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Evaluation of Flood Removal in Combination with Insecticide Seed Treatment for Rice Water Weevil (Coleoptera: Curculionidae) Larval Management in Rice

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Abstract

An experiment was conducted at the Delta Research and Extension Center in Stoneville, MS during 2017 and 2018 to determine whether removal of the flood is an economical method of control for rice water weevil, *Lissorhoptrus oryzophilus* Kuschel. This experiment compared a continuous flood production system to draining a rice field completely and reestablishing a flood for the remainder of the growing season. In addition, two insecticide seed treatments, thiamethoxam and chlorantraniliprole, were compared with an untreated control within each system. Rice water weevil densities were measured prior to draining at 3 wk after flood and again after the flood was reestablished in drained plots. Rice water weevil densities were greater in 2017 than 2018. Chlorantraniliprole at the predrainage and postdrainage sample timing reduced larval numbers compared with the untreated control. The plots where water was removed until soil cracking then re-flooded had significantly lower weevil populations than plots that were continuously flooded during 2018 only. Draining of plots resulted in lower yields in 2018, but not in 2017. Additionally, both of the insecticide seed treatments resulted in greater yields and economic returns than the untreated control. Draining of flooded rice when rice water weevil larvae were present did not provide a consistent benefit, and may result in yield and economic penalties. Insecticide seed treatments consistently provided greater yield benefits in flooded rice. Based on these results, draining of flooded rice is not recommended to manage rice water weevil and insecticide seed treatments should be used to minimize economic losses.

Key words: cultural control, rice, rice water weevil

The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, is the most severe insect pest of rice in North America (Rice et al. 1999). Rice water weevil is native to North America, but accidental introductions into Asia, make it a global threat to rice production (Pathak and Khan 1994, Saito et al. 2005). The adult stage of rice water weevil inflicts minor injury by creating longitudinal scars along the leaf blade from the consumption of leaf material (Stout et al. 2002a, Aghaee et al. 2016). Adult rice water weevils oviposit into submerged portions of the rice plant (Grigarick and Beards 1965, Stout et al. 2002b). After eclosion, the larval stage of rice water weevil migrates to the roots causing significant injury to the root system of cultivated rice (Smith et al. 1986, Way 1990). Pruning damage on the roots results in reduced tillering and plant height, delayed maturity, and reduced grain yield (Bowling 1967, Gifford et al. 1975).

The primary method of control for rice water weevil in the southern U.S. is insecticide seed treatments (Adams et al. 2015). The four insecticidal seed treatments currently labeled for management of rice water weevil provide varying degrees of efficacy. Thiamethoxam (Cruiser, Syngenta Crop Protection, Greensboro, NC) and clothianidin (Nipsit, Valent U.S.A., Walnut Creek, CA) are neonicotinoids that are more commonly used in the upper Midsouth states of Arkansas, Mississippi, and Missouri because of cost and spectrum of activity against other pests common in those states (Bateman et al. 2020). In contrast, chlorantraniliprole (Dermacor, Corteva AgriScience, Wilmington, DE) and cyantraniliprole (Fortenza, Syngenta Crop Protection, Greensboro, NC) (Catchot et al. 2018) are diamides that are more commonly used in the lower Midsouth states of Louisiana and Texas because they also

provide control of stalk boring Lepidoptera (Bateman et al. 2020). The diamide insecticides tend to be less water soluble than the neonicotinoid insecticides, so the diamides generally provide greater reductions of rice water weevil densities than the neonicotinoids. Because oviposition by rice water weevil does not occur until a flood is established, insecticide seed treatments need to provide efficacy for 4 or more weeks after planting. The performance of insecticide seed treatments is further challenged when rice needs to be irrigated (flushed) one or two times before a flood is established or when the establishment of the flood is delayed (Adams et al. 2015). Control of rice water weevil with currently labeled insecticide seed treatments has never been absolute and significant infestations of larvae can occur following the use of one of these insecticides, especially when populations are high (Hummel et al. 2014, Lanka et al. 2014, Adams et al. 2016). Additionally, effective rescue treatments are not available once larvae become established on roots in a flooded rice field.

The temporary draining of rice fields can negatively affect all life stages of rice water weevil (Hesler et al. 1992). Temporary drainage of rice fields is a suggested management practice that can reduce larval damage from significant infestations of rice water weevil (Isely and Schwardt 1934, Morgan et al. 1989, Hesler et al. 1992, Quisenberry et al. 1992). Mortality of larvae feeding on roots appears to be an important factor in reducing rice water weevil populations in drained rice fields, but oviposition may also be reduced (Tucker 1912, Webb 1914, Isely and Schwardt 1934, Hesler et al. 1992). Those studies also suggested that draining of rice fields may not be an economical method to control rice water weevil because fertilizer may be lost, weed control may be hindered, larvae may still complete development, rainfall may prevent complete drying, costs associated with pumping water may be prohibitive, and water stress may reduce yield which may outweigh the benefits. In areas such as the upper Midsouth where neonicotinoid seed treatments are primarily used, research is needed to determine whether it is economical to remove the flood then re-flood the field under current production practices.

Materials and Methods

During the 2017 and 2018 cropping seasons, an experiment was conducted at the Delta Research and Extension Center (DREC) in Stoneville, MS to determine whether draining a flooded rice production system until soil cracking would be economical for effective control of rice water weevil. The rice cultivar 'Rex' was used both years. The experiment was planted on 10 May 2017 and 3 May 2018, and the flood was established on 12 June 2017 and 27 May 2018. Plots measured 1.7-m wide by 4.6-m long. Plots were planted with a cone drop plot planter with eight, 20-cm spaced drills. The seeding rate for both years was 78 kg seed/ha. Standard agronomic practices recommended by the Mississippi State University Extension Service were followed for plot maintenance, weed, and disease control (Buchring 2008).

The experiment was designed as a randomized complete block with a split-plot arrangement of treatments and six replications. The main-plot factor was water management at two levels, delayed continuous flood culture and removal of the flood (drained). Each main-plot was three subplots wide (5.1-m) by 4.6-m long, and a earthen levee was constructed around each main-plot to facilitate flood management. Drained plots were drained after the first sample timing at 3 wk after flood establishment. The plots where the flood was removed were re-flooded after soil cracking occurred. Soil cracking

was determined to be when cracks greater than 1.3-cm were apparent on the soil surface and this occurred 8 and 9 d after draining was initiated in 2017 and 2018, respectively.

The subplot factor was insecticide seed treatment and included thiamethoxam (Cruiser 5FS, Syngenta Crop Protection, Greensborough, NC) at a rate of 236 ml/ 100 kg of seed, chlorantraniliprole (Dermacor X-100, E.I. DuPont de Nemours) at a rate of 164 ml/100 kg of seed and an untreated control. A base fungicide that included fludioxonil, azoxystrobin, and mefenoxam was also applied to all seed at a rate of 1261 ml/100 kg of seed. All seed were treated in a laboratory-scale rotary seed treater before planting.

Data Collection and Analysis

Plant populations were assessed at 14 d after planting from the center two rows of each plot by counting all plants within 1 m of row for a total 2 m of row per plot and converting to plants per ha. The number of rice water weevil larvae were quantified by collecting three core samples from each plot at the third and fifth weeks after flooding. A core sample included removing and discarding the uppermost vegetative growth from a plant that was randomly located in an inner drill pass within each plot. A cylindrical core sampling device (10.0-cm diam) was then placed over the plant, pressed down into the soil where it removed the bottom vegetative portion of the plant, the plant's root system, and surrounding soil to a depth of 15.2-cm.

During the third week after flooding, all plots were sampled from both water management main-plot factors on the same day. After the first sample (3 wk after initial flooding), water was removed from the main-plot factor for drained plots until the soil was cracking and then the flood was reestablished. Once the flood was reestablished on drained plots (5 wk after initial flooding), core samples were collected from all plots to determine larval control. Each sample was placed individually into a 3.8 liter plastic bag (Ziploc, S. C. Johnson & Sons, Inc., Racine, WI) and transported to the laboratory. Once at the laboratory, samples were placed on top of a 0.64 cm mesh hardware cloth screen welded inside of a sheet metal funnel and washed with water to separate larvae from the soil and plant root mass through the funnel. A 40-mesh screen basket was placed below the sheet metal funnel to collect the larvae. The basket was then placed in a 10 % NaCl solution to float the larvae. The basket was swirled in the salt water solution five times to ensure that all larvae within each sample floated to the surface and were visible. The number of rice water weevil larvae were recorded on a per core basis for each plot.

Once plants reached physiological maturity and grain had decreased to at least 18% moisture, plots were harvested with a plot combine that recorded weights and moisture of rice. Yields were standardized to 12% moisture and converted to kg ha⁻¹ in order to obtain rough rice yields. All budgets and costs were derived from the Mississippi State University Extension Service 2017 Rice Planning Budgets (Falconer et al. 2016). Economic returns were calculated by taking the total cost of production, adding the cost of the seed treatments and irrigation costs, and subtracting that amount from the dollar amount received for rough rice yields (Falconer et al. 2016). Variability in irrigation costs between continuously flooded and drained plots was calculated by the price to re-flood drained plots and price to maintain a flood in flooded plots. For the re-flood, it was estimated that 10 ha-cm of water were required to bring the drained plots back to recommended flood depth for a total cost of \$38.76 per ha. A price of \$9.44

per ha-cm was used as a fixed cost of re-flooding plots that were drained on top of the cost of initial flood which was \$12.38 per ha-cm. The seed treatment costs were factored into total costs to calculate returns. The price for the chlorantraniliprole seed treatment was \$46.93 per ha and the price for thiamethoxam was \$19.76 per ha. The price received that was used was \$55 per cwt of seed based on the average prices of rough rice from 2017 (NASS 2018).

All data were analyzed with a general linear mixed model analysis of variance (PROC GLIMMIX, DIST = Gaussian, LINK = Identity, SAS version 9.4, Raleigh, NC). Based on the model fit and data distribution criteria, a Gaussian distribution was used for all data analyses. All rice water weevil count data were log-transformed ($\log_{10}$) to normalize their distribution prior to analysis. Means and standard errors were calculated using the PROC MEANS statement. Means were separated according to Tukey's HSD test ($\alpha=0.05$; Tukey 1953). The SLICE (SLICEBY = Year) procedure was used for all three-way interactions. Nominator degrees of freedom were calculated with the Kenward-Roger method (Kenward and Roger 1997). Fixed effects included year, water management, insecticide seed treatment, sample timing (rice water weevil densities only), and the interactions. The random effects for this experiment were replication, replication nested within water management, and replication by water management nested within sample timing.

Results

Year, water management, and insecticide seed treatments impacted rice water weevil numbers, rice yields, and economic returns, but not plant population. No differences were observed in plant density among water management strategies ($F = 1.96$; $df = 1, 66$; $P = 0.17$), insecticide seed treatments ($F = 1.92$; $df = 2, 66$; $P = 0.15$), or for the interaction between these factors ($F = 0.25$; $df = 2, 66$; $P = 0.78$). An interaction between years, sample timings, and water management strategies was observed for rice water weevil larval densities (Table 1). Overall, rice water weevil larval densities were greater in 2017 than 2018 (Fig. 1). During 2017, there were no differences in rice water weevil larval densities among water management strategies and sample timings based on the SLICE procedure ($F = 1.33$; $df = 3, 30$; $P = 0.28$). In contrast, differences in rice water weevil numbers were observed in 2018 ($F = 13.60$; $df = 3, 30$; $P < 0.01$). Fewer rice water weevil larvae were observed at week five (postdrainage)

compared with week three (predrainage) sample timing in plots where the flood was removed in 2018 (Fig. 1).

An interaction between year, sample timing, and insecticide seed treatment was also observed for rice water weevil larval densities (Table 1). Chlorantraniliprole reduced numbers of rice water weevil larvae below the untreated control in 2017 and 2018 (Fig. 2). Thiamethoxam reduced rice water weevil numbers below the untreated control during week three (predrainage) only in 2018. Additionally, rice water weevil numbers for the untreated control in 2018 were lower in week five (postdrainage) compared with week three (predrainage). No differences in rice water weevil numbers were observed between week three (predrainage) and week five (postdrainage) for any other treatment or year.

A significant interaction between year and water management strategy was observed for rough rice yield and economic returns (Table 2). This interaction was due to the fact that in 2018, flooded plots produced greater rough rice yields and economic returns than the drained plots, but in 2017 no differences were observed between flooded and drained plots (Table 3). Insecticide seed treatment also impacted rough rice yields and economic returns (Table 2). Both of the insecticide seed treatments resulted in greater rough rice yields (1656 to 1953 kg/ha) and economic returns (\$361.18 to \$453.12/ha) than the untreated control (Table 4).

Discussion

Insecticide seed treatments rarely provide complete control of rice water weevil (Hummel et al. 2014, Lanka et al. 2014, Adams et al. 2016), and pest managers sometimes observe significant infestations of larvae once the flood is established. Draining of flooded fields has been a long standing recommendation to manage rice water weevil infestations in flooded rice (Isley and Schwardt 1934) and has been researched as recently as the early 1990s (Hesler et al. 1992, Rice et al. 1999). Typically, producers maintain fields under flooded conditions to stabilize nitrogen fertilizer and suppress various pests (weeds, diseases, and some insects), but rarely remove the flood until grain maturity. Previous research showed that removing the flood can reduce oviposition (Hesler et al. 1992) and inhibit larval development (Rice et al. 1999) if properly timed. In the current experiment, there was little benefit from the draining of flooded fields, especially when an insecticide seed treatment was used at planting. Draining of flooded rice reduced populations of rice water weevil

Table 1. Results from the analysis of variance for rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, numbers in rice, *Oryza sativa* L., for an experiment conducted in Stoneville, MS from 2017 to 2018

Effect	F	df	P
Year	109.28	1, 10	<0.01
Sample	2.54	1, 30	0.12
Water management	1.94	1, 30	0.17
Insecticide	32.28	2, 80	<0.01
Year*Sample	7.95	1, 30	0.01
Year*Water Management	14.85	1, 30	<0.01
Year*Insecticide	2.15	2, 80	0.12
Sample*Water Management	6.77	1, 30	0.01
Sample*Insecticide	5.26	2, 80	<0.01
Water Management*Insecticide	1.81	2, 80	0.17
Year*Sample*Water Management	10.74	1, 30	<0.01
Year*Sample*Insecticide Treatment	3.17	2, 80	0.05
Year*Water Management*Insecticide	1.34	2, 80	0.27
Sample*Water Management*Insecticide	0.25	2, 80	0.78
Year*Sample*Water Management*Insecticide	0.24	2, 80	0.79

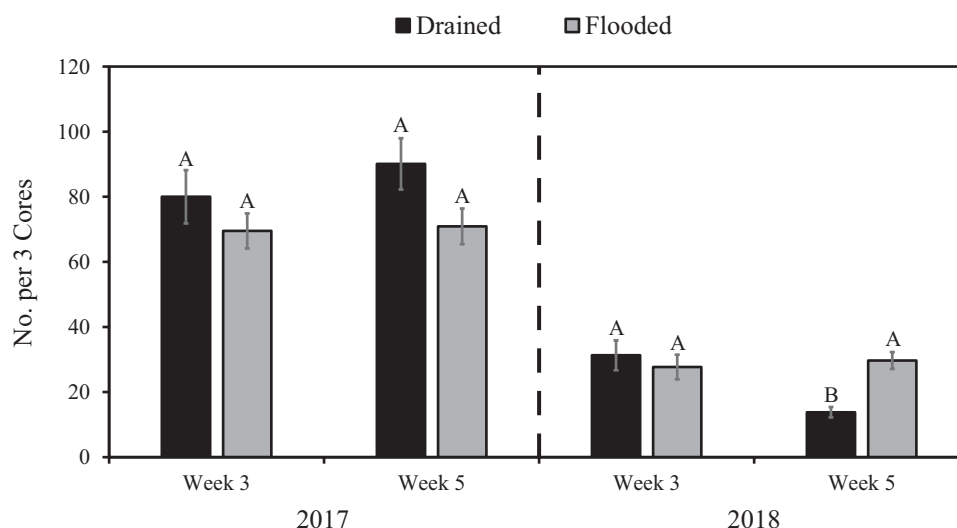


Fig. 1. Effect of the interaction between year (2017 vs 2018), water management (drained vs flooded), and sample timing (predrain vs postdrain) on rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, larval numbers in rice, *Oryza sativa* L., from Stoneville, MS. Means within a year with a common letter are not different according to Tukey's HSD and based on the SLICE procedure ($\alpha = 0.05$).

Table 2. Results from the analysis of variance for rough rice, *Oryza sativa* L., yields and economic returns for an experiment investigating water management and insecticide seed treatment effects on rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, conducted in Stoneville, MS from 2017 to 2018

Effect	df	F, P	
		Rough rice yield	Economic return
Year	1, 21.4	0.08, 0.79	0.08, 0.79
Water Management	1, 21.4	9.00, <0.01	0.94, 0.34
Insecticide	2, 99.6	52.18, <0.01	45.39, <0.01
Year*Water Management	1, 21.4	7.40, 0.01	7.4, 0.01
Year*Insecticide	2, 99.6	1.69, 0.19	1.69, 0.19
Water Management*Insecticide	2, 99.6	0.01, 0.99	0.01, 0.99
Year*Water Management*Insecticide	2, 99.6	0.09, 0.92	0.09, 0.92

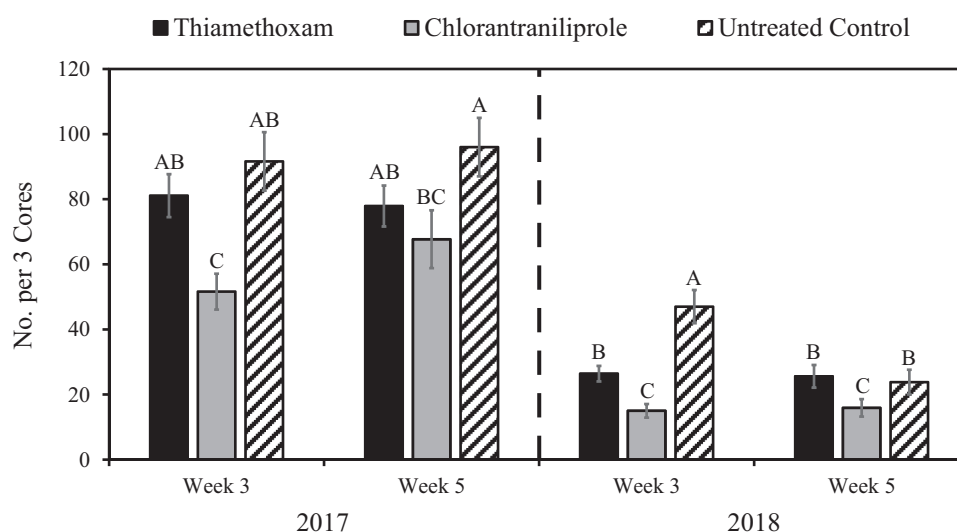


Fig. 2. Effect of the interaction between year (2017 vs 2018), sample (predrain vs. postdrain), and insecticide seed treatment (chlorantraniliprole, thiamethoxam, and untreated control) on mean (SEM) rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, larval numbers in rice, *Oryza sativa* L., from Stoneville, MS. Means within a year with a common letter are not different according to Tukey's HSD and based on the SLICE procedure ($\alpha = 0.05$).

Table 3. Effect of the interaction between year and water management on mean (SEM) rough rice yields and economic returns in Stoneville, MS

Year	Water management	Yield (kg/ha) ^a	Return (\$/ha) ^a
2017	Drained	9,696 (236)A	240.57 (54.77)AB
2017	Flooded	9,705 (247)A	337.79 (58.01)A
2018	Drained	9,100 (277)B	188.97 (66.14)B
2018	Flooded	10,219 (164)A	369.25 (38.15)A

^aMeans within a column followed by the same letter are not significantly different according to Tukey's HSD ($\alpha = 0.05$).

Table 4. Effect of insecticide seed treatment on mean (SEM) rough rice yields and economic returns averaged across years and water management strategies from an experiment conducted in Stoneville, MS during 2017 and 2018

Insecticide treatment	Yield (kg/ha) ^a	Return (\$/ha) ^a
Thiamethoxam	10,469 (107)A	475.12 (23.67)A
Chlorantraniliprole	10,172 (121)A	383.18 (27.22)A
Untreated Control	8,516 (218)B	22.00 (51.90)B

^aMeans within a column followed by the same letter are not significantly different according to Tukey's HSD ($\alpha = 0.05$).

during 2018, when larval densities were low, but not 2017, when larval densities were high. Typically, pest managers find significant numbers of larvae after the use of an insecticide seed treatment only when populations are high. Results of the current study suggest that draining is only effective when larval numbers of rice water weevil are low which is also when an insecticide seed treatment will likely be most effective. As a result, draining does not appear to be an efficient method for effectively reducing numbers of rice water weevil when it is needed most. In contrast, the use of an insecticide seed treatment was more effective at reducing numbers of rice water weevil, and increasing yields and economic returns, which has been shown in previous research (Hummel et al. 2014, Lanka et al. 2014, Adams et al. 2015, 2016). Chlorantraniliprole applied as a seed treatment provided better control of rice water weevil than thiamethoxam over a wider range of conditions (pre-drain vs post-drain). Because chlorantraniliprole (0.88 mg/liter) is less water soluble than thiamethoxam (4,100 mg/liter) (PPDB 2013) and because rice is typically grown under flooded conditions, the lower water solubility of chlorantraniliprole could partially explain why control was better after draining and re-flooding plots than thiamethoxam in the current experiment.

Despite the fact that chlorantraniliprole provided better control of rice water weevil than thiamethoxam, yields and economic returns were similar. In 2017, when densities of rice water weevil were greatest, the draining of fields did not affect rough rice yields or economic returns. Similar results were observed in a previous study where early draining and re-flooding of rice fields to control rice water weevil did not provide an economic benefit relative to treatment with carbofuran (Smith et al. 1986). Rough rice yields and economic returns were greater when maintaining a flood compared with draining a field in a year where rice water weevil populations were low (2018). This suggests that water stress may have been important in terms of rice yields, because yields of drained plots were reduced compared to flooded plots. The current study was conducted in a small plot setting and reestablishing the flood occurred in one day. In a commercial production system where fields are much larger, the impact of water stress may be more dramatic because it

will likely take several days to reestablish a flood. Based on the data from the current experiment, an insecticide seed treatment provided the greatest benefit for managing rice water weevil and draining a conventionally flooded field when larval populations of rice water weevil were present did not provide added control. Multiple factors may contribute to infestations of rice water weevil in flooded rice, even when an insecticide seed treatment was used at planting. Once the flood is established in rice, there are no insecticides currently labeled that will effectively manage an established infestation of rice water weevil larvae on roots. Alternative management strategies, such as draining, will likely be cost prohibitive and may not provide effective control, so those practices are not currently recommended to control rice water weevil in rice.

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