RELATING RICE STINK BUG, *OEBALUS PUGNAX* (F.) (HEMIPTERA: PENTATOMIDAE), SAMPLING TO DIRECT AND INDIRECT YIELD LOSS IN RICE, *ORYZA SATIVA* L.

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Abstract

The rice stink bug is the most important pest of heading rice in the southern United States. Although many studies have sought to quantify the amount of direct and indirect yield loss that rice stink bug is capable of causing to rice, no study has directly related rice stink bug densities used to the sampled area in rice fields. The objective of this study was to estimate direct and indirect yield loss due to different densities of rice stink bug in a defined sampling area of uncaged rice. Field experiments were conducted in 2018 across six locations using a randomized complete block design with 4 replicate blocks per location and 4 treatments. Treatment thresholds included: 1) an untreated control, 2) standard threshold of 5 stink bugs per 10 sweeps the first two weeks of heading followed by 10 stink bugs per 10 sweeps the second two weeks of heading, 3) 10 rice stink bugs per 10 sweeps throughout heading, and 4) 20 rice stink bugs per 10 sweeps throughout heading. When considering indirect yield loss, populations averaging 10 rice stink bugs per 10 sweeps yielded peck levels of 1.8% when no insecticide applications were made. A relationship between milled rice yield and peck was also observed, but no significant relationship was observed for head rice yield or direct yield loss. Results from this study confirm the validity of the current Arkansas indirect yield loss threshold of 10 rice stink bugs per 10 sweeps during the second two weeks of heading.

Introduction

The rice stink bug, *Oebalus pugnax* (L.) (Hemiptera: Pentatomidae), is the most important pest of headed rice, *Oryza, sativa* L., in the southern United States (Webb 1920). Sampling for rice stink bug is performed using a 38cm diameter sweep net, with 10 sets of 10 sweep samples recommended for estimating the population density present in a field. Rice stink bug in Arkansas is managed with two different action thresholds depending upon the growth stages present in each rice field (Lorenz and Hardke 2013). During the first two weeks of heading, the action threshold is 5 rice stink bugs per 10 sweeps to prevent direct yield loss, and during the next 2 weeks of heading, the action threshold is 10 rice stink bugs per 10 sweeps to prevent quality loss. Rice stink bug feeds on the developing kernels of rice and other grasses beginning at the heading phase when the panicle is exerted from the boot until the end of the ripening phase, known as the hard dough growth stage (Swanson and Newsom 1962). Rice stink bug feeding during the flowering stage of rice development often causes blanked kernels and direct rough rice yield loss (Douglas and Tullis 1950, Swanson and Newsom 1962, Espino et al. 2007). This damage is a result of a reduction of the grain content and damage to flowers, where abortion of the flower could lead to a completely blank kernel. Feeding during the milk to soft and hard dough growth stages can result in a loss of quality associated with broken, chalky or discolored kernels, which is commonly known as "peck" (Douglas and Tullis 1950, Swanson and Newsom 1962, Espino et al. 2007). Peck increases the potential that a kernel could break during milling, and a high occurrence of pecky kernels can reduce USDA grade. At 2.5% or 4.0% damaged kernels, rice is considered grade 3 and grade 4, and can incur a deduction of up to $0.003-$0.006 per kg of rice respectively. These reductions in quality could impact producers as much as $34-$68 per ha if assuming potential yield around 10,000 kg per ha for grade 3 and grade 4 rice respectively (Hardke and Siebenmorgen 2013).

Damage studies that utilize cages seek to relate the amount of damage present using a known density, number of rice stink bugs per m^2, to the area that is sampled within the field. This requires a known sampling area (length x width) and a known sampling success within that area (number caught vs. number present). The area sampled is often based on sweep lengths that researchers use (Rashid 2003, Awuni et al. 2015), however, a large amount of variation in sweep length has been observed in Arkansas in the actual area being sampled among consultants, producers, extension, and research personnel. If inaccurate estimations of rice stink bug density to sample relationships are being made, then rice stink bug thresholds will not be accurate when used to make treatment decisions. Sampling area and sampling success do not have to be estimated when relating sweep net sample estimates to damage values without the use of cages. Instead, the sampled area used in an uncaged trial can relate directly to the area being sampled in real world situations.

The objective of this study was to estimate direct and indirect yield loss due to different densities of rice stink bug in a defined sampling area of uncaged rice.

Materials and Methods

Field experiments were conducted in 2018 across six locations: two near Stuttgart, AR, two near Almyra, AR, one near Conway, AR, and one near Harrisburg, AR. Five of the six locations were located within grower fields, with locations chosen based on presence of rice stink bug in surveyed fields. Agronomic practices across locations were decided by field managers rather than researchers, therefore some differences existed in fertility, cultivar, and pest management. No fungicides or insecticides were applied to the test area before or during initiation of this study unless indicated by the assigned treatment.

A randomized complete block design was utilized with 4 replicate blocks per location and 4 treatments. Treatments utilized were variations of rice stink bug thresholds at 4 levels: 1) an untreated control, 2) standard threshold of 5 stink bugs per 10 sweeps the first two weeks of heading followed by 10 stink bugs per 10 sweeps the second two weeks of heading, 3) 10 rice stink bugs per 10 sweeps throughout heading, and 4) 20 rice stink bugs per 10 sweeps throughout heading. These will be referred to as 'untreated', 'standard threshold', '10 all season', and '20 all season' respectively from this point forward. Plots measured between 4.5m-6.1m in width and were 15.5m in length.

Average rice stink bug density was estimated within each plot once per week from flowering until 60-70% hard dough. Sampling was performed using a 38cm sweep net while utilizing 1.8m sweeps taken at a quick pace with at least 1-2 steps between each sweep. Only the left half of each plot was sampled to estimate the rice stink bug density present, with 2 sets of 10 sweeps taken per plot across the 15.5m length. The right half of each plot was not sampled to minimize yield loss and kernel damage due to sweep net sampling. Treatment decisions were then determined by averaging the number of rice stink bugs captured across all 4 replicate blocks, with 8 samples being used per treatment decision each week. When thresholds were exceeded within a single location, both sampled and harvested sides of all plots with that treatment received an application of lambda-cyhalothrin (LAMBDA-CY® EC, UPI, 630 Freedom Business Center, Suite 402, King of Prussia, PA) at a rate of 0.08 kg ai per ha. Insecticide applications were made using a CO^2 backpack sprayer, calibrated at 93.5 L per ha with Tee-Jet hollow cone TX-6 nozzles.
The portion of each plot that was not sweep net sampled were harvested after kernel moisture averaged less than 20%, as determined by a mini GAC® handheld grain moisture tester (DICKEY-john, 5200 Dickey John Road, Auburn, IL). Each plot had 7 rows (1.33m in width) each 5.5m-7.5m in length that was harvested with a Wintersteiger® classic plot combine (Wintersteiger Inc., 4705 W. Amelia Earhart Drive, Salt Lake City, UT). Harvest yields were estimated by adjusting the harvest weight (kg) to 12% moisture. Dry yields were then converted to kg per ha.

A 700g sample of rough rice was obtained from each plot and was dried to 12% moisture before grain quality analysis. Quality of rice was determined by rating samples using USDA grade standards (Hardke and Siebenmorgen 2013) and by determining both percent total milled rice yield (MRY) and percent whole kernel rice yield (head rice, HRY). Samples of rough rice weighing 100g were taken from each plot sample, dehulled to brown rice, and then sorted in to three subcategories: clean brown rice, peck caused by rice stink bug, and peck caused by other factors. The percent peck caused by rice stink bugs (RSB Peck) was determined using the formula: (weight of peck caused by rice stink bug ÷ weight of total brown rice sample including clean and pecky rice) × 100. A 162g sample of rough rice was milled to produce white rice using a laboratory-scale rice mill (McGill #2, Rapsco, Brookshire, Texas, USA). This value was used to calculate the milled rice yield (MRY) = (milled rice mass ÷ rough rice mass) × 100. The head rice, kernels at least three-fourths of original kernel length, were then separated using a laboratory-scale rice sizing device with a No. 11 grate (Grainman Model 61, Grain Machinery Manufacturing Corp., Miami, Florida, USA). This value was used to calculate head rice yield (HRY) = (head rice mass ÷ rough rice mass) × 100.

Data were compared using a two-way analysis of variance utilizing PROC GLIMMIX (SAS v. 9.4, SAS Institute, Cary, NC) and a general linear model with a normal distribution. Denominator degrees of freedom were adjusted using a Kenward-Rogers approximation (Kenward and Roger 1997). Data were compared using only 3 threshold treatment levels because no 20 all season threshold plot received an insecticide application at any location and were therefore considered untreated. If the two-way interaction of location × threshold was found to be non-significant, main effects alone were explored. Block alone was considered a random variable for the response variable RSB peck. Location and block nested within location were considered random variables for the response variables MRY, HRY, and yield when the treatment main effect alone was explored. Means were then separated using Tukey's HSD post hoc analysis at $P<0.05$.

Data were further analyzed using regression analysis. This was performed using a mixed model in PROC GLIMMIX (SAS v. 9.4, SAS Institute, Cary, NC) with location and block nested within location considered as random variables. Denominator degrees of freedom were adjusted using a Kenward-Rogers approximation (Kenward and Roger 1997). Two predictors were used with these analyses: RSB per Week (the average number of rice stink bugs sampled per week) and RSB peck. Four response variables were also used: RSB peck, MRY, HRY, and yield. For each regression analysis performed, data were separated into two subsets before analysis: plots that received an insecticide application (sprayed) and plots that never received an insecticide application (unsprayed). Although the full data sets were presented for RSB peck, separate regression lines and analysis were used with sprayed and unsprayed plots so that conclusions could be drawn independently. The model for all regression analyses tested was: $y = {}^{2}{}_{0} + {}^{2}{}_{1}x +$.

Results and Discussion

Sampled Rice Stink Bug Averages.
All locations received at least one application of insecticide based upon threshold requirements (Figure 1; Figure 2). Of the 6 locations, 4 received insecticide applications to the standard threshold and 10 all season at the same time: Almyra 1, Almyra 2, Harrisburg, and Conway (Table 1, Figure 1). Almyra 1, Almyra 2, and Conway exhibited threshold level densities in the standard threshold plots and 10 all season plots at the first sampling timing (Figure 2). Both Almyra 1 and Almyra 2 never exceeded thresholds in treated plots after the initial insecticide application, however, treated plots in Conway were retreated 2 weeks later (Figure 2). Harrisburg only received an insecticide application later at 60% hard dough when rice stink bug densities averaged over 10, but no threshold was exceeded during the 3 previous weeks of sampling (Figure 1). The standard threshold plots at Stuttgart 1 exceeded threshold only during the first week of sampling (Figure 1). The standard threshold plots at Stuttgart 2 exceeded threshold at the milk/soft dough growth stage and received a single application, and the 10 all season threshold exceeded treatment level and was treated at 60% hard dough (Figure 1).

Table 1 Percent rice stink bug peck (RSB peck) observed in rice across six locations in Arkansas with corresponding application timings for untreated plots, plots sprayed at the standard threshold, and plots sprayed at 10 rice stink bugs throughout the sampling period (2018).

Location	Threshold	Application Timing	Percent RSB Peck
Stuttgart 1	Untreated	.	1.2 a
	Standard*	Flowering	0.8 b
	10 rice stink bugs	60% Hard Dough	0.8 ab
Stuttgart 2	Untreated	.	1.7 a
	Standard*	Milk/Soft Dough	1.0 b
	10 rice stink bugs	60% Hard Dough	1.5 a
Almyra 1	Untreated	.	2.4 a
	Standard*	Milk	1.4 b
	10 rice stink bugs	Milk	1.4 b
Almyra 2	Untreated	.	2.1 a
	Standard*	Soft Dough	1.2 b
	10 rice stink bugs	Soft Dough	1.2 b
Conway	Untreated	.	3.7 a
	Standard*	Flow/Milk + 40% Hard Dough	1.4 b
	10 rice stink bugs	Flow/Milk + 40% Hard Dough	1.2 b
Harrisburg	Untreated	.	1.4 a
	Standard*	60% Hard Dough	0.9 b
	10 rice stink bugs	60% Hard Dough	1.0 b

Means for Percent RSB peck are significantly different within a location when followed by a different lowercase letter according to a Tukey's HSD post hoc analysis at $P<0.05$.
*Standard rice stink bug threshold is 5 rice stink bugs per 10 sweeps in the first two weeks of heading and 10 rice stink bugs per 10 sweeps in the second two weeks of heading

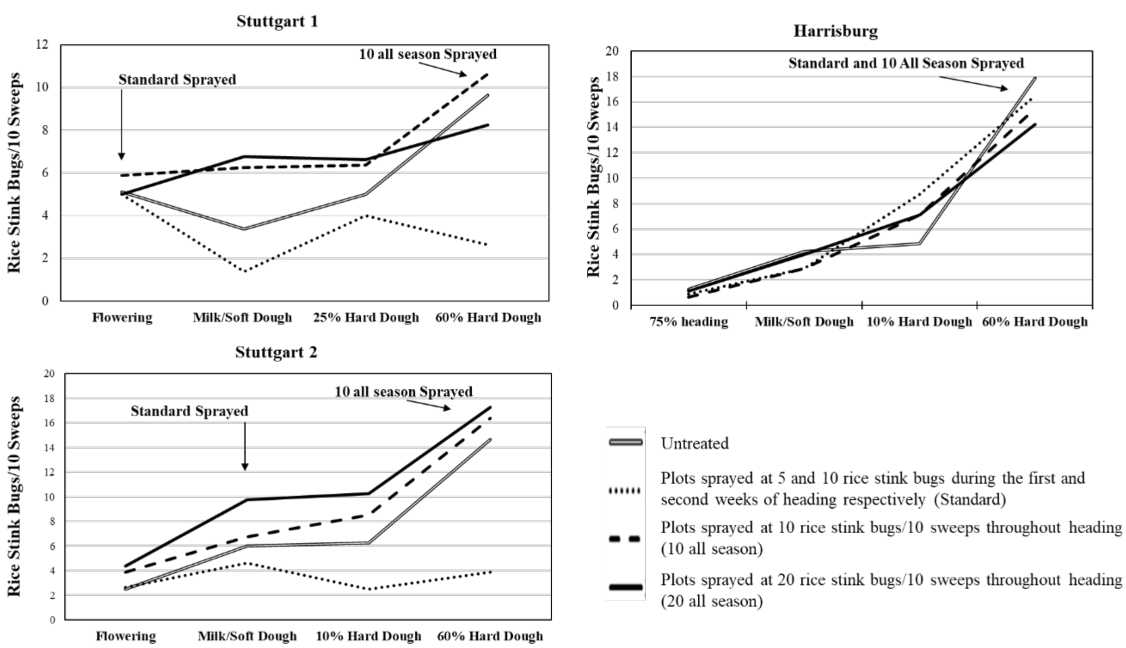

Figure 1. Average number of rice stink bugs per 10 sweep sample when sampled each week in uncaged threshold trials for four treatment thresholds at the Stuttgart 1, Stuttgart 2, and Harrisburg locations located in rice fields across Arkansas (2018).

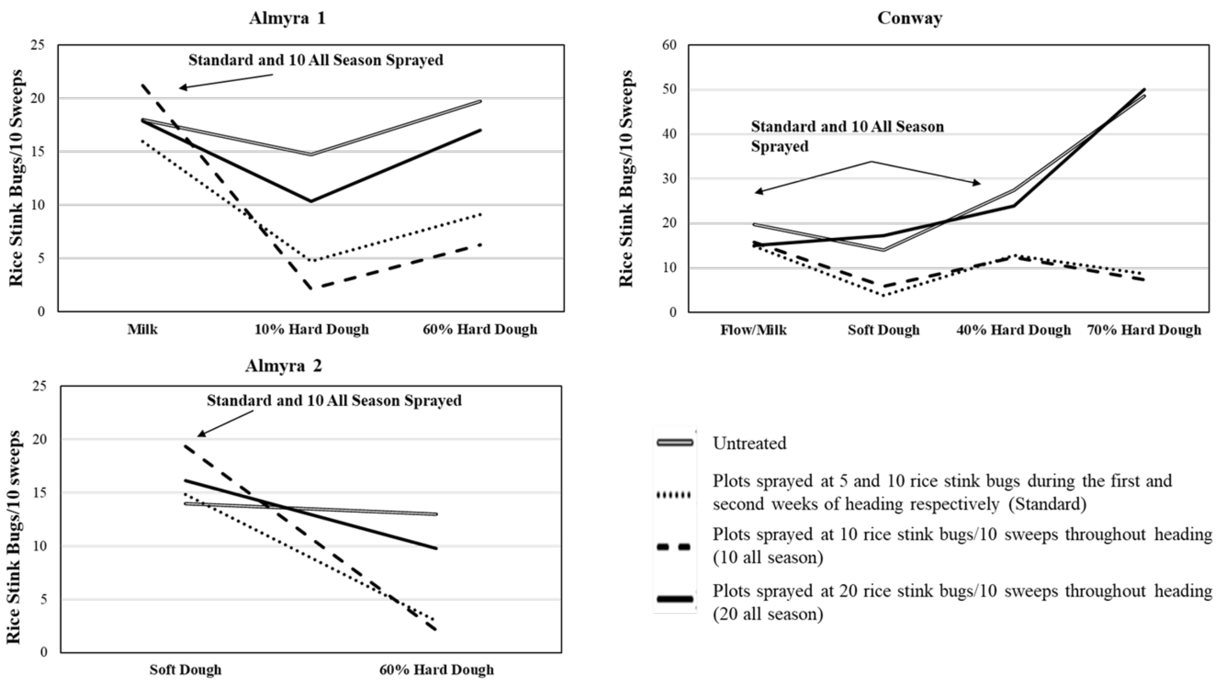

Figure 2. Average number of rice stink bugs per 10 sweep sample when sampled each week in uncaged threshold trials for four treatment thresholds at the Almyra 1, Almyra 2, and Conway locations located in rice fields across Arkansas (2018)

Direct Yield Loss.

Utilizing a two-way ANOVA for yield, no significant interaction of threshold treatment × location was observed (F = 0.91; df= 10, 75; P = 0.53). The treatment main effect was not found to be significant for yield using ANOVA (F = 1.07; df= 2, 70; P = 0.35). When utilizing regression analysis, no significant linear relationship (P=0.59) was observed between yield of untreated plots and the number of rice stink bugs sampled per week (Table 2).

Table 2. Treatment averages for quality and yield measured in percent milled rice yield (MRY), percent head rice yield (HRY), and yield (kg ha^{-1}) analyzed across location for three treatment thresholds in Arkansas rice (2018).

Treatment	MRY	HRY	Yield (kg/ha)	Sample Size
Untreated	69.7 b	55.8 b	10830	48
Standard*	70.4 a	57.2 a	10736	24
10 All Season	70.3 a	56.5 ab	10992	24

Means for MRY, HRY, and Yield are significantly different when followed by a different lowercase letter according to a Tukey's HSD Post Hoc Analysis at P<0.05.
*Standard rice stink bug threshold is 5 rice stink bugs in the first two weeks of heading and 10 rice stink bugs in the second two weeks of heading.

Indirect Yield Loss - RSB Peck

A significant threshold × location interaction was observed for RSB peck (F = 8.84; df = 10, 75; P < 0.01) (Table 1). At all locations except Stuttgart 1 and Stuttgart 2, untreated plots exhibited significantly more RSB peck than the standard and 10 all season thresholds (Table 1). At the Stuttgart 1 and Stuttgart 2 locations, untreated plots were not found to exhibit significantly more RSB peck than 10 all season plots (Table 1). Standard threshold plots were sprayed at least two weeks earlier than 10 all season threshold plots, therefore, standard plots exhibited significantly lower peck at these two locations (Figure 1, Table 1).

A significant linear relationship was observed between the average number of rice stink bugs observed per week and RSB peck when considering plots that did not receive an insecticide application (Table 3, Figure 3). With every 1 rice stink bug averaged per week, an increase in 0.10% RSB peck could be expected (Figure 3). At an average of 15 rice stink bugs caught per week, 2.3% RSB peck could be expected. No significant linear relationship was observed between RSB peck and the average number of rice stink bugs sampled per week for treatments receiving an insecticide application (Table 3, Figure 3). Neither predicted line approached 0% RSB peck when samples averaged 0 RSB per week, as RSB peck was not fully distinguishable from other potential causes and still existed at low levels in the absence or rice stink bugs.

Table 3. Results of regression analysis across all data utilizing 2 predictors (rice stink bug per 10 sweep sample per week and percentage RSB peck) and 4 response variables (percentage of RSB peck, milled rice yield (MRY), head rice yield (HRY), and yield (kg/ha)) to analyze data from both sprayed and unsprayed plots in rice in Arkansas (2018).

Predictor	Response	Treatment	Equation (y = ² 0 + ² 1x +)	Standard Error (² 0 and ² 1)	RSE*	*T*	df	*P*
RSB/ Week	RSB Peck	Sprayed	y = 0.90 + 0.027x	0.15 and 0.02	0.06	1.57	27	*0.13*
		Unsprayed	y = 0.08 + 0.096x	0.18 and 0.01	0.05	8.04	29	*<0.01*
	MRY	Unsprayed	y = 70 – 0.03x	0.83 and 0.05	0.20	-0.70	30	*0.48*
	HRY	Unsprayed	y = 56 – 0.02x	2.71 and 0.12	1.30	-0.16	45	*0.88*
	Yield	Unsprayed	y = 10579 + 19.2x	945 and 35	88306	0.54	45	*0.59*
RSB Peck	MRY	Unsprayed	y = 71 – 0.58x	0.82 and 0.31	0.22	-1.86	40	*0.07*
	HRY	Unsprayed	y = 56 – 0.03x	2.74 and 0.82	1.35	-0.04	45	*0.97*

* Standard error of residual covariance parameter estimate.

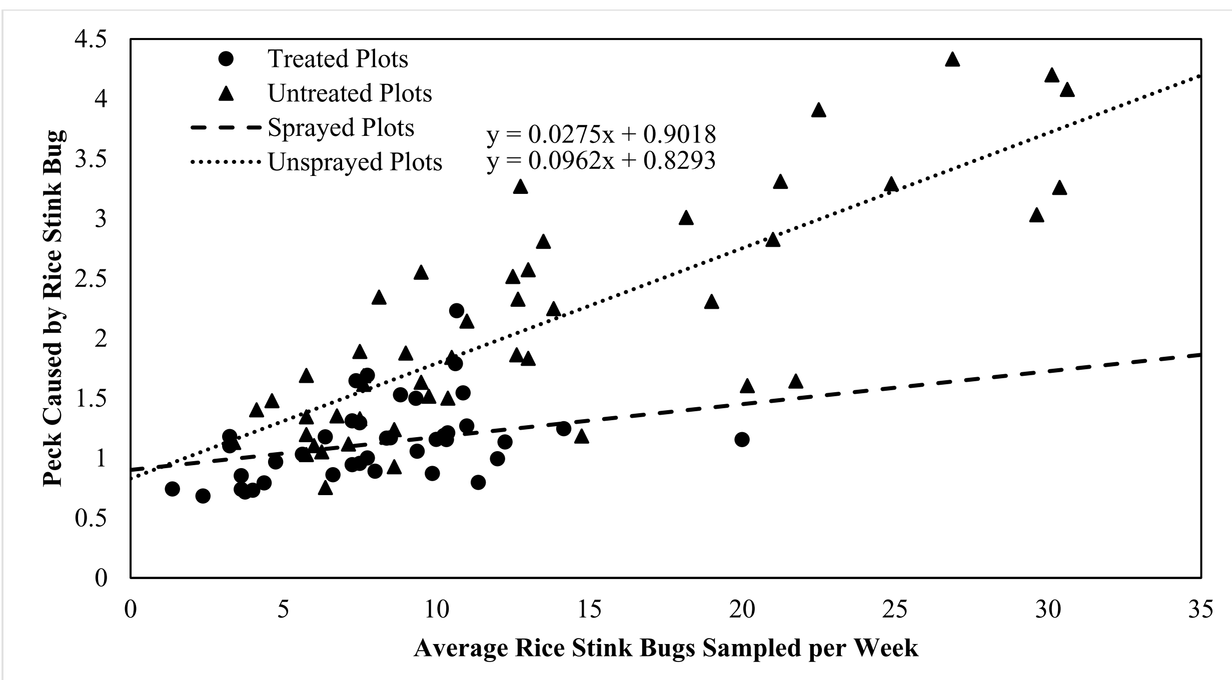

Figure 3. Peck caused by rice stink bug (RSB peck) predicted by the average number of rice stink bugs sampled per week in both sprayed (*P*=0.13) and unsprayed plots (*P* <0.01) for plots at 6 locations across Arkansas rice (2018).

Milling and Head Yields.

No significant treatment × location interaction was observed for MRY (F = 1.27; df= 10, 75; P = 0.26), but the main effect of treatment was found to be significant (F = 10.01; df= 2, 70; P < 0.01). Untreated plots exhibited significantly lower MRY at 69.7% when compared to both the standard and 10 all season treatments at 70.4% and 70.3% respectively (Table 2). No significant treatment × location interaction was observed for HRY (F = 0.47; df = 10, 75; P = 0.91), but a significant treatment main effect was observed (F = 4.71; df= 2, 70; P = 0.01). Significantly lower HRY was observed in the untreated compared to the standard treatment at 55.8% and 57.2% respectively, but neither treatment was found to differ from the 10 all season threshold at 56.5% HRY (Table 2). No significant relationship (P=0.07) was observed between RSB peck and MRY for untreated plots (Table 3). MRY was also not found to have a significant linear relationship (P=0.48) with the average number of RSB observed each week (Table 3). No significant linear relationship was observed between HRY and the average number of rice stink bugs caught per week (P=0.88) or RSB peck (P=0.97) (Table 3).

Summary

Arkansas rice stink bug thresholds require control at 10 rice stink bugs per 10 sweeps in the last two weeks of heading. Our study established a sampling area without the use of cages and confirmed that the current Arkansas threshold will prevent appreciable levels of peck. Our data indicates that when using a 1.8m (6ft) sweep length for a 10 sweep sample, an average of 15 rice stink bugs per 10 sweeps would lead to economic losses from the rice stink bug, making 10 rice stink bugs per 10 sweeps in the second two weeks of heading an acceptable economic threshold. Our study also observed loss in milling quality (MRY and HRY) in unsprayed plots when compared to plots receiving an insecticide, which corroborates the necessity to prevent rice stink bug infestations and peck accumulation. However, more work is needed to relate the number of rice stink bugs in samples to rice grain quality loss measurements such as MRY and HRY, and also the amount of direct yield loss caused by rice stink bugs in the first two weeks of heading.

Within the last 3-4 years many states have lowered thresholds for indirect yield loss. Data from this study indicates that lower thresholds to prevent additional indirect yield loss are unnecessary. Additionally, an increase in rice stink bug population in the hard dough timing was observed, and significant peck can still be caused by large infestations. If applications are made to low pest populations during the milk-soft dough stages, it is possible that additional applications may be necessary during the hard dough growth stages.

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