Crop Protection 65 (2014) 37–42

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Evaluation of seed treatment insecticides for management of the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae), in commercial rice fields in Louisiana

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ARTICLE INFO

Article history:
Received 22 November 2013
Received in revised form
26 June 2014
Accepted 27 June 2014
Available online 22 July 2014

Keywords:
Rice water weevil
Lissorhoptrus oryzophilus
Rice
Oryza sativa
Integrated pest management
Prophylactic seed treatments

ABSTRACT

The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae), is the most injurious insect pest in US rice production. Yield losses in excess of 25% can occur from severe infestations. Management demonstrations were conducted in the 2008, 2009, 2010, and 2011 growing seasons to evaluate the use of commercially available insecticides to control *L. oryzophilus* in commercial rice fields. The demonstration tests, conducted on farms throughout Louisiana, compared the efficacies of recently registered seed treatment insecticides to untreated controls and to foliar applications of pyrethroids. Efficacy was assessed by collecting root/soil core samples three to four weeks after application of permanent flood and counting numbers of larvae and pupae in core samples. Tests were replicated across locations in multiple rice-producing Louisiana parishes. Densities of larvae and pupae in core samples exceeded the larval threshold (three larvae or pupae per core sample) in over 80% of untreated plots/cuts, confirming the ubiquity and severity of this insect as a pest of rice. Use of chlorantraniliprole (Dermacor® X-100, DuPont™ Crop Protection, Wilmington, DE), thiamethoxam (CruiserMaxx® Rice, Syngenta® Crop Protection, Greensboro, NC), and clothianidin (NipsIt Inside®, Valent® USA Corporation, Walnut Creek, CA) seed treatments significantly reduced *L. oryzophilus* infestation compared to untreated checks. Fewer larvae and pupae were observed in rice treated with chlorantraniliprole than in rice treated with other insecticides.

1. Introduction

The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, is the most widely distributed and destructive early-season insect pest of rice, *Oryza sativa* L., in the United States (Way, 1990). *L. oryzophilus* has recently invaded important rice-producing regions of Asia and Europe (Saito et al., 2005) and thus poses a global threat to rice production. The seasonal history of this insect begins in early spring, when adults emerge from overwintering sites, which include leaf litter, bunch grasses, and stubble in and around rice fields, and fly to rice fields (Shang et al., 2004). The semi-aquatic adults feed on the leaves of rice, but this form of injury is not economically important except under unusually heavy infestations. Females oviposit primarily in leaf sheaths beneath the water surface (Stout et al., 2002). Oviposition, and hence larval infestations, largely commence after rice fields are flooded. Larvae may feed in or on leaves for a short period of time, but soon move down to the roots, where they feed on or in the roots. The insects pass through four larval stadia and a pupal stage in approximately 30 days (Zou et al., 2004a). Although populations are multivoltine, only a single peak of larval abundance is usually observed in a rice field (Shang et al., 2004). Feeding by larvae on the roots of rice plants results in reduced tillering and shoot growth in the vegetative phases of rice development, and reduced panicle densities and grain weights at harvest (Zou et al., 2004b). Yield losses attributable to injury by this insect can exceed 25% (Zou et al., 2004b,c).

Prior to 1998, *L. oryzophilus* was managed with post-flood applications of granular carbofuran (Furadan 3G, FMC Corporation, Philadelphia, PA) to eliminate larvae feeding on roots. Following the disallowance by the United States Environmental Protection Agency (EPA) of carbofuran in rice in the late 1990s, several

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http://dx.doi.org/10.1016/j.cropro.2014.06.025
0261-2194/

Table 1
Summary table of demonstration tests conducted in 2008–2011 indicating locations of sites (Louisiana parishes), varieties, seeding rates, and treatments. For a single location, the variety, seeding rate, and planting date were consistent across all treatments except for Jeff Davis parish (2008) and Acadia Parish (2010). Treatment designations: UNT, untreated; CAP, chlorantraniliprole; TMX, thiamethoxam; CLO, clothianidin.

Year	Site #	Parish	Variety	Seeding rate (kg/ha)	Treatments
2008	1	Acadia	CL161	67	UNT, CAP
	2	Avoyelles	CL161	67	UNT, CAP
	3	Concordia	Cocodrie	78	UNT, CAP, PYR
	4	Jeff-Davis	CLXP745 & CLXP729	34	UNT, CAP
	5	St. Landry	CL151	56	CAP, PYR
	6	St. Landry	CL161	56	UNT, CAP
	7	St. Landry	CL171	84	UNT, CAP
	8	Tensas	Cocodrie	90	UNT, CAP
	9	Vermilion	CL161	73	UNT, CAP, PYR
	10	Vermilion	Cocodrie	56	UNT, CAP
2009	1	Acadia	CL161	78	UNT, CAP, PYR
	2	Vermilion	CL151	67	UNT, CAP, PYR
	3	Evangeline	CLXL745	34	UNT, CAP, PYR
	4	Concordia	Catahoula	73	UNT, CAP, PYR
	5	Concordia	Catahoula	95	UNT, CAP, PYR
	6	Acadia	Jazzman	N/A	UNT, CAP
	7	Acadia	CL151	N/A	UNT, CAP
	8	Acadia	CL151	73	UNT, CAP
	9	Jeff-Davis	745	N/A	UNT, CAP
	10	Acadia	CLXL729	N/A	UNT, CAP
	11	Concordia	CLXL729	N/A	UNT, CAP
	12	Concordia	CLXL729	N/A	UNT, CAP
	13	Concordia	XL723	N/A	UNT, CAP
	14	Concordia	XL723	N/A	UNT, CAP
	15	Evangeline	CL151	N/A	CAP, PYR
2010	1	Acadia	CL111	73	UNT, CAP, TMX, PYR
	2	Vermilion	CL111	84	UNT, CAP, TMX, PYR
	3	Evangeline	XL746	28	UNT, CAP, TMX, PYR
	4	Concordia	CL161	62	UNT, CAP, TMX, PYR
	5	Tensas	Catahoula	81	UNT, CAP, TMX, PYR
	6	Jeff-Davis	CL261	69	UNT, CAP, TMX, PYR
	7	Evangeline	CLXL729	28	UNT, CAP, TMX, PYR
	8	Acadia	CL131	N/A	UNT, CAP, TMX,
	9	St Landry	CL151	73	UNT, CAP, TMX,
	10	Jeff Davis	XL745	28	UNT, CAP, TMX,
2011	1	Acadia	CLXL745	25	UNT, CAP, TMX, CLO
	2	Calcasieu	CLXL745	28	UNT, CAP, TMX, CLO
	3	Evangeline	CLXL745	28	UNT, CAP, TMX, CLO
	4	St Landry	CLXL745	28	UNT, CAP, TMX, CLO
	5	Rapides	Cheniere	84	UNT, CAP, TMX, CLO
	6	Jeff Davis	CLXL745	28	UNT, CAP, TMX, CLO

pyrethroids and a seed treatment of fipronil were registered for *L. oryzophilus* control, targeting adults and larvae, respectively (Stout et al., 2000). The fipronil seed treatment was voluntarily removed from the market in 2004. Removal of fipronil was accompanied by concerns over possible non-target toxicity to crawfish, *Procambarus* spp. (Stout et al., 2011b,c). Crawfish are produced for human consumption on a large commercial scale in Louisiana, and rice fields and crawfish ponds are often found in close proximity. Furthermore, crawfish and rice are co-cultivated by many producers using rotational schemes in which rice fields are transitioned to crawfish ponds by reflooding rice fields after harvest and managing rice stubble for regrowth in late summer or fall (Stout et al., 2011c).

After fipronil was removed from the market, pyrethroids remained for several years the only insecticides registered for *L. oryzophilus* management in rice. Pyrethroids are extremely toxic to crawfish (Barbee and Stout, 2009), which may be exposed through drift arising from insecticide applications made to nearby rice fields. In addition, crawfish in ponds used previously for rice production may be exposed to residual insecticides in the soil, and water released from insecticide-treated rice fields may injure or kill crawfish if the water is diverted to nearby ponds. Because of the need for alternatives to pyrethroids, the efficacies of a number of alternative insecticides against *L. oryzophilus* have been evaluated over the past decade. This research contributed to the recent registration of three seed treatments: the anthranilic diamide chlorantraniliprole (Dermacor® X-100, DuPont™ Crop Protection, Wilmington, DE) and the neonicotinoids thiamethoxam (CruiserMaxx® Rice, Syngenta® Crop Protection, Greensboro, NC) and clothianidin (NipsIt INSIDE®, Valent® USA Corporation, Walnut Creek, CA). Chlorantraniliprole was used under a Section 18 registration in 2008 and 2009 in Louisiana before a full Section 3 registration was approved by the EPA in 2010. Thiamethoxam was registered under a Section 3 in 2010. Clothianidin was registered under an Experimental Use Permit in 2011 and 2012, and received a Section 3 registration in late 2012.

All three seed treatments have been shown to reduce densities of *L. oryzophilus* larvae and pupae in small plot experiments (e.g., Stout and Frey, 2007a,b; Hummel and Stout, 2010a,b; Stout et al., 2010, 2011a), although they appear to exert their effects on *L. oryzophilus* in different ways and have differing effects on non-targets and on other pests (Lanka et al., 2014). In small-plot efficacy trials, seed treatments of chlorantraniliprole have generally given greater and more persistent suppression of *L. oryzophilus* larvae than have seed treatments of the neonicotinoids, particularly under heavy weevil pressure. However, the neonicotinoids have given suppression equal to or greater than suppression given by applications of pyrethroids (Hummel and Stout, 2010a,b; Stout et al., 2010, 2011a). In greenhouse studies, chlorantraniliprole seed treatments had no effect on survival of adult *L. oryzophilus* feeding on leaves, but deterred egg laying and killed larvae once they began feeding on roots (Lanka et al., 2014). Neonicotinoid seed treatments, in contrast, reduced survival and feeding by adults on rice leaves by virtue of their greater systemicity, and also reduced egg-laying and larval survival (Lanka et al., 2014). In addition, chlorantraniliprole controls lepidopteran pests of rice, including *Spodoptera frugiperda* (J.E. Smith), *Diatraea saccharalis* (F.), and *Eoreuma loftini* (Dyar), whereas neonicotinoid insecticides have little effect on lepidopteran pests but control early season insect pests such as *Colaspis* spp., *Blissus leucopterus leucopterus* (Say), and *Thrips* spp. (Stout et al. 2011b; Stout, unpublished data). Laboratory assays have shown that chlorantraniliprole, thiamethoxam, and clothianidin, while still capable of killing crawfish, are approximately 1000 times less acutely toxic to crawfish than pyrethroids (Barbee and Stout, 2009; Barbee et al., 2010). Furthermore, in field tests using crawfish stocked in cages in plots treated with the new seed treatments, none of the pyrethroid alternatives caused crawfish mortalities significantly higher than observed in control plots (Stout et al., 2011c).

Although the efficacies of the newly registered insecticides have been firmly established in small-plot tests, there have been no side-by-side comparisons of the efficacies of these seed treatments in commercial fields using practices typical of large-scale rice production. This paper reports the results of *L. oryzophilus* management demonstrations conducted to compare the efficacies of the new insecticide seed treatments and pyrethroids to an untreated control. These demonstrations were conducted on commercial farms throughout Louisiana over four growing seasons. The demonstration program was a cooperative effort between research and extension faculty and a large team of extension agents, rice farmers, agricultural consultants, and agri-chemical representatives and represents the most complete and realistic assessment to date of the effectiveness of these new insecticides in Louisiana.

2. Materials and methods

2.1. Insecticide efficacy

L. oryzophilus management demonstrations were conducted over four production seasons from 2008 to 2011. Commercial rice farms were selected in southwest and northeast Louisiana, the two major rice-producing regions in the state. The 2008 demonstrations were conducted in seven parishes on ten farms (Table 1). In 2009, demonstrations were conducted in five parishes at 15 field sites. In 2010 and 2011, demonstrations were conducted in five parishes at 10 and six field sites, respectively (Table 1). Commercial rice producers (hereafter, “cooperators”) identified by LSU AgCenter Extension Agents assisted with demonstrations. Seed treatments of chlorantraniliprole were evaluated in all four years, with treatment rates adjusted by applicators to achieve a rate of approximately 80 g AI/ha at all seeding rates. Thiamethoxam (140 g AI/100 kg of seed, or approximately 0.034 mg AI/seed) was evaluated in 2010 and 2011, and clothianidin (75 g AI/100 kg of seed) was evaluated in 2011 (Table 1). Seed treatments were applied by regional commercial applicators (Crowley Grain Drier Inc., LA, USA; G&H Seed Company, Inc., LA, USA; Angelina Seed Company, LLC, LA, USA). An untreated control was also included in each demonstration, with the exception of one farm in each of 2008 and 2009 (Table 1). In addition, a standard insecticide treatment consisting of one or two foliar applications of a pyrethroid insecticide (lambda-cyhalothrin at 0.045 kg AI/ha or zeta-cypermethrin at 0.028 kg AI/ha) was assessed in selected demonstrations in 2008, 2009, and 2010 (Table 1). In these demonstrations, a single pyrethroid application was made within 7 days of permanent flood establishment as needed based on weekly scouting for *L. oryzophilus* adults following LSU AgCenter recommendations. Four demonstrations conducted in 2009 also included a treatment with two pyrethroid applications made within 7 days of permanent flood establishment. Applications were made by certified applicators using a commercial ground rig (for pre-flood applications) or an airplane (for post-flood applications). On each farm, the cooperator determined the rice variety and seeding rate (Table 1). Agronomic practices varied among farms, but for each individual farm, the variety, date of planting, date of establishment of permanent flood, and date of insect sampling were identical for all insecticide treatments, except for Jeff Davis Parish in 2008 and Acadia Parish in 2010 (Table 1). Planting occurred between mid-March and late April on all farms.

Experimental units on each farm varied among years. On each farm in 2008, each treatment was applied to a “cut”, an area of a field separated from other areas of the same field by at least one earthen levee. In 2009 and 2010, each treatment was applied to one to three cuts on each farm. In 2011, in which only seed treatments were evaluated, the demonstration field on each farm was separated into two blocks, and each treatment was applied to one “plot” in each block, where “plot” was defined as an area of a field not separated from other areas of the same field by a levee. In 2008, 2009, and 2010, the size of cuts significantly varied by farm and year from approximately 0.1 to 12.1 ha with an average size of 3 ha. Generally, untreated cuts were the smallest to minimize economic losses to the cooperators. In 2011, the sizes of treated and untreated plots on a farm were the same. The average plot size was 0.56 ha, the smallest being 0.11 ha, the largest being 1.22 ha.

Insecticide efficacy was determined by estimating densities of *L. oryzophilus* larvae and pupae three to four weeks after establishment of permanent flood. Root/soil core samples were collected into plastic bags haphazardly by walking through the cuts or plots of each treatment from one corner to another in an S-shaped pattern and pulling core samples at approximately equally spaced intervals of at least 25 m. Samples were not taken close to the edge or the levee of the plot or cut. The core sampler was a metal cylinder with a diameter of 9.2 cm and a depth of 7.6 cm attached to a metal handle. Root/soil cores were then placed into 40 mesh screen sieve buckets and soil was washed from roots. Buckets were placed into basins with salt water, and larvae and pupae were counted as they floated to the water surface. In 2008, 5 to 14 core samples were taken from each cut. In 2009, 6 to 10 cores were taken per cut; in 2010, 10 cores were taken per cut. In 2011, 10 cores were taken per plot.

2.2. Effect of seed treatment on plant height and plant density

Possible effects of seed treatments on densities and heights of rice seedlings were evaluated on nine and five farms in 2010 and 2011, respectively. Seedling height and density data were collected approximately two weeks after rice emergence. In 2010, five, 122-cm long, row sections (stops) were selected by walking through one randomly selected cut of each treatment of interest. In 2011, five stops were selected in each plot. The stops were at least 50 m apart. At each stop, the number of plants in the 122-cm row section was counted and the heights of ten haphazardly selected seedlings were measured. Plant height was measured from the soil surface to the highest leaf tip of the plant.

2.3. Statistical analysis

Core sample data were analyzed separately for each year using linear mixed models (PROC MIXED, SAS Institute, 2008), with the

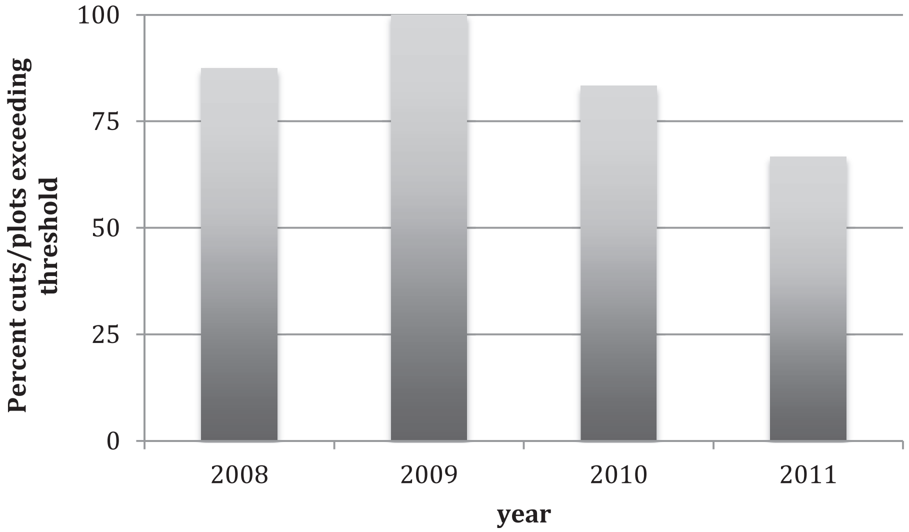

Fig. 1. Percentage of untreated cuts or plots in which *L. oryzophilus* immature counts exceeded the treatment threshold (three larvae per core sample) over a four-year period.

number of immature *L. oryzophilus* from each core sample entered as a data point. For all analyses, insecticide treatment was entered into the model as a fixed effect. Random effects for the analyses differed by year. For 2008, farm and farm*treatment were entered as random effects into the model to estimate covariances for core samples collected on the same farm and in the same cut, respectively. For 2009 and 2010, random effects were farm and cut (farm*treatment) for comparable reasons. However, the effect of cuts was entered into the models as cut (farm*treatment) and not farm*treatment because, on each farm, each treatment was applied to a single cut in 2008 and to one to three cuts in 2009 and 2010. For 2011, random effects were farm, block (farm), and treatment*block (farm) to estimate covariances for core samples collected on the same farm, in the same block, and in the same plot, respectively.

Plant density and height data collected in 2010 and 2011 were also analyzed using linear mixed models. Insecticide treatment was entered as a fixed effect in all models. Random effects used in models comparing plant density as affected by insecticide treatment were farm and farm*treatment in 2010, and farm, block (farm), and treatment*block (farm) in 2011. Random effects were included to estimate covariance in the observations associated with sampling from the same farm and cut in 2010, and same farm, block, and plot in 2011. For plant height data, the random effects were farm, farm*treatment, stop (farm*treatment) in 2010. In 2011, random effects were farm, block (farm), treatment*block (farm), stop (treatment*block farm). The model used to compare plant height included an additional random effect relative to the model comparing plant density in order to estimate the covariance associated with data collection at each stop in each cut (2010) or block (2011).

Linear mixed models were used for count data analyses because preliminary comparisons using generalized linear mixed models (PROC GLIMMIX, SAS Institute, 2008) with a Poisson distribution of residuals did not converge for plant density data. In addition, the generalized linear mixed models that converged for core sample data yielded results comparable to those of the linear mixed models. A square root transformation of count data did not change results of the linear mixed models. Thus, statistical analyses were conducted using raw data. The Kenward–Roger adjustment for denominator degrees of freedom was used in all models to correct for inexact *F* distributions (PROC MIXED, SAS Institute, 2008).

3. Results

3.1. Insecticide efficacy

Over a four-year period, *L. oryzophilus* immature counts exceeded the threshold previously used to trigger post-flood applications of carbofuran (three larvae per core sample) in 84% of the untreated cuts or plots located on farms where seed treatments were evaluated (Fig. 1). Insecticide treatments significantly reduced *L. oryzophilus* densities (larvae and pupae per core sample) in all demonstration program years. In 2008, densities were significantly ($P < 0.05$) lower in chlorantraniliprole-treated cuts than in untreated cuts (Table 2). Densities in pyrethroid-treated cuts were intermediate and did not differ significantly from densities in untreated cuts or in chlorantraniliprole-treated cuts. In 2009, significant ($P < 0.05$) differences in *L. oryzophilus* densities were detected between untreated cuts and cuts treated with chlorantraniliprole and pyrethroids. Densities were the lowest in cuts treated with chlorantraniliprole but differences in densities in chlorantraniliprole- and pyrethroid-treated cuts were not significant (Table 2). In 2010, a significant ($P < 0.05$) difference was detected between untreated and insecticide treated cuts. No significant differences in *L. oryzophilus* densities were detected in cuts treated

Table 2

Densities of *L. oryzophilus* larvae and pupae (insects per core sample ± s.e.) in cuts or plots of rice treated with insecticides or untreated. Not all insecticides were evaluated in all years. Pyrethroid treatments consisted of foliar applications of lambda-cyhalothrin or zeta-cypermethrin; the remaining insecticides were applied as seed treatments. Data were analyzed using linear mixed models. Means followed by the same letters within a column are not significantly different (Tukey–Kramer adjustment, alpha = 0.05).

Treatments	Means of number of larvae and pupae per core sample			
	2008	2009	2010	2011
Untreated	11.7 ± 1.1a	11.4 ± 0.9a	8.3 ± 1.5a	12.9 ± 2.9a
Pyrethroid	5.1 ± 2.1ab	2.6 ± 0.9b	3.2 ± 1.8bc	–
Chlorantraniliprole	1.7 ± 1.1b	0.6 ± 0.9b	1.3 ± 1.4c	2.6 ± 2.9c
Thiamethoxam	–	–	4.2 ± 1.4b	7.9 ± 2.9b
Clothianidin	–	–	–	7.9 ± 2.9b
ANOVA				
F	20.7	40.4	12.2	13.3
df	28.7	240.4	337.9	339.0
$P > F$	0.0005	<0.0001	<0.0001	<0.0001

with thiamethoxam and pyrethroids, and densities in cuts treated with foliar pyrethroids and chlorantraniliprole also did not significantly differ. However, chlorantraniliprole seed treatment provided significantly ($P < 0.05$) better control of *L. oryzophilus* than did thiamethoxam seed treatment (Table 2). In 2011, when only seed treatments were evaluated, a significant ($P < 0.05$) difference was detected between untreated and treated plots. Significant differences in densities of *L. oryzophilus* were not observed in plots treated with the two neonicotinoids (thiamethoxam and clothianidin), but densities in neonicotinoid-treated plots were lower than untreated plots. Plots treated with chlorantraniliprole showed the lowest densities of *L. oryzophilus* larvae and pupae (Table 2).

3.2. *Effect of seed treatment on plant height and plant density*

In 2010, limited evidence was found for differences in plant heights among treatments (Table 3*)*. Heights were marginally lower ($P = 0.054$) in untreated cuts than in cuts treated with chlorantraniliprole or thiamethoxam (Table 3). In 2011, seed treatments had small but significant ($P < 0.05$) effects on plant height. Plants were generally taller in cuts treated with thiamethoxam or clothianidin than in untreated or chlorantraniliprole-treated plots. No differences in plant heights were detected among untreated and chlorantraniliprole treated plots (Table 3).

In 2010, no significant differences in stand counts were found among treatments (Table 3). In 2011, seed treatments had a marginally significant effect on stand counts ($P = 0.06$). In both years, there was a trend toward higher stand counts in cuts treated with neonicotinoids than in untreated cuts or cuts treated with chlorantraniliprole (Table 3).

4. Discussion

Insecticidal seed treatments containing chlorantraniliprole, thiamethoxam, and clothianidin have been widely adopted by rice growers since the introduction of Dermacor X-100 in US rice in 2008. In a recent survey of grower practices in Louisiana, over 90% of growers and consultants reported using seed treatments in one or more of the fields for which they were responsible in 2010 and 2011 (Mészáros, Hummel, and Stout, unpublished data). The data reported here from commercial rice fields over four growing seasons in two major rice-producing areas of Louisiana demonstrate the use of insecticidal seed treatments provides control of *L. oryzophilus* at least as effective as that provided by foliar pyrethroids, which are generally applied immediately before or after flooding to eliminate adult *L. oryzophilus* before they oviposit. Chlorantraniliprole seed treatments were generally more effective against weevils than neonicotinoid seed treatments; reductions in larval densities in rice treated with chlorantraniliprole ranged from 80 to 94% relative to controls in the four years of the study, whereas reductions in larval densities in thiamethoxam or clothianidin-treated plots were more modest, ranging from 39 to 50%. In the only year in which neonicotinoid seed treatments were directly compared to foliar pyrethroid applications (2010), weevil densities in plots treated with thiamethoxam seed treatment and foliar pyrethroids were similar. These results from commercial fields are consistent with the results of numerous small-plot trials conducted with these products in Louisiana. Stout et al. (2010), for example, showed in small-plot trials that chlorantraniliprole seed treatment reduced population densities of *L. oryzophilus* larvae to a greater extent than did thiamethoxam seed treatment over three planting dates. Stout et al. (2011a) showed that chlorantraniliprole gave greater control of larvae than did clothianidin (CruiserMaxx® Rice or Cruiser 5FS Syngenta® Crop Protection, Greensboro, NC) under light weevil pressure but that control given by the neonicotinoid seed treatments was superior to that given by a single pre-flood application of a pyrethroid.

One of the foundational tenets of integrated pest management is to use insecticides only when pest populations are large enough to justify their use (Higley and Peterson, 2009; Frisvold, 2009). The compatibility of this principle with the use of prophylactic seed treatments depends on the regularity with which populations of a pest exceed thresholds. Average densities of *L. oryzophilus* larvae in untreated rice exceeded 11 larvae per core over the four years of this study and ranged from a low of 8.3 larvae and pupae per core sample in 2010 to a high of 12.9 in 2011. Based on estimates of the relationship between larval density and yield obtained from small plot experiments, a larval density of 11 weevils per core sample would be expected to cause yield losses ranging from 5.5 to 11% (Zou et al., 2004c). Moreover, densities of *L. oryzophilus* larvae exceeded three larvae per core sample, the threshold value formerly used for applying the post-flood larvicide carbofuran, in 84% of the individual plots or cuts in which no insecticide was used. These data thus confirm the status of *L. oryzophilus* as a ubiquitous and damaging pest of rice in Louisiana.

Use of seed treatment insecticides in rice may provide benefits in addition to the control of *L. oryzophilus* they provide. All three of the seed treatments evaluated in this study provide some control of other insect pests of rice, although the neonicotinoid and anthranilic diamide active ingredients in the three seed treatments differ in the spectra of insects they control. Of particular importance in southwest Louisiana, chlorantraniliprole seed treatment provides suppression of mid- to late-season stem borers, including the long-established *D. saccharalis* and the invasive *E. loftini* (Sidhu et al., 2014). The neonicotinoid seed treatments, on the other hand, are effective against *Colaspis* spp. and *B. leucopterus leucopterus*, early stand-reducing pests important in some parts of Arkansas, Mississippi, and Louisiana (Wilf et al., 2009; J. Gore, Mississippi State University, personal communication). In addition, neonicotinoid seed treatments have been reported to stimulate germination and

Table 3

Heights and densities of rice seedlings in untreated and insecticide-treated rice over two years. Data were analyzed using linear mixed models. Means followed by the same letters within a column were not significantly different (Tukey–Kramer adjustment, alpha = 0.05).

Treatments	Plant growth and density in 2010 and 2011			
	Stand counts (plants per 122 cm row section ± s.e.)		Plant heights (cm ± s.e.)	
	2010	2011	2010	2011
Untreated	38.7 ± 5.5a	25.3 ± 5.4a	11.8 ± 1.6a	12.7 ± 1.1bc
Chlorantraniliprole	44.3 ± 5.7a	25.2 ± 5.4a	13.1 ± 1.6a	12.6 ± 1.1c
Thiamethoxam	45.8 ± 5.5a	28.5 ± 5.4a	13.4 ± 1.6a	13.8 ± 1.1a
Clothianidin	–	30.8 ± 5.4a	–	13.4 ± 1.1ab
ANOVA				
F	1.0	2.8	3.6	5.5
df	215.3	327	214.4	3182.9
$P > F$	0.3812	0.0594	0.054	0.0012

early season growth of crop plants. Possible confirmation of the growth-stimulating effects of neonicotinoids was observed in this study in 2010 and 2011; both stand counts and plant heights were generally greater in rice treated with thiamethoxam or clothianidin than in untreated rice or in rice treated with chlorantraniliprole, although the effect was significant only for plant heights in 2011 (but marginally significant for plant heights in 2010 and stand counts in 2011). Finally, treating fields with the newer seed treatments rather than foliar applications of pyrethroids will likely have fewer adverse effects on non-target *Procambrus* crawfish, which are cultured with, or in close proximity to, Louisiana rice fields. This reduced impact results not only from the lower inherent toxicity of the newer active ingredients towards crawfish (Barbee and Stout, 2009; Barbee et al., 2010), but also from their application as seed treatments rather than by drift-prone aerial application.

The compatibility of integrated pest management with prophylactic pest management approaches such as the use of *Bt* crops and insecticidal seed treatments is an important question, particularly from the perspective of managing insecticide resistance (Frisvold, 2009; Hoy, 2009). In rice in Louisiana, however, the ubiquity and serious nature of the primary target pest, the efficacy of the seed treatments, the potential threats posed by several sporadic pests, and the reduced impact of seed treatments relative to foliar pyrethroid applications on non-target *Procambrus* crawfish argue strongly for a role for prophylactic seed treatments in an integrated management program. Further work is necessary to document the benefits of seed treatments on rice growth and yields and to integrate the use of seed treatments with other management tactics.

Acknowledgments

The authors gratefully acknowledge the assistance of the following rice farms and farmers: Angelina Plantation, F. Cramer, C. Dauzat, R. Dauzat, C. Fontenot, M. Fruge, R. Hardee, J. Hensgens, D. Hoffpauir, A. Horton, K. LaHaye, A. Lawson, N. Lejeune, D. Morein, M. Pousson, R. Ratcliff, G.Simon, W. Simon, M. Stelly, B. Wild, and T. Wild. The authors also acknowledge the following LSU AgCenter extension specialists and agents: R. Levy, D. Burns, B. Courville, T. Clark, G. E. Daniels, V. Deshotel, C. E. Eskew, R. Ferguson, K. Fontenot, S. Gauthier, D. Lee, M. Martin, J. Meaux, and D. Zaunbrecher and. The following crop consultants and industry representatives also assisted with the trials: D. Denais, R. Elston, B. D. Fontenot, D. Fontenot, K. Guillory, R. Gilder, C. Greene, T. McCown, C. Minter, D. Reed, R. Verret and J. Zaunbrecker,. D. Albano, N. Colligan, J. Fryoux, T. Pasco, L. Thompson and M. Frey assisted with the collections and processing of core samples. This project was supported by Hatch funds from the USDA National Institute of Food and Agriculture. Demonstration trials were also financially supported by the Louisiana Rice Research Board, DuPont Crop Protection, Crowley Grain, FMC Corporation, G&H Seed Company, Landis International, Syngenta Crop Protection, and Valent USA Corporation. Approved by the Director, Louisiana Agricultural Experiment Station, manuscript number 2013-234-11842.

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