl. oz./A applied preflood and Dermacor 2.5 fl. oz./100 lbs. seed applied on the seed. This was to control a natural infestation of RWW, if it occurred. In the untreated plots, three rings (10.7 sq. ft.) were placed per plot and infested with a low or a high RWW rate, as well as an insecticide treatment (same as detailed above) for the third entry. The measurements collected included RWW leaf scarring, RWW larval levels, plant density, panicle density at harvest, and grain yields as previously detailed. Key dates are as follows:

18 May – preflood applications
19 May - flooding
20 May – seeding
6 June – RWW infestation 1
13 June – RWW infestation 2
13 and 20 June – scar evaluations
2, 3 July and 16, 17 July – RWW larval counts
9 October - rice yield

Results:

This study in 2013 was generally conducted as planned. However, data are still being interpreted and analyzed. The different seeding rates resulted in a range of plant densities, as planned; 17.2, 23.4, 27.7, and 29.9 plants per sq. ft. for the 50, 100, 150, and 200 lbs./A seeding rates, respectively for M-202 and 18.9, 22.3, 25.3, and 32.9 plants per sq. ft. for the 50, 100, 150, and 200 lbs./A seeding rates, respectively for M-206. The natural RWW infestation was low (averaging across varieties and seeding rates 0.25 RWW per core sample in untreated plots), so the "open" plots were not stressed enough to show any meaningful differences. This is typical for this part of the RES. RWW populations from the rings, i.e. infested, were generally high and as planned. Results are shown in Fig. 11; the highest average was 1.7 RWW per sample for M-206 at 150 lbs./A. Grain yields from the open plots are shown in Fig. 12. The highest yield was ~8630 lbs./A for M-202 at 150 lbs./A. Overall averaged over the seeding rates and the RWW treatments, M-202 outyielded M-206 by ~1200 lbs./A (7980 vs. 6790 lbs./A).

Objective 3: Conduct appropriate monitoring, exploratory research, and educational activities on emerging and new exotic rice invertebrate pests.

3.1). Investigate possible insect-related causes for rice seed damage.

Pecky rice is generally not a factor in rice production in California. The standards for seed damage are relatively low and the grain quality in the state is of utmost importance. Pecky rice is more commonplace in southern rice production and the rice stink bug (*Oebalus pugnax*) is one of the primary culprits involved in this. This insect is not known to occur in California. In recent years, some reports of "pecky" rice have been received. Several agronomic and environmental factors can cause grain malformations. However, there is also the possibility that an insect could be involved. In 2012, Luis Espino and I searched for possible insect causes in one of the areas with some pecky rice in 2011. A low level of red-shouldered stink bug, *Thyanta pallidovirens* (= *T. accerra*), was found. This insect has been reported from Mississippi as a pest of rice and causes peck rice. This is not an invasive, new insect but rather has been in California for numerous years. It does seem likely that the biology of this pest is changing. Studies in 2013 were conducted to determine the ability of this species to damage rice.

Methods:

Two studies were conducted. The general approach was to cage red-shouldered stink bugs (RSSB) onto rice plants/panicles and to determine the amount of kernel damage at harvest. The RSSB used were all adults and collected in Yolo Co. from weeds. A laboratory colony was started and maintained in the UC-Davis lab. In the first study, four RSSB adults were placed within a cage made from mesh material; the cage covered the rice plants in a 1 x 1 ft. area. The bugs were replaced each week starting at the milk stage for 4 weeks. At harvest, percentage damaged kernels (peck) on brown rice and on milled rice and milled rice and head rice yields were determined. Uninfested cages were also used for comparison. In the second study, individual panicles were infested with RSSB. Small cages were made from an empty 16 oz. plastic bottle with sections removed and replaced with screening to allow ventilation. These were slipped over the developing panicle and secured. RSSB adults (2 per cage) were placed in these cages when the rice was in the milk stage and in the dough stage (15 cages per treatment). Stink bugs were checked weekly and those dying were replaced with live ones. Mortality was rare and there was some reproduction occurring in the cages as evidenced by the presence of nymphs. Cages were left on the panicles until maturity was reached. Uninfested cages were used for comparison. Grain weight and kernel damage were determined. Study 1 was coordinated by Luis Espino and the Godfrey lab personnel conducted study 2 but we all helped each other.

Results:

For the first study, on brown rice the percentage peck rice was 0.4% from the uninfested cages and 2.8% from the stink bug infested cages (Fig. 13a). Similarly, on milled rice the means for pecky rice were 0.3 and 1.8% for the uninfested and infested treatments, respectively. On both brown and milled rice, the differences between the uninfested and infested treatments were statistically significant. Percentage milling yields (averaging 67.6%) and head rice yields (averaging 58.8%) were not affected by stink bug infestation (Fig. 13b).

Kernel damage was higher in the second study but the same general trends were seen. Since the stink bugs were caged right on the developing panicles and could only feed in this area, this maximized the damage. With the infestation at the milk stage, the damage was 5.4% for the infested and 0.3% for the uninfested (Fig. 14b). The damage was reduced with the dough stage infestation but still the stink bug infestation appeared to cause a level of kernel damage. Means were 3.2% and 0.4% for the infested and uninfested, respectively (Fig. 14b). Grain yield was also measured from the 15 panicles in each treatment. For the milk stage treatments, the caged but uninfested panicles produced 44.1 gr. of rice compared with 33.4 gr. for the 15 panicles that were infested with RSSB - ~24% reduction (Fig. 14a). For the dough stage treatments, there was a 26% reduction in kernel yield by weight - 46.4 gr. for the infested and 62.6 gr. for the uninfested. So this pest reduced grain yields and increased grain damage in this “worst-case situation”, i.e., caged right on the developing panicles. It was also evident that the process of caging the panicles reduced yield; comparing the uninfested treatments for the two timings showed a difference in grain weight. But since the infested treatments were obviously covered with the same cage, the effects of the RSSB infestation are still valid. Questions such as how widespread is this pest, how much damage is it doing in grower fields, does it need to be controlled and if so how, etc. remain to be answered.

Acknowledgments:

There are several people to be acknowledged that contributed to the operations and success of the 2013 rice invertebrate pest management project. We thank Cheminova, Syngenta, FMC, Phyllom, Inc., Valent, and Dupont for products and UC Cooperative Extension Sacramento Valley Farm Advisors for grower contacts and assistance. The UC Davis Rice Project student assistants, Stacey Rice, Jesjeet Dhanota, Briana Nakawatase, Hudson Hollister, and Matt Supan, provided excellent technical assistance and Kris Tollerup and Amy Bell helped greatly as well. I particularly acknowledge Kevin Goding for his excellent efforts in handling the technical (SRA) duties. Lastly, we are grateful to the staff at the Rice Experiment Station for the study sites and management. Ray Stogsdill is thanked for his excellent assistance including, among others, daily light trap collections. The California Rice Research Board provided the funding necessary to achieve our objectives and this is greatly appreciated.

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CONCISE GENERAL SUMMARY OF CURRENT YEARS (2013) RESULTS:

Larry D. Godfrey

Research was conducted in 2013 on the biology and management of key invertebrate pests of California rice. Rice water weevil (RWW) and tadpole shrimp are long-time pests of California rice and were the primary targets of the research in 2013. The entire agroecosystem of the rice field was the focus of another study conducted in 2013. Finally, research was conducted on the red-shouldered stink bug, a potential rice insect pest identified in 2012, in order to assess the potential of this insect to damage rice. The studies were generally conducted as planned and the results were robust and usable. A couple of the rice water weevil studies were hindered by low weevil populations. This limited the amount of data which could be collected in these studies. However, some of our plots at RES had very high infestations (in one case adjacent to a study with very low populations). In many of our studies, we introduce rice water weevil adults to insure a usable infestation; these were successful. Tadpole shrimp is an increasing concern and in 2013 this pest was present at the highest levels. We continued tadpole shrimp management studies. Armyworms, another important insect pest of rice, were present in several areas in 2013. Some limited studies were conducted on this pest. The goal of this research was to refine and advance IPM schemes for these rice pests while maximizing protection of the environmental aspects of the rice agroecosystem and enhancing the cost effectiveness of management efforts in rice.

Management - Rice Water Weevil: Studies were conducted on management of rice water weevil (RWW), several aspects of the insect's biology that could provide valuable information to assist with control efforts, and rice cultivar response to rice water weevil injury. For the management efforts, work was done in aluminum ring plots (10.7 sq. ft.), small field plots (~600 and 1750 sq. ft.), and greenhouse studies to evaluate experimental insecticides versus registered standards for rice water weevil control. The ring plots are a cost-effective way to utilize resources (space and people) for comparing many products/treatments. But this method does introduce some artificial aspects into the testing; for instance, the RWW adults are introduced into the rings in clutches to lay eggs and to start the infestation instead of more gradually. Twenty-one treatments (a total of seven different active ingredients) were established in ring plots to accomplish this research at the Rice Experiment Station. Follow-up studies in open field plots with eight different treatments were conducted. In summary, the pyrethroid insecticides still have good activity on RWW. Warrior was very active on RWW through a preflood, early post-flood, and 3-leaf stage application. Only the Warrior® II product was tested and I assume the generic products of lambda-cyhalothrin preform equally well but these were not tested. The protection of yield and control of RWW larvae were consistent for Warrior across all 4-5 studies in 2013. Declare® (gamma-cyhalothrin) preformed equally well against RWW in the ring study in 2013 via a preflood and 3-leaf stage application. Mustang (zeta-cypermethrin) provided a lower level of RWW control than the other two pyrethroids. Mustang was particularly weak with the preflood application, which is not recommended for this product. In recent years, there have been complaints that in some cases the pyrethroid insecticide application is not adequately controlling RWW. A laboratory bioassay on field-collected RWW adults was conducted and there was no evidence of resistance development. Belay® was evaluated preflood, early post-flood, 3-leaf stage, and the 5-6 leaf stage as a rescue treatment in the ring study. The preflood application was moderately effective, but less so than the post-flood applications. The early post-flood and 3-leaf stage applications were very effective. The rescue application showed good activity and may have utility in some situations. In an open field study, the preflood application was largely ineffective reinforcing the need to apply this product into the water. Belay has been registered for the 2014 use-season. Dimilin® was not highly active on RWW and appears to have largely fallen out of the rice market. Coragen® was applied preflood and post-flood in the ring study and 3 rates in the open plot study. The preflood applications in the ring study were effective; the post-flood applications were not very effective which reinforces previous results. In the open field study, the results with Coragen were somewhat positive. From these data, it appears the product is effective but just very slow to effectively control RWW. The yield results with Coragen were positive. *Bacillus thuringiensis* spp. *galleriae* , a biological insecticide, in greenhouse studies showed potential for RWW control. The high rate of the WDG formulation showed activity although not as good as Warrior.

Tadpole shrimp: Warrior with all application methods provided excellent TPS control. The experimental product Coragen also showed excellent TPS control. Belay was effective with a post-flood application but less so when applied preflood.

Rice System: As new insecticides are being proposed for inclusion into rice pest management programs, the fit of these into the overall rice agroecosystem needs to be determined. Specifically, the effects of insecticides on populations of aquatic non-target invertebrates (both insects and related organisms are considered) in rice are important as this can impact mosquito populations arising from rice fields. The preflood treatments in 2012 (2013 data are still being tabulated), Warrior and Coragen, had minimal effects on populations of aquatic non-targets for the first 2 months after application. Conversely, the insecticides applied at the 3-leaf stage were very detrimental to these populations. Declare had the most severe impacts on aquatic insects with reductions >75% for 6 of the first 7 weeks after application. Comparable results were seen with Warrior although the reductions were not as severe as with Declare. Belay was "easier" on populations of aquatic insects. Declare and Warrior also had the most negative effects of the three insecticides on populations of other aquatic invertebrates at this timing. Warrior applied in July (such as for armyworm control) generally had low to moderate effects on non-target organisms.

Biology – RWW Flight: In 2013, RWW spring flight was unusually prolonged. There were peaks in flight ~April 10, April 26-30, May 8-14, and May 14. Some RWW were captured on 20 separate nights in 2013. Flight was low to moderate in 2013 with a total of 832 RWW captured. This is ~1/5 the number of RWW captured in 2012 but more than twice the number from 2011.

Cultivar Response –Host plant resistance for RWW has been extensively studied with low to moderate success. The "silver bullet", i.e., a rice genotype that the insect will not damage, has not been found. However, another approach to host plant resistance is using it to provide partial control as part of an integrated program. Examining the commercial rice cultivars to see if there are any differences in the ability of key invertebrate pests to feed upon and damage these plants is one method to facilitate this goal. As new varieties are developed and production practices improve, the rice plants are more vigorous, i.e., higher yielding, and this may influence the pest interactions and responses. Two studies were done in 2013 to examine the response of commonly-grown California rice cultivars to RWW in terms of 1.) severity of infestation and 2.) yield loss upon infestation. In a study done in rings with introduced RWW adults, there were significantly more scarred plants in M-202 than the experimental PI line and L-206. For the infested rings, L-

206 consistently had the highest RWW infestation and S-102 had the lowest infestation. RWW populations in M-202 and the PI line were intermediate. M-202 was severely impacted by the RWW infestation with a calculated ~3600 lbs./A grain yield loss per 1 RWW larva (64% of the potential yield). The PI line, suffered a low yield loss (~500 lbs./A per 1 RWW larva); this amounted to 14.0% due the low yield potential of this unimproved line. Twelve rice varieties were compared in a similar study using a natural RWW infestation. This plot had a very low RWW infestation and thus no meaningful data were collected on RWW. Grain yields ranged from ~7400 lbs./A (M-206) to a low of 5230 lbs./A (M-205). Finally, a study continued in 2013 to examine RWW impacts on rice productivity with two varieties and four seeding rate. Observations suggest the M-206 may offer a level of resistance / tolerance to RWW compared with the very susceptible M-202 and this interaction is influenced by seeding rate. Data are still being analyzed but the different seeding rates resulted in a range of plant densities, as planned. RWW populations from the infested rings were generally high up to 1.7 RWW per sample for M-206 at 150 lbs./A. Grain yields from the open plots peaked at ~8630 lbs./A for M-202 seeded at 150 lbs./A.

Invasive Invertebrate Pests - Invasive pests are affecting agriculture and natural systems world-wide. In January 2009, the panicle rice mite, *Steneotarsonemus spinki*, was found in California in UC-Davis greenhouses; this pest has subsequently been eradicated. Pecky rice is generally not a factor in rice production in California, but in recent years some reports of “pecky” rice have been received. The rice stink bug (*Oebalus pugnax*) commonly causes peck rice in southern rice production. This insect is not known to occur in California. Several agronomic and environmental factors can cause grain malformations. In 2012, Luis Espino and I searched for possible insect causes in one of the areas with some pecky rice in 2011 and found a low level of red-shouldered stink bug, *Thyanta pallidovirens* (= *T. accerra*). This is not an invasive, new insect but rather has been in California for numerous years. Studies in 2013 were conducted to determine the ability of this species to damage rice. The approach was to cage red-shouldered stink bugs (RSSB) onto rice plants/panicles and to determine the amount of kernel damage at harvest. A laboratory colony of RSSB was started and maintained in the UC-Davis lab. In the first study, four RSSB adults were placed within a mesh cage which covered several rice plants. In the second study, individual panicles were infested with RSSB in small cages which covered developing panicles. RSSB adults (2 per cage) were placed in these cages when the rice was in the milk stage and in the dough stage. Cages were left on rice until grain maturity and ninfested cages were used for comparison in both studies. Grain damage (peck) ranged from 2.8% (entire plant infestations) to 5.4% (infestations of panicles at the mike stage). Percentage milling yields and head rice yields were not affected by RSSB infestation. There was an indication that RSSB has the potential to reduce rough rice grain yield as well. Infestation of the panicles at the milk and dough stages reduced yields by ~24 and 26%, respectively. Questions such as how widespread is this pest, how much damage is it doing in grower fields, does it need to be controlled and if so how, etc. remain to be answered. Other recent invasive insects to the area are concerns for the rice industry, but clearly there are insect pests of greater concern to rice world-wide. Two invasive stink bug species have recently invaded the Central Valley and research will be conducted on these in 2013. The Cereal Leaf Beetle has the potential to damage rice and invaded the Klamath Basin in 2013. Research will be conducted on this species as soon as possible. There are even recently-invaded mosquito species such as *Aedes aegypti* , the yellow fever mosquito. This was introduced into Madera and Clovis in June and San Mateo in August. Besides yellow fever, this species transmits dengue and several other viruses. This species prefers to breed in containers so may not infest agricultural fields.

Table 1. Treatment list for RWW management ring study, 2013.

Product	**Rate (lbs. AI/A)**	**Formulation per A**	**Timing**
1. Dimilin 2L	0.125	8 fl. oz.	2-3 leaf
2. Untreated	---	---	---
3. Warrior II	0.04	2.56 fl. oz.	Preflood
4. Warrior II	0.04	2.56 fl. oz.	Early post flood
5. Warrior II	0.04	2.56 fl. oz.	2-3 leaf
6. Belay 2.13 SC	0.075	4.5 fl. oz.	Preflood
7. Belay 2.13 SC	0.075	4.5 fl. oz.	Early post flood
8. Belay 2.13 SC	0.075	4.5 fl. oz.	2-3 leaf
9. Belay 2.13 SC	0.092	5.5 fl. oz.	5-6 leaf
10. Mustang	0.05	4.3 fl. oz.	2-3 leaf
11. Mustang	0.05	4.3 fl. oz.	Preflood
12. Declare	0.015	4.3 fl. oz.	2-3 leaf
13. Declare	0.02	2.05 fl. oz.	2-3 leaf
14. Declare	0.02	2.05 fl. oz.	Preflood
15. Coragen	0.08	6.1 fl. oz.	Preflood
16. Coragen	0.10	7.7 fl. oz.	Preflood
17. Coragen	0.12	9.2 fl. oz.	2-3 leaf
18. Coragen	0.12	9.2 fl. oz.	5-6 leaf
19. MAR-12	---	4 lbs.	Early post flood
20. MAR-12	---	8 lbs.	Early post flood
21. MAR-12	---	16 lbs.	Early post flood

Table 2. Rice plant stand and adult feeding damage in chemical ring study, 2013.

Product	Formulation per A	Timing	Stand Rating (1 - 5)		% Scarred Plants [a]	
1. Dimilin 2L	8 fl. oz.	2-3 leaf	3.0	a	16.3	A
2. Untreated	---	---	3.0	a	15.0	Ab
3. Warrior II	2.56 fl. oz.	Preflood	2.75	a	5.7	D
4. Warrior II	2.56 fl. oz.	Early post flood	2.9	a	5.8	D
5. Warrior II	2.56 fl. oz.	2-3 leaf	3.0	a	6.8	Cd
6. Belay 2.13 SC	4.5 fl. oz.	Preflood	3.0	a	11.3	Abcd
7. Belay 2.13 SC	4.5 fl. oz.	Early post flood	2.9	a	5.3	D
8. Belay 2.13 SC	4.5 fl. oz.	2-3 leaf	3.0	a	7.8	Bcd
9. Belay 2.13 SC	5.5 fl. oz.	5-6 leaf	2.75	a	16.3	A
10. Mustang	4.3 fl. oz.	2-3 leaf	2.9	a	7.5	Bcd
11. Mustang	4.3 fl. oz.	Preflood	3.0	a	14.0	Abc
12. Declare	4.3 fl. oz.	2-3 leaf	3.0	a	8.0	Bcd
13. Declare	2.05 fl. oz.	2-3 leaf	3.0	a	8.8	Abcd
14. Declare	2.05 fl. oz.	Preflood	2.6	a	14.5	Abc
15. Coragen	6.1 fl. oz.	Preflood	3.0	a	6.8	Cd
16. Coragen	7.7 fl. oz.	Preflood	3.0	a	7.5	Bcd
17. Coragen	9.2 fl. oz.	2-3 leaf	2.9	a	9.8	Abcd
18. Coragen	9.2 fl. oz.	5-6 leaf	3.0	a	11.6	Abcd
19. MAR-12	4 lbs.	Early post flood	2.75	a	14.5	Abc
20. MAR-12	8 lbs.	Early post flood	3.0	a	15.0	Ab
21. MAR-12	16 lbs.	Early post flood	3.0	a	15.3	Ab

[a] Average of two sample dates

Means within columns followed by same letter are not significantly different; least significant differences test ($\rho < 0.05$).

Table 3. RWW immature density (first and second sample dates and average) in chemical ring study, 2013.

Product	Formulation per A	Timing	RWW per Core Sample – 10 July		RWW per Core Sample – 23 July		Avg. RWW per Core Sample
1. Dimilin 2L	8 fl. oz.	2-3 leaf	0.35	bc	0.55	Ab	0.45
2. Untreated	---	---	1.3	a	0.85	A	1.1
3. Warrior II	2.56 fl. oz.	Preflood	0.4	bc	0.1	B	0.25
4. Warrior II	2.56 fl. oz.	Early post flood	0	c	0	B	0
5. Warrior II	2.56 fl. oz.	2-3 leaf	0.05	c	0.1	B	0.08
6. Belay 2.13 SC	4.5 fl. oz.	Preflood	0.4	bc	0.35	Ab	0.38
7. Belay 2.13 SC	4.5 fl. oz.	Early post flood	0.1	c	0.05	B	0.08
8. Belay 2.13 SC	4.5 fl. oz.	2-3 leaf	0.1	c	0.1	B	0.1
9. Belay 2.13 SC	5.5 fl. oz.	5-6 leaf	0.15	c	0.35	Ab	0.25
10. Mustang	4.3 fl. oz.	2-3 leaf	0.25	c	0.45	Ab	0.35
11. Mustang	4.3 fl. oz.	Preflood	0.2	c	0.55	Ab	0.38
12. Declare	4.3 fl. oz.	2-3 leaf	0	c	0.2	B	0.1
13. Declare	2.05 fl. oz.	2-3 leaf	0.1	c	0	B	0.05
14. Declare	2.05 fl. oz.	Preflood	0	c	0.1	B	0.05
15. Coragen	6.1 fl. oz.	Preflood	0.1	c	0	B	0.05
16. Coragen	7.7 fl. oz.	Preflood	0.1	c	0.45	Ab	0.28
17. Coragen	9.2 fl. oz.	2-3 leaf	0.3	bc	0.5	Ab	0.4
18. Coragen	9.2 fl. oz.	5-6 leaf	0.45	abc	0.55	Ab	0.5
19. MAR-12	4 lbs.	Early post flood	0.6	abc	0.45	Ab	0.53
20. MAR-12	8 lbs.	Early post flood	0.7	abc	0.9	A	0.8
21. MAR-12	16 lbs.	Early post flood	1.15	ab	0.2	B	0.68

Means within columns followed by same letter are not significantly different; least significant differences test ($\rho < 0.05$).

Table 4. Effect of RWW populations on rice biomass and grain yields in ring study, 2013.

Product	**Formulation per A**	**Timing**	**% Grain Moisture**		**Grain Yield (lbs./A)**		**Biomass (Straw+Grain) (t/A)**	
1. Dimilin 2L	8 fl. oz.	2-3 leaf	12.7	ab	3922.4	abc	4.8	ab
2. Untreated	---	---	12.9	ab	4795.5	abc	5.2	ab
3. Warrior II	2.56 fl. oz.	Preflood	12.8	ab	4228.5	abc	5.4	ab
4. Warrior II	2.56 fl. oz.	Early post flood	13.3	a	4879.7	abc	5.5	ab
5. Warrior II	2.56 fl. oz.	2-3 leaf	13.4	a	5385.9	ab	7.0	a
6. Belay 2.13 SC	4.5 fl. oz.	Preflood	13.4	a	4211.0	abc	6.7	ab
7. Belay 2.13 SC	4.5 fl. oz.	Early post flood	12.9	ab	5932.2	a	6.4	ab
8. Belay 2.13 SC	4.5 fl. oz.	2-3 leaf	13.1	ab	4733.6	abc	5.5	ab
9. Belay 2.13 SC	5.5 fl. oz.	5-6 leaf	13.1	ab	4058.4	abc	4.6	ab
10. Mustang	4.3 fl. oz.	2-3 leaf	13.1	ab	4621.9	abc	5.4	ab
11. Mustang	4.3 fl. oz.	Preflood	13.5	a	3570.5	bc	4.3	ab
12. Declare	4.3 fl. oz.	2-3 leaf	11.9	ab	4014.8	abc	5.4	ab
13. Declare	2.05 fl. oz.	2-3 leaf	12.8	ab	4300.9	abc	5.4	ab
14. Declare	2.05 fl. oz.	Preflood	12.6	ab	4243.3	abc	5.1	ab
15. Coragen	6.1 fl. oz.	Preflood	13.6	a	4823.5	abc	5.8	ab
16. Coragen	7.7 fl. oz.	Preflood	10.5	b	4682.2	abc	5.5	ab
17. Coragen	9.2 fl. oz.	2-3 leaf	13.3	a	4055.9	abc	4.6	ab
18. Coragen	9.2 fl. oz.	5-6 leaf	13.7	a	3368.4	bc	4.5	ab
19. MAR-12	4 lbs.	Early post flood	12.8	ab	4437.2	abc	5.7	ab
20. MAR-12	8 lbs.	Early post flood	13.3	a	2616.3	c	3.8	b
21. MAR-12	16 lbs.	Early post flood	13.0	ab	3448.8	bc	4.5	ab

Means within columns followed by same letter are not significantly different; least significant differences test ($\rho < 0.05$).

Table 5. Treatment list for large plot Coragen study, 2013.

Treatment	**Formulation per A**	**Rate (lbs. AI/A)**	**Timing**	**Appl. Date**
1. Coragen	6.1 fl. oz.	0.08	Preflood	27 May
2. Coragen	7.7 fl. oz.	0.10	Preflood	27 May
3. Coragen	9.2 fl. oz.	0.12	Preflood	27 May
4. Belay	6 oz.	0.1	Preflood	27 May
5. Warrior II	2.56 fl. oz.	0.04	Preflood	27 May
6. Untreated	---	---	---	---

Table 6. RWW scarred seedlings and stand rating from Coragen large plot study, 2013.

Treatment	**Formulation per A**	**Stand Rating (1 - 5)**		**% Scarred Plants [a]**	
1. Coragen	6.1 fl. oz.	3.0	a	6.0	a
2. Coragen	7.7 fl. oz.	2.9	a	3.8	a
3. Coragen	9.2 fl. oz.	3.0	a	4.5	a
4. Belay	6 oz.	2.9	a	3.5	a
5. Warrior II	2.56 fl. oz.	2.9	a	2.8	a
6. Untreated	---	2.9	a	5.5	a

[a] Average of two sample dates

Means within columns followed by same letter are not significantly different; least significant differences test ($\rho < 0.05$).

Table 7. RWW populations from Coragen large plot study, 2013.

Treatment	**Formulation per A**	**RWW per Core – 17 July**		**RWW per Core – 2 Aug.**		**Avg. RWW per Core**
1. Coragen	6.1 fl. oz.	0.3	bc	0.25	a	0.28
2. Coragen	7.7 fl. oz.	0.6	abc	0.2	a	0.4
3. Coragen	9.2 fl. oz.	0.55	abc	0.1	a	0.38
4. Belay	6 oz.	0.95	ab	0.5	a	0.73
5. Warrior II	2.56 fl. oz.	0.05	c	0	a	0.03
6. Untreated	---	1.25	a	0.45	a	0.85

Means within columns followed by same letter are not significantly different; least significant differences test ($\rho < 0.05$).

Table 8. Yield results from Coragen large plot study, 2013.

Treatment	**Formulation per A**	**% Grain Moisture**		**Grain Yield (lbs./A)**	
1. Coragen	6.1 fl. oz.	31.1	a	6818.3	a
2. Coragen	7.7 fl. oz.	30.8	a	6604.4	a
3. Coragen	9.2 fl. oz.	30.1	a	6712.0	a
4. Belay	6 oz.	28.7	a	6224.7	a
5. Warrior II	2.56 fl. oz.	30.8	a	6627.6	a
6. Untreated	---	29.8	a	6464.7	a

Means within columns followed by same letter are not significantly different; least significant differences test ($\rho < 0.05$).

Table 9. Products and rates tested for both greenhouse and field.

Product	**Active Ingredient**	**Rates**
Warrior II	lambda-cyhalothrin	1.92 fl. oz./A
Aza-Direct	Azadirachtin	16 fl. oz./A
Btg Phy-4-12	*Bacillus thuringiensis* serovar *galleriae*	1.2 to 1.8 grams/sq. ft.
Btg WDP	*Bacillus thuringiensis* serovar *galleriae*	4, 8, and 16 lbs./A

Table 10. Treatments evaluated in non-target study, 2010-13.

Product	Rate (lbs. AI/A)	Timing	Rationale	2010	2011	2012	2013
1. Untreated	---	---	Comparison	X	X	X	X
2. Warrior	0.03	3-leaf	Registered standard	X	X	X	X
3. Warrior	0.03	Preflood	Registered standard	X	X	X	X
4. Warrior	0.03	July armyworm timing	Registered standard	X	X	X	X
5. Dimilin 2L	0.125	3-leaf	Registered standard	X			
6. Trebon 3G	0.18	3-leaf	Under development; discontinued	X			
7. Belay 2.13 SC	0.092	Preflood	Registered - 2014	X	X		X
8. Belay 2.13 SC	0.092	3-leaf	Registered - 2014	X	X	X	X
9. Dermacor X-100 5FS	0.10	Preflood	Under development	X	X		
10.Dermacor X-100 5FS	2.50 oz/100 lbs. seed	seed treatment	discontinued as seed treatment	X			
11. Coragen	0.12	Preflood	Under development; considered for registration			X	X
12. Declare	0.02	3-leaf	Registered			X	
13. Coragen	0.12	3-leaf	Under development; considered for registration				X

Table 11. RWW scarred seedlings and stand rating from non-target study, 2013.

Treatment	Formulation per A	Timing	Stand Rating (1 - 5)		% Scarred Plants [a]	
1. Warrior II	2.56 fl. oz.	3-leaf	3.5	a	4.7	a
2. Warrior II	2.56 fl. oz.	Preflood	3.4	a	3.7	a
3. Warrior II	2.56 fl. oz.	July armyworm timing	3.0	a	5.3	a
4. Coragen	9.2 fl. oz.	Preflood	3.5	a	1.7	a
5. Belay 2.13 SC	5.5 fl. oz.	Preflood	2.9	a	1.3	a
6. Coragen	9.2 fl. oz.	3-leaf	3.3	a	1.7	a
7. Belay 2.13 SC	5.5 fl. oz.	3-leaf	3.0	a	0	a
8. Untreated	---	---	3.0	a	1.7	a

[a] Average of two sample dates

Means within columns followed by same letter are not significantly different; least significant differences test (ρ <0.05).

Table 12. RWW populations from non-target study, 2013.

Treatment	Formulation per A	Timing	RWW per Core – 5 July		RWW per Core – 18 July		Avg. RWW per Core
1. Warrior II	2.56 fl. oz.	3-leaf	0	a	0	b	0
2. Warrior II	2.56 fl. oz.	Preflood	0.2	a	0	b	0.1
3. Warrior II	2.56 fl. oz.	July armyworm timing	0.4	a	0.13	ab	0.27
4. Coragen	9.2 fl. oz.	Preflood	0.2	a	0.07	ab	0.14
5. Belay 2.13 SC	5.5 fl. oz.	Preflood	0	a	0.07	ab	0.04
6. Coragen	9.2 fl. oz.	3-leaf	0	a	0	b	0
7. Belay 2.13 SC	5.5 fl. oz.	3-leaf	0.07	a	0	b	0.04
8. Untreated	---	---	0.07	a	0.27	a	0.17

Means within columns followed by same letter are not significantly different; least significant differences test ($\rho < 0.05$).

Table 13. Yield results from non-target study, 2013.

Treatment	Formulation per A	Timing	% Grain Moisture		Grain Yield (lbs./A)	
1. Warrior II	2.56 fl. oz.	3-leaf	21.8	a	8256.1	a
2. Warrior II	2.56 fl. oz.	Preflood	19.8	a	8157.4	a
3. Warrior II	2.56 fl. oz.	July armyworm timing	19.4	a	8288.5	a
4. Coragen	9.2 fl. oz.	Preflood	18.9	a	8384.1	a
5. Belay 2.13 SC	5.5 fl. oz.	Preflood	21.2	a	8257.3	a
6. Coragen	9.2 fl. oz.	3-leaf	21.9	a	8153.8	a
7. Belay 2.13 SC	5.5 fl. oz.	3-leaf	21.7	a	8050.9	a
8. Untreated	---	---	19.9	a	8453.6	a

Means within columns followed by same letter are not significantly different; least significant differences test ($\rho < 0.05$).

Table 14. Treatments evaluated for tadpole shrimp control studies, 2013.

Product	Rate (lbs. AI/A)	Formulation per A	Timing
1. Untreated-no TPS	---	---	---
2. Belay 2.13 SC	0.075	4.5 fl. oz.	preflood
3. Coragen	0.1	2.46 fl. oz.	preflood
4. Belay 2.13 SC	0.075	4.5 fl. oz.	early post-flood
5. Coragen	0.1	2.46 fl. oz.	early post-flood
6. Dimilin 2L	0.125	8 fl. oz.	early post-flood
7. Untreated with TPS	---	---	---
8. Warrior II	0.04	2.56 fl. oz.	early post-flood
9. Warrior II	0.04	2.56 fl. oz.	preflood
10. Warrior II	0.04	2.56 fl. oz.	preflood and early post-flood

Table 15. Influence of treatments for tadpole shrimp on mortality & seedling damage, 7 June 2013.

			Bin			Ring		
Product	**Formulation per A**	**Timing**	**Live TPS**	**Dead TPS**	**Floating Seedlings**	**Live TPS**	**Dead TPS**	**Floating Seedlings**
1. Untreated-no TPS	---	---	0	0	0	0	0	0
2. Belay 2.13 SC	4.5 fl. oz.	preflood	2.5	1.56	0.5	2.5	1.5	0.25
3. Coragen	2.46 fl. oz.	preflood	0	4	0	0	4	0
4. Belay 2.13 SC	4.5 fl. oz.	early post-flood	0	4	0	0	4	0
5. Coragen	2.46 fl. oz.	early post-flood	0	4	0	0	4	0
6. Dimilin 2L	8 fl. oz.	early post-flood	0	4	0	0	4	0
7. Untreated with TPS	---	---	4	0	0.25	4	0	0.50
8. Warrior II	2.56 fl. oz.	early post-flood	0	4	0	0	4	0
9. Warrior II	2.56 fl. oz.	preflood	0	4	0	0	4	0
10. Warrior II	2.56 fl. oz.	preflood & early post-flood	0	4	0.25	0	4	0

Table 16. Influence of treatments for tadpole shrimp on established seedlings 13 & 20 June, 2013.

			13-Jun				20-Jun	
Product	**Form. per A**	**Timing**	**Established seedlings – Bin**		**Established seedlings - Ring**		**Established seedlings - Bin**	**Established seedlings - Ring**
1. Untreated-no TPS	---	---	26.25	ab	70.5	ab	28.25	75.75
2. Belay 2.13 SC	4.5 fl. oz.	Preflood	30.25	a	65.5	b	33	68
3. Coragen	2.46 fl. oz.	Preflood	24.5	ab	72.75	ab	26.5	75
4. Belay 2.13 SC	4.5 fl. oz.	early post-flood	16.25	b	65.5	ab	20.5	72.75
5. Coragen	2.46 fl. oz.	early post-flood	24.75	ab	84.5	a	25.75	89.75
6. Dimilin 2L	8 fl. oz.	early post-flood	18.0	b	75.5	ab	18.5	79.5
7. Untreated with TPS	---	---	23.5	ab	71.75	ab	25.25	78.5
8. Warrior II	2.56	early	24.5	ab	80.25	ab	27.5	84.5

	fl. oz.	post-flood						
9. Warrior II	2.56 fl. oz.	Preflood	25.25	ab	75.5	Ab	26.5	81.5
10. Warrior II	2.56 fl. oz.	preflood & early post-flood	30.5	a	71.5	Ab	32.75	77.75

Means within columns followed by same letter are not significantly different; least significant differences test (ρ <0.05).

Table 17. Influence of treatments for tadpole shrimp on rice yield, 2013.

Product	**Formulation per A**	**Timing**	**% Moisture**		**Grain Yield (lbs/A)**		**Straw + Grain Wt (t/A)**	
1. Untreated-no TPS	---	---	12.6	ab	4118.9	A	5.2	abc
2. Belay 2.13 SC	4.5 fl. oz.	Preflood	12.6	ab	2588.8	B	4.6	bc
3. Coragen	2.46 fl. oz.	Preflood	11.9	ab	2970.2	B	5.3	abc
4. Belay 2.13 SC	4.5 fl. oz.	early post-flood	11.9	ab	2864.2	B	4.3	c
5. Coragen	2.46 fl. oz.	early post-flood	11.6	b	3189.5	Ab	5.5	abc
6. Dimilin 2L	8 fl. oz.	early post-flood	12.2	ab	3374.5	Ab	5.0	abc
7. Untreated with TPS	---	---	13.0	a	3709.7	Ab	6.1	a
8. Warrior II	2.56 fl. oz.	early post-flood	12.6	ab	3463.7	Ab	5.9	ab
9. Warrior II	2.56 fl. oz.	Preflood	11.9	ab	2917.4	B	4.9	abc
10. Warrior II	2.56 fl. oz.	preflood and early post-flood	11.5	b	3457.2	Ab	5.5	abc

Means within columns followed by same letter are not significantly different; least significant differences test (ρ <0.05).

Table 18. RWW plant scarring and immature density (first and second sample dates and average) in variety response ring study, 2013.

Rice Cultivar	RWW Infestation	% Scarred Plants		RWW per Core Sample – 11 July		RWW per Core Sample – 24 July		Average RWW per Core Sample
M-202	None-treated	2.25	d	0.15	cd	0.05	c	0.1
S-102	None-treated	4.25	cd	0.05	d	0.05	c	0.05
L-206	None-treated	2.0	d	0	d	0	c	0
PI	None-treated	4.0	cd	0.2	bcd	0.05	c	0.13
M-202	Yes-infested	14.0	a	0.55	bc	0.45	bc	0.5
S-102	Yes-infested	12.5	ab	0.34	bcd	0.15	c	0.25
L-206	Yes-infested	8.25	bc	1.05	a	0.75	a	0.9
PI	Yes-infested	8.0	bc	0.60	ab	0.625	ab	0.6

Means within columns followed by same letter are not significantly different; least significant differences test ($\rho < 0.05$).

Table 19. Rice biomass and grain yields from rice cultivar response to RWW ring study, 2013.

Rice Cultivar	RWW Infestation	% Grain Moisture		Grain Yield (lbs./A)		Loss from RWW (lbs./A)	Loss from RWW (lbs./A)*	% Yield Loss	Biomass (Straw+Grain) (t/A)	
M-202	None-treated	14.3	a	5581.9	a				8.09	a
S-102	None-treated	10.3	d	4938.9	ab				6.21	b
L-206	None-treated	11.7	c	4543.5	bc				5.95	b
PI	None-treated	12.2	c	3845.9	cd				6.16	b
M-202	Yes-infested	13.3	b	3794.9	cd	1787.0	3574.0	64.0	5.93	b
S-102	Yes-infested	9.6	d	2832.5	e	2106.4	4938.9+	100+	3.97	c
L-206	Yes-infested	12.2	c	3225.7	de	1317.8	1464.2	32.2	4.63	c
PI	Yes-infested	11.7	c	3500.6	de	345.3	539.5	14.0	5.80	b

* assuming 1 RWW per core sample

Means within columns followed by same letter are not significantly different; least significant differences test ($\rho < 0.05$).

Table 20. California rice cultivars (and one experimental line) evaluated in small plot study designed to evaluate susceptibility to RWW, 2013.

Variety	RWW Controlled*	RWW Present at Natural Levels
1. M-105	X	X
2. Calhikari-202	X	X
3. PI experimental line	X	X
4. Calmochi-101	X	X
5. L-206	X	X
6. M-104	X	X
7. M-202	X	X
8. M-205	X	X
9. M-206	X	X

10. M-208	X	X
11. M-401	X	X
12. S-102	X	X

* Warrior II @ 2.56 fl. oz./A preflood + Dermacor 2.5 fl.oz./100 lbs. seed

Table 21. RWW adult feeding damage, larval populations, and yield data in small plot variety susceptibility comparison to RWW study, 2013.

Variety	**RWW Status**	**% Scarred Plants** [A]	**RWW per Core Sample** [A]	**% Moisture**		**Grain Yield (lbs./A)**	
M-105	Controlled	4.0	0.1	20.2	bcde	6559.4	abc
Calhikari-202	Controlled	1.5	0	23.1	abc	5539.7	bcd
PI experimental line	Controlled	0.5	0	20.6	bcde	6439.3	abc
Calmochi-101	Controlled	3.5	0.05	19.2	cde	6494.3	abc
L-206	Controlled	4.25	0.05	19.4	cde	6407.2	abc
M-104	Controlled	2.5	0	20.5	bcde	6794.2	abc
M-202	Controlled	2.0	0	21.3	abcde	6819.8	abc
M-205	Controlled	2.0	0.05	22.2	abc	4215.2	d
M-206	Controlled	1.75	0.05	20.3	bcde	7564.3	a
M-208	Controlled	1.5	0.05	21.1	abcde	5929.3	abcd
M-401	Controlled	2.38	0	22.2	abc	7550.2	a
S-102	Controlled	2.25	0	21.9	abcd	5045.3	cd
M-105	Present	2.5	0	19.9	bcde	7024.4	ab
Calhikari-202	Present	2.25	0.1	22.4	abc	5385.7	bcd
PI experimental line	Present	2.75	0.05	19.9	bcde	6267.5	abc
Calmochi-101	Present	3.5	0.05	18.8	cde	6245.3	abc
L-206	Present	2.0	0.05	17.2	e	6471.6	abc
M-104	Present	2.5	0	20.4	bcde	6446.6	abc
M-202	Present	1.75	0	19.8	bcde	5573.0	bcd
M-205	Present	3.25	0.05	25.5	a	6251.3	abc
M-206	Present	1.5	0.1	21.4	abcde	7207.7	ab
M-208	Present	3.25	0.05	19.6	bcde	6670.7	abc
M-401	Present	1.0	0	24.0	ab	6787.3	abc
S-102	Present	3.5	0	17.4	de	5967.8	abcd

[A] average of two sample dates.

Means within columns followed by same letter are not significantly different; least significant difference test ($P< 0.05$).

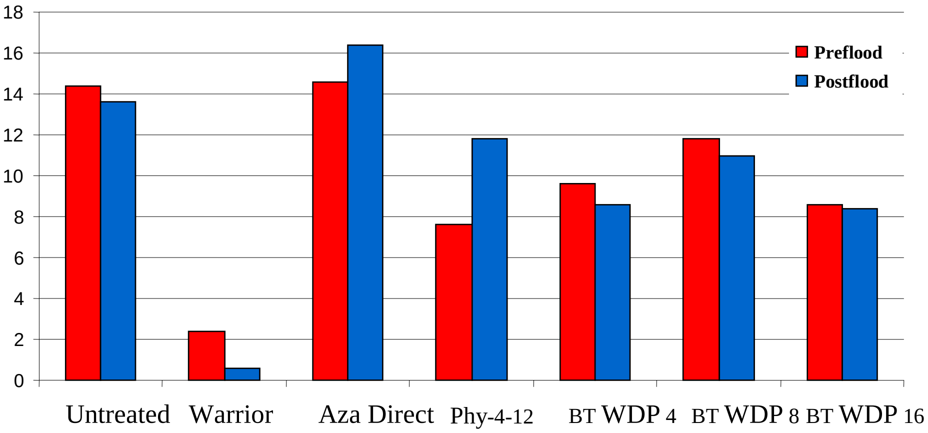

Fig. 1. Rice water weevil population from the *Bt. galleriae* greenhouse study.

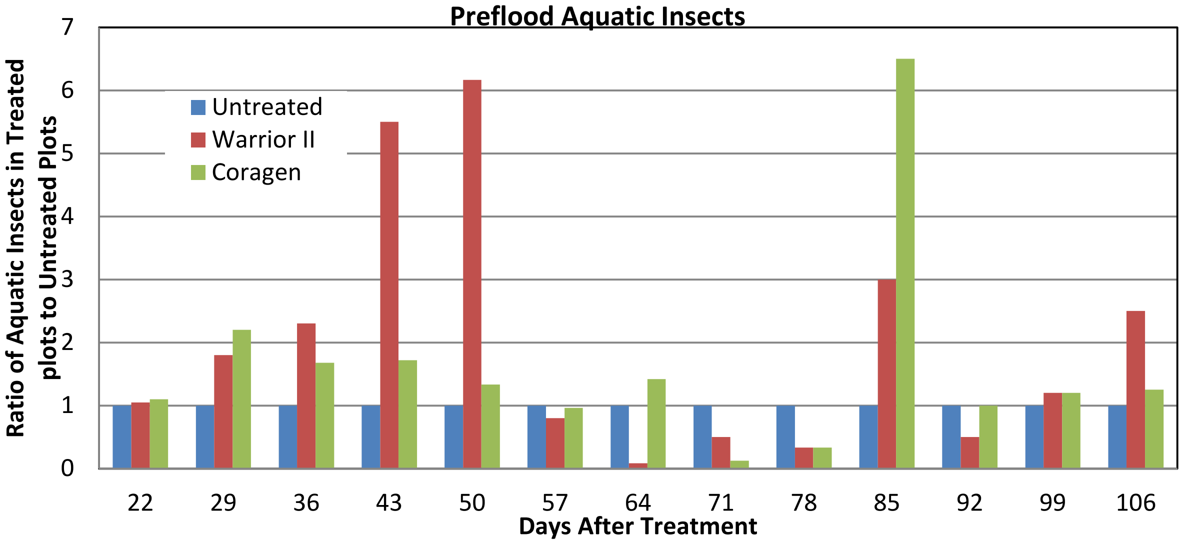

Fig. 2. Populations of aquatic insects at various intervals following application of preflood insecticides.

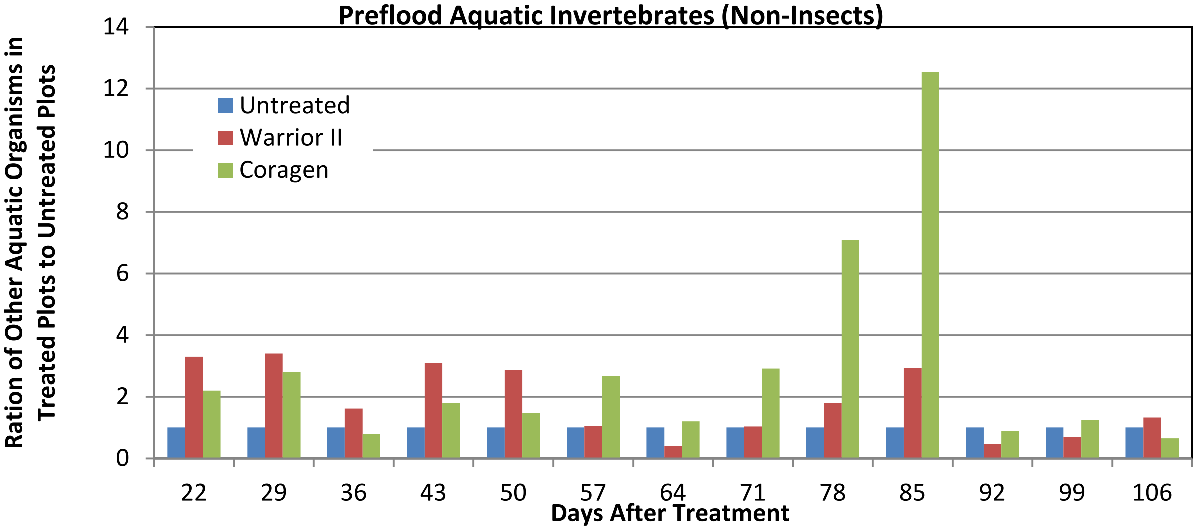

Fig. 3. Populations of aquatic invertebrates (non-insects) at various intervals following application of preflood insecticides.

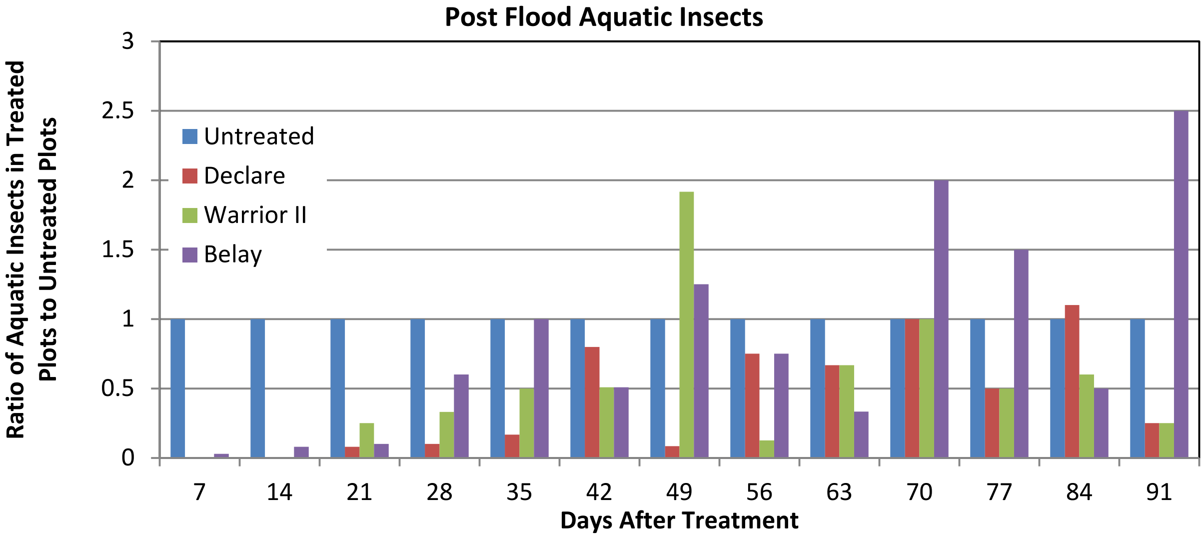

Fig. 4. Populations of aquatic insects at various intervals following application of postflood insecticides.

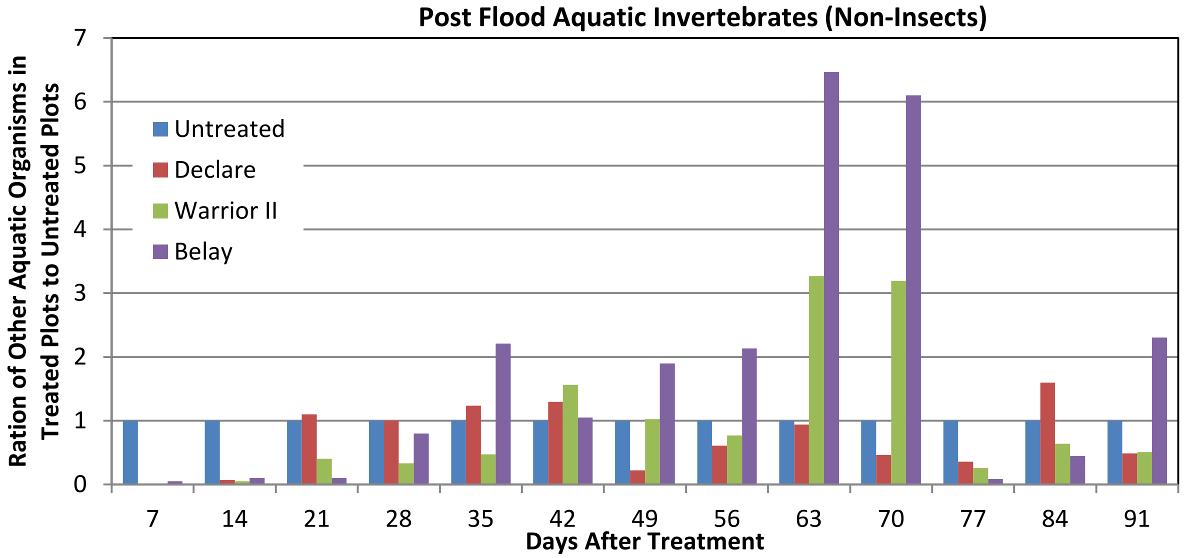

Fig. 5. Populations of aquatic invertebrates (non-insects) at various intervals following application of postflood insecticides.

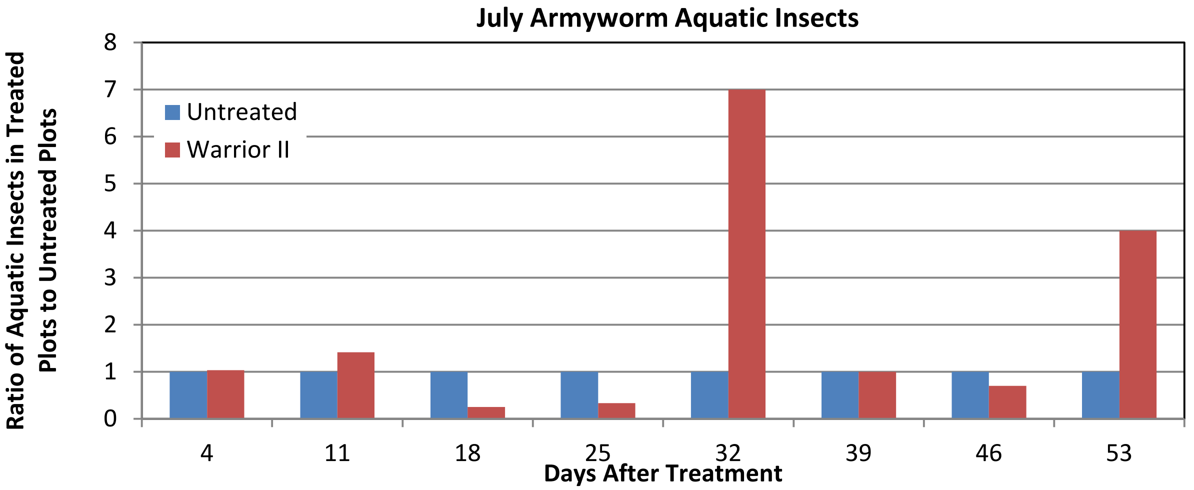

Fig. 6. Populations of aquatic insects at various intervals following insecticide application (July timing).

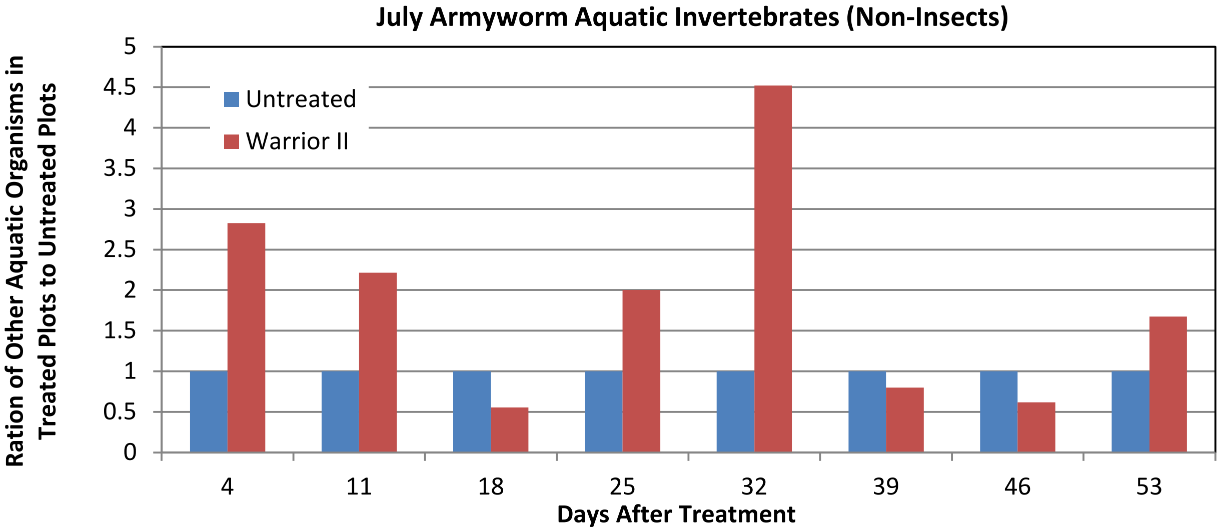

Fig. 7. Populations of aquatic invertebrates (non-insects) at various intervals following insecticide application (July timing).

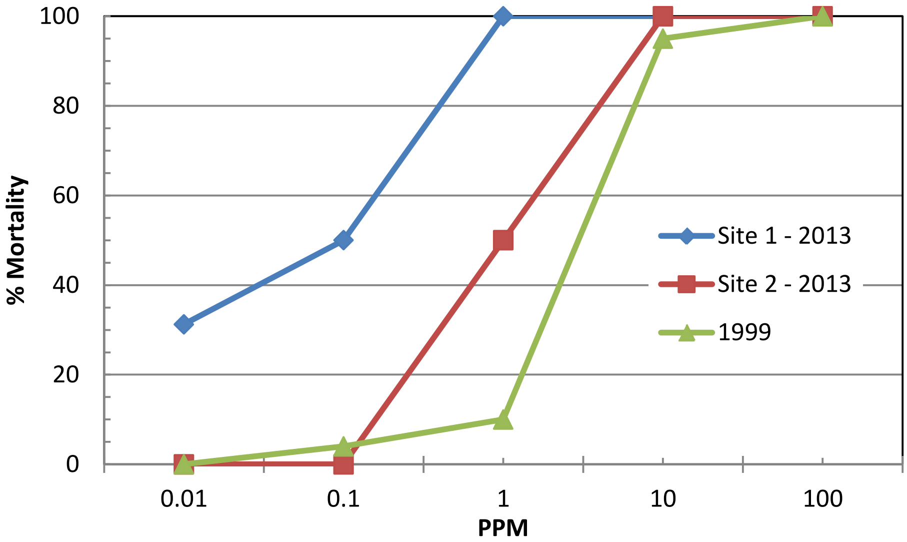

Fig. 8. Dose response of Rice Water Weevil mortality to lambda-cyhalothrin – 1999 vs. 2013.

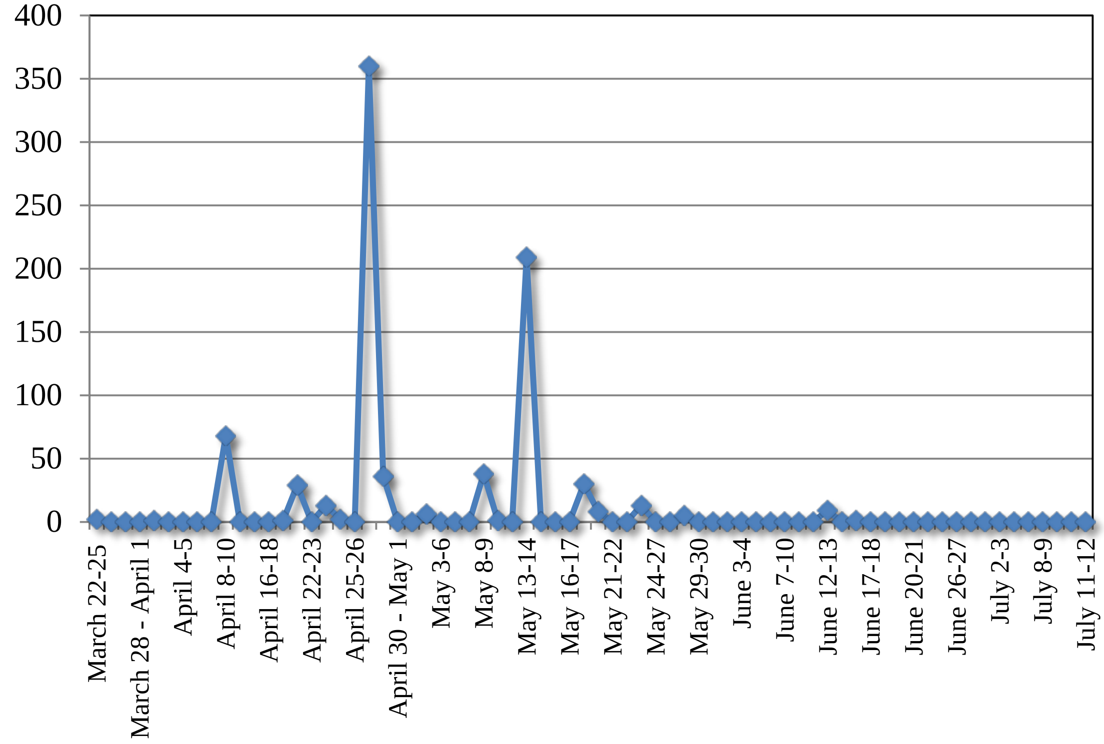

Fig. 9. Rice Water Weevil adults captured per collection period – 2013.

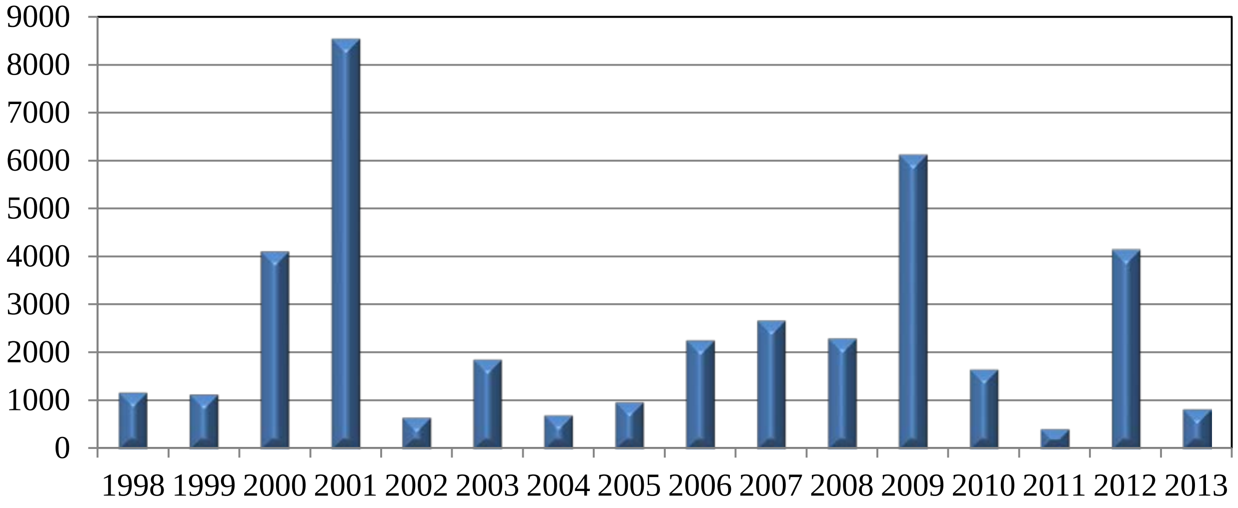

Fig. 10. Total seasonal Rice Water Weevil capture over recent years – 1998 to 2013.

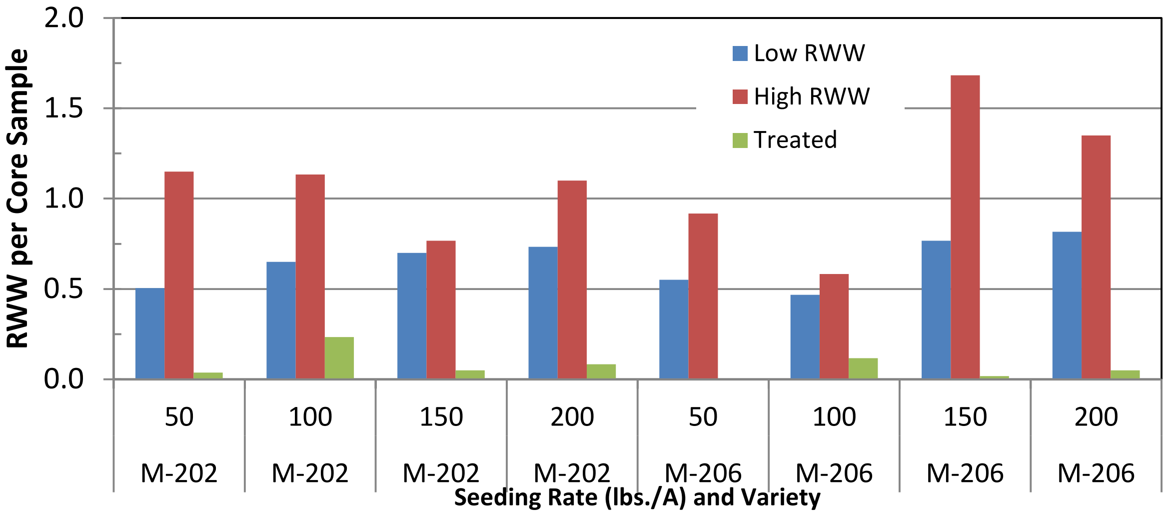

Fig. 11. Populations of RWW from infested rings in two rice varieties with four seeding rates, 2013.

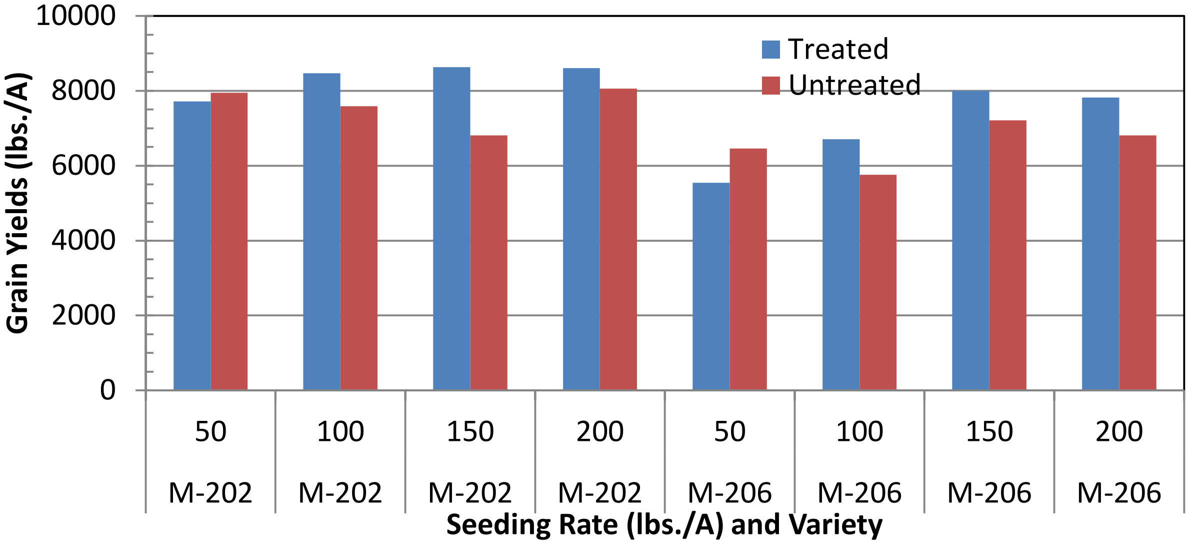

Fig. 12. Rice grain yield from open plots by RWW level, rice variety, and seeding rate, 2013.

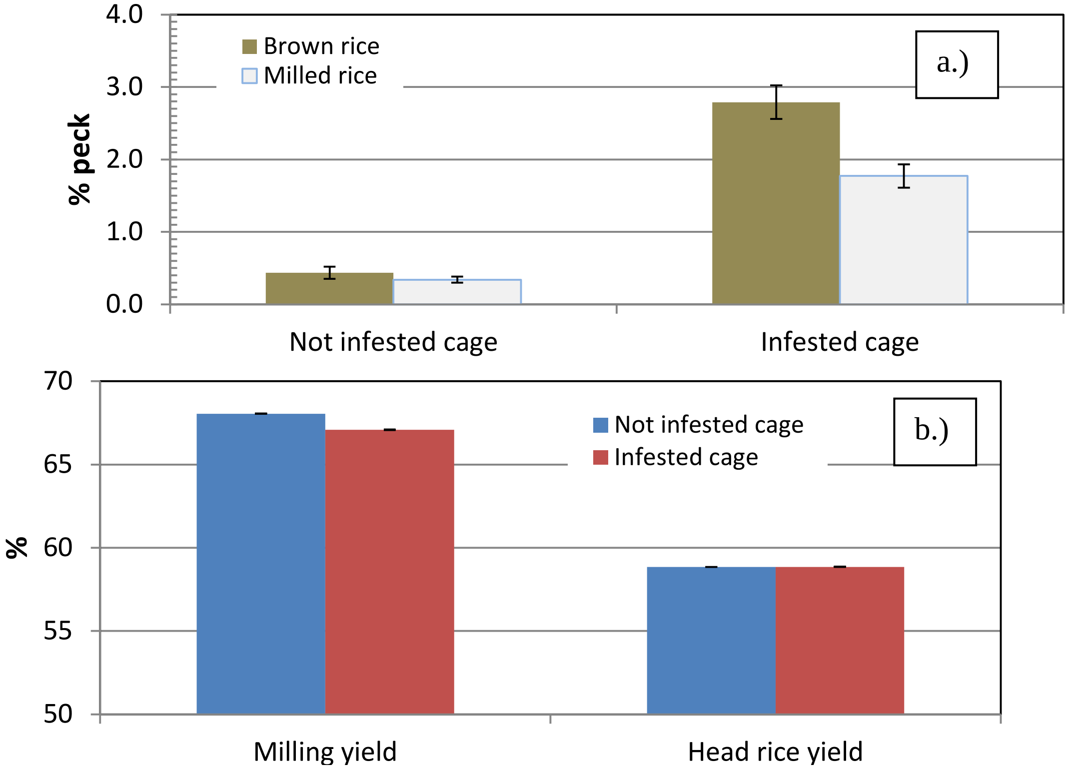

Fig. 13. Effects of red-shouldered stink bug enclosure onto rice plants at the milk stage of panicle development, a.) grain damage, b.) milling yields; 2013.

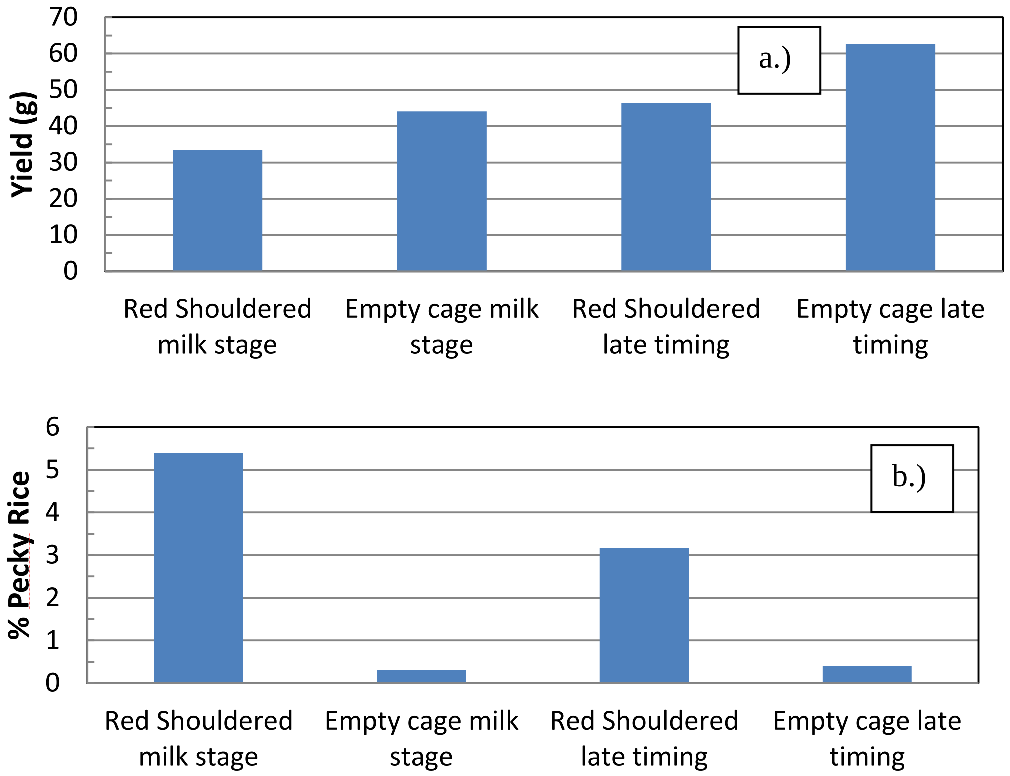

Fig. 14. Effects of red-shouldered stink bug enclosure onto individual panicles at the milk stage and the dough stage of panicle development, a.) grain yield per 15 panicles, b.) grain damage; 2013.