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OCCURRENCE AND ABUNDANCE OF *LISSORHOPTRUS ORYZOPHILUS* (COLEOPTERA: CURCULIONIDAE) RELATIVE TO FIELD BORDERS IN CALIFORNIA RICE

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Abstract

Field experiments were conducted during 2009 and 2010 on commercial rice fields in the Sacramento Valley of California to validate observations regarding the prevalence of immature populations of the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae), near field borders, and to assess their impact on yield. In 5 commercial fields, insecticide-treated and untreated plots were established 4.5, 30 and 60 m from one edge of the field. Soil core samples were collected on 2 dates and inspected for *L. oryzophilus* immatures. Rice yields were determined by harvesting 15 m^2 plots in 2009 or 1 m^2 per plot in 2010. Analysis of variance (ANOVA) showed that in most locations, immature populations were higher in plots 4.5 or 30 m from the field's edge than in plots 60 m from the field's edge. Yields from treated and untreated plots did not differ significantly. Linear regression of immature populations and rice grain yield per plot per location did not yield a significant, inverse density-yield relationship. Results indicate that border applications of insecticides for *L. oryzophilus* management are appropriate; however, growers are advised to inspect their fields to confirm border populations and effects on yield. Research needs regarding sampling and economic thresholds are discussed.

Key Words: *Oryza sativa*, rice water weevil, field border, border treatments

Resumen

Durante los años 2009 y 2010, cinco experimentos fueron realizados en campos comerciales de arroz en el valle del río Sacramento en California, para confirmar observaciones previas respecto a la distribución de inmaduros del gorgojo acuático del arroz, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae), cerca a los bordes del campo y su impacto en el rendimiento. En cada campo se establecieron un par de parcelas experimentales, una tratada con insecticida y otra sin tratar, a 4.5, 30 ó 60 m del borde del campo. En dos fechas se colectaron muestras de suelo para determinar la densidad poblacional de inmaduros del gorgojo. Para determinar los rendimientos, en el 2009 se consecharon las parcelas experimentales completas (15 m^2) y en el 2010 se cosechó una muestra de 1 m^2 por parcela. El resultado del análisis de variancia mostró que en la mayoría de los experimentos las poblaciones de inmaduros del gorgojo fueron mayores en las parcelas que estaban a 4.5 ó 30 m del borde del campo que en las parcelas que estaban a 60 m del borde del campo. Los rendimientos de las parcelas tratadas o sin tratar fueron estadísticamente similares. No se encontró una relación lineal inversa entre el rendimiento de las parcelas y el número de inmaduros. Los resultados indican que las aplicaciones de insecticidas en los bordes del campo para controlar *L. oryzophilus* son apropiadas. Sin embargo, los productores deben monitorear sus campos para confirmar la presencia de *L. oryzophilus* en los bordes y su efecto en el rendimiento. Finalmente, se incluye una discusión acerca de la necesidad de desarrollar métodos de muestreo y niveles de daño economico.

The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae), is the most important pest of rice, *Oryza sativa* L., in the United States (Way 2003). The insect was first found in California rice in 1959 (Lange & Grigarick 1959) and has since been considered an important pest (Godfrey & Espino 2009). Both adults and larvae feed on rice, but only the larvae, which feed on developing roots, are considered damaging. Larval root pruning causes stunting, chlorosis, and reduction of shoot biomass and tillers produced (Zou et al. 2004a).

In California, border and levee insecticide applications are recommended for *L. oryzophilus* control (Godfrey & Espino 2009). The majority (> 99%) of applications with insecticides labeled for this pest are applied by an airplane (DPR 2009). Generally, applications consist of 1 or 2 passes along field borders and 1 pass over levees. Average airplane swath is 15 m, therefore, 1 or 2 airplane passes will cover 15 or 30 m from the field border, respectively. This recommendation was developed soon after *L. oryzophilus* was found in California, and is based on field observations and few published studies (Lange & Grigarick 1959; Grigarick 1964, 1970; Cuneo & Godfrey 1998). Since the publication of these studies, many cultural and pest management practices have changed in California rice culture (Hill et al. 2006); however, border treatments are still common. Validation of early observations regarding *L. oryzophilus* border distribution is needed so growers can - with confidence - continue to limit insecticide applications to field borders.

Rice grain yield losses due to *L. oryzophilus* in studies conducted in California have ranged from 21% to 86% (Godfrey & Palrang 1996; Hesler et al. 2000). In these and earlier studies (Grigarick 1970; Grigarick & Way 1978), artificial infestation of experimental plots was used to simulate commercial field conditions. Results from these studies show that the potential for yield reduction exists; however, the impact of natural infestations on commercial fields has not been documented. Research conducted in other rice producing states has shown that yield reductions due to *L. oryzophilus* can be greatly affected by cultivar, cultural practices and other management factors, and environmental conditions (Stout et al. 2002; Tindall & Stout 2003; Zou et al. 2004b; Espino et al. 2009). Research is needed to determine the impact of *L. oryzophilus* in California commercial rice fields under current management practices.

The objectives of the studies reported herein were to validate observations regarding the prevalence of *L. oryzophilus* larval populations around field borders, and to assess their impact on yield in commercial rice fields.

Materials and Methods

Experimental Sites

Five experiments were conducted in commercial rice fields located near Colusa, Maxwell and Princeton in the Sacramento Valley of California during 2009 and 2010. In 2009, experiments were conducted in Colusa, Maxwell and Princeton fields (Colusa-09, Maxwell-09 and Princeton-09 experiments), and in 2010, in Colusa and Maxwell fields (Colusa-10 and Maxwell-10 experiments). Colusa-09 and Colusa-10 were conducted in the same field, but in different basins. The basins used were rectangular in shape and between 3.5 and 7 ha. Planting systems differed among years and locations. Princeton-09 and Maxwell-10 experiments were conducted in water-seeded fields, the traditional and most common rice planting system in California. Water-seeding consists of flying pre-germinated seeds onto a flooded field. The Maxwell-09 experiment was conducted in a dry-seeded field. Dry-seeding is performed by flying dry seed onto a dry field and immediately applying water to promote seed germination. Colusa-09 and Colusa-10 experiments were conducted in a no-till, stale seedbed, water-seeded field. The stale seedbed was created by irrigating the field to encourage weed germination before seeding. After the weeds had become established, they were sprayed with a non-selective herbicide and the field was flooded and seeded. Planting, flood application, *L. oryzophilus* sampling dates and other cultural information are presented in Table 1. Seeding, water management, weed control, fertility and cultural practices were typical of California rice (Flint 1993; Hill et al. 2006). After flooding, the flood was maintained in all fields until harvest.

Experimental Plots

At each experimental site, plots were established 4.5, 30 and 60 m from one of the edges of the field. These distances were chosen considering coverage of typical aerial insecticide applications for *L. oryzophilus*. One airplane pass around field borders covered the 4.5 m plots, and two passes covered the 4.5 and 30 m plots. In a typical aerial insecticide application against *L. oryzophilus*, plots 60 m from the field edge are not treated. The edge of the field refers to the field margin formed by the width of the basin, or the headland. Plots were 2.5 × 6 and 2.5 × 4.5 m in 2009 and 2010, respectively. To create a range of *L. oryzophilus* densities that would produce a range of yields, an insecticide treatment was included in the experiments. Treatments assigned to plots were insecticide application (treated and untreated) and distance from the edge of the field. Treated and untreated plots were separated by a 2.5 m buffer of untreated rice plants. Treated plots were sprayed with λ-cyhalothrin (Warrior II, Syngenta Crop Protection, Greensboro, NC) at 33.6 g a.i./ha once in 2009 (at flooding) and twice in 2010 (at flooding and 2 wk later), using a hand-held, CO_2 pressurized, 4 nozzle spray rig (TT110015 Turbo TeeJet Wide Angle Spray tips, 15 gpa). In 2010, to avoid movement of insecticides with irrigation water, treated plots were isolated using barriers made of roofing metal flashing 20 cm high held in place with wood stakes. The metal flashing was pushed into the soil after applying the flood and was removed before harvest. Plots were managed in the same manner as the rest of the field.

Insect Data Collection

Three soil core samples (10 cm diam × 10 cm deep) per plot were collected on 2 sampling dates, about 6 to 8 wk after seeding and 14 d later; cores taken in the first and second sampling dates are herein referred to as first and second core samples, respectively, as indicated in Table 1. To take cores, plots were visually divided in thirds and a core was taken from each third, at 1 m from one of the sides of the plot. For each sampling date, a different side was used. Each core contained the roots of at least one rice plant. Cores were washed following the procedure described in Espino et al. (2009), and *L. oryzophilus* larvae and pupae were counted. For analyses, larval and pupal numbers were combined and considered as immature *L. oryzophilus*.

Yield Data Collection

Rice was harvested from entire plots (15 m^2) and threshed with a small plot combine in 2009, and by hand from a 1 m^2 per plot section in 2010. The 1 m^2 sections were harvested from the center of the plot and plants mechanically threshed immediately after harvest. Past research has shown that harvesting a portion of a plot can be used successfully to evaluate yield (Zou et al. 2004a). Grain yields were converted to kg/ha and standardized to 14% moisture. The experimental design used in all experiments was a completely randomized design replicated 4 times.

Statistical Analyses

All analyses were performed using IBM SPSS Statistics Version 19 (SPSS 2010). Each experiment was analyzed separately. Number of immatures per core per sampling date and rice yields were analyzed using a two way analysis of variance (ANOVA) with fixed factors being insecticide treatment and distance from the edge of the field and random factor replication. To stabilize variances, dependent variables were transformed using ln (x+1) before applying ANOVA. Comparisons among levels of significant factors were made using Fisher's least significant difference (LSD) test. For each experiment, simple linear regression was used to determine the relationship between the average number of immatures per core per plot during first and second sampling dates and yield per plot. Because the planting systems varied among experiments, no attempt was made to pool data from all experiments. The level of a used in all analyses was 0.05.

Results

Lissorhoptrus oryzophilus Prevalence Near Field Borders

In the 2009 experiments, ANOVA results for number of immatures per first or second core samples showed that the interaction between insecticide treatment and distance from the edge of the field was not significant. This indicates that numbers of immatures in treated and untreated plots at different distances from the edge of the field followed the same pattern.

In Colusa-09, significant differences in the number of immatures in first (F = 22.879; df =

Table 1. Agronomic information and important dates for *Lissorhoptrus oryzophilus* experiments in California during 2009 and 2010.

Agronomic practice	Experiment				
	Colusa-09	Maxwell-09	Princeton-09	Colusa-10	Maxwell-10
Planting system	No till, stale seedbed, water-seeded	Dry-seeded	Water-seeded	No till, stale seedbed, water-seeded	Water-seeded
Variety	'M-206'	'M-206'	'M-401'	'M-206'	'M-206'
Planting date	8 Jun	15 May	24 Apr	17 Jun	4 May
Flooding date	8 Jun	17 Jun	24 Apr	16 Jun	4 May
Insecticide application date	6 Jun	15 Jun	23 Apr	15 Jun, 1 Jul	30 Apr, 20 May
First *L. oryzophilus* larval sampling date	21 Jul (6 waf[1])	10 Jul (3 waf)	10 Jun (7 waf)	29 Jul (6 waf)	22 Jun (7 waf)
Second *L. oryzophilus* larval sampling date	3 Aug (8 waf)	27 Jul (6 waf)	23 Jun (9 waf)	12 Aug (8 waf)	7 Jul (9 waf)
Harvest date	8 Oct	8 Oct	10 Oct	2 Nov	21 Oct

[1]waf: weeks after flood

2, 63; $P < 0.001$) and second ($F = 3.724$; df = 2, 63; $P = 0.030$) core samples at different distances from the field edge were found (Fig. 1). In first core samples, there were significantly more immatures per core at 4.5 than at 30 or 60 m from the field's edge. There was no significant difference in number of immatures from plots 30 and 60 m from the field's edge. In second core samples, there were no significant differences in the number of immatures found at 4.5 and 30 m from the field's edge, and at 30 and 60 m from the field's edge. Plots at 4.5 m from the field's edge had significantly more immatures than plots 60 m from the field's edge.

In Maxwell-09, significant differences in the number of immatures at different distances from the field's edge were found in first ($F = 4.300$; df = 2, 63; $P = 0.018$) but not in second core samples (Fig. 1). In first core samples, significantly more immatures were found in plots 4.5 m from the field's edge than in plots 30 or 60 m from the field's edge. There was no significant difference in the number of immatures between plots 30 and 60 m from the field's edge.

In Princeton-09, significant differences in the number of immatures at different distances from the field's edge were found in first ($F = 5.205$; df = 2, 62; $P = 0.008$) but not in second core samples (Fig. 1). In first core samples, significantly more *L. oryzophilus* immatures were found in plots 4.5 and 60 m from the field's edge than in plots 30 m from the field's edge. No significant differences were found in the number of *L. oryzophilus* immatures between plots 4.5 and 60 m from the field's edge.

In the Colusa-10 and Maxwell-10 experiments, ANOVA results for number of immatures per core sample showed that the interaction between insecticide treatment and distance from the edge of the field was significant for second ($F = 5.188$; df = 2, 63; $P = 0.005$) and first core samples ($F = 5.188$; df = 2, 63; $P = 0.008$), respectively. A significant interaction indicates that the differences in number of immatures among distances from the edge of the field did not follow the same pattern for treated and untreated plots. No significant differences in the number of immatures per first or second core samples were found among treated plots at different distances from the edge of the field. However, there were significant differences among the untreated plots. In untreated plots from Colusa-10, first core samples had significantly more immatures ($F = 3.925$; df = 2, 63; $P = 0.025$) in plots 4.5 and 30 m from the field's edge than in plots 60 m from the field's edge. In second core samples, significantly more immatures ($F = 12.231$; df = 2, 63; $P < 0.001$) were found 4.5 from the field's edge than at 30 or 60 m from the edge of the field.

In untreated plots from Maxwell-10, significantly more immatures ($F = 7.906$; df = 2, 63; P

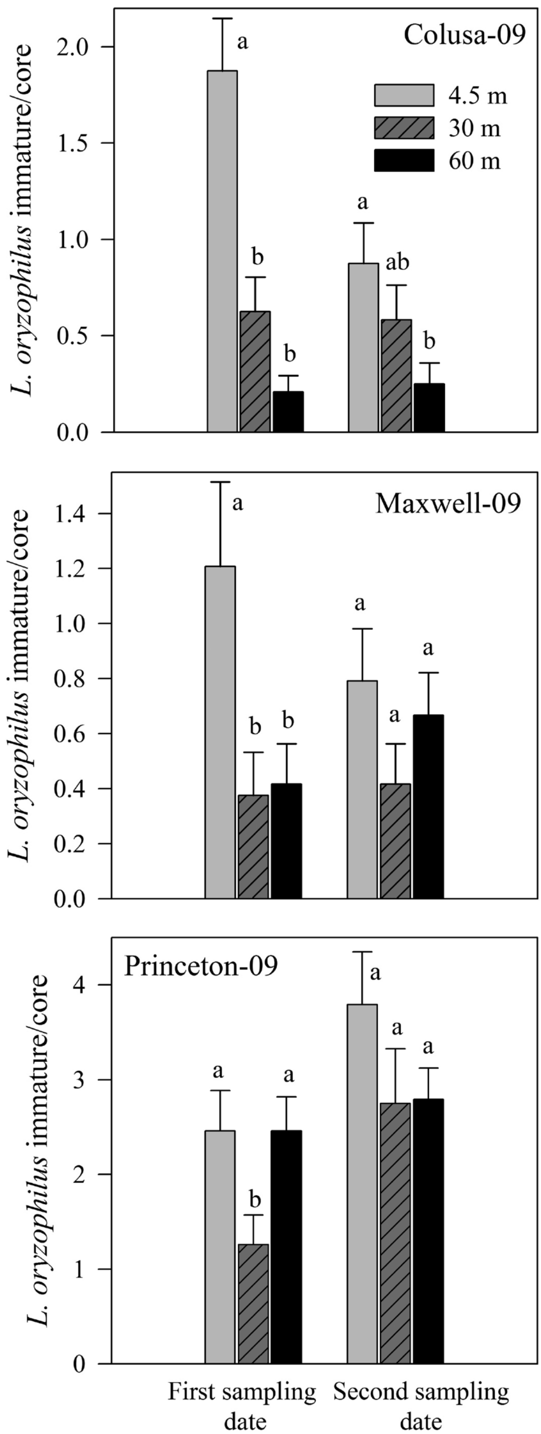

Fig. 1. Mean number of *Lissorhoptrus oryzophilus* immatures per core ± SEM by distance from the edge of the field in Colusa-09, Maxwell-09 and Princeton-09, California, 2009. For each core sampling date, bars followed by different letters are significantly different ($P < 0.05$; LSD).

= 0.001) were recovered at 4.5 m than at 30 or 60 m from the field's edge. In second core samples, significantly more immatures (F = 8.560; df = 2, 63; P = 0.001) were recovered from plots at 4.5 m from the field's edge than from plots 30 or 60 m from the field's edge.

Lissorhoptrus oryzophilus Impact on Yield

To create a range of rice water weevil densities that would produce a range in yields, an insecticide treatment was included in the experiments. In Colusa-09 and Maxwell-09, no significant differences in the number of immatures per first or second core samples were found between treated and untreated plots (Table 2). In Princeton-09, significantly more immatures were found in untreated than in treated plots in first core samples (F = 18.748; df = 1, 62; P < 0.001) (Table 2), but not in second core samples. In the 2010 experiments, very few or no immatures were recovered from treated plots in first or second core samples (Fig. 2 and Table 3).

ANOVA of yields resulted in a non significant treatment by distance interaction and a non significant treatment and distance effect in all experiments, except in Maxwell-10, where the distance effect was significant (F = 13.049; df = 2, 15; P = 0.001). Average yields were 5,750 ± 133.81 kg/ha for Colusa-09, 10446 ± 286.79 kg/ha for Maxwell-09, 11,545 ± 53.29 kg/ha for Princeton-09, and 9,661 ± 153.95 kg/ha for Colusa-10. In Maxwell-10, yields from plots 4.5 m from the field's edge (11,198 ± 457.54 kg/ha) were significantly higher than yields from plots 30 (9,403 ± 194.75 kg/ha) or 60 m from the field's edge (9,031 ± 238.74 kg/ha). There was no significant difference between yield of plots 30 and 60 m from the field's edge.

Simple linear regressions between yield and average number of immatures per core per plot per sampling date for each experiment were not significant, except for Maxwell-10 (F = 11.593; df = 1, 22; P = 0.003 for first core samples; and F = 4.813; df = 1, 22; P = 0.039 for second core samples). For this experiment, the relationship between yield and immature population per core sample was direct and slope estimates were positive.

Discussion

In 4 out of the 5 experiments, immature populations were higher in plots 4.5 or 30 m from the field's edge than in plots 60 m from the field's edge on at least one of the sampling dates (Figs. 1 and 2). In the 2010 experiments, this was observed in untreated plots only. These results agree with previous reports in which immature infestations are found to occur mostly near field borders (Lange & Grigarick 1959; Grigarick 1964, 1970). Only in the Princeton-09 experiment were immatures found at similar densities in plots near and far from the field's edge on both sampling dates (Fig. 1). The immature population density in this experiment was the highest from all experiments (Table 2) and can be considered high for California. In a previous study, Cuneo and Godfrey (1998) found relatively higher larval populations farther from the levee (13.7 m) than close to the levee in 3 out of 17 commercial fields sampled. These results indicate that, although immature populations are commonly higher near borders and levees than farther within the field, infestations can be relatively high far from borders and levees in some cases.

It is unknown why *L. oryzophilus* immature populations in California are usually higher near field borders and levees than towards the center of the field. In the southern United States, where *L. oryzophilus* is considered a major pest of rice, populations and damage are distributed rather uniformly throughout rice fields (Way 2003). Insecticide applications consist of seed treatments or foliar sprays applied to whole fields (Bernhardt 2001; Hummel et al. 2009; Way & Espino 2010). One possible factor influencing the pattern observed in California may be the presence of only parthenogenic females (Godfrey & Espino 2009). In the southern United States, both sexes are present (Way 2003). During the 1970s, *L. oryzophilus* was introduced into Japan, most likely from California (Saito et al. 2005). In Japan, Takeda (1993) found that immature populations were aggregated along the edges of fields early in the season, but distributed randomly later on. Other factors that may influence the distribution of immatures in California rice fields include the presence of permanent levees, grassy weed popu-

Table 2. Mean number of immature *L. oryzophilus* per core sample ± SEM in treated and untreated plots, Colusa-09, Maxwell-09 And Princeton-09, California, 2009.

	First sampling date		Second sampling date	
Experiment	Treated	Untreated	Treated	Untreated
Colusa-09	0.83 ± 0.18 a[1]	0.97 ± 0.21 a	0.44 ± 0.10 a	0.69 ± 0.10 a
Maxwell-09	0.58 ± 0.16 a	0.75 ± 0.21 a	0.53 ± 0.12 a	0.72 ± 0.15 a
Princeton-09	1.31 ± 0.25 a	2.80 ± 0.32 b	3.08 ± 0.43 a	3.14 ± 0.40 a

[1]For each sampling date, means within rows followed by different letters are significantly different (P < 0.05; LSD)

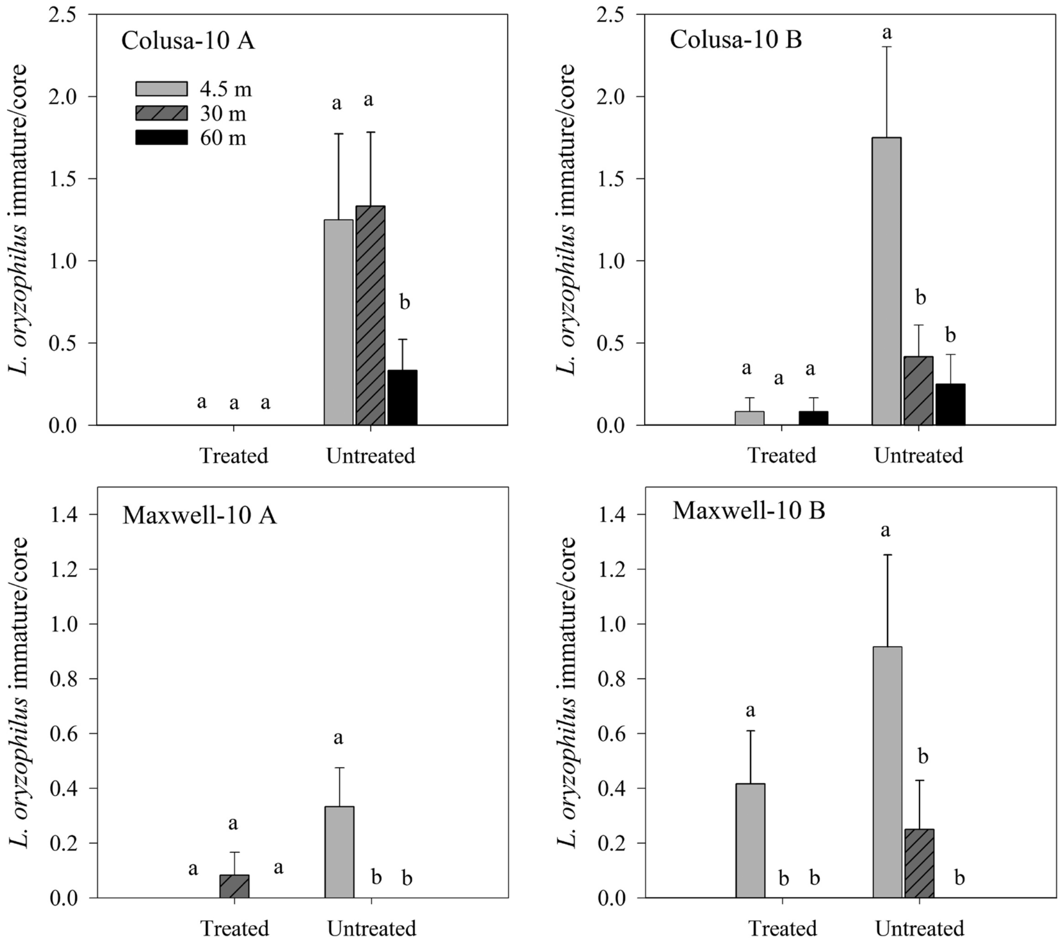

Fig. 2. Mean number of *Lissorhoptrus oryzophilus* immatures per core ± SEM by distance from the edge of the field and treatment for Colusa-10 and Maxwell-10 in first (A) and second (B) core samples, California, 2010. For each treatment, bars followed by different letters are significantly different ($P < 0.05$; LSD).

lations around fields, weather patterns, etc. Research to explain the distribution of immatures in California rice fields is needed.

Treatment with λ-cyhalothrin did not reduce *L. oryzophilus* immature populations in 2009. Only in Pricenton-09 was there a significant reduction in the number of immatures per first core samples in treated plots. However, this effect was not observed in second core samples (Table 2). In 2010, λ-cyhalothrin significantly reduced immature populations in plots 4.5 m from the field's edge in both experiments (Table 3). In plots 30 or 60 m from the field's edge, populations were very low and in some cases no immatures were recovered. Lambda-cyhalothrin kills adults, thereby reducing oviposition and later larval populations; pre-flood soil applications or treatments at the 1 to 3 leaf stage of rice are recommended in California (Godfrey & Espino 2009). When applied to the soil, synthetic pyrethroid insecticides are mostly adsorbed to soil particles and immobilized in the field; however, they can be moved by irrigation with suspended solids and dissolved organic matter (Liu et al. 2004). In Colusa-09 and Princeton-09, λ-cyhalothrin was applied pre-flood. In these experiments, the insecticide in treated plots may have moved off-site, reducing the effectiveness of the application. To restrict pesticide movement with water or soil and reduce *L. oryzophilus* numbers in treated plots in 2010, plots were surrounded by metal barriers and λ-cyhalothrin sprayed twice, before flooding and at the 3 leaf stage of rice. Maxwell-09 experiment was conducted in a dry-seeded field. In this experiment, treated plots were sprayed with insecticide when rice plants were at the 3 leaf stage, before the flood was applied (Table 1). This timing of λ-cyhalothrin application is common for *L. oryzophilus* control in the southern United States (Way & Espino 2010); however, immature popula-

TABLE 3. MEAN NUMBER OF IMMATURE *L. ORYZOPHILUS* PER CORE SAMPLE ± SEM IN TREATED AND UNTREATED PLOTS AT THREE DISTANCES FROM THE EDGE OF THE FIELD, COLUSA-10 AND MAXWELL-10, CALIFORNIA, 2010.

	4.5 m		30 m		60 m	
Experiment, sampling date	Treated	Untreated	Treated	Untreated	Treated	Untreated
Colusa-10, first	0.0 ± 0.0 a[1]	1.25 ± 0.52 b	0.0 ± 0.0 a	1.33 ± 0.45 b	0.0 ± 0.0 a	0.33 ± 0.19 a
Colusa-10, second	0.08 ± 0.08 a	1.75 ± 0.55 b	0.0 ± 0.0 a	0.42 ± 0.19 a	0.08 ± 0.08 a	0.25 ± 0.18 a
Maxwell-10, first	0.0 ± 0.0 a	0.33 ± 0.14 b	0.08 ± 0.08 a	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a
Maxwell-10, second	0.42 ± 0.19 a	0.92 ± 0.34 b	0.0 ± 0.0 a	0.25 ± 0.18 a	0.0 ± 0.0 a	0.0 ± 0.0 a

[1]For each distance, means within rows followed by different letters are significantly different ($P \leq 0.05$; LSD)

tions were not reduced in this experiment. Adult weevils typically move into rice fields when they are flooded (Way 2003). In California, rice fields are typically flooded before seeding, therefore, adult *L. oryzophilus* infestations tend to occur before the 3 leaf stage of rice (Godfrey & Espino 2009). Maxwell-09 was conducted in a dry-seeded field within a farm where all other rice fields were water-seeded. Two flush irrigations (water applied to saturate the soil but not flood the field) were applied to encourage rice seed germination and stand establishment. The early presence of *L. oryzophilus* in nearby water-seeded rice fields may have facilitated infestation and oviposition in Maxwell-09 treated plots during flush irrigations before λ-cyhalothrin was applied, and eggs and larvae may have survived periods of low soil moisture until the flood was established. Experiments conducted in Texas and Louisiana in drill-seeded fields found that adults can infest rice before flood (Way & Wallace 1993; Shang et al. 2004). In California, Hesler et al. (1992) found that eggs are not affected by drainage of fields and that first instar larvae are able to survive periods of no soil moisture. The objective of including an insecticide treatment in the experiments was to create a range of rice water weevil populations that would produce a range of yields. In the 2009 experiments *L. oryzophilus* population differences between treated and untreated plots were not significant; however, a range of populations were obtained by having plots at different distances from the edge of the field.

Yields were not negatively affected by immature *L. oryzophilus* populations. Insecticide treatment significantly reduced immature populations in 2010; this did not translate into significant yield increases in treated plots. The location of plots at different distances from the edge of the field resulted in a range of immature populations for each experiment. However, linear regressions between yield and immature population were not significant. Only in Maxwell-10 were yields and immature numbers significantly related, but with a positive slope. In this experiment, yields of plots 4.5 m from the field's edge were significantly higher than yields of plots 30 or 60 m from the field's edge. Lower yields in plots 30 and 60 m from the field's edge were most likely caused by a heavy watergrass (*Echinochloa* spp.) infestation in the area where these plots were established. Infestation by this weed can cause yield reductions of more than 50% (Fischer et al. 2000). Higher yields due to better weed control in plots 4.5 m from the field's edge explain the positive linear relationship between yield and immature population.

Yield losses due to *L. oryzophilus* infestation in California rice have been documented. Grigarick (1963) recorded yield reductions of up to 32% in rice grown in cages infested with 1 adult weevil per plant; however, he noted that this population level was not representative of California rice fields at the time. Other estimates of yield reduction range from 48 to 65% (Grigarick 1970; Grigarick & Way 1978). More recently, in a small-plot, 3 yr-study, Godfrey & Palrang (1996) found reduced biomass accumulation by rice plants when larval populations were higher than 7 larvae per core. In 2 of the 3 years, a significant relationship was found between yield reduction and larval density with increasing losses at population densities of 4 to 5 larvae per plant. Yield reductions in their study ranged from 21 to 45%. Hesler et al. (2000) found grain yield reductions of 27 and 86% when larval populations averaged 5.8 and 9.5 per core, respectively. Godfrey & Lewis (2004) infested rice small plots with adults at various stages of rice seedling development, obtaining larval populations of up to 9.4 immatures per core sample. They found that infestation with adults at the 2 leaf stage produced 50% yield reduction. All these studies suggest that rice yield reductions in California due to *L. oryzophilus* occur when population levels are between 4 and 9.5 larvae per core. In the studies presented here, populations were lower than this level in all except one experiment, Princeton-09. Low *L. oryzophilus* populations explain why yield losses were not observed. In Princeton-09, the variety used was 'M-401', a medium grain, premium quality, late-maturing variety. The studies mentioned above used the popular medium grain varieties 'M-202' or 'M-206'. Unfortunately, no information is available about the response of 'M-401' to *L. oryzophilus* infestation, and because this variety was only used in 1 experiment, it is impossible to conclude if this variety is more tolerant to *L. oryzophilus* than other commonly planted medium grain varieties.

Considering that aerial application of insecticides for *L. oryzophilus* management can cover the area between the field margin and 30 m into the field, results of the experiments presented here indicate that border applications target the areas with higher *L. oryzophilus* populations. Currently, there are no established economic injury levels for *L. oryzophilus* in California. Because of this, it cannot be concluded that the populations found 4.5 or 30 m from the field's edge are above the economic injury level or that populations found 60 m from the field's edge are below this level.

Based on these experiments, the recommendation to treat only the area adjacent to field borders is still valid in most cases. Growers need to inspect their fields by looking for adults and their feeding scars in rice leafs to determine if infestations are limited only to field borders. Growers should evaluate the effect of *L. oryzophilus* infestation in their fields to determine if insecticide applications are needed. In the past, the need for an insecticide application was determined by sampling *L. oryzophilus* adult feeding scars (Flint 1993). The ban of the insecticide carbofuran and the adoption of pyrethroid insecticides for *L. oryzophilus* control rendered this practice ineffective. Commercial sampling methodologies and economic thresholds need to be updated. Currently, growers rely on past experiences and field history to make management decisions. Research is needed to determine practical sampling methodologies and economic thresholds that growers can use to make decisions regarding *L. oryzophilus* control.

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