Influence of Three Types of Borders on Field Evaluation of Insecticides for Fall Armyworm (Lepidoptera: Noctuidae) Control in Seedling Corn[1,2]

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ABSTRACT The performance of insecticides when applied against the fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), larvae in whorl stage corn was studied in relation to larval movement within and between test plots. The effectiveness of individual treatments varied in accordance with their toxicity to FAW. The degree of FAW suppression was critically influenced by the type of adjacent treatment (Exp 1). Side-by-side experimental plots with no borders gave results that made better performing insecticides look worse than they were, while poorer performers looked better. Plots having fallow (tillage only), untreated, and insecticide-treated borders (Exp 2) contained 21, 14, and 9% dead plants, respectively, from FAW feeding. Methomyl and monocrotophos gave the greatest control of FAW larvae, while trichlorfon and carbaryl were the least effective insecticides. Permethrin gave poor control with one application but improved with multiple applications to equal the effect of the methomyl standard after three applications. Azinphosmethyl gave slightly better control of FAW larvae than did carbaryl or trichlorfon but was not as effective as methomyl. Reinfestation of whorl stage corn by FAW larvae occurred with all treatments and border types. The greatest reinfestation occurred after the first of three weekly applications. Studies suggested that border types, adjacent treatments, and cumulative effect of multiple applications are factors that critically influence the performance of insecticides applied to FAW larvae in small field plots.

KEY WORDS Fall armyworm, *Spodoptera frugiperda,* corn, insecticide evaluation.

Movement of fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), just after hatching or during first instar to adjacent plants, has been reported by Luginbill (1928) and Morrill and Greene (1973). Movement of larger larvae is largely undocumented. Luginbill (1950) indicated that when larvae consume all the food available at a site they will "mass together and crawl or 'march' in search of other food." Navas (1974) indicated that in insecticide treatments there "was a reduction in the number of larvae on the check and the urea treated plots due possibly to migration within the plots and sampling errors." Hodjat (1970) reported a significant increase in walking movement with crowding of *S. littoralis* (Boisduval)

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when the larvae were reared with 10 or more larvae per 500 ml cage. Morrill and Greene (1974) suggested that larval movement occurs between rows. They did not give data to support this movement but indicated that survival of larvae was inversely related to density of larvae per plant. Joyce (1952) working with the insect pest, *Empoasca libyca* de Berg (Jassidae), noted that "in small-scale spraying experiments infestation by this pest on the unsprayed plots fell after spraying to a level comparable with that on adjacent sprayed plots." Joyce and Roberts (1959) suggested that populations of mobile insect species "are in dynamic equilibrium, whereby numbers lost by emigration are balanced by immigration." They also indicated that spraying with insecticides changes the distribution (i.e., disturbs the equilibrium) and continues until the previous equilibrium or a new equilibrium is achieved. They adopted the term 'interplot effect' to describe the interaction between adjacent plots. Joyce and Roberts (1959) increased the distance between sprayed plots from adjacent to seven times the plot size. They found that cotton yields remained high for adjacent plots but decreased with increasing distances between sprayed plots. The decreasing yields were attributed to increased insect population pressure that occurred in the untreated areas between the treated plots.

Preliminary experiments in Georgia (Experiment 1) utilizing field plots adjacent to each other in a RCB design illustrated that insecticide trials with these typical designs demonstrated similar results as those reported by Joyce (1952, 1956). Thus, it appeared that typical plot size was not sufficient to stop highly mobile insects from influencing the neighboring plots. Therefore, we designed an experiment where the effects of movement on all possible pairs of a group of recommended insecticides and borders were evaluated (Experiment 2).

Methods and Materials

Experiment 1. In an insecticide screening program using standard statistical designs, such as the RCB used in this study, we observed that insecticide treatments that were expected to give excellent insect control (Harrell et al. 1977, Bass 1978, Young 1986) did not. The arrangement of the plots in relation to neighboring plots posed the real problem that Joyce and Roberts (1959) and we observed when working with highly mobile insects. Checks and poorer insecticide treatments demonstrated insect control better than expected. The trial was conducted in a field (Tifton, GA) with young field corn (DeKalb XL-19) planted at 49,400 plants per ha. that was 100% infested with FAW. The trial was composed of 39 treatments of insecticide formulations. Some of the treatments were several rates of a single formulation; some were different formulations of an insecticide; and some were different manufacturer's product of the same basic chemical. Included among the treatments were untreated checks. Each plot was 2 rows × 6 m in size. These treatments were applied three times in accordance with established procedures following label directions with a plot sprayer using 38 l/ha. Efficacy was measured by counting the number of damaged plants in six meters of row before each application and counting the plants showing new damage in the whorl 48 hours after treatment. A performance index was calculated by dividing the post-treatment count of damaged plants by the pre-treatment count and multiplying by 100. The treatments were placed in a RCB design with 4 reps, and data were analyzed using analysis of variance techniques (Service 1972).

Experiment 2. Six insecticides approved by the EPA for FAW control in corn and an untreated check were chosen to give a range in potential field plot response. Trichlorfon and carbaryl were considered to give poor FAW control because of resistance (Bass 1978, Young and McMillian 1979); permethrin and azinphosmethyl, fair control; and monocrotophos and methomyl, good control (Harrell et al. 1977).

DeKalb XL-19 field corn was planted Aug. 5, 1977, at 45,000 plants/ha (Tifton, GA), using an in-furrow application of 2.2 kg AI/ha carbofuran + 2.2 kg AI/ha phenamiphos and recommended fertilizer. Prior to planting, 3.76 kg AI/ha butylate was incorporated into the rows. To insure a stand and allow the seedling plants to grow to a size having a leaf surface suitable for this study, a blanket treatment of 0.84 kg AI/ha monocrotophos was applied to control small FAW larvae, and 2.2 kg AI/ha zinc ion-maneb complex was applied to control blight and rust.

Three applications of insecticide were made at weekly intervals. The weekly applications were made so that reinfestation and establishment could occur before the next treatment was applied. Infestation counts were made prior to insecticide application, and evidence of new damage was determined 48 hours later.

Infestation counts were made on all plants in each plot by inspecting the whorl. Any visible damage to the unfurling leaf caused the plant to be classified as infested. No attempt was made to quantify the amount of damage nor the number or size of larvae occurring in each plant.

Stand counts were taken prior to the initiation of the experiment on Aug. 23 and after termination on Sept. 16. As dead plants do not support FAW larvae as feeding sites, infestation data for the 3rd application period were corrected to reflect the fewer number of plants available for feeding and/or infestation.

The experimental layout was a split plot design where the main plots consisted of a RCB with 2 reps and 3 types of borders: fallow (tillage only), untreated, or treated with methomyl. Each main plot consisted of a BIB with 21 pairs of the 7 treatments or 42 subplots and each treatment appeared 6 times (BIB, plan 11a, Cochran and Cox 1957 - Analysis in Table 1). Each subplot was 4 rows × 6 m in size. There were 21 left- and right-sided subplots. One pair of teatments occupied a left- and right-sided subplot. Left-sided subplots had 2 rows of border on the left and the assigned treatment on the right 2 rows. Right-sided subplots were reversed in that the right 2 rows were borders. The data were analyzed with the analysis of variance model (Cochran and Cox, 1957) with a computer program using the method of fitting constants (Service 1972, PROC REGR). Means were adjusted using the same computer program. The adjusted means were separated by hand using the Duncan's procedure (Cochran and Cox, 1957).

Results and Discussion

Experiment 1. Each application period produced significant differences in performance index (Table 2). Note that the ratio of the mean squares (MS) for treatment and error decreased with the second application, and all MS increased dramatically with the 3rd application. The FAW population seemed to be waning during the 2nd application but was increasing by the 3rd application that may have coincided with a new generation. It is evident that a few of the treatments were effective. Other treatments were inconsistent among the replications which may have exaggerated the MS with the 3rd application. Examination of key treatments and their placement in the field plan revealed that their performance was dependent upon their neighboring treatments and not on field location. If these neighbors were exerting that much influence on the center treatment, then a reasonable analytical method would be to adjust the center plot by the performance of its neighbors so as to better ascertain treatment effects. Therefore, we adjusted for the neighboring plots using the method described by Pearce and Moore (1976). This method removes sums of squares (SS) from rep, experimental and sampling error terms. The side and end components are treated as covariates, and the results of the analysis are shown in Table 2. Both covariates were highly significant in all 3 treatment periods having reduced the rep plus both error SS by 84.4, 70.8, and 77.7%, respectively.

Means of selected treatments classified as knock-out (high kill rate), knock-back and hold (moderate kill rate with a residual effect), and knock-back (moderate kill rate) are presented in Table 3. Thus, protection could be gained by using a knock-out insecticide (methomyl) or a knock-back and hold insecticide (permethrin). The performance index indicates the ability for the insecticide to immediately stop damage to the plants; therefore, any mean < 100 indicates that the plants were being protected from further FAW damage.

These results showing the effects on insecticide performance were used as a basis for incorporating border effects in designing Experiment 2. In Experiment 2, the parameters associated with neighboring effects were evaluated to show how to obtain unbiased performance data from field evaluation of insecticides.

Experiment 2. No significant differences were found among the means of the initial stand count, indicating a reasonably uniform stand among all plots (Table 4). There were significant differences among the means of the final stand count for three borders and seven treatments. The greatest reduction in stand occurred with

Table 1. Analysis of Variance of BIB design when it is a split in a RCB design as recommended by Cochran and Cox (1957).*

Source of Variation	df
Total	503
Between replications for Border treatments	1
Among Border treatments	2
Main plot error (Error a)	2
Among the reps of 7-pair groups within main plots (Error b)	12
Among insecticide treatments	6
Interaction between Borders and Insecticides	12
Interaction between main plot reps and Insecticides	6
Among the 7 blocks (pair of insecticides) within main plots and 7-pair groups (Error c)	108
Between rows within each insecticide plot (Error d)	252
Residual Error	102

* Error b can be used to test main plot effects in the event that Error b MS > Error a MS. Error c is the measure of error associated with the insecticide plots and thus is used to test subplot effects. Error d can be used to test subplot effects in the event that Error d MS > Error c MS.

Table 2. Mean Squares (MS) for performance index for the three applications.*

		First		Second		Third	
Source of Variation	df	MS	F	MS	F	MS	F
Among Replications	3	9375	17**	4581	8**	16553	3**
Among Treatments	38	2552	5**	2328	4**	10929	2**
Experimental Error	114	561	2*	472	1	5881	1
Sampling Error	156	262	—	609	—	4833	—
†							
Among Treatments	38	2418	31**	2315	13**	10788	9**
End Neighbors	2	7794	101**	17552	100**	187017	153**
Side Neighbors	2	6225	80**	9393	54**	70006	57**
Residual Error‡	269	77	—	176	—	1222	—
Percent Reduction in Rep+Exp.+Samp. MS		84		71		78	

* *, ** indicates F-test significant at 5 and 1% level of probability, respectively.

† Adjusted MS for performance index for the three application periods when adjusting for end and side neighbors.

‡ End and side neighbor adjustments affect sums of squares for Among Replications, Experimental Error, and Sampling Error.

the poorer treatments (note trichlorfon and carbaryl, 29 and 37%, respectively, with the fallow border and 19 and 16%, respectively, for untreated borders). Note also that with the treated border, none of the chemicals was associated with a significant reduction in stand. The greatest loss in plants among borders occurred in the fallow with 21%; 14% with untreated; and 9% with methomyl treated. The stand in the methomyl treated borders was significantly different ($P < 0.05$) from the fallow borders but not different from the untreated. It was expected that loss in plants in the fallow vs. treated border would have been similar with the greatest loss in the untreated. This is based on the assumption that the untreated border would provide more and larger larvae to be controlled and act as a reservoir for reinfestation. However, in this experiment this was not observed; the greatest loss

Table 3. Example of means for performance index from analysis of variance (ANOVA) and analysis of covariance (ANCOVA) (Table 1).*

		Application 1		Application 2		Application 3	
Insecticide (Formulation)	kg AI/ha	ANOVA	ANCOVA	ANOVA	ANCOVA	ANOVA	ANCOVA
Permethrin	0.22	57 a-i	58 e-h	22 a-c	22 ab	58 a	54 ab
FMC35171†	0.22	90 j-m	88 n-q	82 kl	80 n	111 a-d	119 g-k
BAS 9009†	0.22	47 a-e	51 c-f	19 a-b	22 ab	68 a	61 a-d
Azinphosmethyl	0.84	51 a-f	50 b-e	45 b-i	44 e-j	104 a-c	102 d-j
Methomyl	0.67	44 a-d	44 bc	43 a-i	39 c-h	89 ab	76 a-f
FMC30980†	0.22	95 lm	93 pq	51 e-j	55 h-l	114 a-d	131 h-l

* Means not followed by the same letter within the same column are significantly different at the P = 0.05 level, Duncan's NMRT.

† Selections of compounds including pyrethroids out of a screening study containing multiple compounds at various rates to demonstrate plot effects.

Table 4. Mean number of living plants in test area before (Pre) and the % remaining after (Post) 3 applications of each treatment.*

	Border Type					
	Fallow		Treated		Untreated	
Treatment	Pre	Post %	Pre	Post %	Pre	Post %
Trichlorfon	23.7 a	71 d	25.0 a	93 a	25.1 a	81 bc
Carbaryl	24.1 a	63 d	24.7 a	85 a	25.1 a	84 bc
Permethrin	24.4 a	82 bc	24.3 a	92 a	25.3 a	90 b
Azinphosmethyl	24.3 a	83 bc	25.3 a	92 a	25.5 a	83 bc
Monocrotophos	25.6 a	95 a	25.1 a	94 a	25.3 a	90 b
Methomyl	24.8 a	89 ab	24.9 a	93 a	25.8 a	100 a
Untreated control	24.3 a	71 d	25.8 a	84 a	25.0 a	75 c
Mean Percent Dead Plants*, †	21 b		9 a		14 ab	

* Means not followed by the same letter within a column are significantly different at the P = 0.05 level, Duncan's NMRT (line for mean percent dead plants).

† Dead plants after 3rd application.

occurred in the fallow border. The plot size used in this study was not sufficient to prevent FAW larvae from moving from non-adjacent plots and from grass borders to the field.

The methomyl plots had the lowest percent infested plants of any treatment (Table 5). Monocrotophos, which was expected to be equal to methomyl, exhibited significantly lower FAW control and higher FAW reinfestation at both the 1st and 2nd applications but was equal at the 3rd. Permethrin, expected to give less control than methomyl (Harrell et al. 1977), gave significantly lower FAW control in the 1st application but increased in performance until it was similar at the 3rd application. This type of activity by permethrin has been reported (Personal communication) on cotton also when used in multiple applications. Azinphosmethyl and tricholorfon gave similar FAW control for applications 1 and 2, but azinphosmethyl demonstrated significantly better control with the 3rd application. Neither compound reduced the number of infested plants relative to the untreated check at the 1st application but did so at both the 2nd and 3rd applications. Carbaryl performed as expected and the number of infested plants was similar to the number found in the untreated check plots at all 3 applications. FAW populations in Georgia have been reported to be resistant to carbaryl (Bass 1978, Young and McMillian 1979).

There were significantly more plants infested after one application in the fallow border than in the treated, with the untreated being intermediate (Table 6). However, with the 2nd and 3rd applications, the plots in the treated border were significantly less infested than either the fallow or untreated. This is probably explained by the effects of the treated border eliminating the migration of FAW larvae from inside and outside the plot.

Table 5. Mean percent corn plants infested with FAW larvae before (Pre) and after (Post) foliar applications of each treatment. Corn was planted 8/5/77 using 2.2 kg AI/ha carbofuran in-furrow in all treatments.*

		Application dates†					
		8/26/77		9/2/77		9/9/77	
Treatment	kg AI/ha	Pre	Post	Pre	Post	Pre	Post
Trichlorfon	1.7	100	90 d	89 b	84 c	96 de	72 c
Carbaryl	2.2	100	92 d	91 b	93 d	100 e	83 d
Permethrin	0.45	100	77 c	84 ab	56 b	56 b	38 a
Azinphosmethyl	1.1	100	92 d	86 ab	84 c	89 d	63 b
Monocrotophos	0.8	100	70 b	82 ab	57 b	64 c	39 a
Methomyl	0.7	100	56 a	77 a	37 a	46 a	34 a
Untreated control		100	94 d	89 b	94 d	100 e	90 d

* Means not followed by the same letter within a column are significantly different at the P = 0.05 level, Duncan's NMRT.

† Stand count for 3rd application corrected for dead plants.

Table 6. Mean percent plants infested with FAW larvae before (Pre) and after (Post) 3 foliar applications of insecticides with 3 types of border.*

	Application dates†					
	8/26/77		9/2/77		9/9/77	
Border Type	Pre	Post	Pre	Post	Pre	Post
Fallow	100	89 b	91 a	79 b	87 b	69 b
Treated	100	73 a	85 a	59 a	69 a	45 a
Untreated	100	83 ab	94 a	78 b	83 b	65 b

* Means not followed by the same letter within a column are significantly different at the P = 0.05 level, Duncan's NMRT.

† Stand count for 3rd application corrected for dead plants.

The effects of borders on the cumulative mean percent reduction or clean-up in infested plants (Mean of values presented in Figure 1) were significantly greater (75%) in the treated than in either the untreated (58%) or the fallow (46%) border, while the fallow and untreated borders were not significantly different. It has been observed that FAW will oviposit on uninfested plants over infested when given a choice (unpublished data). Other factors are the pressure that results from high populations and the dispersal behavior that results from multiple larvae per plant as described by Joyce (1956), Joyce and Roberts (1959), Luginbill (1928, 1950), Morrill and Greene (1973, 1974) and Navas (1974). There were more plants and they were more virgorous in the treated border plots (data not collected) regardless of insecticide than those plants in the untreated or fallow border plots. It was unexpected that the fallow border plants were more severely damaged than were the untreated border plants (mean percent dead plants, Table 4).

The cumulative effect of applications varied considerably among individual treatments (Figure 1). The cumulative mean reduction in percent plants infested in the methomyl treated plots was 118% with treated borders, 102% with untreated borders, and 76% with fallow borders. The methomyl results are partially explained by the phenomenon discussed concerning the borders in the previous paragraph. Azinphosmethyl followed the same pattern, with 60, 45, and 33% reduction for treated, untreated and fallow borders, respectively. Carbaryl had 67, 22, and 9% reduction for these respective border types.

Generally, the insecticides that gave the best FAW control, methomyl, monocrotophos, and permethrin, ranked similarly within each border (Figure 1) producing maximum reduction in infested plants with all applications. The poorer insecticides, such as carbaryl, varied with the performance between borders and applications, with inconsistent reductions for each application. For example, with the 3rd application of carbaryl, there was a net increase (-7%) in damaged plants in the plots with the fallow border, but decreasing 38% with the treated border, and 7% with the untreated border.

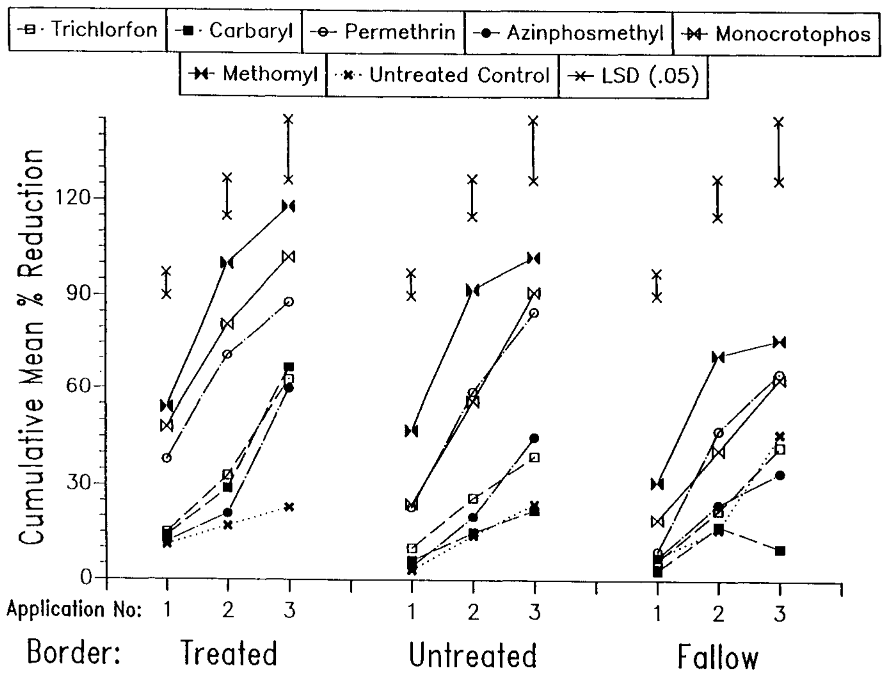
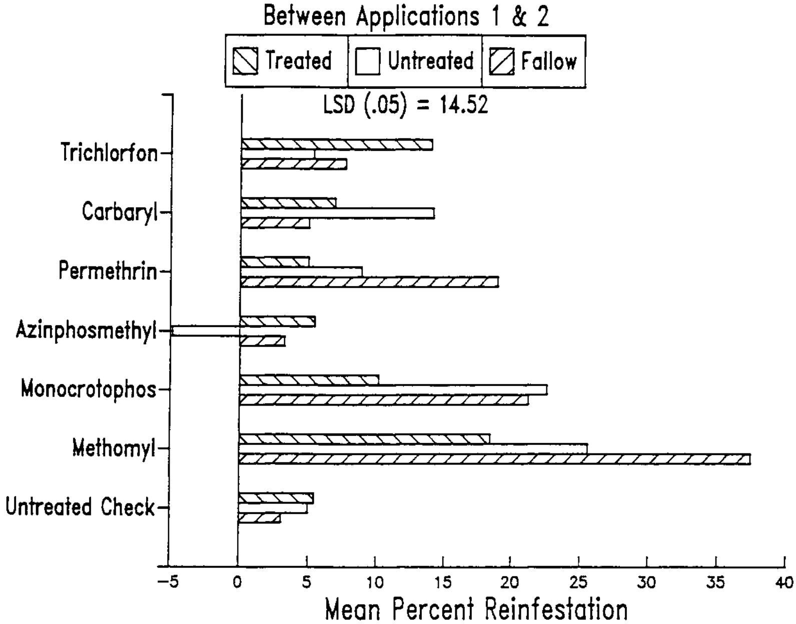


Fig. 1. Mean percent reduction in the number of plants with FAW infested whorls (pretreatment less posttreatment) for 3 border types and three applications of insecticide.

None of the insecticides gave adequate plant protection from FAW damage with a single application. This is indicative of the difficulty of controlling FAW in corn with insecticides using conventional application equipment (Young 1986). Also, cumulative reduction in infested plants in the plots over the three applications exceeded 100% in both the treated and untreated borders with methomyl, while monocrotophos exceeded 100% in the treated. However, neither insecticide exceeded 100% in the fallow border. This is believed to be an indication of the population pressure, e.g. oviposition and larval dispersal, within each border type (Morrill and Greene, 1973).

FAW reinfestation was affected by both the border treatments and the performance of the insecticides. The means were corrected by including dead plants (Mean of values presented in Figure 2). Reinfestation was higher, as expected, during the interval between the 1st and 2nd applications when compared with the 2nd and 3rd. During the first interval, the least ($P > .05$) reinfestation (9.3%) occurred in the fallow border versus the treated (11%) and untreated (14%). Because the plants were in better condition during this interval, the untreated border plots acted as a reservoir for reinfestation. The FAW behavior of dispersing when crowded would subject the fallow and the treated border plots to increased larval pressure. However, during the second interval, the greatest reinfestation occurred with the treated (10%) ($P < .05$) border. It also had the least number of dead plants (Table 4) of the border types. The plants in the untreated border declined in reinfestation from the first interval to the second interval (14 vs. 2.4%) indicating that the remaining plants were of such low quality that they were no longer attractive, nor could they support the population that was present. The plants in the treated border did not change in reinfestation (11 vs. 10%) indicating that the remaining plants were still attractive for reinfestation and could support the present population pressure. The plants in the treated border were protected, while the plants in the untreated border were not. Therefore, the plants died from excessive FAW damage. There was a 25% reduction in the number of plants remaining in the untreated check in the untreated border (Table 4), thereby acting as a reservoir of FAW during the 1st interval but was not a source during the 2nd.

FAW reinfestation of plants in the treated plots was related to the degree of control achieved with each insecticide. The insecticide treatments that had the greatest decrease in infested plants after treatment also had the greatest reinfestation. In interval 1, methomyl and monocrotophos demonstrated 18 and 10% reinfestation and during interval 2, 13 and 8%, respectively. Those insecticide treatments that gave the intermediate control had the least reinfestation, even to the point of a decline in reinfestation. In interval 1, permethrin and azinphosmethyl demonstrated 5 and 6% reinfestation and during interval 2, -1 and -1%, respectively. Those insecticide treatments that gave the least control had intermediate levels of reinfestation. In interval 1, trichlorfon and carbaryl demonstrated 15 and 7% reinfestation and during interval 2, 2 and 1%, respectively. The varying levels of reinfestation were due partially to how many plants were remaining and the quality of those plants. Insecticides that provided good protection increased survival of plants which were then available for reinfestation.



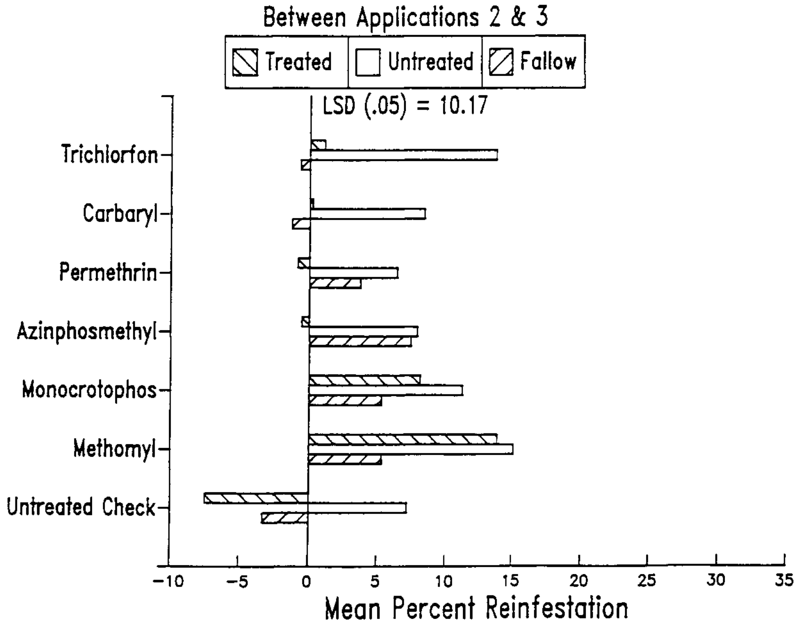


Fig. 2. Mean percent reinfestation by FAW of corn whorls with three types of plot borders during the interval between applications 1 and 2, and between applications 2 and 3 of insecticides.

The data presented indicate that for field evaluations of insecticides applied to small plots, some factors should be considered to determine their effectiveness against FAW. These factors are: the type of border surrounding the plots, the effects of adjacent treatments on individual insecticides, and the cumulative effect of treatment applications. This study revealed interactions that were measured directly by the BIB design. The interaction was the inconsistent behavior of the treatments with the borders and repeated applications.

In field evaluation of insecticides, the treatment plots must be free from adjacent plot influences. The neighboring plots analysis can be used to minimize inter-plot influences when mobile insects are present, such as the FAW. This correction is necessary because their mobility is a major contributing factor to inter-plot influences. The BIB uses proximity as a design feature to measure the inter-plot influences. Both analyses were able to measure gross effects of the insecticides. But only the BIB could measure directly the confounding effects produced by adjacent plots. Therefore, this BIB design is recommended for field testing insecticides for their effectiveness against FAW in corn.

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