Insecticidal Management of *Eoreuma loftini* (Lepidoptera: Pyralidae) on Texas Sugarcane: A Critical Review

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ABSTRACT Large-plot field experiments using aerially applied insecticide treatments composed of different insecticides, seasonal and diurnal timing, and carriers were used to determine the effectiveness of chemical control against *Eoreuma loftini* (Dyar) on southern Texas sugarcane. In 1983, plots with at least 17 monocrotophos applications initiated after above-ground internode formation contained lower numbers of dead hearts and dead tops and higher levels of sugarcane yield and quality than did late-season applied or untreated plots. These results documented the reduction of bored internodes, increased yield and sugarcane quality, and provided evidence for the financial incentive to control *E. loftini* only under conditions of high borer pressure and weekly insecticide applications. Using regression equations derived from data collected in this experiment (dependent variable = metric ton sugar/ha, independent variable = percent bored internodes), monetary loss to growers was estimated to be $287, $431, and $575/ha, for 10, 15, and 20% bored internodes, respectively. Results from recent studies with different insecticides showed statistically significant reductions in percent bored internodes but rarely an increase in sugarcane yield or commercially recoverable sugar, because insecticide efficacy was not improved to the level apparently needed to be associated with increases in sugar quality and yield or to provide an economic return on the insecticide investment. Cottonseed oil as a carrier and the use of different diurnal application times did not influence the effect of insecticides.

KEY WORDS *Diatraea saccharalis*, insect control, sugarcane stalkborers

STALK BORING PYRALIDS have been the most serious pests of sugarcane (interspecific hybrids of *Saccharum*) in the lower Rio Grande Valley, Texas, since renewal of the industry in 1972. During the 1970s, sugarcane borer, *Diatraea saccharalis* (F.), was the key insect pest (Fuchs et al. 1973) until establishment of the braconid parasitoid *Cotesia flavipes* (Cameron) resulted in biological control (Fuchs et al. 1979b). Before establishment of *C. flavipes*, injury by *D. saccharalis* ranged between 18% (Fuchs et al. 1973) and 31% (Reeves 1978) bored internodes (ratio of number of internodes with tunnels to total internodes present) in plots unprotected with insecticides. Early insecticidal control efforts were moderately successful, based on reports of between 60–80% reduction in bored internodes with 1–3 applications of either azinphosmethyl or monocrotophos (Fuchs et al. 1973, Fuchs et al. 1979a).

Mexican rice borer, *Eoreuma (=Chilo, Acigona) loftini* (Dyar), originally was described in experimental plantings of sugarcane from Arizona in 1917 (Dyar 1917) and subsequently identified as a pest of commercial sugarcane in the Mexican Pacific states (Morrill 1925). During the 1923–1924 growing season at Los Mochis, Sinaloa, 85% of the sugarcane stalks were infested, and 14% of the internodes were damaged (van Zwaluwenburg 1926). Also in Sinaloa, Flanders (1930) reported 97% of sugarcane stalks infested and 25% internodes bored by *E. loftini* and two species of *Diatraea*. Both van Zwaluwenburg (1926) and Flanders (1930) described secondary injury by the sucrose-reducing fungus, *Colletotrichum*. More recently, *E. loftini* injury at the La Primavera sugarmill near Culiacan, Sinaloa, was 13% bored internodes in 1973 and increased to 35% in 1980, even though a pesticidal control program (initially with endrin, progressing to systemics) was in place for over 20 yr (Fors 1981). *E. loftini* was first detected in the lower Rio Grande Valley in 1980 (Johnson 1981, Johnson & van Leerdam 1981) and is now the key insect pest of sugarcane. Although *E. loftini* has expanded its range from the sugarcane-growing areas in western Mexico to eastern Mexico and

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Texas (Riess 1981, Johnson 1984), it has not been found in the other sugarcane-producing states of Louisiana, Florida, and Hawaii.

Little was known about the biology of *E. loftini* or effective control measures when *E. loftini* initially colonized gramineous crops in the lower Rio Grande Valley. *E. loftini* life history is generally similar to that of most stalkborers; however, females oviposit cryptically on the dried plant material near the base of the stalks by insertion of the egg mass into folded leaf crevices (van Leerdam et al. 1984, 1986). Most other stalkborers that attack sugarcane oviposit on leaves or stalks (Smith et al. 1993). Newly eclosed larvae usually feed on leaves for a short period before mining in the leaf sheaths, and the older-instar larvae tunnel in the stalk and pupation occurs at the terminus of the tunnel excavated by the mature larvae (Smith et al. 1993). Larvae injure several crops (sugarcane, corn, sorghums, and rice) by leaf sheath feeding and by causing *dead hearts* (green shoots having a dead whorl center) (Browning et al. 1989). Dead hearts are caused by the older larvae boring into the plant and killing the apical meristem. Small ratoon shoots are more prone to dead hearts from larval feeding than older sugarcane because of the size of the stem. Injury (effect of insect feeding) and damage (economic results of insect injury) to sugarcane include feeding on internodes and buds, lodging, and reduction of sugar juice quantity and quality (van Zwaluwenburg 1926, Flanders 1930, Johnson 1981, Rozeff 1981). Surveys in the lower Rio Grande Valley for 1989 and 1990 showed an average of nearly 19% bored internodes by *E. loftini* in sugarcane fields, with more variability among fields than among locations within fields (Meagher et al. 1992). This variation is explained by management practices that differ between growers (e.g., insecticide sprays, irrigation, fertilizer), salinity levels, or proximity of fields to other gramineous crops infested by *E. loftini*.

Economic loss by stalkborers includes both field loss (reduced cane tonnage) and processing or factory loss (reduced available sugar per unit weight of millable cane) (Metcalfe 1969). Loss in sugarcane weight results from tissues being eaten, desiccation, stalk breakage, impaired growth, and translocation and the redirection of energy from sugar formation to development of side shoots and late tillers. Stalkborer injury causes decreased levels of brix and pol and increased impurities such as nitrogen, gums, and ash (Metcalfe 1969); lower cane quality increases factory costs in sugar processing and reduces extractable sugar. Historically, measurement of stalkborer injury from larval tunneling has been calculated by counting the number of bored internodes. Percent bored internodes may be estimated by either external (entrance or exit holes; Long et al. 1959, Johnson 1985) or internal (dissection of stalks; Bessin et al. 1990a, Ring et al. 1991) examination of the stalk.

A preliminary management plan based on initiation of scouting for *E. loftini* larvae before above-ground internode formation, insecticide use, and certain cultural practices was developed (Johnson 1981). Scouting for timing of insecticide applications was initiated to coincide with increased moth flight and subsequent spring larval activity. Concurrently, several insecticides labeled for *D. saccharalis* control on sugarcane also were shown to reduce injury by *E. loftini* larvae (percent internodes bored) compared with untreated controls (Johnson 1985). However, the best insecticide and rate combination provide only a subeconomic (74.5%) reduction in bored internodes after nine applications in ground applicator-delivered small plot evaluations (Johnson 1985).

When early research suggested that multiple insecticide applications were required to reduce *E. loftini* injury, subsequent research was designed to define better the gross phenological windows of sugarcane susceptibility to *E. loftini* injury. A second objective was to search for alternative application techniques to enhance the efficacy of the limited number of insecticides labeled for sugarcane (e.g., monocrotophos and azinphosmethyl). We report the results of selected large- and small-scale insecticide management experiments conducted over the last 9 yr, which have contributed to more prudent ecological and economical management of sugarcane infested by *E. loftini*. We also report a simple economic analysis of sugarcane yield and quality measurements to develop some insight into any short-term economic advantage that could be gained from multiple insecticide applications. Finally, we give a critical review of insecticidal management practices for *E. loftini* on sugarcane.

Materials and Methods

Larval Sampling. Field sampling was used to estimate population densities of early-instar larvae, late-instar larvae, and bored plant internodes to determine timing of insecticide applications (action threshold) and estimate the effect of insecticide applications. Visually estimating the density of all larval instars requires complete plant destruction. Randomly selected plants were cut at ground level and dissected, and the presence of stalkborer larvae was recorded according to feeding microhabitat. Leaf-sheath infestation with early-instar larvae (less than third instar) was estimated by removing the leaf sheaths and visually inspecting each leaf sheath on a plant for live larvae. Feeding injury such as the discoloration and superficial tunneling in the leaf sheaths and the presence of frass were used to direct the search for stalkborer larvae. The percentage of plants infested with one or more live larvae in their leaf sheaths was recorded. Stalk injury, expressed as percent bored internodes, was determined by counting the internodes with internal evidence (or external evidence, see experiment 2) of larval tunneling and the number of formed internodes.

Experiment 1. Stalkborer Injury–Crop Phenology. Treatment plots (plot, one treatment by replication area), 30 rows each (≈372-m length on 1.5-m centers) were located in a commercial field of second-ratoon sugarcane ('CP 65-357') near Runn, TX, in 1983. Each plot (east–west) was three airplane swaths wide. Only the center 11 rows of each plot were sprayed. Edges of adjoining plots overlapped by 1–2 rows and were not sampled. A border swath also was sprayed weekly along the southern and western field edges to protect sugarcane not in the experiment. Foliar applications of 1.14 kg (AI) monocrotophos (Azodrin 5, Du Pont, Wilmington, DE) per hectare with 354.75 ml Nalcotrol (a polyvinyl polymer, Helena Chemical Co., Memphis, TN) per 378.4 liters water (46.8 liters/ha total spray volume) were applied by commercial aircraft early on mornings with minimal wind.

To determine the most susceptible phenological window for stalkborer injury, we divided the production season into early, middle, and late season. Early season is characterized by plant growth and tillering before internode formation. This period is typically during spring before June. Middle season is characterized by rapid plant growth and formation of most of the harvestable internodes and typically occurs from June through August (90–100 d). During late season, from September until harvest in October–March, the sugarcane plant forms only the most apical internodes, which do not elongate. Most of the harvestable sugar is produced in the internodes that are formed during middle season (Fernandes & Benda 1985). Internodes bored during this plant phenological age are expected to have a greater effect on yield than stalkborer attack during either early or late season (Ring et al. 1991). Concurrent with middle-season, internode formation is the highest seasonal density of *E. loftini* (Johnson 1985). Thus, the heaviest pest pressure appears to occur at the time when the crop yield is thought to be most at risk.

To define better the temporal window of crop susceptibility, we initiated weekly insecticide applications in early March (early season), late May (middle season), and early September (late season) and continued these applications until 15 September 1983 to provide continued protection from stalkborer injury. Thus, the early-season treatment initiated 9 March was continued weekly until 15 September, resulting in 28 applications. At initial internode formation (elongation) on 25 May, the middle-season treatment was begun and received 17 weekly applications by 15 September. Late-season treatment was initiated 2 September and received only three applications. An untreated control completed a four-treatment, randomized complete-block design with four replications. Yield and quality parameters were determined at harvest (17–18 November, see *Yield and Quality Parameters*).

E. loftini infestation was monitored weekly by sampling randomly (row and pace within plot determined by random number table) 25 plants from the middle five rows of the center swath of each plot. Each plant and its leaf sheaths were dissected and searched for live larvae. Percent leaf sheath infestation and percent stalk infestation were calculated as the percentages of stalks with one or more larvae in the leaf sheaths or stalks, respectively. The number of dead hearts and number of live plants were counted on 1–2 June from one 20-m sample in the center row of the center swath of each plot 25 paces into the field. Similarly, the number of dead stalk tops and number of live stalk tops were counted from one section of a 20-m row on 30 August and 4 November. Percent dead tops and total number of millable stalks (dead or live tops) were calculated.

Experiment 2. Insecticide Carriers. Two experiments evaluated enhancement of insecticide efficacy using spray carriers. The 1982 experiment was conducted in first-ratoon sugarcane ('CP 52-58') near Donna, TX, and included application of several rates of azinphosmethyl (Guthion 2L, Mobay, now Miles, Kansas City, MO) and one rate of monocrotophos using water or cottonseed oil as carrier for each insecticide. Insecticides mixed in oil were applied at a total volume of 7.0 liters/ha, and, when mixed with water, the total volume was 46.8 liters/ha applied in a 16.8-m swath width. Individual plots were ≈0.6 ha (11 rows on 1.5-m centers by 365.7-m length) and were arranged in a randomized complete-block design with five replications.

Weekly samples of 20 plants per plot were collected and the leaf sheaths and stalks searched for stalkborer larvae. Azinphosmethyl at 0.841 kg (AI)/ha was applied when predetermined plots reached 5% leaf-sheath infestation. Another set of plots (18% threshold) received azinphosmethyl (0.841 kg [AI]/ha) applications when 18% of the plants were infested with larvae in the leaf sheaths. Insecticide applications were made in the 5% threshold plots on 26 May, 7 and 25 June, 19 July, and 9 August. The 18% action threshold plots received only three applications (26 May, 25 June, and 9 August). Efficacy was evaluated 25–29 October by examining 25 stalks from each plot and determining the percent internodes sustaining externally visible stalkborer injury. Sugarcane yield was estimated by commercially harvesting the middle seven rows from each plot (13–14 October).

In the 1991 experiment, foliar sprays of azinphosmethyl in water (0.841 kg [AI]/ha) or cottonseed oil and of cyfluthrin (Baythroid 2E, Miles) in water (0.049 kg [AI]/ha) were applied to first-ratoon sugarcane ('TCP 81-3058') located in Hidalgo County, Texas. Azinphosmethyl (3.51 liter/ha) + cottonseed oil (Valco Chemicals, Harlingen, TX; 2.35 liter/ha) was sprayed at ultra-low volume. The field was sectioned into plots of 27 rows (1.5-m centers) by 374.3-m length, with the 11 center rows treated and used in the evaluation. Treatments were applied to plots arranged in a randomized complete-block design with four replications. Each spray was applied in 16.8-m swath widths (11 rows) at a rate of 46.8 liters of finished formulation (insecticide + water + buffering agent [Val-Buf, Valco Chemicals, Harlingen, TX] 250 ml/100 liter)/ha.

A pretreatment assay of percent plants (leaf sheaths) infested from randomly collected samples (25 plants per replication, 100 plants per treatment) was made 28 May and sampling continued at biweekly intervals until late July. Treatments were applied 4 June 1991 and repeated when leaf sheath infestations exceeded 10% (azinphosmethyl treatments, 19 June, 4, 18, and 31 July; cyfluthrin treatment, 19 June and 4 July). After treatment, samples of stalks were taken to determine bored internodes (25 stalks per plot, 100 stalks per treatment) on 16 July and 2 October. Yield and quality were measured at harvest (14–15 October, see *Yield and Quality Parameters*).

Experiment 3. Application Techniques. This experiment was designed to determine if time of day or the addition of a spray adjuvant would enhance insecticidal efficacy. Foliar sprays of azinphosmethyl were applied to a field of first-ratoon sugarcane ('TCP 81-3058'), near Santa Rosa, TX. The field was sectioned into plots 22 rows (1.5-m centers) by 374.3-m length, with the 11 rows in the center treated. Treatments were assigned to plots in a randomized complete-block design with four replications. Each spray was applied in 16.8-m swath widths (11 rows) at a rate of 46.8 liter finished formulation (insecticide + water + Val-Buf at 250 ml per 100 liter)/ha.

Counts of the number of infested plants from randomly collected plant samples (25 plants per replication, 100 plants per treatment) were made 28 May 1991 before treatment and biweekly until late July. Azinphosmethyl (0.841 kg [AI]) was applied 4 June and repeated when leaf-sheath infestations exceeded 10% (19 June; 4, 18, and 31 July). Treatments included morning (before 0700 hours) and evening (after 1900 hours) applications with and without addition of X-Plus Sticker-Spreader (Valco Chemicals, Harlingen, TX; 125 ml/100 liter). Counts of bored internodes (internal determination, 25 stalks per plot, 100 stalks per treatment) were made 29 July and 2 October to estimate injury. Yield and quality were measured at harvest (10–12 October, see *Yield and Quality Parameters*).

Yield and Quality Parameters. Plots were harvested using commercial Claas harvesters. Sugarcane yield (gross metric tons cane/ha) was calculated from the weight of sugarcane harvested from each plot and the area of each plot. Sugarcane samples were removed from the front bin on each truck with a core sampler at the sugarmill. Juice and sugarcane quality (including: brix, percentage by mass of total soluble solids of a pure aqueous sucrose solution; pol, apparent sucrose content expressed as a percentage by mass and determined by a direct polarization method; fiber, the water insoluble matter of cane and bagasse [residue obtained after crushing cane] from which the brix-free water has been removed by drying; and purity, percentage ratio of sucrose [or pol] to the total soluble solids [or brix] in a sugar product; SASA 1985) were measured and calculated at the Rio Grande Valley Sugar Growers laboratory following methods of Birkett (1975, 1979). Quality measures are economically important because they affect factory efficiency in sugar production and because they are used to calculate commercially recoverable sugar (kilogram sugar/metric ton cane). Commercially recoverable sugar is combined with sugarcane yield to calculate sugar yield (metric ton sugar/ha) by which growers are paid through the cooperatively owned sugarmill.

Economic Analysis. One objective of the stalkborer injury–crop phenology experiment was to minimize stalkborer injury in insecticide treated plots while allowing severe injury in untreated plots. Data from this experiment presented us with the opportunity to calculate the economic value of maximum numbers of insecticide applications and the opportunity to estimate the economic effect of *E. loftini* at the highest input level. Growers are paid through the cooperative sugarmill using the following formula:

$$P = \text{CRS} \times \text{MTCH} \times \text{sugar price}$$

where P = price paid to growers, CRS = commercially recoverable sugar (kilogram sugar/metric ton cane), MTCH = metric ton cane/ha and sugar price = $0.265/kilogram sugar.

To obtain an estimate of the economic effect of *E. loftini*, we used regression equations (dependent variable = metric ton sugar/ha, independent variable = percent bored internodes) and used harvest and quality statistics from the 1983–1984 production season (N. Rozeff, Rio Grande Valley Sugar Growers, personal communication). The following formula estimates the monetary loss to growers:

$$\text{loss} = \text{sugar} \times \text{BI} \times \text{price} \times \text{area},$$

where sugar = regression coefficient (loss metric ton/ha per 1% bored internode) from regression equations calculated from field data, BI = percent bored internodes, price = price paid to

Table 1. ***Eoreuma loftini*** **larvae and plant injury from sugarcane plots ('CP 65-357') with differing timing of monocrotophos applications, Runn, TX, 1983**

Phenological stage (no. of applications)	Fall samples[a]				No. dead hearts[b]	% Dead tops		No. millable stalks[c]
	LSI[d]	SI[e]	TI[f]	BI[a]		30 Aug	4 Nov	
Early season (28)	0.6a	0.03a	0.8a	0.7a	9.5a	2.7a	2.6a	248.0a
Middle season (17)	0.5a	0.10a	1.0a	2.0a	34.0b	1.9a	2.6a	244.5a
Late season (3)	26.5b	29.20b	47.0b	39.5b	52.3b	16.1b	31.4b	151.3b
Untreated (0)	33.7b	38.30b	58.7b	49.0b	49.3b	16.1b	31.7b	163.5b

Means in a column followed by the same letter are not significantly different ($P > 0.05$, least significant difference [LSD]). Statistical analyses were completed on arcsine-transformed data. Untransformed means are reported.

[a] Means are from weekly samples taken 2 September to 2 November.

[b] Sampled 1–2 June from 20-m row.

[c] Includes both dead and live tops, estimated 4 November.

[d] Percent leaf sheath infestation, plants with one or more larvae in the leaf sheaths.

[e] Percent stalk infestation, stalks with one or more larvae in the stalks.

[f] Percent total infestation, plants with one or more larvae in leaf sheaths or internodes.

[g] Bored internodes, calculated as percentage of internodes with larval tunneling divided by the number of total internodes.

growers ($/kilogram sugar), and area = number of harvested hectares sugarcane. Economic analyses were not completed in experiments in which there were no significant differences among treatments in yield and quality parameters.

Statistical Analysis. Data were analyzed by analysis of variance (PROC GLM); treatment means were separated using least significant difference or Duncan's new multiple range test (SAS Institute 1985). For all statistical tests, the significance level was set at $\alpha = 0.05$. All data were transformed before analysis, with percentage data using arcsine-square root and the yield and quality data using $\log_{10}$. Untransformed means are reported in all tables and figures. The 1991 insecticide-carrier and application-techniques experiments were analyzed further using the CONTRAST option of PROC GLM (SAS Institute 1985). Planned comparisons for the carrier experiment were water-applied versus cottonseed oil applied, azinphosmethyl versus cyfluthrin, and insecticide treated versus untreated. Planned comparisons for the application-techniques experiment were morning applied versus evening applied, spreader-sticker versus no spreader-sticker, and insecticide treated versus untreated.

Results

Experiment 1. Stalkborer Injury–Crop Phenology. Insecticide prophylaxis during the early- and middle-season growth periods reduced the season-long averages of larval infestation in the leaf sheaths and internodes below infestation levels in the late-season initiation of insecticidal treatments and the untreated control. Early- and middle-season prophylaxis reduced the season-long averages of leaf-sheath infestation by early-instar larvae by 98%, stalk infestation by older-instar larvae by 99%, and total plant infestation by 98% (Table 1). Plant injury followed a similar pattern and reflected larval suppression. Early- and middle-season protected plants had a 95–98% reduction in bored internodes, a 83–92% reduction in dead tops, and a 49–64% increase in millable stalks (Table 1). Dead hearts was the only exception to these plant injury trends with the only reduction in dead hearts occurring when the sugarcane was protected from larvae feeding during the early season.

Yield and quality responses were similar to plant injury, indicating that insecticide applications protected the plants from *E. loftini* larval feeding during internode formation (Table 2). Values for brix, pol, purity, commercially recoverable sugar, metric tons cane/ha, and metric tons sugar/ha were highest when the early- and middle-season growth stages were protected. For the late-season initiated treatment, brix, pol, purity, and commercially recoverable sugar values were greater than the untreated values but were less than the same values for early- and middle-season.

Table 2. Sugarcane yield and quality in plots ('CP 63-357') with differing timing of weekly monocrotophos applications, Runn, TX, 1983

Phenological stage (no. of applications)	% Sugarcane			Yield and quality measurements		
	Brix	Pol	Purity	CRS	MTCH	MTSH
Early season (28)	15.2a	13.0a	85.1a	95.3a	82.1a	7.83a
Middle season (17)	15.4a	13.1a	84.8a	95.7a	81.2a	7.78a
Late season (3)	13.4b	10.8b	80.4b	76.4b	47.6b	3.58b
Untreated (0)	11.8c	9.0c	76.3c	61.0c	44.5b	2.70b

Means in a column followed by the same letter are not significantly different ($P > 0.05$, LSD). Statistical analyses were completed on arcsine-transformed data. Back-transformed means are reported. CRS, commercially recoverable sugar (kilograms sugar/metric ton sugar cane), MTCH, metric ton sugar cane/ha, including stalks and leaves, MTSH, metric ton sugar/ha.

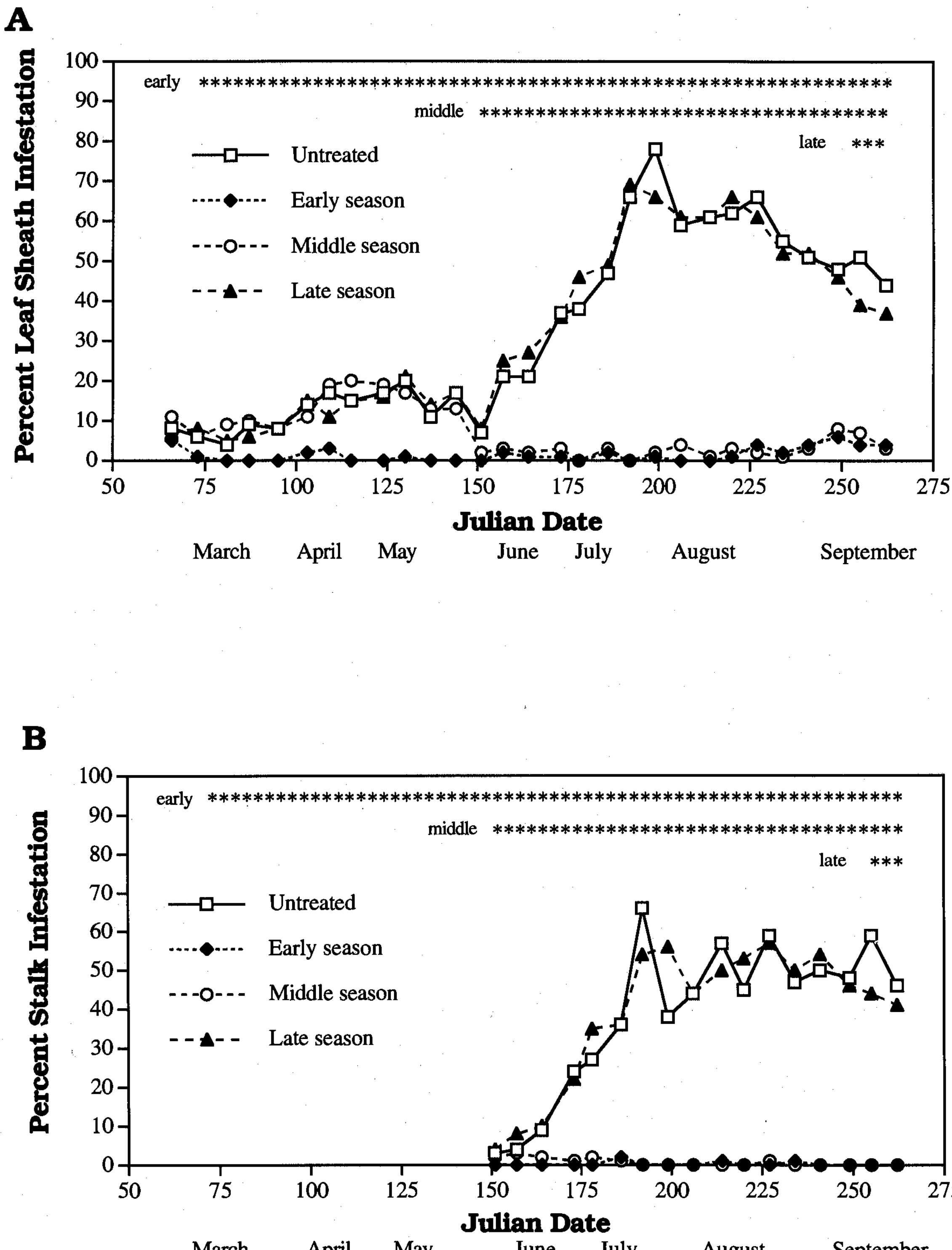

Fig. 1. Percentage (A) leaf-sheath and (B) stalk infestation by *E. loftini* larvae in the stalkborer injury–crop phenology experiment. Symbols at top of graphs indicate time of weekly insecticide applications, initiated during early season (Julian date = 68), middle season (Julian date = 145), or late season (Julian date = 245). Larvae were not found infesting stalks until Julian date = 151.

Table 3. Evaluation of aerially applied insecticides mixed either in water or cottonseed oil in sugarcane ('CP 52-58') against *Eoreuma loftini*, Donna, TX, 1982

Treatment	Rate (kg [AI]/ha)	% Bored internodes	Sugarcane yield (metric ton/ha)
Monocrotophos + oil	1.12	49.1ab	77.5ab
Monocrotophos + water	1.12	45.1a	89.4a
Azinphosmethyl + oil	0.56	60.3d	76.2ab
Azinphosmethyl + oil	0.84	53.2bcd	84.7ab
Azinphosmethyl + oil	1.12	47.7ab	82.9ab
Azinphosmethyl + water	0.56	58.3cd	72.2b
Azinphosmethyl + water	0.84	49.2ab	82.5ab
Azinphosmethyl + water	1.12	49.5ab	88.1a
Azinphosmethyl @ 18%[a]	0.84	51.7abc	87.2a
Untreated	—	57.3cd	73.5b

Bored internode and sugarcane yield means followed by the same letter are not significantly different ($P > 0.05$, Duncan's new multiple range test).

[a] Azinphosmethyl 18% was delivered in water at 46.8 liter/ha and applications were made when leaf sheath infestations were >18%.

The only advantage gained by initiating insecticide prophylaxis in early season was an 80–90% reduction in dead hearts (Table 1). The dead-heart reduction was not reflected as a gain in sugar quality or yield (Table 2). However, in subsequent years, dead-heart damage may reduce the ratoon population from a stool and cause economic damage by causing an earlier than anticipated replanting of sugarcane or reduced yields, or both.

Initiating insecticide prophylaxis in late season after most of the harvestable internodes had been formed and subjected to continuous *E. loftini* larval infestations (Fig. 1 A and B) did not reduce larval infestations in the leaf sheaths or internodes (Table 1) but did increase some sugar quality and yield parameters when compared with the untreated control (Table 2). Values for brix, pol, purity, and commercially recoverable sugar were increased, but the overall yield values were not different from the untreated control (Table 2). All values for sugar quality and yield for late-season treatments were less than the values obtained when insecticide prophylaxis protected the internode-formation period.

Experiment 2. Insecticide Carriers. *E. loftini* population pressure in the 1982 experiment was high, with almost 60% bored internodes in the untreated plots (Table 3). Although there were differences in bored internodes among individual treatments, there were no differences for chemicals or rates between carriers. Monocrotophos and azinphosmethyl at 1.12 kg (AI)/ha reduced stalk injury caused by larval tunneling in internodes. Sugarcane yield was not decreased in plots receiving monocrotophos and azinphosmethyl at 1.12 kg (AI)/ha or in plots receiving azinphosmethyl at 0.841 kg (AI)/ha with the 18% action threshold.

Samples of plant infestation for the 1991 experiment taken before application (28 May) and the first taken after application (11 June) showed no differences among treatments (Fig. 2A). The 25 June and 8 July samples showed more infested plants in the untreated plots. Fewer infested plants were found in the azinphosmethyl + water plots than in all other plots in the final sample. Insecticide applications did not reduce bored internodes (data not shown) compared with untreated plots for either sampling date; however, for the 16 July samples, cyfluthrin plots contained stalks with higher percent bored internodes than the combined azinphosmethyl plots (5.77 ± 0.9% versus 5.67 ± 3.1%, respectively; $F = 5.95$; df = 1, 9; $P = 0.0375$). Yield and quality parameters were not different among treatments, nor were any planned comparisons significantly different (data not shown).

Experiment 3. Application Techniques. No differences in leaf-sheath infestation among treatments occurred until after three insecticide applications (Fig. 2B). On the final two sample dates, all insecticide-treated plots contained fewer infested leaf sheaths than untreated plots. Differences in percent bored internodes between treated and untreated plots occurred on 29 July and 2 October (Table 4). Differences in injured internodes between evening and morning applications (8.9 ± 1.8% versus 5.0 ± 3.2%, respectively; $F = 15.6$; df = 1, 12; $P = 0.0019$) occurred in late-July samples, but this was not true for the early-October samples (evening, 10.5 ± 6.7% versus morning 7.9 ± 4.7%; $F = 1.92$; df = 1, 12; $P = 0.1907$). The addition of a sticker-spreader adjuvant did not reduce bored internodes (29 July, with 7.6 ± 3.8% versus without 6.3 ± 2.6%; $F = 1.20$; df = 1, 12; $P = 0.2945$; 2 October, without 10.4 ± 6.0% versus with 8.0 ± 5.0%; $F = 1.62$; df = 1, 12; $P = 0.2271$).

Although there were differences in bored internodes among treatments, there were no differences in sugarcane yield, sugar yield, commercially recoverable sugar, brix, or fiber; only purity differed among treatments (Table 4). In planned comparisons, sugar yield (MTSH) was higher in treated versus untreated plots (6.14 ±

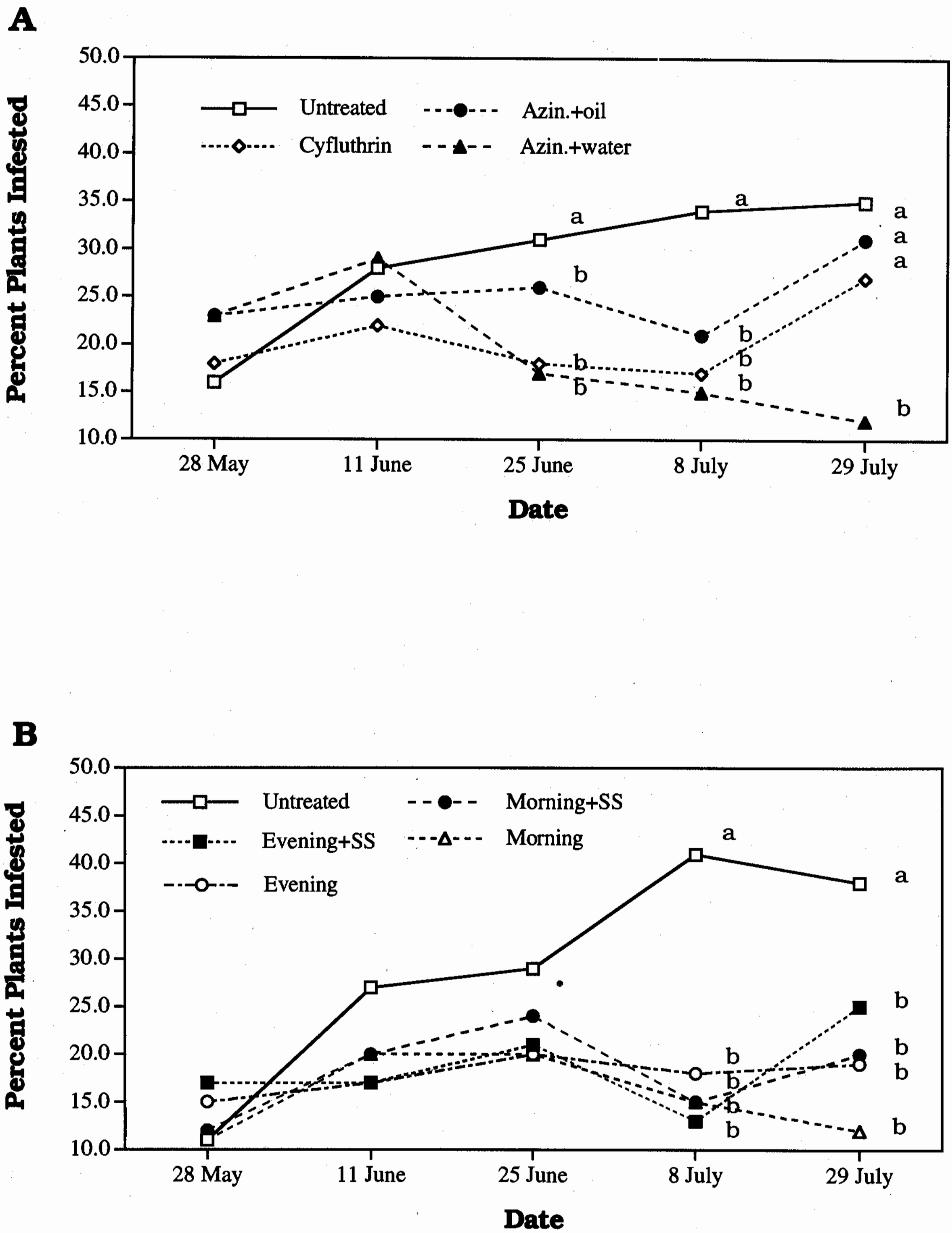

Fig. 2. Percentage plants infested for (A) 1991 insecticide-carriers experiment and (B) 1991 application-techniques experiment. Applications from the insecticide-carriers experiment were as follows: azinphosmethyl treatments, 4 and 19 June, 4, 18 and 31 July; cyfluthrin treatment, 19 June and 4 July. Applications for the application-techniques experiment were as follows: 4 and 19 June, 4, 18 and 31 July. Means within a sample date followed by the same letter are not significantly different ($P > 0.05$; LSD).

Table 4. Percent bored internodes and sugarcane yield and quality measurements for the 1991 application techniques experiment, Santa Rosa, TX

Treatment	% Bored internodes		Yield and quality measurements			% Sugarcane		
	29 July	2 Oct	CRS	MTCH	MTSH	Brix	Fiber	Purity
Untreated	16.7 (4.0)d	20.9 (13.9)b	65.1 (2.8)a	84.7 (16.9)a	5.49 (1.1)a	14.7 (0.9)a	14.8 (0.7)a	75.9 (0.3)d
Evening + SS	9.8 (0.9)c	9.1 (5.7)a	69.5 (2.2)a	89.6 (14.8)a	6.23 (1.0)a	14.7 (0.4)a	14.9 (0.3)a	79.3 (1.3)a
Evening	8.0 (2.2)bc	12.0 (7.2)a	67.9 (4.2)a	88.3 (10.7)a	5.96 (0.5)a	14.4 (0.7)a	14.5 (0.3)a	78.5 (1.4)ab
Morning + SS	5.5 (4.5)ab	7.0 (4.8)a	66.2 (3.8)a	93.9 (13.1)a	6.21 (0.9)a	15.1 (0.8)a	14.6 (1.0)a	77.4 (1.2)bc
Morning	4.6 (1.9)a	8.9 (5.0)a	66.9 (3.5)a	92.6 (11.8)a	6.19 (0.8)a	14.8 (0.5)a	14.4 (1.0)a	76.7 (0.8)cd

Means (SD) within each column with the same letter are not significantly different ($P > 0.05$; LSD). SS, sticker-spreader adjuvant.

0.7 versus 5.50 ± 1.1, respectively; $F = 6.68$; df = 1, 12; $P = 0.0339$). Purity was higher in evening-applied versus morning-applied plots (78.9 ± 1.3% versus 77.1 ± 1.0%, respectively; $F = 20.39$; df = 1, 12; $P = 0.0007$) and treated versus untreated plots (78.0 ± 1.5 versus 75.9 ± 0.3, respectively; $F = 19.85$; df = 1, 12; $P = 0.0008$).

Economic Analysis. Results from experiment 1 (stalkborer injury–crop phenology) suggested that bored internode reduction increased both yield and sugarcane quality when high numbers of insecticide applications were used to subdue a high stalkborer population. The average increase in grower payment in early-, middle-, and late-season plots over that of the untreated plot was $1,357, $1,342, and $245/ha, respectively (Table 5). The cost of an insecticide application on sugarcane in Texas is estimated at $25/ha per application, which resulted in an added net return of $657, $917, and $170/ha for early-, middle-, and late-season plots compared with untreated plots, respectively (Table 5). Also, using middle-season insecticide timing rather that early-season timing provided a 39% reduction in insecticide usage (28 versus 17 applications).

Using the regression coefficient derived from the equation for sugar (0.1083 metric ton/ha per 1% bored internodes = 108.3 kg/ha per 1% bored internodes; Table 6), the sugar price paid to growers ($0.265/kg sugar) and selected bored internode averages of 10, 15, and 20%, loss to growers was estimated to be $287, $431, and $575/ha, respectively. Loss to the sugarcane region with the same estimated percent bored internodes and an estimated 14,449 harvested hectares, would be $4,153,076, $6,229,575, and $8,306,100, respectively, for 10, 15, or 20% bored internodes.

Discussion

Crop Phenology and Life Stage Targeted. Sugarcane is most susceptible to *E. loftini* attack during the phenological growth window when internodes are being formed. Increases in sugarcane yield and quality were not evident when insecticide treatment was initiated before internode formation, and only a small increase in quality occurred when treatment was initiated after most of the internodes were formed. Leaf-sheath and stalk infestation in the untreated plots show that larvae were found continuously in the leaf sheaths throughout the growing season but not found in stalks until the 31 May sample, when internode formation was initiated (Julian date = 151; Fig. 1). Thus, although larvae were present during the entire season, they did not become damaging (e.g., bore into harvestable internodes) until initiation of the insecticide applications in middle season.

The phenological window for protection of internodes from boring by *E. loftini* larvae can be narrowed further and the number of insecticide applications limited further. Sugarcane requires roughly 10 d to produce an internode, and internodes are susceptible to *E. loftini* larval boring for ≈70 d after formation (Ring et al. 1991). The first internode formed makes a greater contribution to yield than any other single internode (Fernandes & Benda 1985). Thus, single internode contributions to total yield decreases as the season progresses, and internode susceptibility

Table 5. Economic analysis of sugarcane plots ('CP 65-357') in the crop phenology experiment, Runn, TX, 1983

Phenological stage (no. applications)	CRS	MTCH	Grower payment ($/ha)[a]	Spray application cost ($)[b]	Net return ($/ha)[c]	Increase over untreated ($/ha)
Early season (28)	95.3	82.1	2,077	700	1,377	657
Middle season (17)	95.7	81.2	2,062	425	1,637	917
Late season (3)	76.4	47.6	965	75	890	170
Untreated (0)	61.0	44.5	720	0	720	—

[a] Grower payment, CRS × MTCH × 0.2654.
[b] Calculated at $25 per application per ha.
[c] Net return, grower payment–spray application cost.

to *E. loftini* attack decreases with internode age (Ring et al. 1991). Therefore, the most important internode to protect is the first, with internode importance decreasing with each additional internode formed. Internode susceptibility and internode contribution to total yield must be temporally and spatially coincident with *E. loftini* larvae boring into the stalk before yield losses potentially can occur.

Characteristics inherent to *E. loftini* biology and sugarcane growth patterns are impediments to a contemporary integrated pest management (IPM) program that is based on scouting to estimate target pest density and applications of insecticides to reduce increasing populations that are approaching an economic threshold. The life stages that are exposed to insecticides applied to the plant surface are ovipositing females, neonate larvae that migrate from ovipositional sites at the base of the sugarcane stool to green parts of the plant, and older larvae that travel between leaf sheaths and stalks. The life stage targeted for insecticide applications is the early-instar larvae because they are susceptible to insecticides (R.L.M., unpublished data), they travel on the outside of the plant, and they precede the more concealed and more damaging older larvae tunneling in the stalk.

Larval leaf-sheath infestations declined after insecticide applications, but we do not know if the decline observed in subsequent infestation estimates was a result of mortality of larvae that were currently inhabitating the leaf sheath or mortality of neonate larvae that were yet to infest the leaf sheath. With continuous and apparently overlapping *E. loftini* generations during the warmest periods of the 12–19-mo growing season (Fig. 1), one or two insecticide applications reduced leaf-sheath infestations and, presumably, larval tunneling for a brief period, but this reduction in injury was not adequate to produce a corresponding sugar quality or yield increase.

Difficulties with estimating *E. loftini* density and obtaining insecticidal contact with the pest are exacerbated further by the enormous biomass of sugarcane. Scouting for any immature life stage is laborious and very time consuming because of the cryptic nature of the life stages and large amount of biomass that must be examined. The sugarcane biomass also constrains the desired distribution of spray within the plant canopy, especially targeting spray coverage to the lower leaves and leaf sheaths. The dense upper leaves form a shield that reduces spray penetration from overhead into the lower canopy where the dried leaves and whorls preferred for *E. loftini* oviposition and neonate activity are concentrated.

Insecticide Efficacy. In the crop-phenology experiment, the early- and middle-season plots averaged 97.3% reduction in bored internodes compared with 19.4% for the late-season plots.

Table 6. Regression equation comparing different sugarcane yield and quality measurements to *Eoreuma loftini*—percent bored internodes in two insecticidal management experiments

Experiment/ dependent variable	Regression equation	r^2	$Pr > F$
Carrier 1982			
Cane yield (metric ton/ha)	=129.96–0.931x	0.567	0.0119
Crop Phenology 1983			
Cane yield (metric ton/ha)	= 82.49–0.8178x	0.991	0.0044
Sugar (metric ton/ha)	= 7.94–0.1083x	0.999	0.0004
CRS (kg sugar/metric ton sugar cane)	= 96.88–0.6481x	0.947	0.0269
Brix, %	= 15.44–0.065x	0.938	0.0314
Pol, %	= 13.21–0.076x	0.947	0.0269
Purity, %	= 85.31–0.1605x	0.935	0.0333

Although these insecticide efficacy levels provided increases in sugar quality and yield and high economic returns (Tables 2 and 5), this experiment was not designed to be practical or to ascribe to label regulations. The 1982 and 1991 experiments were designed to increase insecticide efficacy by improving application carriers and techniques. Results from these experiments showed average reduction in bored internodes of only 10.0 and 55.8% for the 1982 and 1991 application techniques experiments, respectively. Texas sugarcane growers currently are permitted five azinphosmethyl applications per season. However, growers have become increasingly reluctant to invest in insecticidal control (N. Rozeff, Rio Grande Valley Sugar Growers, personal communication). Whether this reluctance is the result of lower than average *E. loftini* populations during the 1991–1993 growing seasons (R.L.M., unpublished data) or of the increasing cost of multiple insecticide applications is not known. Attempts to reduce the number of insecticide applications by defining a narrower damage window or attempts to improve application technology by modifying the insecticidal delivery systems (cottonseed oil as carrier, addition of sticker-spreader, varying temporal applications) were generally successful in decreasing larval injury. However, insecticide efficacy was not improved to the level apparently needed to be associated with increases in sugar quality and yield or to provide an economic return on the insecticide investment.

Economic Analysis. One goal of an IPM program is to be able to relate insect density or injury to end-of-season-harvest yield. A functional relationship between bored internodes and sugar yield can occur only when there are statistical differences among treatments with these parameters. Our best estimate of loss per *E. loftini*-bored internode was 0.1083 metric ton sugar/ha (Table 6). Experimental field data collected since 1989 (and the loss of monocrotophos) have shown statistically significant reduc-

Table 7. Regression coefficients calculated from historical data comparing sugar yield with *Diatraea saccharalis*—percent bored internodes

Regression coefficient (metric ton sugar/ha)	Reference[a]	Regression coefficient (metric ton sugar/ha)	Reference
0.0339	Mathes et al. 1953, 1965[b]	0.0398	Hensley et al. 1961
0.0229	Martorell & Bangdiwala 1953[c]	0.0346	Hensley et al. 1961
0.0335	Long et al. 1959	0.0660	Hensley et al. 1963
0.0387	Long et al. 1959	0.0510	Long & Concienne 1964
0.0379	Long et al. 1959	0.0587	Long & Concienne 1964
0.0430	Long et al. 1959	0.0362	Long & Concienne 1964
0.0371	Long et al. 1959	0.0553	White & Hensley 1987

[a] Unless otherwise noted, regression coefficients were calculated from data shown in the text and tables of the references cited.
[b] Regression equation and coefficient calculated in citation.
[c] Regression coefficient calculated in citation from 12-yr average.

tions in bored internodes for both ground (Pfannenstiel et al. 1990a) and aerially applied (Pfannenstiel et al. 1990b, Scott et al. 1990) insecticides. However, these reductions rarely resulted in a corresponding increase in sugarcane yield or in commercially recoverable sugar.

We also determined relationships among differing *D. saccharalis* injury levels and harvest and sugar quality measurements from data found in publications on insecticidal efficacy evaluations in Louisiana and the Caribbean. Again, only insecticide treatments that resulted in differences in the percentage of bored internodes and sugar yield were used. The average regression coefficient from the equations was approximately half of coefficient calculated for *E. loftini* (from 0.023 to 0.066 metric ton sugar/ha loss; Table 7). The corresponding *D. saccharalis* percent bored internodes from the studies in Table 7 ranged from 1–64%.

Both larval behavior and noninsect-related factors may explain differences in the injury to sugar yield relationship between stalkborer species. The tunneling behavior of *E. loftini* and *D. saccharalis* in sugarcane stalks is different, in that the majority of *E. loftini* tunneling occurs near the outer surface of the stalk adjacent to the rind and that tunnels may be vertical, as with other stalkborers including *D. saccharalis*, or may be horizontal or diagonal within the stalk (Browning et al. 1989). Noninsect-related factors include sugarcane cultivar (yield and quality estimates such as sugar loss can be highly dependent on cultivar [Ellis et al. 1959, White & Hensley 1987]), age of cane when injury occurs (Ogunwolu et al. 1991), and incidence of stalk rot fungus (*Colletotrichum* spp.) (Ogunwolu et al. 1991). Therefore, the only valid comparison of sugar loss coefficients between these two stalkborers would be in a same-year–same-field experiment.

Perhaps one problem with finding a relationship between stalkborer injury and sugar yield is that injury is expressed as percent bored internodes. Ellis et al. (1959) discussed the weaknesses of using percent bored internodes as a parameter, including the fact that important variables such as sugarcane cultivar and agronomic factors are not taken into account. They advocated calculating the number of bored internodes per unit weight of cane as a more accurate measurement of stalkborer injury. McGuire et al. (1965) recommended identification of the position of insect injury on the stalk as an additional variable in the measurements. Bessin et al. (1990a, b) suggested population density measurements such as moth production index (product of the number of adult exit holes and the stalk density per hectare) and relative survival (number of exit holes per number of bored internodes) to quantify stalkborer control. In studies comparing management strategies, insecticidal control, when measured by percent bored internodes, was the predominant factor preventing plant injury. But when moth production was considered, insecticidal control and varietal resistance were shown to be equally important in overall *D. saccharalis* management. Moth production and relative survival, measured by either exit holes or other moth-sampling procedures such as pheromones traps, has not been tested with *E. loftini*.

Future Management Strategies. Research on sugarcane stalkborers in Texas should continue to be directed toward integration of chemical control with a more biologically intensive pest-management strategy (Frisbie & Smith 1989). Chemical control efficacy can be increased by developing improved insecticides, application techniques, and action thresholds. Biologically intensive management tactics such as resistant cultivars (Pfannenstiel & Meagher 1991), biological control (Pfannenstiel et al. 1990c, Smith et al. 1993), and cultural control (Browning et al. 1989) will require a more indepth knowledge of plant–herbivore–natural enemy interactions and a firmer foundation in population and community ecology. The more rigorous scientific data base needed to develop properly and implement biological tactics and to predict the behavior of the system after biological intervention will require greater attention to the complex interactions of biological attributes and less attention to immediate efficacy.

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