PROJECT NO. RP-3

ANNUAL REPORT
COMPREHENSIVE RESEARCH ON RICE

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PROJECT TITLE: Rice protection from invertebrate pests.

PROJECT LEADER AND PRINCIPAL UC INVESTIGATOR:
L. D. Godfrey, Extension Entomologist/Entomologist in Ag. Expt. Stn.
Kevin Goding, Staff Research Associate
Ray Stogsdill, Rice Experiment Station
Mohammad-Amir Aghaee, Graduate Student Researcher
Luis Espino, UC Advisor, cooperator
Department of Entomology, One Shields Avenue,
University of California, Davis 95616

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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 field ring plots.
  1.1.a) evaluation of conventional insecticides for rice water weevil control
  1.1.b) evaluation of a biological insecticide for rice water weevil control.

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.
  1.2.c) evaluation of the efficacy of insecticides used as seed treatments for controlling rice water weevil in ring plots.

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

1.4) Completion of the evaluation of a biological insecticide for Rice Water Weevil in greenhouse studies.

1.5) Evaluation of the effects of silicon augmentation on Rice Water Weevil populations.

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

1.7) Impact of winter flooding on Rice Water Weevil populations.

1.8) Tadpole Shrimp control – Evaluation of efficacy with registered and experimental insecticides.

1.9) Evaluation of biological control of Armyworm eggs in rice.

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

2.2) Quantify the relative susceptibility of commonly grown rice varieties to Rice Water Weevil infestation and the yield response of these varieties to Rice Water Weevil 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) Interaction between rice variety and Rice Water Weevil density on the rice plant growth, development, and yield.

Objective 3: To study the insect-related causes of pecky rice and the factors influencing the incidence of this damage.

3.1) Investigate the extent of rice damage (kernel damage and potential yield loss) from Redshouldered Stink Bug.
    3.1.a) Quantify the influence of rice grain maturity on stink bug damage
    3.1.b) Investigate the susceptibility of a range of rice varieties to stink bug damage

3.2) Quantify the incidence of stink bugs in Sacramento Valley grower rice fields during the grain filling period.
    3.2.a) Identify the stink bug species and developmental stage
    3.2.b) Identify agronomic factors which are associated with stink bug populations

3.3) Study the propensity of common Sacramento Valley stink bugs to survive on and damage rice kernels and panicles.

Objective 4: Conduct appropriate monitoring, exploratory research, and educational activities on emerging and new exotic rice invertebrate pests.

4.1) Investigate the potential of the recently invaded pest, Brown Marmorated Stink Bug, to reproduce, develop, and damage rice.

SUMMARY OF 2014 RESEARCH BY OBJECTIVE:

Objective 1:

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

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 totality for ease of comparison across treatments and the conclusion from each sub-objective will be reported. Each treatment was replicated four times. Twenty-six treatments (a total of ten 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 22 May and seeded with 100 lbs./A of M-202 on 23 May. 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:

21 May, pre-flood (PF) applications
3 June, early post-flood applications (1-2 leaf stage [ls])
11 June, 3-leaf stage applications
23 June, 5-6 leaf stage applications (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 (RWW) infestation was supplemented with 7 adults placed into each ring on 8 June followed by 5 more RWW adults added on 20 June. The standard production practices were used. Bolero® and Shark® were applied on 9 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: 7 June
Adult Leaf Scar Counts: 11 June and 23 June
Larval Counts: 2 July and 16 July
Rice Yield: 7, 8 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 per date)
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 1.9 to 3.1. There were differences among treatments in terms of seedling vigor and emergence (Table 2). A stand rating of 3.0 is approximately 100 seedlings per ring which is the preferred density. The ratings from the Dimilin plots as well as the two seed treatments #24 (A17469 and A17960) and #26 (A9382, A9459, A12050, and STP22245) were significantly lower than 6 of the other treatments. The stand rating in the untreated plots averaged 3.0 which is ideal. Seed treatment #24 contained a fungicide and two insecticides and #26 contained three fungicides and one insecticide.

Adult Leaf Scar Counts

RWW adult feeding scars were counted twice at a ~10-day interval. The two counts and the average of these two dates are shown in Table 2. Rice plant leaf scarring ranged from 0 to 30% on the first date and from 1.5 to 23.5 % on the second date. Research in California has shown that a damaging level of RWW larvae is associated with a RWW feeding scar incidence of ~20%. The values from untreated plots were intermediate among all the values at 10 and 11%, somewhat lower than expected. The seed treatment, preflood, and early post-flood (1-2 ls) treatments were applied before the addition of RWW adults and before the scar count data were collected. Damage values were numerically highest in the Belay 5-6 ls treatment (which was still untreated when the data were collected) and the seed treatments #26 (A9382, A9459, A12050, and STP22245) for the first timing and for seed treatment #26 and for *Bacillus thuringiensis* spp *galleriae* preflood for the second timing. The lowest scar count values were for Warrior and Belay (both applied at the early post-flood timing, i.e., 1-2 ls) and for Coragen 7.7 oz. preflood for the first sample. These same treatments also showed good results in the second sample as well as Warrior preflood. The positive results with Belay and Coragen are interesting. Coragen, from my observations, is tightly bound to the soil and I am uncertain how much of the active ingredient moves into the plant. The reduction in leaf feeding indicates that some must be moving into the leaves (although the adults could also be exposed by burrowing in the treated soil). Belay is more water soluble than Coragen and does likely move into the plant so the results are not as surprising. If the leaf scarring is reduced, the insecticide most likely has toxicity to adults. This is particularly important and interesting when evaluating preflood (soil-applied) and very early post-flood 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). Since the larvae are within the soil/mud, the exact stage of development is unknown as they are unseen. They develop in response to temperature which obviously is recorded. But the air temperature is a poor predictor of the temperature experienced by the larvae in the mud. The water temperature is a better predictor but still the temperature in the mud would be best. So we just sample twice, bracketing the dates, to insure that at least one of the sample dates coincides with the population peak. The smallest size larvae are difficult to accurately sample/count and the largest (pupal stage) are also not the preferred stage to sample (susceptible to crushing). The two dates also allow us to look at residual control from products. Sometimes a product initially reduces the larval population but does not provide long-term, residual control.

In 2014, RWW populations in the ring plots were at a fairly high level. Levels averaged 2.6 RWW immatures per core sample in the untreated plots (Table 3). I target at least 1 RWW immature per core sample, so this was surpassed. This level should stress the plants and provide a strong challenge for the insecticides. On both sample dates, all the insecticide-treated plots provided a significant level of RWW reduction compared with the untreated plots. Within the treatments, on the first sample date, RWW levels were higher in Mustang – PF, both Bacillus, and treatments #19 and #26 (seed treatments) than in all the other treatments except treatment #24 (seed treatment) which was intermediate. Results were similar in the second sample date. Treatment #26 (seed treatment) provided some RWW control (better than the untreated but not as effective as all the other treatments). Similarly, treatment #19 (seed treatment) had higher populations than all the other treatments except both Bacillus and treatments 20 and 21 (both seed treatments). For the overall averages, the Warrior and Mustang 3 ls treatments zeroed the populations as well as the Coragen 6.1 oz. treatment (the other two higher rates of Coragen averaged only 0.05 RWW per sample). The Dimilin, Warrior 1 ls, Belay 1 ls, and Declare treatments were also highly effective.

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 13.8 to 16.1% (Table 4). There were very few significant differences among the treatments; the % moisture was higher in the Mustang 3 ls treatment than in the Belay 6 ls and Coragen 6.1 oz. treatments. The Mustang treatment provided good RWW control so the higher moisture was not related to poor control (something we have seen in the past as the RWW feeding delays plant development and maturity). Twenty-three of the treatments had statistically similar moisture values. Rice grain yields ranged from ~5710 to slightly over 10,000 lbs./A. The yield in the untreated plots was intermediate but nearer to the highest than the lowest yield at 8740 lbs./A. Statistically, the yield in the untreated did not differ from any of the other yields. The grain yields in the Warrior PF and Belay – 1 ls treatments were significantly higher than those in the Belay PF and 6 ls, Bacillus 1 ls, and treatments #19 (seed treatment A9382, A9459, A12050) and #26 (seed treatment A9382, A9459, A12050, STP22245). Yields in the other treatments did not differ and were in the 7000 to 8000 lbs./A range. Results on plant biomass (grain + straw) were similar. Values were significantly higher in the Warrior PF treatment than in the Belay 6 ls, treatment #19 (seed treatment A9382, A9459, A12050). There was about a 40% range in biomass weights across the 26 treatments.

In summary, the pyrethroid products continue to provide excellent RWW control. Rumors of resistance and reduced efficacy have been made but in limited studies in 2013 I saw no evidence of this. Plans were in place for additional studies of this type in 2014 but the opportunity did not present itself. Belay, which was registered for the 2014 use-season, provided very good RWW control with a 2-3 leaf stage timing. The preflood application of Belay was also fairly effective which differs from previous studies. It appears the optimal timing with Belay is the 3-leaf stage. Coragen with a preflood timing provided excellent RWW control; this material is in the registration pipeline. Dimilin (2-3 leaf stage) performance was also good. *Bacillus thuringiensis* spp *galleriae* was less effective than several of the other treatments but showed promise. Finally, three of the seed treatments were as effective as the registered products and three of the other seed treatment entries were moderately effective.

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

Coragen is a new insecticide product for the rice market that is in the registration pipeline. As shown in Table 1, it comes from a different class of chemistry than other insecticides registered in rice, i.e., not a pyrethroid and not a neonicotinoid. It is available in southern rice production 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. As shown in Tables 2-4, Coragen worked well in ring plots. The preflood application timing appears to be most appropriate for Coragen on RWW. Of course, the industry has experience with preflood insecticides for RWW with the use of Furadan for many years in the 1980-90’s.

Besides evaluations in rice plots, we have been studying Coragen efficacy on RWW in field plots. Testing insecticides in ring plots is a way to effectively utilize resources (space and people) as many products can be compared and evaluated. But if an area has a history of RWW infestations, testing in open field plots has many advantages in that it is better for evaluating length of residual control, yield impacts, etc. The mobile nature of insects such as RWW means that fairly large plots must be used which potentially adds to the cost (space needed). One advantage which facilitates doing this type of testing with Coragen is that the product does not appear to move after being applied to the soil. This allows plots to be set-up without barriers that may be needed to separate treatments. A barrier would to some extent disrupt the RWW adult infestation and movement.

Methods:

Coragen was examined in ~600 sq. ft. plots at the Rice Experiment Station in 2014. 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:

21 May- preflood applications (trt. 1-5)
22 May - flooding
23 May – seeding
7 June – stand establishment ratings
11 June and 23 June - adult leaf scar counts
30 June and 14 July - larval counts
10 October - rice yield

Results:

Stand establishment was generally good in this study (Table 6). Five of the six treatments had a 3.0 stand rating which is a good stand. The stand in the Coragen 7.7 fl. oz. treatment was slightly, but significantly lower, than the other five treatments. Two of the four plots had a “weaker” stand. RWW induced leaf scarring was evaluated twice. The percentage scarring values were extremely low, generally 5% or less. However, on the first sample date, all the insecticide-treated plots had a significantly reduced level of leaf scarring compared with the untreated plots (Table 6). Differences were not as clear-cut on the second sample date, but the amount of scarring was still low. RWW larval populations were moderate in this plot. On the first sample date, RWW immature numbers were reduced in all the treated plots compared with the numbers in the untreated plot (Table 7). Four of the five treatments zeroed the population. Populations in untreated plots averaged 1.0 RWW per core sample. On the second (14 July) sample date, there were no significant differences among the number of RWW in the six entries with numbers ranging from 0.1 to 0.4 RWW per sample. Rice grain yields were similar among all treatments in this study except for the Coragen 7.7 oz. treatment (Table 8). This is the same treatment that had a significantly lower stand rating that the other treatments. The two plots with a “weak” stand corresponded with the two low yielding plots. This accounted for the overall lower grain yield in this treatment. Similarly, this Coragen 7.7 oz. treatment also had grain that had a higher moisture content. This may indicate plants that were delayed in development and maturity. The RWW populations were not high enough and did not last long enough to negatively impact yields (at least not enough to show statistical significance). However, the Coragen 9.2 oz. plots produced about 1000 lbs./A more grain than the untreated plots. All the treated plots (except for the Coragen 7.7 oz. plots as detailed above) produced at least 500 lbs./A more grain than the untreated plots.

Overall, Coragen appears to have a good fit for RWW control with a preflood timing. This product, once registered, will be a good complement to Belay which is best used postflood at the 1-3 ls.

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

Reduced risk, biorational, and biological insecticides are the emphasis of the agrichemical companies today (along with biotechnology options). Several biological insecticides are commonly used in agriculture. Microorganisms and by-products from microorganisms can have insecticidal properties. *Bacillus thuringiensis* is a bacterium that is a commonly used insecticide.

In 2012, about 250-300,000 acres were treated with *Bacillus thuringiensis* in agriculture for Lepidoptera larvae (immature stages of butterflies and moths). This is the market and type of B.t. that is most fully developed and utilized. Another subspecies of *Bacillus thuringiensis* is commonly used for mosquito management (the larval stages in water). There are thousands of different B.t. strains, producing over 200 cry proteins (the insect-active part of the bacteria). These have different characteristics including what insect types and species they kill, toxicity, speed-of-kill, persistence, etc. In the late 1990's, my lab evaluated a biological insecticide for RWW that was 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* subspecies *galleriae)* in greenhouse studies against RWW (Asano, S., C. Yamashita, T. Iizuka, K. Takeuchi, S. Yamanaka, D. Cerf, and T. Yamamotoc. 2003. A strain of *Bacillus thuringiensis* subsp. *galleriae* containing a novel cry8 gene highly toxic to *Anomala cuprea* (Coleoptera: Scarabaeidae). Biol. Control. 28:191-8). 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. In 2014, this material was evaluated in ring plots as previously shown in Objective 1.1. We had previously conducted studies in the greenhouse. No additional greenhouse research was done in 2014 but the data from 2012 and 2013 were analyzed. The summary of this work was that, "The Btg [*Bacillus thuringiensis* spp. *galleriae*] granular formulation (Phy-4-12) performed as well as the leading pyrethroid (lambda-cyhalothrin) in use in California in our greenhouse and field trials."

1.5) Evaluation of the effects of silicon augmentation on Rice Water Weevil populations.

Silicon has been shown to have positive effects in several species of plants. This substance is useful for plant signaling which is the relay which induces the plant to produce protective compounds once fed upon by insect pests. Induced resistance has been proven in rice in response to insect feeding. In addition, silicon aids in reinforcement of plant tissues and is important for yield in plants. Rice is a silicon hyperaccumulator which makes the straw difficult to degrade. Silicon augmentation has been shown to protect rice against rice leafhopper and fungal diseases in studies in Japan.

Methods:

Two approaches were used 1.) liquid silicon fertilizer addition and 2.) addition of rice straw.

- The liquid silicon fertilizer was added to potted rice plants in a greenhouse study. The plants were covered with a piece of clear plastic sheeting with a mesh top for ventilation. Three RWW adults were added to each covered pot and weevil larval numbers compared between the untreated and silicon treatments. Plant silicon levels were monitored in the rice tissue at UC Davis Analytical laboratory.
- The straw approach was studied in a lath-house. Soil was added to buckets – some with straw and a control. Rice was planted into the buckets after a 4-month winter breakdown period and one-month spring drydown period. RWW adults were infested into the buckets and larval population compared between the straw and no straw treatments. Plant silicon levels were monitored in the rice tissue.

Results:

The organic silicon fertilizer did not alter levels in the plant. The rice straw addition significantly increased plant silicon levels although not by a large amount (no straw=3.0% per gram of dry plant material; with straw= 3.6% per gram of dry plant material). This accordingly decreased RWW larval numbers again significantly so from a statistical standpoint but not a large numerical difference (no straw=10.7 RWW; with straw= 7.9 RWW).

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

Standing water is required for rice production in California and is also a requirement for mosquito reproduction and development. However, as with rice production, water "use" can be manipulated to minimize the production of mosquitoes from rice fields. In both cases, the final result cannot be zero, i.e., not possible to produce rice without water and also probably not possible to produce rice without also producing some mosquitoes. But minimizing the use/output is the goal and very achievable. Doing so is part of "best management practices" that are important for maintaining the "environmental fit" of rice in the Sacramento Valley as well as reducing complaints and enhancing the "good neighbor policy".

Several species of mosquitoes have evolved to use the aquatic rice system in their lifecycle. Correspondingly, several species of invertebrates have evolved as important predators of aquatic mosquito stages. A healthy system will have a balance of predators that feed on available prey items such as mosquito larvae and help to keep populations in check. Besides being a nuisance, mosquitoes also transmit human (and to other mammals) diseases. West Nile Virus has been a factor in recent years and this disease was very prevalent in 2014 with 29-WNV-related human fatalities and 789 WNV human cases in California (data California Dept. of Public Health). Some of the key WNV vectors potentially breed in rice fields. There are numerous other mosquito-borne diseases that could become issues especially if climate change continues as some predict. In addition, mosquitoes, as are crop pests, are often introduced to new areas. In 2013, *Aedes aegypti*, the yellow fever mosquito, was introduced into California (first in Madera and Clovis in June, followed by Fresno and the Bay Area [San Mateo] in August). Besides yellow fever, this species transmits dengue and several other viruses to animals. This species prefers to breed in containers and is likely not "connected" to rice fields.

Insecticides are key inputs for rice production. These inputs are used annually on about 40% of the rice acreage. Most of the usage is during the first 14-21 days after seeding and also the majority of insecticides are applied in the area (50-75 feet) adjacent to the levees. Both of these characteristics are positive in terms of protecting populations of non-target invertebrates and for therefore minimizing populations of mosquitoes. Using insecticides that have favorable attributes, such as low risk to natural enemies/non-targets, is another 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. This study was designed to evaluate the environmental fit of insecticides used in rice production. The criteria used were the effects on populations of non-target invertebrate organisms as well as the control of key invertebrate pests. Populations of mosquito larvae were also 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:

1 June – preflood applications
2 June - flooding
4 June – seeding
11 June and 23 June – leaf scar evaluations
24 June – 3-leaf stage applications
11 July and 25 July – RWW larval counts
25 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 from ~ June to September

As new insecticides are tested for efficacy on key pests and are proposed for registration, the fit of these into the rice system is a critical consideration. Belay and Coragen are recent examples of this. The environmental fate of these products is a key aspect evaluated by UC researchers. Another important consideration is the effects of insecticides on populations of aquatic non-target invertebrates in rice. These animals are key for keeping populations of mosquitoes in check and minimizing mosquito production from rice fields.

Collecting the samples for this study during the growing season is laborious. However, the largest effort for this project is separating, counting, and identifying the specimens in the laboratory which occurs during the winter. This quantification often takes 12 months and therefore the data summaries are often “1 year” behind when the field samples were collected. The treatments used the last 4 years are listed in Table 9. The treatment list changes annually so experimental products that could potentially have a fit in rice can be evaluated. Data from 2013 will be discussed in detail. The procedures followed are similar for each year and the exact procedures and dates used in 2014 are given above. Treatments evaluated in 2014 are listed in Table 10.

Results:

Non-Target Populations – This study attempts to sample all aquatic invertebrates 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. In 2013, only three active ingredients were studied – Belay, Coragen, and Warrior with all three applied preflood and at the 3-leaf stage; Warrior was also timed in the July period as for armyworm control.

Preflood applications:

<u>Quadrant samples:</u> *Aquatic Insects* – For the first 2 months after application, impacts on aquatic insects from the preflood treatments were very minimal (Fig. 1a). Coragen reduced populations compared with the untreated only at 42 DAT and Belay had no negative effects. In fact, in many cases there were more aquatic insects in the treated plots than in the untreated plots and in some cases 5-8 times more specimens. Warrior had a negative effect on two of the first nine sample dates (weeks). The most severe reduction was at 14 DAT with 30% as many aquatic insects in the Warrior-treated plots as in the untreated. *Other Aquatic Invertebrates* – Results with populations of other aquatic organisms (non-insects) were similar to those on aquatic insects (Fig. 1b). Neither Belay nor Coragen caused any reductions in populations for the first 2 months. In most cases the treated plots had more organisms than the untreated plots. The primary reduction was from Warrior at 28 DAT (~90% reduction), but the week before and after this point showed no negative effects.

3-Leaf stage applications:

<u>Quadrant samples:</u> *Aquatic Insects* – Results were similar with the insecticides applied at the 3-leaf stage of rice growth (Fig. 2a). For the first nine sample dates (~2 months after treatment), only Coragen reduced numbers of aquatic insects compared with the untreated (at 28 and 35 DAT) and Belay similarly at 63 DAT. In some cases, the numbers of aquatic insects in the treated plots were significantly higher than in the untreated such as 15.75 times more in the Belay-treated plots compared with the untreated at 28 and 35 DAT. *Other Aquatic Invertebrates* – Impacts of the insecticides on other aquatics were also minimal (Fig.2b). Only Coragen showed any negative effects and these were fairly significant at 14 DAT (~70%) and only slight at 21 and 28 DAT (averaging 25%). Interestedly, all three insecticides caused reductions in other aquatic invertebrates at 49 DAT.

Armyworm timing:

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

<u>Quadrant samples:</u> *Aquatic Insects* and *Other Aquatic Invertebrates* – The mid-season Warrior application had moderate effects on populations of aquatic organisms (Fig. 3a,b). Samples were collected for five weeks post-treatment and reductions occurred at 21 and 7 DAT for aquatic insects and other aquatics, respectively.

<u>Larval Mosquito Populations</u> - Mosquitoes were reasonably common in the plots (Fig. 4). Populations were rare early-season but developed in August. Numbers were highest in the Warrior preflood, untreated and Coragen 3 ls applications. Populations spiked and then cycled out so it appears the system was not significantly “upset” by the applications.

Pest Populations – The data on pest populations are summarized from the 2014 study. This is not the primary objective of this study but it is another chance to collect some efficacy data. RWW was the only pest present in any significant numbers. Data will be briefly summarized but not presented in its entirety in tables. Feeding damage on plants by RWW adults was minimal with a high of 5.3 and 10% of the seedlings fed upon on 11 June and 23 June, respectively. RWW larval populations were moderate. For the average RWW levels, RWW levels were highest in the Bacillus and two Belay treatments and averaged ~0.5 RWW per core sample. Curiously, no RWW immatures were found in the untreated plots. The other five treatments had RWW levels less than 0.2.

Grain Yield – Grain yields ranged from 6500 to 7200 lbs./A. There were no significant differences among treatments.

Over the several years I have done this study, the impacts of the insecticides on aquatic nontarget populations from 2013 studies were the lowest that have been seen. In past years, the effects are always short-term but nevertheless significant for a 2-4 week period. The 2013 data showed, at most, moderate reductions and these were recorded in only isolated samples during the first 9 weeks after application. Of the three insecticides (Belay, Coragen, and Warrior) and three types of applications (preflood, 3-leaf stage, and mid-season), there were no general trends for the most significant impacts. Mosquito larval populations were present in moderate numbers in August. Again there were no trends for the most impactful treatment(s). The three treatments with the highest mosquito levels were the untreated, two insecticides (Coragen and Warrior) and two timings (preflood and 3 ls).

1.7) 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 in 2012-13 and 2013-14. Plastic bins (~1 x 1.5 x 0.5 ft.) was filled with 5 inches of rice field 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 4-month "winter" period, 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 adults were placed in small cages in each bin in 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 and again 2 weeks later. Gas samples were taken five times in June and July. In August, 1 gram of rice leaf was collected from each bin and sent to the UC Davis Analytical laboratory for analysis of arsenic and silicon content. These factors were examined as possible reasons for the decline in RWW larval numbers with winter flooding.

Results:

Immature counts. In 2013, the flood by straw interaction was significant for RWW immature numbers. Examination within each level showed that in the absence of straw, there were significantly fewer RWW immatures in the flood treatment (Fig. 5). In the presence of straw, this effect was not present. The effect of straw was not significant at either level of the flood effect. In 2014, there was a significant interaction effect between flood and straw for RWW numbers. Analyzing by the simple effect, flood treatments had a significant effect in the absence of straw. Straw treatments also had a significant effect on the number of immatures in the absence of flood (Fig. 5).

Methane concentrations. In 2013, there was a significant effect of the flood on methane output but not of the straw effect. The methane output in the flooded and flood x straw treatment had an average of less than 1 ug/ml of methane when compared with the straw and control treatments that had methane production averages greater than 6 ug/ml (Fig 6). In 2014, the straw treatment had a significant effect on the level of methane output from the bins but the flood had no effect and there was no significant interaction. The data revealed that the flooded and control bins had less methane output averaging at 0.65 ug/ml compared with the straw and combination treatments that averaged over 4 ug/ml (Fig. 6).

Plant tissue analysis. There were no significant differences in the percentage silicon in any treatment or interaction in 2013. In 2014, there was a significant difference in the percentage silicon in the flood treatment (plants in the flooded treatments having more silicon than those that were not flooded). There were no differences found in the straw treatment or the interaction.

In 2013, there were significant differences in plant concentrations of arsenic in the flood treatment with flood and combinations treatments having lower arsenic concentrations than the non-flooded. The straw and interaction treatments had no significant effect on arsenic levels. In 2014, there were significantly lower concentrations of arsenic in plants that had not been treated with straw; treatments receiving straw had concentrations of arsenic above 4 ppm compared to treatments without straw at 2.2 ppm (Fig. 7). The flood treatment had no effect on arsenic levels and there was no interaction between the treatments.

As for the plant nutrients, there were significant effects of the flood on the levels of nitrogen, phosphorus, and potassium in 2013 but not in 2014.

1.8) Tadpole Shrimp control – Evaluation of efficacy with registered and experimental insecticides.

During the last few years, tadpole shrimp has emerged as a significant pest of rice. This is not a new pest but has always been a factor to consider in rice pest management. However, the populations have been much higher and potentially damaging in recent years. The reasons for this are unknown. Insecticide resistance, the reduction of copper sulfate use, a build-up of straw residue in rice fields, etc. have all been proposed as reasons.

Tadpole shrimp eggs, once deposited in a rice field, can lay “dormant” in dry soil for ~10 years and still be viable. Once the water is added, the eggs will readily hatch. The hatchlings grow and develop very fast and upon reaching a “large” size they can inflict damage to a rice stand. They will feed upon the seeds and seedlings but the more serious damage is from their digging and burrowing actions. This dislodges seedlings and creates turbidity in the water. 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 the damage is minimized by the treatment (after the initial rice establishment period TPS do not damage to the crop). Thus, there is the need for alternative management methods.

Methods:

A field study was conducted on tadpole shrimp control in 2014 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 11. Four replicates in a randomized complete block design were used.

The key dates were as follows:

1 June, pre-flood (PF) applications
2 June, flooding
4 June, seeding (‘M-202’)
14 June, tadpole shrimp were collected from a neighboring field and introduced into rings – 10 shrimp were placed into each of the metal rings and plastic bins; rice was in the ~1-2 leaf stage
15 June, post-flood applications

Sample Dates:

18 June – live and dead tadpole shrimp, floating seedlings in both structures
11 June and 23 June - RWW adult leaf scar counts
10 July - RWW larval counts
13 October - rice yield

Sample Method:

Floating Seedling Counts: Seedlings counted in aluminum ring and plastic bin
Tadpole Shrimp Mortality/Seedling Damage: 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 alive were counted from the plastic bin enclosure as well as from the larger ring (Table 12). The highest number of alive TPS for both the ring plot and the smaller bin was in the untreated plots where TPS were added. Conversely no TPS were found in the untreated plots where no TPS were added (included due to the possibility that TPS could already be in the field/soil and be accidentally trapped in the ring plot). In both cases, the Belay-PF treatment had significantly fewer TPS than the untreated but more than all the other treatments. For the smaller bin structure, all the other treatments were grouped together although Belay – early post-flood and copper sulfate still had a few live TPS whereas the other treatments were void of live TPS. In the larger ring structure, the Belay – early post-flood treatment had an intermediate number of living TPS and all the other treatments were had lower numbers. The number of dislodged seedlings was higher in the untreated with TPS added and Dimilin then in Belay-PF, Coragen-PF, Warrior-both timings, and the seed treatment. These five treatments lost ~5 seedlings out of the ~100 in the ring.

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. Moisture values were tightly grouped ranging from 15.8 to 16.7%. The yields ranged from ~5920 to ~6825 lbs./A for grain yield and from 8.3 to 9.7 t/A for biomass yield (Table 13). There were no significant differences among yields. For both the grain and biomass, the yields for the untreated plots with TPS added were among the lowest ones. This is not surprising given that ~1/4 of the seedlings were dislodged by TPS. However, the remaining plants appeared to compensate well for the reduced stand.

In summary, Warrior, especially with the post-flood timings, provided excellent TPS control. The experimental product Coragen also showed excellent TPS control. Belay was moderately effective but less so compared with Warrior and Coragen. The seed treatment also showed a high level of efficacy. Copper sulfate was also in the moderate category.

1.9) Evaluation of biological control of Armyworm eggs in rice.

Two species of armyworms are pests of rice; populations frequently develop in July to September in parts of the Sacramento Valley. The western yellow-striped armyworm and the “true” armyworm both feed on rice leaves and panicles. Insecticide treatments are generally not needed for these larvae and one reason for this is that insect parasitoids often kill the pest armyworm larvae. The effects of these parasitoids on armyworms are very obvious in rice fields. However, one problem with these beneficial insects is that the armyworm larvae have often already damaged the rice before they die. Another type of parasitoid is one that stings, infests, and kills insect eggs. *Trichogramma* is a genus of small wasps that specialize on Lepidoptera (armyworms, cutworms, etc.) eggs. These small wasps occur naturally but they can also be purchased in any number from insectaries. Different species of *Trichogramma* prefer different species of eggs. The goal of this project was to evaluate three species of *Trichogramma* that are available for purchase to see if they would parasitize armyworm eggs.

Methods:

Armyworm larvae were collected from rice fields and a laboratory colony was started. Eggs were deposited on artificial substrates and exposed to *Trichogramma* egg parasites, *T. brassicae, T. platneri/minutum,* and *T. pretiosum.*

Results:

All three *Trichogramma* egg parasite species readily parasitized armyworm eggs.

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

Rice Water Weevil

1.) The pyrethroid products continue to provide excellent RWW control. Rumors of resistance and reduced efficacy have been made but in limited studies in 2013 I saw no evidence of this. Based on field performance in research plots, Warrior via a preflood or post-flood application and Mustang with the postflood application provided good RWW control. Dimilin (2-3 leaf stage) performance was also good.

2.) In terms of new registrations, Belay, which was registered for the 2014 use-season provided very good RWW control with a 2-3 leaf stage timing. The preflood application of Belay was equally effective which is in contrast to results from previous years. Even as a rescue type of treatment at the ~6 leaf stage, Belay effectively controlled RWW larvae.

3.) Coragen is another new product in consideration for registration. A preflood timing of this product controlled RWW larvae. Although not the “recommended” timing, Coragen was able to manage an ongoing larval infestation, i.e., application at the 5-6 leaf stage.

4.) *Bacillus thuringiensis* spp *galleriae,* a bioinsecticide provided a similar level of RWW control as Warrior in greenhouse studies. In field studies, the Bacillus product was moderately effective. The use rate and cost-effectiveness of this product remain to be investigated.

5.) Seed treatments containing combinations of insecticides and fungicides were active against RWW in small ring plots. Seeds with these experimental treatments were soaked and pregerminated using the standard water-seeded California practices.

6.) Augmentation of silicon level was studied as a means of pest management. Rice readily accumulates silicon and published studies have shown this substance can alter plant tolerance to pest stresses. Through application of liquid silicon to rice plants, concentrations in plants and RWW populations were not affected. By using exposure to degrading rice straw, silicon levels in rice plants were slightly increased and RWW larval levels were decreased.

7.) The mechanism through which winter flooding (with and without straw) reduces levels of RWW larvae the following spring was investigated. RWW larval numbers were reduced by winter flooding but there were no consistent trends for arsenic, methane, silicon, nitrogen, potassium, and phosphorus levels; these substances were hypothesized as causing this effect.

Tadpole shrimp

Warrior, especially with the post-flood timings, provided excellent TPS control; the preflood timings were less effective. The experimental product Coragen also showed excellent TPS control. Belay was moderately effective but less so compared with Warrior and Coragen. The experimental seed treatment also showed a high level of efficacy. Copper sulfate was also in the moderate category.

Rice System

The impacts of the insecticides on aquatic nontarget invertebrate populations were the lowest that have been seen. In past years, the effects are always short-term but nevertheless significant for a 2-4 week period. The 2013 data showed, at most, moderate reductions and these were recorded in only isolated samples during the first 9 weeks after application. Of the three insecticides (Belay, Coragen, and Warrior) and three types of applications (preflood, 3-leaf stage, and mid-season), there were no general trends for the most significant impacts. Mosquito larval populations were present in moderate numbers in August. Again there were no trends for the most impactful treatment(s). The three treatments with the highest mosquito levels were in the untreated, two insecticides (Coragen and Warrior) and two timings (preflood and 3 ls).

Armyworms

Three species of *Trichogramma*, a genus of small wasps that parasitize and kill Lepidoptera (armyworms, cutworms, etc.) eggs, were studied. Armyworm larvae were collected from rice fields and a laboratory colony was started. Eggs were exposed to *T. brassicae, T. platneri/minutum,* and *T. pretiosum*, which were obtained from a commercial insectary. All three species readily parasitized armyworm eggs.

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

The RWW was first found in California in 1958 although it may have been here for a few years prior to that. As shown in a report by John Lindt in 1965, RWW was a pest of concern but it appears that rice leafminer, occurring at the same time, was more of a problem. RWW was still establishing itself across the Sacramento Valley. This pest has been the subject of considerable research in California and the southern rice states. 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 (70-80^0F) and calm winds (<5 MPH) are optimal. In 2014, RWW spring flight occurred fairly consistently from 7 April to 17 April. Another large flight peak occurred from 27 April to 2 May and a small flight peak from 13 May to 15 May (Fig. 8). The flight was earlier compared with other recent years. The flight was 90% concluded on 30 April. In terms of numbers, flight was low to moderate in 2014 and nearly identical to 2013 (822 vs. 832 RWW captured). This was ~1/5 the number of RWW captured in 2012 but more than twice the number from 2011.

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

Host plant resistance is an important part of IPM programs. In certain crops such as wheat, this approach is of utmost importance. This is due to the genetic diversity in the wheat lines, the importance of insect (and disease) pests which respond to these genes, the large acreage of wheat, and the relatively low value of wheat which makes spending money on insecticides often not cost-competitive. Rice is another crop that world-wide has an excellent fit with host-plant resistance. Many of the plant disease-vectoring insect pests, stem borers, and other pests are best managed with host-plant resistance in world rice culture.

Studies on RWW and host-plant resistance began in the 1960's. Initially this pest would appear to be an excellent target for host-plant resistance but the lack of genetic diversity in rice with activity on RWW has hindered the research. For instance in 1970's and 1980's research, out of the thousands of lines tested one variety in California and only four of exotic origins were found to show any resistance to RWW. In addition, these lines were overall weak for grain quality and agronomy aspects.

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 is a challenge in the aquatic rice agroecosystem and this is likely to intensify but a challenge that can be met through effective research and development.

Host plant resistance may provide only partial control of the pest and still be useful for IPM systems. This is especially the case when other means of control are also used such as cultural measures, etc. The partial control provided by the plant variety may be enough to make pest populations non-economic. 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. 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 2014.

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

Methods:

Four varieties, M-202, S-102, L-206, and a PI experimental line, were grown in 10.7 sq. ft. aluminum rings as detailed in subobjectives 1.1 and 1.2 for assessing adult scarring, larval populations, and yields. These varieties were selected to represent a range of genotypes (grain types) within California rice. The rings were to be infested with adults to insure that a population was present; examining yield loss was the primary goal. 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 on 21 May to make sure no damage occurred and 2.) the natural rice water weevil infestation which was supplemented with RWW adults placed into each ring. The plots were flooded on 22 May and seeded on 23 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.

Results:

Stand ratings were made on 7 June and ranged from 0.9 to 1.4; a rating of ~3 is an acceptable stand. A combination of deep water on this end of the basin and some TPS had effected the stand. The study was moved to another location but the plants were already too large and the season was too advanced to collect adequate RWW for infestation. The study was discontinued for 2014.

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

Methods:

The rice varieties as shown in Table 14 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 21 May] + Dermacor 2.5 fl. oz./100 lbs. seed [applied at seeding on 23 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:

11 June and 23 June - RWW adult leaf scar counts
1 July and 15 July - RWW larval counts
10 October - rice yield

Results:

This plot had a very low RWW infestation and thus no meaningful data were collected on RWW. This is the second year this has happened. The basin to the immediate north from this plot had a moderate RWW infestation. Leaf scarring averaged only 1.8 and 3.5% for the treated and untreated plots respectively (average of all 12 variety entries in both cases). RWW larval counts averaged 0.06 RWW per core sample (Table 15). Due to the very low population, there were no differences between the treated and untreated plots or across the varieties.

Grain yields ranged from 7750 (Calhikari-202 - untreated) to 9770 (M-401 – treated) lbs./A (Table 16). In 8 of the 12 variety comparisons (treated vs. untreated), the treated plots outyielded the untreated plots. I cannot attribute this to RWW control due to the very low pest numbers.

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

A study was conducted from 2011 to 2013 based on some of our findings from the varietal susceptibility to RWW studies 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. This study conducted in ring plots and in small open field plots (10 x 20 feet) utilized M-202 and M-206, seeding rates of 50, 100, 150, and 200 lbs./A, and uninfested, low, and high RWW infestation rates (in the ring plots). Rice yield was the primary factor of interest. Results were interesting and some interesting differences were noted. Results are currently being fully summarized, analyzed, and written for publication as a 3-year study. The seeding rate aspect of this study was less interesting. A variation of this study was started in 2014 emphasizing the RWW aspect/response of M-202 and M-206. Two deficiencies of the previous study were addressed, 1.) the RWW sampling and other human activities within the rings often created stresses/damage on the other plants in the rings and 2.) having only a one-time snapshot of the plant growth and development at season-end was not sufficient to study the plant responses.

Methods:

Two rice varieties, M-202 and M-206, were used. These were planted in ring plots (standard 10.7 square feet aluminum rings). Within each variety, four RWW infestation regimes were used – 0, 0.2, 0.4, and 0.6 RWW adults per plant (100 plants per ring). These were intended to set-up a range of RWW larval densities. The measurements collected included RWW leaf scarring, RWW larval levels, number of tillers, root length (cm), stem length (cm), length of the newest fully developed leaf (cm) and of the next newest leaf (cm), total dry weight (g), and root dry weight (g), panicle density at harvest, and grain yield. The length and weight data were collected about every 14 days from early July to Sept. Eight replicates of each treatment were used; four replicates were sampled and the other four were left untouched for yield sampling. Key dates are as follows:

2 June, flooding
4 June, seeding
24 June – RWW infestation
27 June and 3 July – scar evaluations
10 July and 25 July – RWW larval counts
15 October - rice yield

Results:

The RWW infestations were established as desired. The plant scarring responded to RWW infestation level. Scarring was somewhat higher on M-206 than on M-202, especially at the high RWW level (Fig. 9). The maximum RWW level was somewhat lower than desired peaking at ~1.8 RWW per sample (Fig. 10). I have previously used this type of RWW infestation and achieved larval numbers up to 5 RWW per sample. Larval numbers did respond well with the infestation level and the numbers were about 20% higher on M-206 than M-202. Yield data were also somewhat low averaging ~5500 lbs./A for the entire study. The grain yields from the rings are often higher than normal because the aluminum warms the water and enhances early-season plant growth. The reason(s) for the low yields in this study are unknown perhaps a fertility problem. Regardless, the % yield losses were calculated comparing the yields in the infested plots with the uninfested within variety. For M-206, losses were 0, 1.2, and 5.8% for the low, medium, and high infestations, respectively (Fig. 11). Losses were 4.5 and 5.4% for the low and medium infestations, respectively, in M-202 which appears to be more severe than in the similar treatments of M-206. The yield loss value for the high infestation (M-202) was not calculated because of a poor stand in one ring and rat damage in another ring. But overall it appears that the grain loss in M-202 was higher than M-206 given similar RWW infestations. The plant data (weights, lengths, number of tillers, etc.) are still being summarized but should provide some more insights into how these two varieties responded to RWW injury.

Objective 3: To study the insect-related causes of pecky rice and the factors influencing the incidence of this damage.

3.1) Investigate the extent of rice damage (kernel damage and potential yield loss) from Redshouldered Stink Bug.

3.1.a) Quantify the influence of rice grain maturity on stink bug damage
3.1.b) Investigate the susceptibility of a range of rice varieties to stink bug damage

Pecky rice is generally not a factor in rice production in California. The standards for seed damage are relatively low (0.5% damage) and the grain quality in the state is of utmost importance and a key to the marketability. The rice stink bug (*Oebalus pugnax*) is a key rice pest in the southern states and in many areas it is the most important IPM challenge for rice production. Sampling, treatments, costs, resistance development, etc. are some of the issues faced annually for the rice stink bug. This insect is not known to occur in California.

In recent years, some reports of "pecky" rice have been received from parts of the Sacramento Valley. Pecky rice can be caused by sucking insects but similar appearing damage can also be caused by several agronomic and environmental factors. 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 as well as mentioned in a report from 1965 as damaging rice in 1939 in California. Stink bugs overall appear to be increasing in severity statewide on several crops. It appears that the biology of several species is changing in terms of numbers and length the season. In addition, there are several invasive species of stink bugs that are poised to cause IPM problems on several crops. Studies were initiated in 2013 and continued in 2014 to determine the damage potential of this species to rice. In 2014, research was expanded to examine a range of rice varieties.

Methods:

As a means of review of the 2013 study and for details of the 2014 work, the general approach was to cage redshouldered 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 boot (2014 only), 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. These studies were conducted on M-202. In 2014, study 2, was also conducted on M-206, Calmochi-101, Calhikari-202, S-102, and L-206 (milk and dough stages only).

Results:

In 2013, for the first study, the percentage peck rice was ~0.4% from the uninfested cages and 2.8% (brown rice) and 1.8% (milled rice) from the stink bug infested cages. 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. The uninfested cages had ~0.4% kernel damage. For the stink bug infested cages, the damage ranged from 5.4% (milk stage infestation) to 3.2% (dough stage infestation). The stink bugs also decreased the grain/kernel weights by 20-30%; again this was from the bugs confined on the developing panicles.

In 2014, the uninfested cages yielded grain with <0.35% pecky rice. Caging RSSB on the developing panicles produced kernel damage of 1.4, 2.3, and 2.8% for the boot, milk, and dough stage infestations, respectively (Fig. 12). Similarly, kernel dry weights were reduced by 36.3, 14.3, and 18.6% by the RSSB for the boot, milk, and dough stage infestations (Fig. 13), respectively and by 59.9, 31.9, and 39.8% for milled rice from the boot, milk, and dough stage infestations, respectively.

As shown in Fig. 12 and 13, similar kernel damage values were seen on the other five rice varieties. Although there was some variability, a 3-6% damage value from RSSB was commonly seen. Across varieties, the damage averaged 2.7, 2.0, and 3.4% on the boot, milk, and dough stage infestations, respectively.

3.2) Quantify the incidence of stink bugs in Sacramento Valley grower rice fields during the grain filling period.

3.2.a) Identify the stink bug species

3.2.b) Identify agronomic factors which are associated with stink bug populations

Stink bug levels in Sacramento Valley rice fields were monitored in September. The presence of stink bugs would be indicative of kernel damage potential and stink bugs nymphs would indicate reproduction in the rice fields.

Methods:

Forty-nine rice fields were surveyed. The surveys involved sweeping the rice with the standard 15 inch diameter sweep net and visual inspections. Stink bug species and developmental stage were identified.

Results:

Stink bugs were found in fields of five of the six rice production counties (Table 17). Redshouldered stink bug was the most common species found and, in addition, nymphs of this species were found in four counties. Consperse stink bug was the other species commonly found and nymphs of this species were also found. Three other species were found as well. These species are all common Sacramento Valley stink bugs often found in field crops as well as weedy areas. Fields with higher stink bug numbers tended to have a higher level of grassy weeds, be near riparian habitat, and be in areas with more crop diversity (row crops).

3.3) Study the propensity of common Sacramento Valley stink bugs to survive on and damage rice kernels and panicles.

Two other common stink bug species were studied for their ability to damage rice kernels. The consperse stink bug, *Euschistus conspersus*, and southern green stink bug, *Nezara viridula*, are very common in the Sacramento Valley.

Methods:

The methods as described in Objective 3.1 were used (study 2 approach). Infestations for these two species were done at the milk and dough stages only on M-202.

Results:

Infested cages had 2.0 and 0% damage for the consperse stink bug at the milk and dough stages, respectively, and higher values, 4.4 and 3.2% for the southern green stink bug at the milk and dough stages, respectively. As stated previously, the uninfested cages had ~0.4% damage.

Objective 4: Conduct appropriate monitoring, exploratory research, and educational activities on emerging and new exotic rice invertebrate pests.

4.1) Investigate the potential of the recently invaded pest, Brown Marmorated Stink Bug, to reproduce, develop, and damage rice.

The brown marmorated stink bug, *Halyomorpha halys*, is a relatively new invader to the U.S. It was first found in Pennsylvania in 1998 and initially spread throughout the eastern coastal area. This pest has now spread (or been moved) to the west coast. Currently, this species has been detected in 22 states, and in another 20 states (including California) there are reproducing populations. In California, the brown marmorated stink bug (BMSB) is established in 5 counties and in another 10-15 counties it has been found. This pest is a voracious eater that damages fruit, vegetable, field, and ornamental crops in North America. Over 200 hosts have been identified for this pest with berries, corn, cotton, beans, cherry, peaches, apple, etc. being common hosts. Rice has not been studied with regard to this pest as it has not infested the southern rice production area yet. We wanted to evaluate the relationship of brown marmorated stink bug and rice.

Methods:

Studies were conducted in the Contained Research Facility just west of the Davis campus. This is a secure environment for research on invasive plant pests. The rice was grown under conditions of 30 C and 16L: 8D photoperiod. Each pot was inoculated with BMSB, 2 males and 2 females, during three different stages of plant growth, 1.) panicle initiation – near the time of tillering but before panicles are evident, 2.) early grain filling (milk stage), 3.) panicle ripening (dough stage). Each pot (ten replicates used for each timing) was encased in a plastic tube with an organdy mesh to prevent a buildup of humidity and to prevent the BMSB escape. Uninfested plants were similarly caged and monitored. The ability of the insects to survive and reproduce on rice and to damage the plants and kernels were of interest. The BMSB were left on the rice plants for 3 weeks or until panicles fully matured. Panicles were removed and examined for signs of "peckiness" and grain spotting.

Results:

The BMSB did reproduce and develop on rice plants (Table 18). These populations started from adults caged onto the plants. The conditions in the facility/greenhouse prevented us from evaluating plant/grain damage. There was a high level of blanking probably due to cool nighttime conditions in the greenhouse, however, this is a shared facility so we could not precisely control the conditions.

Studies will continue in 2015 to examine the plant and grain damage aspect. We now have a permit to have a BMSB colony in the laboratory so this study can be done under more optimal conditions for rice.

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CONCISE GENERAL SUMMARY OF CURRENT YEARS (2014) RESULTS:

Larry D. Godfrey

Research was conducted in 2014 on the biology and management of key invertebrate pests of California rice. Four invertebrate pests were the subjects of the research including the rice water weevil, tadpole shrimp, armyworms, and redshouldered stink bug. In addition, some research was done on other stink bug species including the recent invasive species to California, the brown marmorated stink bug. The stink bug program is a new research effort on this group of pests that are increasing in severity and appear to be posing a threat to rice yield and grain quality. Tadpole shrimp has increased in importance the last ~5 years and studies were conducted to improve management of 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:

Insecticides are used on ~35-40% of the rice acreage and rice water weevil and other early-season pests are frequent targets. The pyrethroid products continue to provide excellent rice water weevil control. Rumors of resistance and reduced efficacy have been made but in limited studies in 2013 I saw no evidence of this. Based on field performance in research plots, Warrior® via a preflood or post-flood application and Mustang® with the postflood application provided good weevil control. Dimilin® applied at the 2-3 leaf stage also showed good performance. Newer products, such as Belay®, which was registered for the 2014 use-season, provided very good rice water weevil control with a post-flood (2-3 leaf stage) timing. The preflood application of Belay was equally effective in 2014 studies which is in contrast to results from previous years. Even as a rescue type of treatment at the ~6 leaf stage, Belay effectively controlled weevil larvae. Coragen®, another new product being considered for registration, was shown to effectively control rice water weevil with a preflood application timing. Plots treated with Coragen generally produced at least 500 lbs./A more grain than the untreated plots under moderate weevil pressure. Seed treatments are used in the southern states for rice pest control. Experimental seed treatments containing combinations of insecticides and fungicides were very active against rice water weevil in small ring plots. Seeds with these experimental treatments were soaked and pregerminated using the standard water-seeded California practices.

Reduced risk, biorational, and biological insecticides are the emphasis of the agrichemical companies today (along with biotechnology options). Research was conducted on two approaches within this area. *Bacillus thuringiensis* spp. *galleriae,* a bioinsecticide, provided a similar level of RWW control as Warrior in greenhouse studies. In field studies, the *Bacillus* product was moderately effective. The use rate and cost-effectiveness of this product remain to be investigated. Augmentation of silicon level was studied as a means of pest management. Rice readily accumulates silicon and published studies have shown this substance can alter plant tolerance to pest stresses. Through application of liquid silicon to rice plants, concentrations in plants and rice water weevil populations were not affected. By using exposure to degrading rice straw, silicon levels in rice plants were slightly increased and rice water weevil larval levels were decreased.

Winter flooding is a common practice used to enhance straw breakdown; winter flooding has been shown to also reduce rice water weevil larval numbers the next spring. The mechanism through which winter flooding (with and without straw) reduces levels of weevil larvae was investigated in a controlled lath-house study. Rice water weevil larval numbers were reduced by winter flooding but there were no consistent trends for arsenic, methane, silicon, nitrogen, potassium, and phosphorus levels; these were substances that were hypothesized as causing this effect.

Tadpole shrimp: Warrior, especially with the post-flood timings, provided excellent tadpole shrimp control; the preflood timings were less effective. The experimental product Coragen also showed excellent shrimp control. Belay was moderately effective but less so compared with Warrior and Coragen. The experimental seed treatment also showed a high level of efficacy. Copper sulfate was also in the moderate category.

Rice System: The impacts of the insecticides on aquatic nontarget invertebrate populations were the lowest that have been seen in the several years I have studied this. In past years, the effects are always short-term but nevertheless significant for a 2-4 week period. The 2013 data showed, at most, moderate reductions and these were recorded in only isolated samples during the first 9 weeks after application. Of the three insecticides (Belay, Coragen, and Warrior) and three types of applications (preflood, 3-leaf stage, and mid-season), there were no general trends for the most significant impacts. Mosquito larval populations were present in moderate numbers in August. Again there were no trends for the most impactful treatment(s). The three treatments with the highest mosquito levels were in the untreated, two insecticides (Coragen and Warrior) and two timings (preflood and 3 ls). These studies contribute to developing Best Management Practices.

Armyworms: Armyworms are under very good biological control by parasitic wasps that kill the larval stages. This is important for keeping populations from building-up to severe levels but the larvae succumb after the plant damage (leaf/panicle feeding) has largely already occurred. *Trichogramma* are small wasps that parasitize and kill Lepidoptera (armyworms, cutworms, etc.) eggs. Several species of *Trichogramma* can be purchased from insectaries and each species has different properties. Armyworm larvae were collected from rice fields and a laboratory colony was started. Armyworm eggs were exposed to *T. brassicae, T. platneri/minutum,* and *T. pretiosum* and all three species readily parasitized the eggs.

Biology – Rice Water Weevil Flight: In 2014, rice water weevil spring flight occurred fairly consistently from 7 April to 17 April. Another large flight peak occurred from 27 April to 2 May and a small flight peak from 13 May to 15 May. The flight was earlier compared with other recent years and was 90% concluded on 30 April. In terms of numbers, flight was low to moderate in 2014 and nearly identical to 2013 (822 vs. 832 RWW captured). This was ~1/5 the number of RWW captured in 2012 but more than twice the number from 2011.

Cultivar Response: Host plant resistance is an important part of IPM programs. Rice is a crop that world-wide has an excellent fit with host-plant resistance as many of the plant disease-vectoring insect pests, stem borers, and other pests are best managed with host-plant resistance in world rice culture. Studies on rice water weevil and host-plant resistance began in the 1960’s. Initially this pest would appear to be an excellent target for host-plant resistance but the lack of genetic diversity in rice with activity on this pest has hindered the research. For instance in 1970’s and 1980’s research, out of the thousands of lines tested one variety in California and only four of exotic origins were found to show any resistance to rice water weevil. In addition, these lines were overall weak for grain quality and agronomy aspects. Host plant resistance may provide only partial control of the pest and still be useful for IPM systems. This is especially the case when other means of control are also used such as cultural measures, etc. The partial control provided by the plant variety may be enough to make pest populations non-economic. 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 rice water weevil to infest and survive on some cultivars. Therefore, we have been examining the response of commonly-grown California rice cultivars to rice water weevil in terms of 1.) severity of infestation and 2.) yield loss upon infestation. Three studies were done in 2014. Two of the studies were hindered by technical issues – poor stand establishment in one and a low natural rice water weevil infestation in the second. The third study examined response of M-202 and M-206 to varying levels of rice water weevil infestation. Similar infestation regimes were set-up for these two varieties in ring plots. M-206 had more extensive adult feeding than M-202 and about 20% higher weevil larval levels. Grain yield losses appeared to be more severe with M-202 than with M-206, i.e., a 1.2% loss with M-206 compared with a 5.4% loss for M-202 from ~0.7-0.8 larvae per core sample.

Pecky Rice: Pecky rice is generally not a factor in rice production in California. The standards for seed damage are relatively low (0.5% damage) and the grain quality in the state is of utmost importance and a key to the marketability. In recent years, some reports of “pecky” rice have been received from parts of the Sacramento Valley. Examination of these fields in 2012 revealed a low level of redshouldered stink bug, *Thyanta pallidovirens* (= *T. accerra*). This insect has been reported from Mississippi as a pest of rice and was mentioned in a report from 1965 as damaging rice in California in 1939. Studies were initiated in 2013 and continued in 2014 to determine the damage potential of this species to rice. Redshouldered stink bugs were caged on developing rice panicles in field plots. In 2014, the uninfested cages yielded grain with <0.35% pecky rice. Caging redshouldered stink bugs on the developing panicles of M-202 produced kernel damage of 1.4, 2.3, and 2.8% for the boot, milk, and dough stage infestations, respectively. Similarly, kernel dry weights were reduced by 36.3, 14.3, and 18.6% by the redshouldered stink bugs for the boot, milk, and dough stage infestations, respectively and by 59.9, 31.9, and 39.8% for milled rice from the boot, milk, and dough stage infestations, respectively. Five other varieties, M-206, Calmochi-101, Calhikari-202, S-102, and L-206, were examined for incidence of redshouldered stink bug damage. There was some variability in incidence of pecky rice with 3-6% damage from redshouldered stink bugs. Across varieties, the damage averaged 2.7, 2.0, and 3.4% on the boot, milk, and dough stage infestations, respectively. Finally, forty-nine grower rice fields were surveyed in September for stink bugs. Stink bugs were found in fields from five of the six rice production counties. Redshouldered stink bug was the most common species found and, in addition, nymphs of this species were found in four counties. Four other stink bug species were found as well. These species are all common Sacramento Valley stink bugs often found in field crops as well as weedy areas. Fields with higher stink bug numbers tended to have a higher level of grassy weeds, be near riparian habitat, and be in areas with more crop diversity (row crops).

Invasive Invertebrate Pests – The brown marmorated stink bug, *Halyomorpha halys*, is a relatively new invader to the U.S.; initially problematic on the east coast and now in 20 states including California. This pest is a voracious feeder that damages fruit, vegetable, field, and ornamental crops in North America. Rice has not been studied with regard to this pest as it has not infested the southern rice production area yet. We evaluated the relationship of brown marmorated stink bug and rice. Studies were conducted in the Contained Research Facility, a secure quarantine environment for research on invasive plant pests. The rice was grown in pots and inoculated with brown marmorated stink bug, 2 males and 2 females, during three different stages of plant growth. The ability of the insects to survive and reproduce on rice and to damage the plants and kernels were of interest. The BMSB did reproduce and develop on rice plants. Fourth instar nymphs were found as early as 18 days after inoculation and persisted up to 33 days. The conditions in the facility/greenhouse prevented us from evaluating plant/grain damage. There was a high level of blanking probably due to cool nighttime conditions in the greenhouse. Studies will continue in 2015 to examine the plant and grain damage aspect.

Table 1. Treatment list for RWW management ring study, 2014.

Product	**Rate (lbs. AI/A)**	**Product per A (fl. oz.)**	**Timing**	**Properties**
1. Dimilin 2L	0.125	8	2-3 leaf	Insect growth regulator
2. Untreated	---	---	---	---
3. Warrior II	0.04	2.56	Preflood	Pyrethroid insecticide
4. Warrior II	0.04	2.56	early post-flood (~1 ls)	Pyrethroid insecticide
5. Warrior II	0.04	2.56	late post-flood (~3 ls)	Pyrethroid insecticide
6. Belay 2.13 SC	0.075	4.5	Preflood	Neonicotinoid insecticide
7. Belay 2.13 SC	0.075	4.5	early post-flood (~1 ls)	Neonicotinoid insecticide
8. Belay 2.13 SC	0.075	4.5	late post-flood (~3 ls)	Neonicotinoid insecticide
9. Belay 2.13 SC	0.092	5.5	5-6 leaf	Neonicotinoid insecticide
10. Mustang	0.05	4.3	2-3 leaf	Pyrethroid insecticide
11. Mustang	0.05	4.3	Preflood	Pyrethroid insecticide
12. *Bacillus thuringiensis* spp *galleriae*	8.0 lbs./A		Preflood	Biological insecticide - bacteria
13. *Bacillus thuringiensis* spp *galleriae*	8.0 lbs./A		early post-flood (~1 ls)	Biological insecticide - bacteria
14. Declare	0.02	2.05	2-3 leaf	Pyrethroid insecticide
15. Coragen	0.08	6.1	Preflood	Anthranilic diamide insecticide
16. Coragen	0.1	7.7	Preflood	Anthranilic diamide insecticide
17. Coragen	0.12	9.2	Preflood	Anthranilic diamide insecticide
18. Coragen	0.12	9.2	5-6 leaf	Anthranilic diamide insecticide
19. A9382; A9459; A12050			seed treatment	Experimental – contains three fungicides
20. A17469			seed treatment	Experimental – contains a fungicide and an insecticide
21. A17469; A17960	Lowest rate		seed treatment	Experimental–contains a fungicide and two insecticides
22. A17469; A17960	Low rate		seed treatment	Experimental – contains a fungicide and two insecticides
23. A17469; A17960	Medium rate		seed treatment	Experimental – contains a fungicide and two insecticides
24. A17469; A17960	High rate		seed treatment	Experimental – contains a fungicide and two insecticides
25. A9382; A9459; A12050; STP15201			seed treatment	Experimental – contains three fungicides and an insecticide
26. A9382; A9459; A12050; STP22245			seed treatment	Experimental – contains three fungicides and an insecticide

Table 2. Rice plant stand and adult feeding damage in chemical ring study, 2014.

Product	**Product per A (fl. oz.)**	**Timing**	**Stand Rating (1 - 5)**		**% Scarred Plants – 11 June**		**% Scarred Plants – 23 June**		**% Scarred Plants [a]**
1. Dimilin 2L	8	2-3 leaf	2.5	b	17.3	ab	8.7	cd	13.0
2. Untreated	---	---	3.0	ab	10.0	b	11.0	bcd	10.5
3. Warrior II	2.56	Preflood	3.0	ab	5.0	b	1.5	d	3.3
4. Warrior II	2.56	early post-flood (~1 ls)	3.0	ab	0	b	1.5	d	0.8
5. Warrior II	2.56	late post-flood (~3 ls)	3.1	a	9.5	b	9.0	bcd	9.3
6. Belay 2.13 SC	4.5	Preflood	2.9	ab	5.0	b	10.0	bcd	7.5
7. Belay 2.13 SC	4.5	early post-flood (~1 ls)	3.0	ab	0	b	7.5	cd	3.8
8. Belay 2.13 SC	4.5	late post-flood (~3 ls)	3.1	a	11.0	b	9.0	bcd	10.0
9. Belay 2.13 SC	5.5	5-6 leaf	2.9	ab	29.8	a	17.0	abc	23.4
10. Mustang	4.3	2-3 leaf	3.3	a	10.5	b	13.0	a-d	11.8
11. Mustang	4.3	Preflood	3.1	a	12.5	b	14.0	abc	13.3
12. *Bacillus thuringiensis* spp *galleriae*	8.0 lbs./A	Preflood	2.9	ab	14.3	ab	21.0	ab	17.6
13. *Bacillus thuringiensis* spp *galleriae*	8.0 lbs./A	early post-flood (~1 ls)	2.9	ab	16.5	ab	9.0	bcd	12.8
14. Declare	2.05	2-3 leaf	3.1	a	13.0	ab	11.5	bcd	12.3
15. Coragen	6.1	Preflood	3.0	ab	3.5	b	6.0	cd	4.8
16. Coragen	7.7	Preflood	3.0	ab	0	b	7.0	cd	3.5
17. Coragen	9.2	Preflood	3.1	a	14.5	ab	11.0	bcd	12.8
18. Coragen	9.2	5-6 leaf	3.0	ab	11.0	b	11.0	bcd	11.0
19. A9382; A9459; A12050		seed treatment	2.9	ab	7.5	b	17.5	abc	12.5
20. A17469		seed treatment	2.8	ab	1.5	b	17.0	abc	9.3
21. A17469; A17960	Lowest rate	seed treatment	2.75	ab	4.5	b	17.0	abc	10.8
22. A17469; A17960	Low rate	seed treatment	2.9	ab	4.0	b	8.5	cd	6.3
23. A17469; A17960	Medium rate	seed treatment	3.0	ab	5.5	b	10.5	bcd	8.0
24. A17469; A17960	High rate	seed treatment	2.5	b	13.5	ab	11.0	bcd	12.3

25. A9382; A9459; A12050; STP15201		seed treatment	2.8	ab	3.0	b	12.0	a-d	7.5
26. A9382; A9459; A12050; STP22245		seed treatment	1.9	c	30.0	a	23.5	a	26.8

[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, 2014.

Product	**Product per A (fl. oz.)**	**Timing**	**RWW per Core Sample – 2 July**		**RWW per Core Sample – 16 July**		**Avg. RWW per Core Sample**
1. Dimilin 2L	8	2-3 leaf	0.1	d	0	d	0.05
2. Untreated	---	---	1.55	a	3.65	a	2.6
3. Warrior II	2.56	Preflood	0.05	d	0.2	d	0.13
4. Warrior II	2.56	early post-flood (~1 ls)	0.05	d	0.05	d	0.05
5. Warrior II	2.56	late post-flood (~3 ls)	0	d	0	d	0
6. Belay 2.13 SC	4.5	Preflood	0	d	0.25	d	0.13
7. Belay 2.13 SC	4.5	early post-flood (~1 ls)	0	d	0.1	d	0.05
8. Belay 2.13 SC	4.5	late post-flood (~3 ls)	0	d	0.15	d	0.08
9. Belay 2.13 SC	5.5	5-6 leaf	0.05	d	0.1	d	0.08
10. Mustang	4.3	2-3 leaf	0	d	0	d	0
11. Mustang	4.3	Preflood	0.65	bc	0.2	d	0.43
12. *Bacillus thuringiensis* spp *galleriae*	8.0 lbs./A	Preflood	0.95	b	0.7	cd	0.83
13. *Bacillus thuringiensis* spp *galleriae*	8.0 lbs./A	early post-flood (~1 ls)	0.8	b	0.85	cd	0.83
14. Declare	2.05	2-3 leaf	0	d	0.05	d	0.03
15. Coragen	6.1	Preflood	0	d	0	d	0
16. Coragen	7.7	Preflood	0.05	d	0.05	d	0.05
17. Coragen	9.2	Preflood	0	d	0.1	d	0.05
18. Coragen	9.2	5-6 leaf	0.1	d	0.25	d	0.18
19. A9382; A9459; A12050		seed treatment	0.8	bc	1.35	c	1.08
20. A17469		seed treatment	0.1	cd	0.7	d	0.4

21. A17469; A17960	Lowest rate	seed treatment	0.05	cd	0.55	d	0.3
22. A17469; A17960	Low rate	seed treatment	0.05	d	0.15	d	0.1
23. A17469; A17960	Medium rate	seed treatment	0	d	0.15	d	0.08
24. A17469; A17960	High rate	seed treatment	0.25	cd	0.1	d	0.18
25. A9382; A9459; A12050;STP15201		seed treatment	0.05	d	0.85	cd	0.45
26. A9382; A9459; A12050;STP22245		seed treatment	0.7	bc	2.35	b	1.53

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, 2014.

Product	**Product per A (fl. oz.)**	**Timing**	**% Grain Moisture**		**Grain Yield (lbs./A)**		**Biomass (Straw+ Grain) (t/A)**	
1. Dimilin 2L	8	2-3 leaf	15.3	ab	8408	abc	10.9	abc
2. Untreated	---	---	14.3	ab	8740	abc	10.5	abc
3. Warrior II	2.56	Preflood	14.2	ab	10007	a	12.4	a
4. Warrior II	2.56	early post-flood (~1 ls)	14.5	ab	9740	ab	11.0	abc
5. Warrior II	2.56	late post-flood (~3 ls)	14.5	ab	8197	abc	10.6	abc
6. Belay 2.13 SC	4.5	Preflood	14.3	ab	6328	c	8.3	abc
7. Belay 2.13 SC	4.5	early post-flood (~1 ls)	14.6	ab	10008	a	11.9	ab
8. Belay 2.13 SC	4.5	late post-flood (~3 ls)	14.4	ab	8797	abc	10.9	abc
9. Belay 2.13 SC	5.5	5-6 leaf	13.8	b	5835	c	7.6	c
10. Mustang	4.3	2-3 leaf	16.1	a	8617	abc	10.5	abc
11. Mustang	4.3	Preflood	14.4	ab	7689	abc	9.6	abc
12. Bacillus thuringiensis spp galleriae	8.0 lbs./A	Preflood	14.3	ab	7211	abc	8.9	abc
13. Bacillus thuringiensis spp galleriae	8.0 lbs./A	early post-flood (~1 ls)	15.1	ab	5711	c	8.0	bc
14. Declare	2.05	2-3 leaf	15.0	ab	8366	abc	11.0	abc
15. Coragen	6.1	Preflood	14.0	b	8806	abc	10.6	abc
16. Coragen	7.7	Preflood	15.0	ab	8534	abc	10.4	abc
17. Coragen	9.2	Preflood	14.0	ab	8310	abc	10.5	abc
18. Coragen	9.2	5-6 leaf	14.8	ab	7755	abc	9.5	abc
19. A9382; A9459; A12050		seed treatment	14.5	ab	6214	c	7.0	c
20. A17469		seed treatment	15.4	ab	6598	bc	8.0	bc
21. A17469; A17960	Lowest rate	seed treatment	14.3	ab	8207	abc	9.8	abc
22. A17469; A17960	Low rate	seed treatment	15.3	ab	7742	abc	9.9	abc
23. A17469; A17960	Medium rate	seed treatment	15.2	ab	8624	abc	11.0	abc
24. A17469; A17960	High rate	seed treatment	14.6	ab	7285	abc	9.5	abc
25. A9382; A9459; A12050;STP15201		seed treatment	14.8	ab	7721	abc	9.5	abc
26. A9382; A9459;		seed	14.9	ab	6400	bc	7.0	c

A12050;STP22245		treatment						

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, 2014.

Treatment	Product per A	Rate (lbs. AI/A)	Timing	Appl. Date
1. Coragen	6.1 fl. oz.	0.08	Preflood	21 May
2. Coragen	7.7 fl. oz.	0.10	Preflood	21 May
3. Coragen	9.2 fl. oz.	0.12	Preflood	21 May
4. Belay	6 fl. oz.	0.1	Preflood	21 May
5. Warrior II	2.56 fl. oz.	0.04	Preflood	21 May
6. Untreated	---	---	---	---

Table 6. RWW scarred seedlings and stand rating from Coragen large plot study, 2014.

Treatment	Product per A	Stand Rating (1 - 5)		% Scarred Plants 11 June		% Scarred Plants 23 June		Average % Scarred Plants [a]
1. Coragen	6.1 fl. oz.	3.0	a	0.5	a	0	b	0.25
2. Coragen	7.7 fl. oz.	2.75	b	0.5	a	6.0	a	3.25
3. Coragen	9.2 fl. oz.	3.0	a	0.5	a	0	b	0.25
4. Belay	6 fl. oz.	3.0	a	1.0	a	3.5	ab	2.25
5. Warrior II	2.56 fl. oz.	3.0	a	1.5	a	1.5	ab	1.5
6. Untreated	---	3.0	a	5.0	b	3.0	ab	4.0

[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, 2014.

Treatment	Product per A	RWW per Core – 30 June		RWW per Core – 14 July		Avg. RWW per Core [a]
1. Coragen	6.1 fl. oz.	0.1	b	0.4	a	0.25
2. Coragen	7.7 fl. oz.	0	b	0.3	a	0.15
3. Coragen	9.2 fl. oz.	0	b	0.2	a	0.1
4. Belay	6 fl. oz.	0	b	0.2	a	0.1
5. Warrior II	2.56 fl. oz.	0	b	0.1	a	0.05
6. Untreated	---	1.0	a	0.25	a	0.63

[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 8. Yield results from Coragen large plot study, 2014.

Treatment	**Product per A**	**% Grain Moisture**		**Grain Yield (lbs./A)**	
1. Coragen	6.1 fl. oz.	18.2	b	8127.1	a
2. Coragen	7.7 fl. oz.	26.9	a	5848.6	b
3. Coragen	9.2 fl. oz.	19.9	ab	8578.0	a
4. Belay	6 fl. oz.	17.2	b	8289.9	a
5. Warrior II	2.56 fl. oz.	21.0	ab	8380.0	a
6. Untreated	---	20.2	ab	7589.7	a

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

Table 9. Treatments evaluated in non-target study, 2011-14.

Product	**Rate (lbs. AI/A)**	**Timing**	**Rationale**	**2011**	**2012**	**2013**	**2014**
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. Belay 2.13 SC	0.092	Preflood	Registered	X		X	X
6. Belay 2.13 SC	0.092	3-leaf	Registered	X	X	X	X
7. Dermacor X-100 5FS	0.10	Preflood	Under development	X			
8. Coragen	0.12	Preflood	Under development; considered for registration		X	X	X
9. Declare	0.02	3-leaf	Registered		X		
10. Coragen	0.12	3-leaf	Under development; considered for registration			X	X
11. *Bacillus thuringiensis* spp. *galleriae*	8.0 lbs./A	Preflood	Under development; considered for registration				X

Table 10. Treatment list for nontarget study, 2014.

Treatment	**Product per A (fl. oz.)**	**Rate (lbs. AI/A)**	**Timing**	**Appl. Date**
1. Warrior II	2.56	0.04	3-leaf	24 June
2. Warrior II	2.56	0.04	PF	1 June
3. Warrior II	2.56	0.04	July armyworm timing	25 July
4. Coragen	9.2	0.12	PF	1 June
5. Belay 2.13 SC	5.5	0.09	PF	1 June
6. Coragen	9.2	0.12	3-leaf	24 June
7. Belay 2.13 SC	5.5	0.09	3-leaf	24 June
8. *Bacillus thuringiensis* spp. *galleriae*	8.0 lbs./A		PF	1 June
9. Untreated	---	---	---	---

Table 11. Treatment list for Tadpole Shrimp study, 2014.

Product	**Rate (lbs. AI/A)**	**Product per A (fl. oz.)**	**Timing**
1. Untreated without TPS	---	---	---
2. Belay 2.13 SC	0.074	4.5	Preflood
3. Coragen	0.1	2.46	Preflood
4. Belay 2.13 SC	0.074	4.5	early post-flood**
5. Coragen	0.1	2.46	early post-flood**
6. Dimilin 2L	0.125	8.0	early post-flood**
7. Untreated with TPS	---	---	---
8. Warrior II	0.04	2.56	early post-flood**
9. Warrior II	0.04	2.56	Preflood
10. Warrior II	0.04	2.56	PF and early post-flood**
11. A17469 + A17960			Seed treatment
12. Copper Sulfate		10 lbs./A	early post-flood**

** one day after TPS were introduced ~2 ls.

Table 12. Treatment evaluations for Tadpole Shrimp study, 2014.

Product	**Floating Seedlings**		**Alive TPS – small bin**		**Alive TPS – large ring**	
1. Untreated without TPS	1.0	bc	0	c	0	d
2. Belay 2.13 SC - PF	8.75	c	4.5	b	5.0	b
3. Coragen - PF	4.25	c	0	c	0	d
4. Belay 2.13 SC - early post-flood	11.75	abc	1.75	c	2.25	c
5. Coragen - early post-flood	10.5	bc	0	c	0	d
6. Dimilin 2L - early post-flood	20.25	ab	0	c	0	d
7. Untreated with TPS	23.25	a	8.25	a	8.75	a
8. Warrior II - early post-flood	6.75	c	0	c	0	d
9. Warrior II - PF	10.25	bc	0	c	0	d
10. Warrior II – PF and early post-flood	3.5	c	0	c	0	d
11. A17469 + A17960 seed trt.	2.0	c	0	c	0	d
12. Copper Sulfate - early post-flood	11.5	abc	1.25	c	1.75	cd

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

Table 13. Yield results for Tadpole Shrimp study, 2014.

Product	**% Grain Moisture**		**Grain Yield (lbs./A)**		**Biomass (Straw+Grain) (t/A)**	
1. Untreated without TPS	16.1	ab	6609.1	a	8.9	a
2. Belay 2.13 SC – PF	16.3	ab	6427.4	a	8.9	a
3. Coragen – PF	16.2	ab	6070.5	a	8.4	a
4. Belay 2.13 SC - early post-flood	16.8	a	6393.3	a	9.0	a
5. Coragen - early post-flood	16.1	ab	6077.8	a	8.7	a
6. Dimilin 2L - early post-flood	16.3	ab	5921.4	a	8.5	a
7. Untreated with TPS	15.7	b	5997.4	a	8.3	a
8. Warrior II - early post-flood	15.8	ab	6828.6	a	9.5	a
9. Warrior II – PF	16.5	ab	6683.7	a	9.7	a
10. Warrior II – PF and early post-flood	16.3	ab	6600.8	a	9.1	a
11. A17469 + A17960	16.6	ab	6500.1	a	9.6	a
12. Copper Sulfate - early post-flood	16.4	ab	6471.4	a	9.1	a

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

Table 14. California rice cultivars (and one experimental line) evaluated in small plot study designed to evaluate susceptibility to RWW, 2014.

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

Table 15. RWW adult feeding damage and larval populations in small plot variety susceptibility comparison to RWW study, 2014.

Variety	RWW Status	% Scarred Plants - 11 June		% Scarred Plants - 23 June		RWW per Core Sample – 1 July		RWW per Core Sample – 15 July		Average
M-105	Controlled	1.5	bc	0.5	ab	0	b	0.2	ab	0.1
Calhikari-202	Controlled	2.0	bc	2.0	ab	0	b	0.05	b	0.03
PI experimental line	Controlled	0.5	c	1.0	ab	0	b	0.05	b	0.03
Calmochi-101	Controlled	3.0	bc	2.5	ab	0	b	0	b	0
L-206	Controlled	1.5	bc	1.0	ab	0.05	ab	0.25	ab	0.15
M-104	Controlled	1.5	bc	1.5	ab	0.05	ab	0.4	a	0.2
M-202	Controlled	2.0	bc	0.5	ab	0	b	0.25	ab	0.13
M-205	Controlled	5.0	abc	1.0	ab	0	b	0	b	0
M-206	Controlled	1.5	bc	0	b	0.05	ab	0	b	0.025
M-208	Controlled	1.5	bc	2.0	ab	0	b	0	b	0
M-401	Controlled	3.0	bc	0.5	ab	0	b	0.1	ab	0.05
S-102	Controlled	4.5	abc	3.5	ab	0.05	ab	0	b	0.03
M-105	Present	5.0	abc	3.0	ab	0	b	0.05	b	0.03
Calhikari-202	Present	4.5	abc	2.5	ab	0	b	0	b	0
PI experimental line	Present	6.0	ab	0	b	0	b	0.05	b	0.03
Calmochi-101	Present	5.5	abc	2.0	ab	0.15	a	0.05	b	0.1
L-206	Present	2.0	bc	4.5	a	0	b	0.25	ab	0.13
M-104	Present	8.5	a	1.0	ab	0	b	0.4	a	0.2
M-202	Present	2.0	bc	1.5	ab	0	b	0.15	Ab	0.08
M-205	Present	6.5	a	2.0	ab	0	b	0.1	Ab	0.05
M-206	Present	5.0	abc	2.0	ab	0.05	ab	0	B	0.03
M-208	Present	9.5	a	0.5	ab	0	b	0	B	0
M-401	Present	6.0	ab	2.0	ab	0.05	ab	0	B	0.03

S-102	Present	1.5	abc	0	ab	0	b	0	B	0

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

Table 16. Yield data in small plot variety susceptibility comparison to RWW study, 2014.

Variety	RWW Status	% Moisture		Grain Yield (lbs./A)		Grain Yield Loss from RWW (lbs./A)
M-105	Controlled	18.0	c-h	8297.0	a-d	376
Calhikari-202	Controlled	20.2	bc	7785.9	d	32.6
PI experimental line	Controlled	15.8	h	9135.1	a-d	85.2
Calmochi-101	Controlled	18.6	c-g	8822.6	a-d	0
L-206	Controlled	16.5	gh	7959.6	cd	106.4
M-104	Controlled	17.5	e-h	8955.9	a-d	1051.7
M-202	Controlled	18.6	c-h	9384.3	abc	0
M-205	Controlled	18.9	b-f	9362.6	abc	1168.3
M-206	Controlled	19.3	b-e	8769.4	a-d	0
M-208	Controlled	18.0	c-h	8443.2	a-d	0
M-401	Controlled	23.7	a	9773.3	a	12.1
S-102	Controlled	16.8	gh	8889.8	a-d	269.1
M-105	Present	18.65	b-g	7921.0	cd	
Calhikari-202	Present	24.6	a	7753.3	d	
PI experimental line	Present	16.6	fgh	8595.4	a-d	
Calmochi-101	Present	17.4	d-h	9049.9	a-d	
L-206	Present	16.3	gh	7853.2	d	
M-104	Present	20.8	b	7904.2	cd	
M-202	Present	18.6	b-g	9483.6	ab	
M-205	Present	18.6	b-g	8194.1	bcd	
M-206	Present	19.6	b-d	9006.0	a-d	
M-208	Present	17.4	d-h	9095.3	a-d	
M-401	Present	23.4	a	9661.2	ab	
S-102	Present	17.2	e-h	8620.7	a-d	

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

Table 17. Incidence of stink bugs in grower rice fields in the Sacramento Valley, 2014.

County	Fields	Fields with	Stink Bug Species	Nymphs present

	Sampled	**Stink Bugs**	**Found**	
Butte	9	4	Redshouldered, consperse, southern green	Redshouldered
Colusa	10	4	Redshouldered, consperse, Say's stink bug	Consperse
Glenn	10	1	Redshouldered	Redshouldered
Sutter	10	3	Redshouldered, consperse, southern green, Conchuela, Say's stink bug	Redshouldered, consperse,
Yolo	5	3	Redshouldered, consperse, Say's stink bug	Redshouldered, consperse
Yuba	5	0	---	---

Table 18. Development of brown marmorated stink bug on rice plants in a greenhouse study, 2014.

	Days 1st Instars Present	**Days 2nd Instars Present**	**Days 3rd Instars Present**	**Days 4th Instars Present**
BMSB development	1 to 10	3 to 11	11 to 34	18 to 34

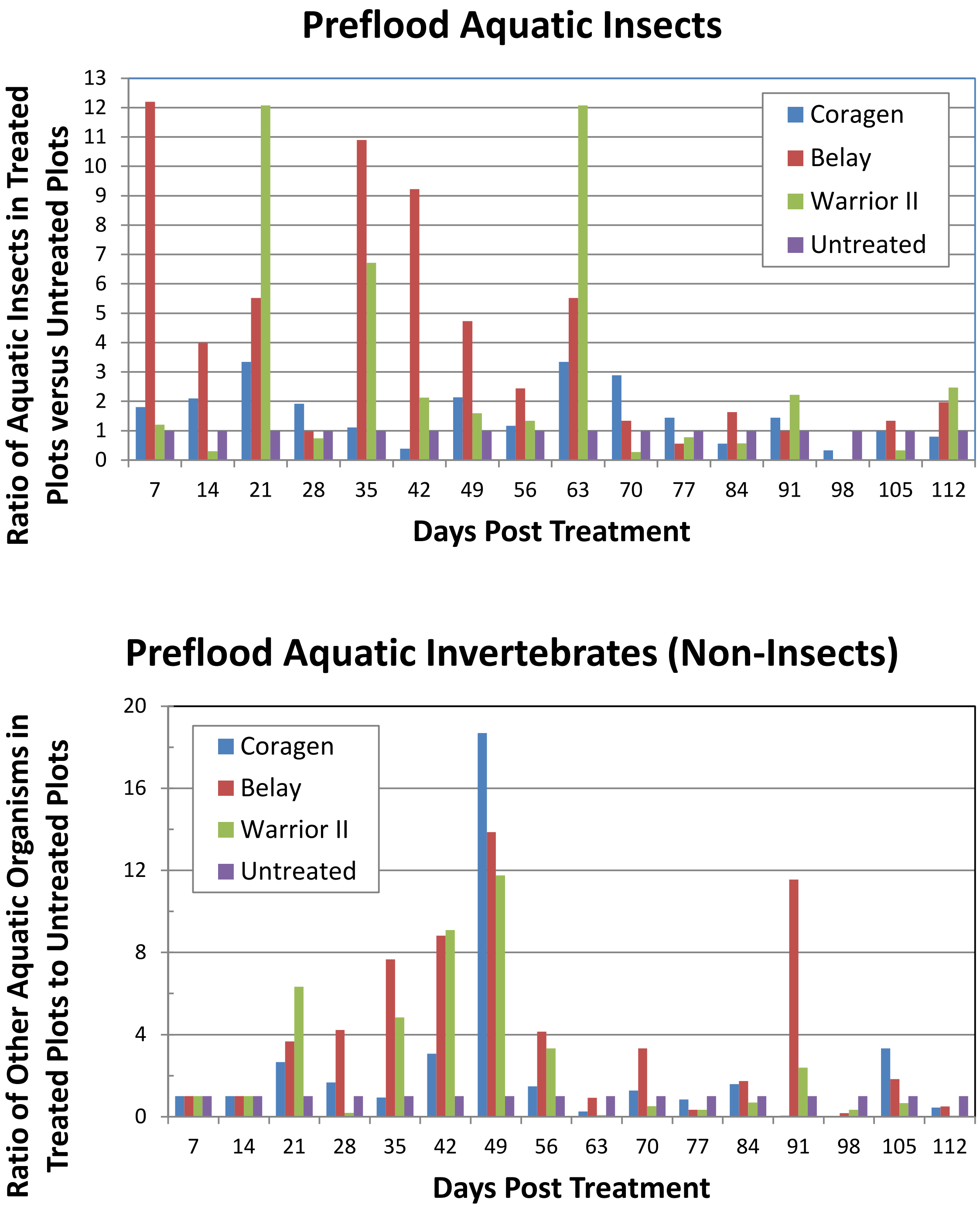

Figure 1. Impact of preflood insecticide treatments on populations of a.) aquatic insects and b.) other aquatic invertebrates in 2013.

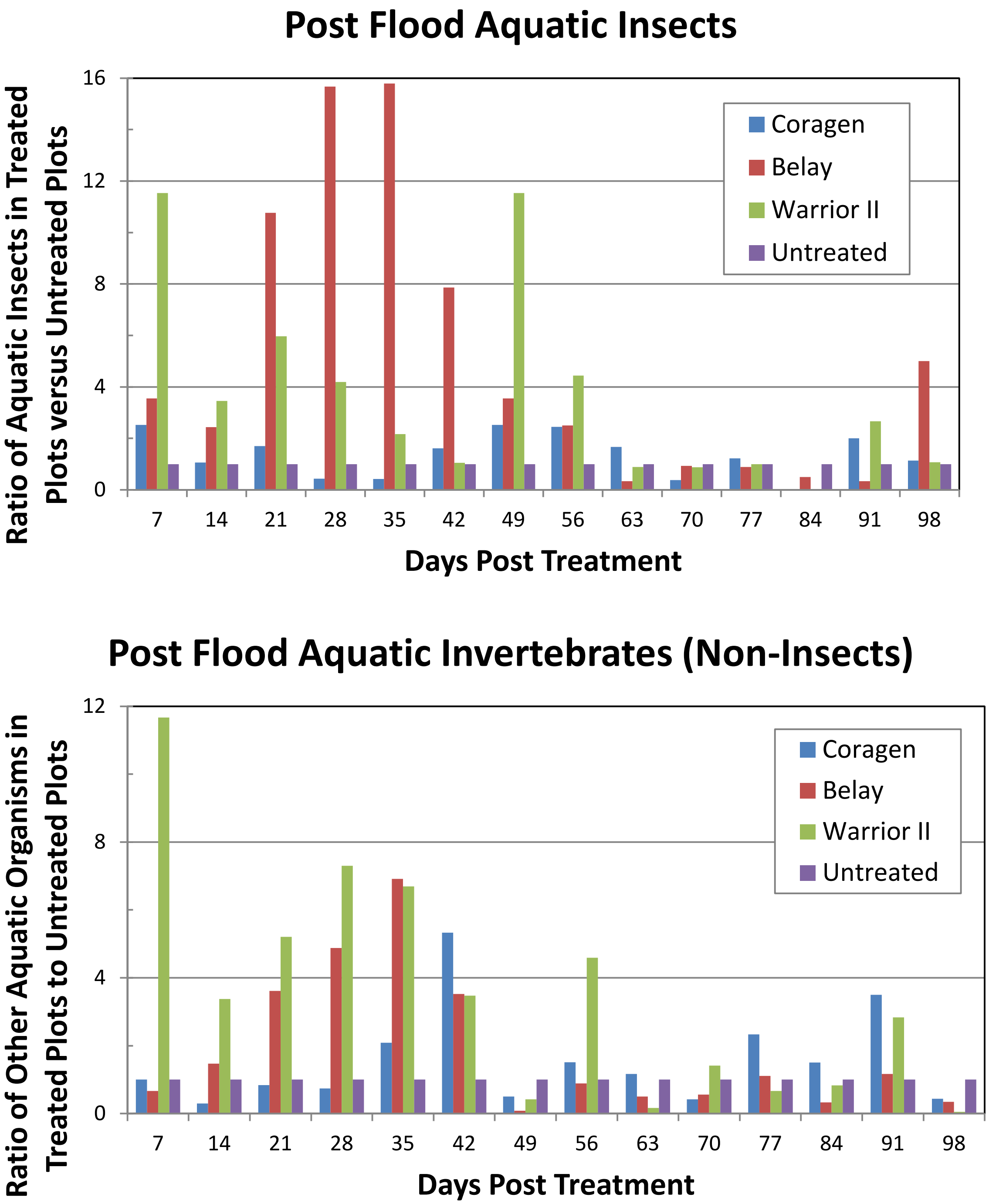

Figure 2. Impact of post-flood (3-leaf stage) insecticide treatments on populations of a.) aquatic insects and b.) other aquatic invertebrates in 2013.

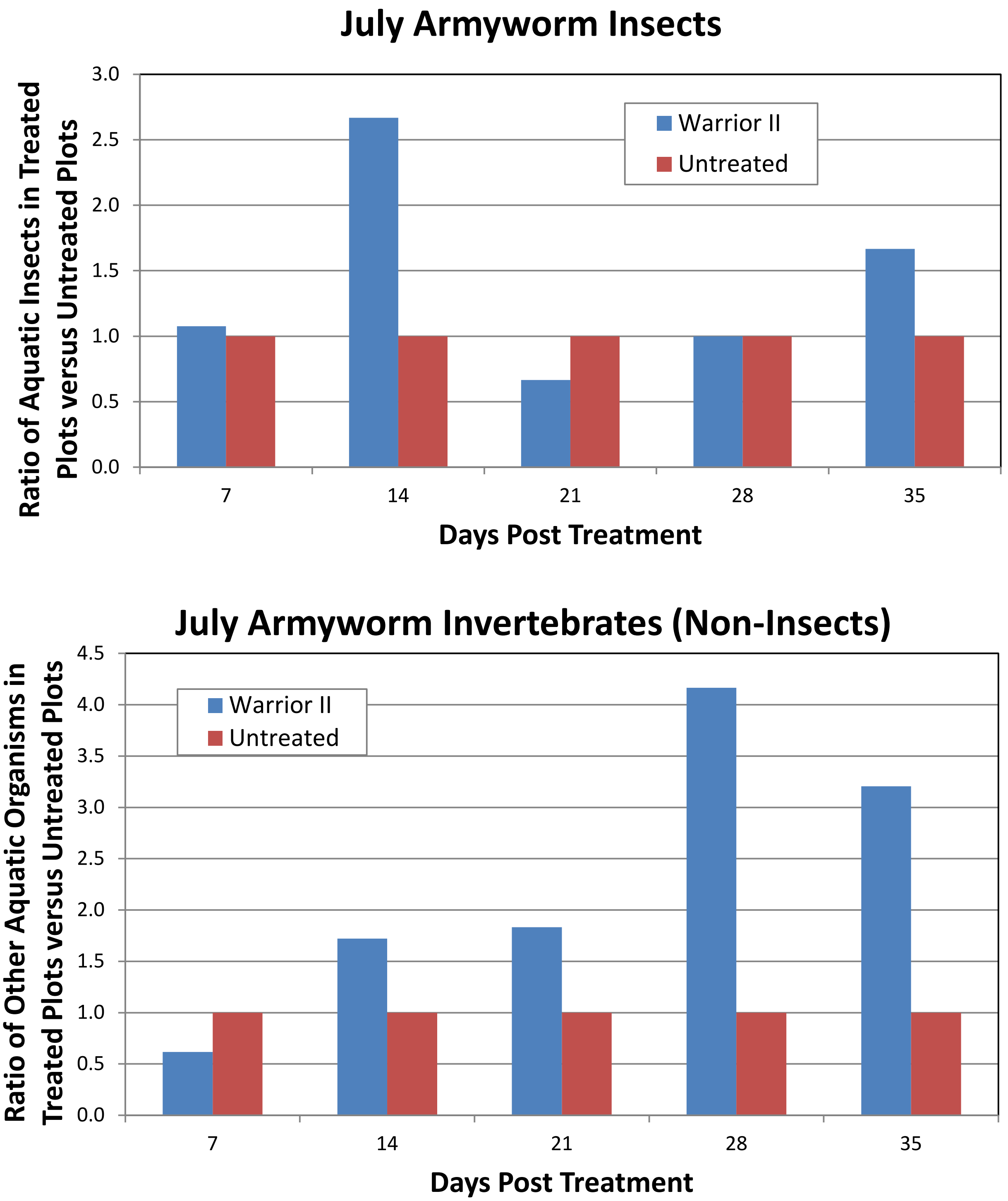

Figure 3. Impact of July insecticide treatment on populations of a.) aquatic insects and b.) other aquatic invertebrates in 2013.

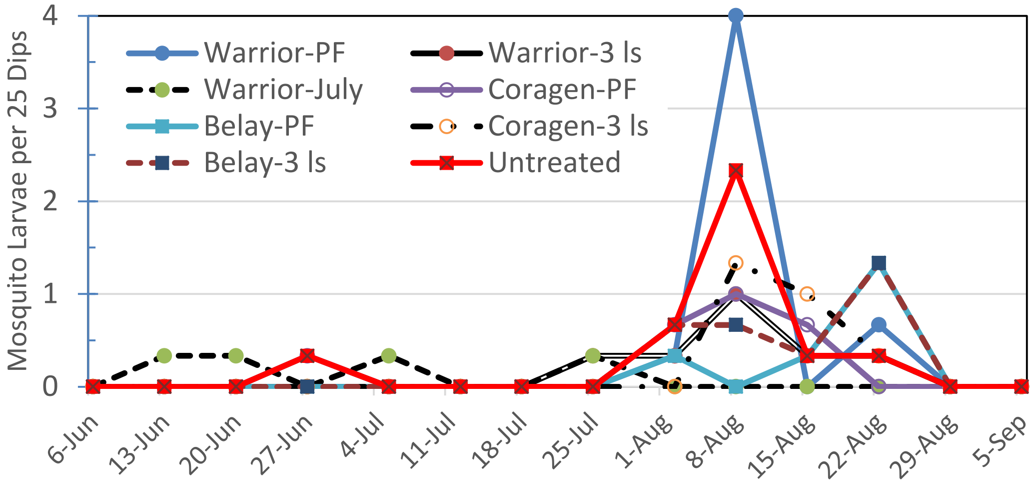

Figure 4. Larval mosquito populations following indicated insecticide treatment in 2013.

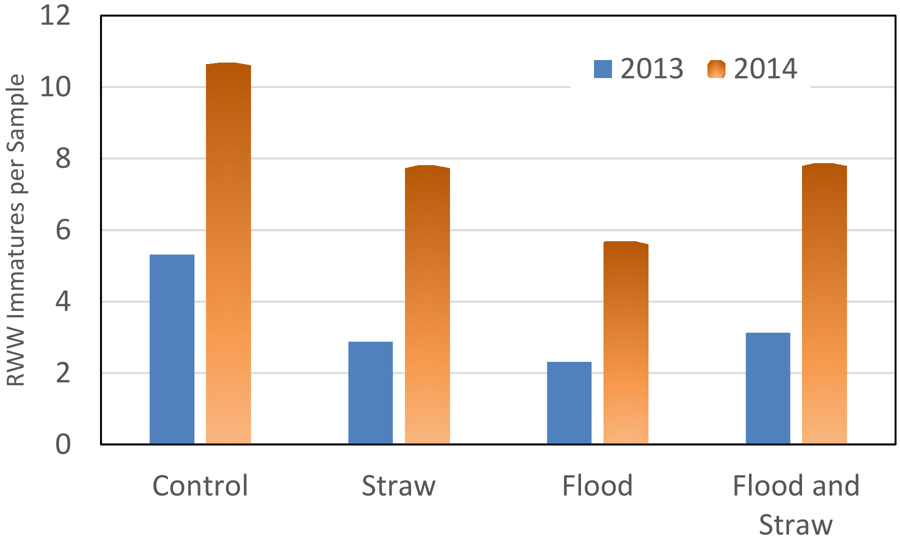

Figure 5. Rice water weevil larval populations following indicated winter condition.

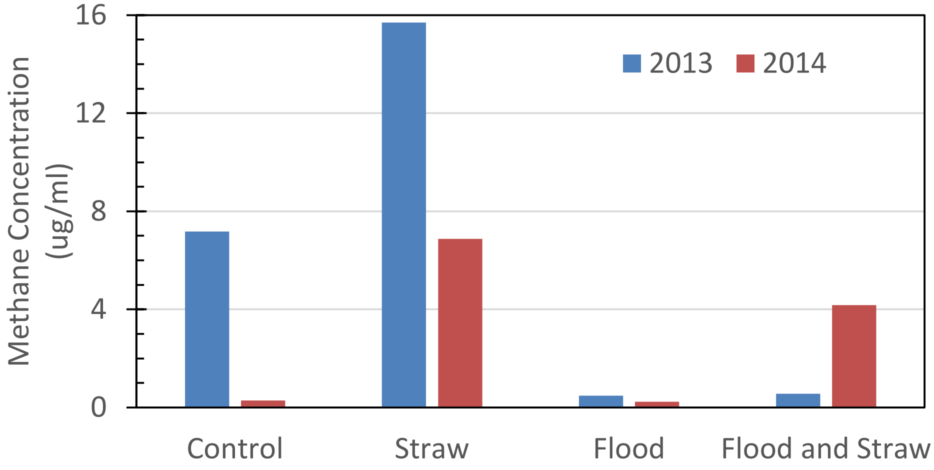

Figure 6. Methane concentration following indicated winter condition.

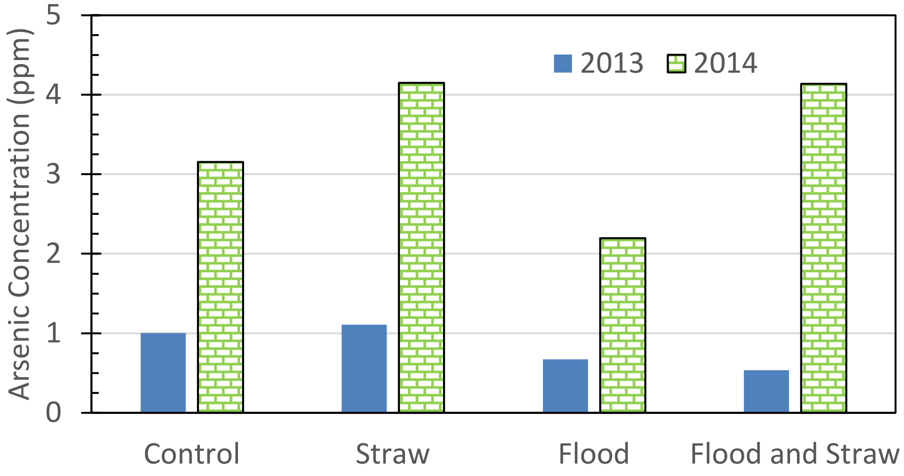

Figure 7. Arsenic concentration following indicated winter condition.

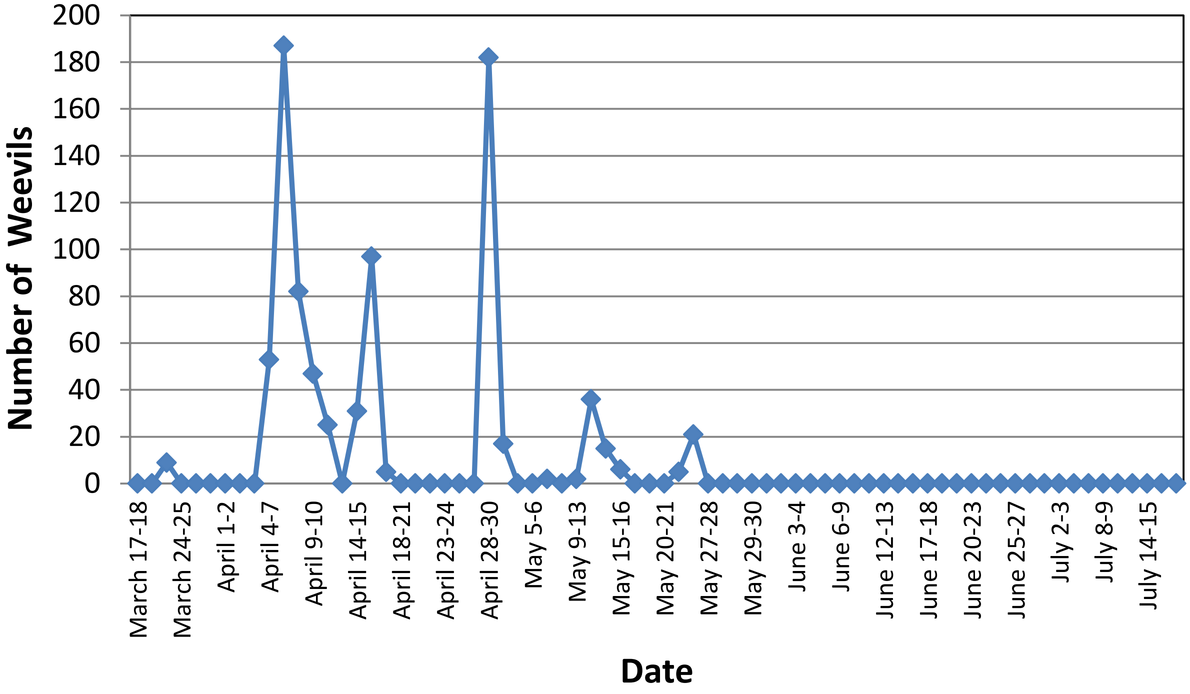

Figure 8. Rice water weevil adult captures in light trap sampling, 2014.

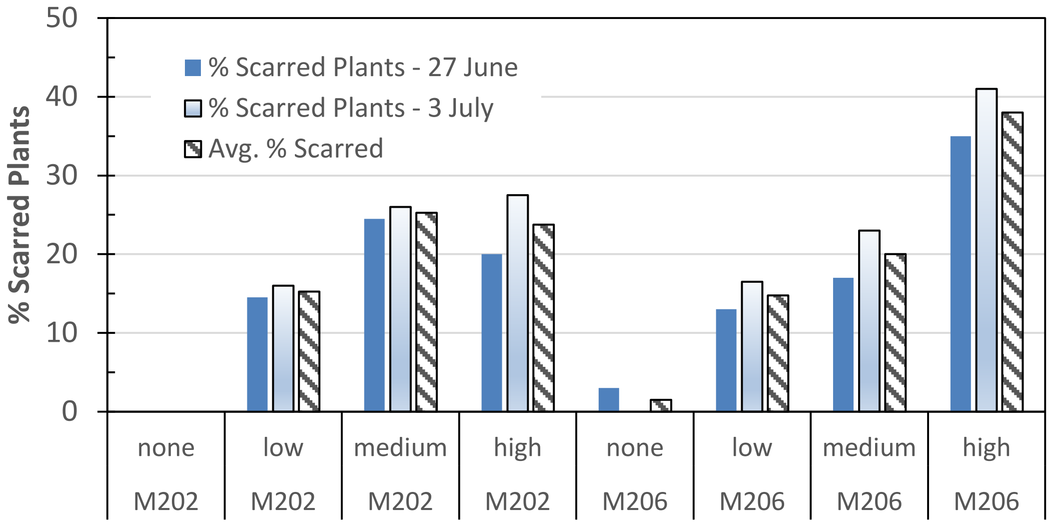

Figure 9. RWW scarred plants (%) as influenced by rice variety and RWW infestation level, 2014.

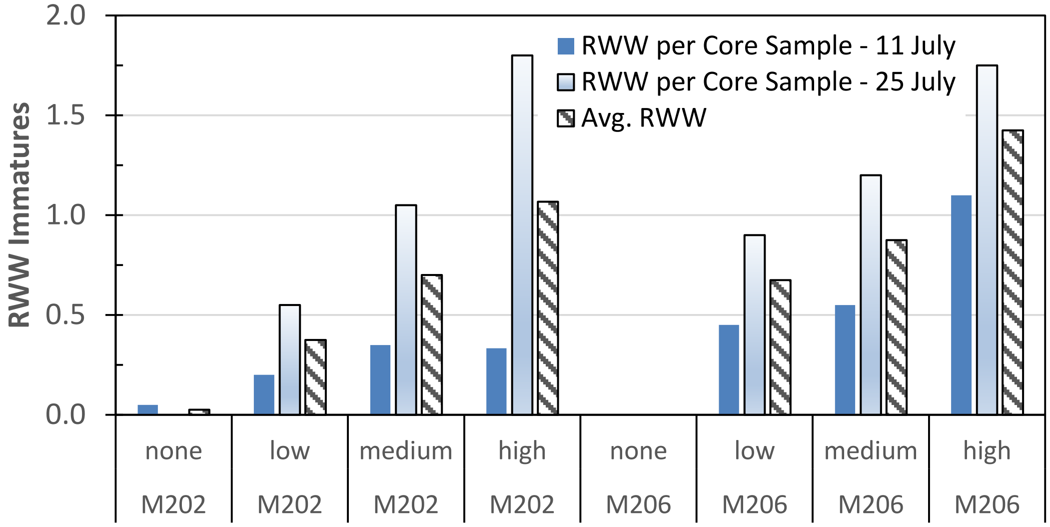

Figure 10. RWW larval populations as influenced by rice variety and RWW adult infestation level, 2014.

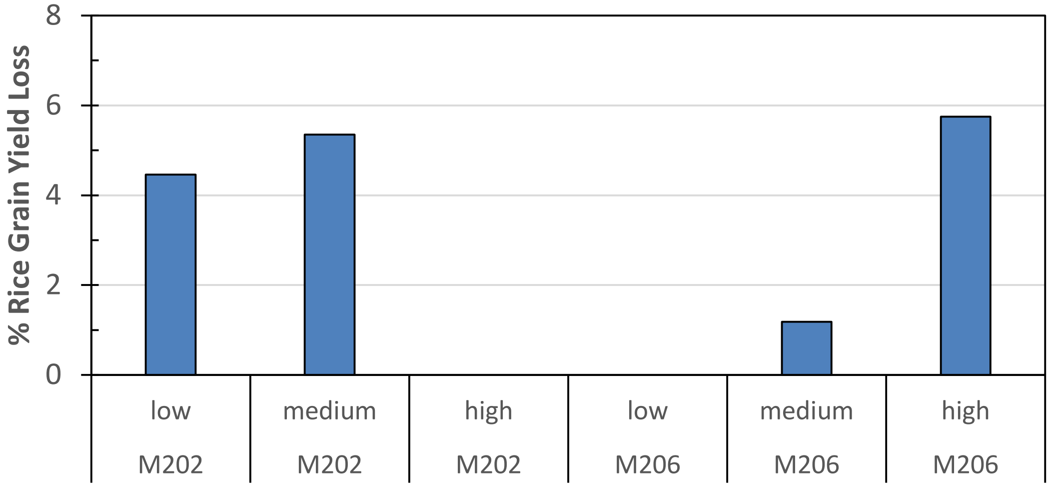

Figure 11. Grain yield loss (%) as influenced by rice variety and RWW infestation level, 2014.

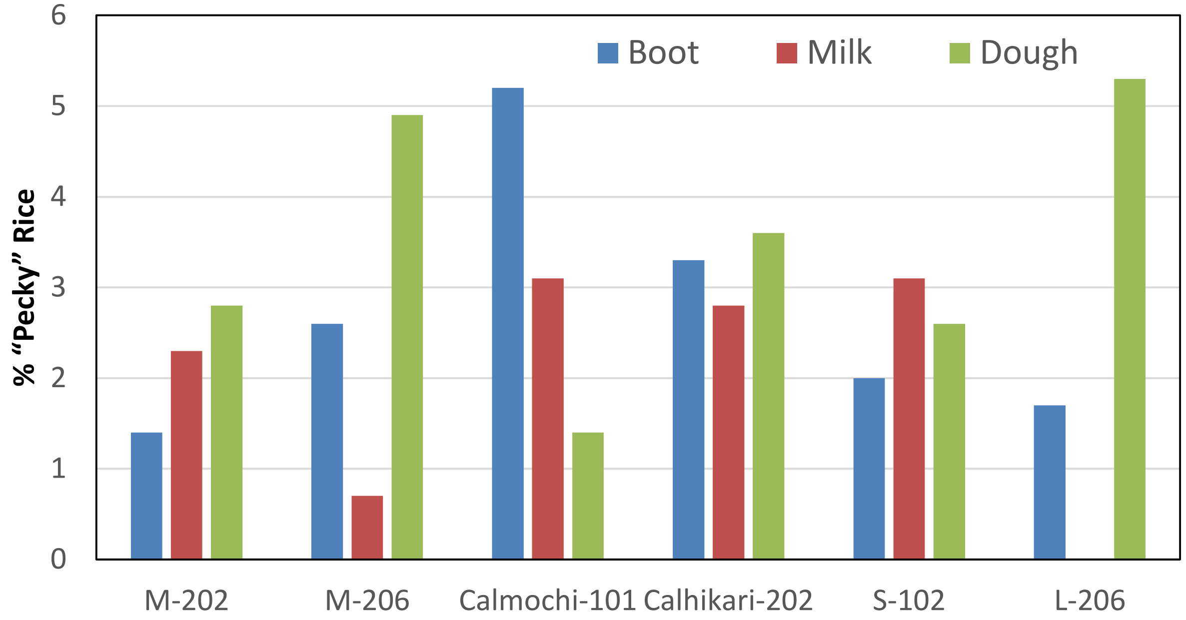

Figure 12. Incidence of pecky rice (%) from redshouldered stink bugs caged on panicles of six rice varieties at three panicle develop stages, 2014.

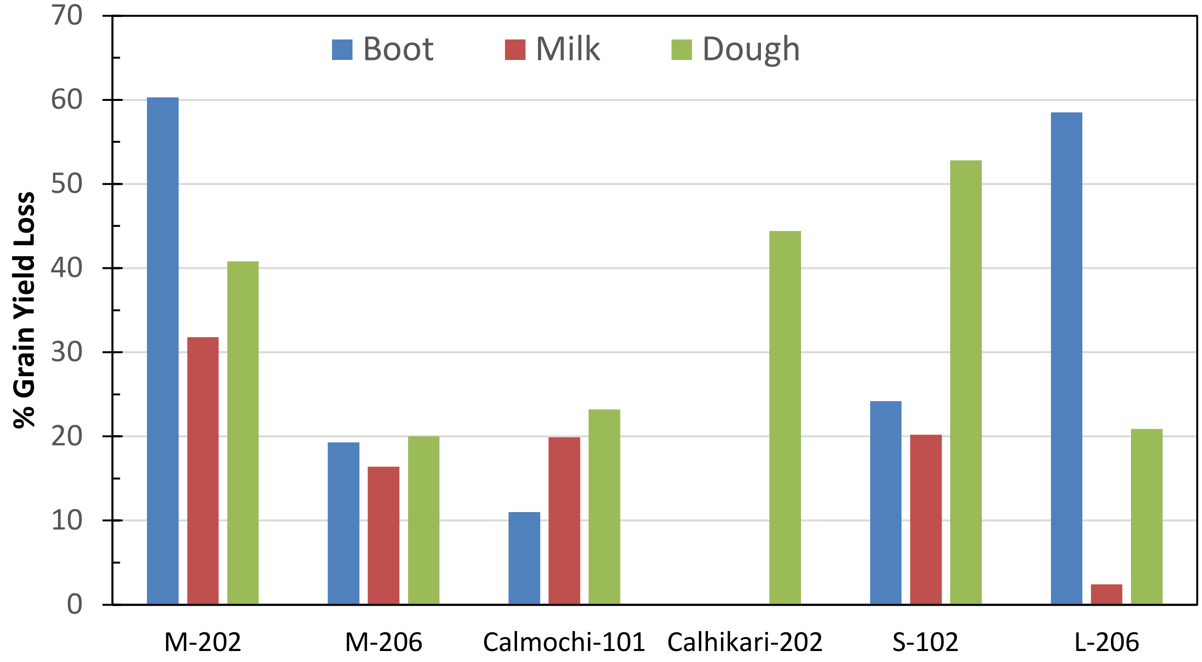

Figure 13. Grain yield loss (%) from redshouldered stink bugs caged on panicles of six rice varieties at three panicle develop stages, 2014.