# Stalkborer Damage on Yield and Quality of Sugarcane in Lower Rio Grande Valley of Texas

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ABSTRACT   In the Lower Rio Grande Valley of Texas, the pyralid stalkborers *Eoreuma loftini* (Dyar) and *Diatraea saccharalis* (F.) damage ≈20% of sugarcane internodes annually. We quantified the relationships between stalkborer damage and sugar yield and quality to estimate the monetary loss incurred at these levels of damage. We also compared damage estimates and sugar quality between 2 important varieties in the region, 'NCo 310' and 'CP 70–321'. NCo 310 showed greater mean percentages of bored internodes (19.4%) than CP 70–321 (10.9%). Sugar per ton also was greater in CP 70–321 (215.97 lb/t or 108 g/kg) than in NCo 310 (190.92 lb/t or 95.5 g/kg); as were juice purity and mean sucrose content. Other variables (sugar per acre, cane per acre, fiber, ash, and stalk weight) did not differ significantly between the 2 varieties. Sugar per acre, juice purity, stalk weight, cane per acre, sucrose per ton of sugarcane, and sucrose content all were inversely related to percentage of bored internodes. Ash content increased with damage, consistent with a plant displaying symptoms of stress. Regression slopes for CP 70–321 were steeper than for NCo 310, perhaps suggesting that although CP 70–321 usually displays less damage, yield and quality may be affected more severely in the event of borer damage because of its higher sugar content. In Texas, the share agreements between farmers and the sugar mill mandate that the mill retains 40% of proceeds as compensation for milling, with economic losses also shared in the same ratio. Assuming the value of raw sugar is $420/t (907.18 kg), 20% bored internodes results in a loss of $1,181.04/ha ($477.96/acre). For average Texas sugarcane acreage of 18,200 ha (45,000 acres), total losses would be $21.5 M ($12.9 M to the producers and $8.6 M to the mill). The ineffectiveness of insecticides and their abandonment by Texas sugarcane growers make it imperative that pest management alternatives, such as resistant varieties and biological control agents, be investigated to alleviate the losses.

KEY WORDS   *Eoreuma loftini*, *Diatraea saccharalis*, economic damage

SUGARCANE REPRESENTS AN important commodity crop in the Lower Rio Grande Valley of Texas. All sugarcane planted in Texas is grown in this region. The industry accounts for ≈10% of the local agricultural economy with an annual economic value of approximately $64 million (Legaspi et al. 1997a). Land planted to sugarcane fluctuates but averages ≈18,200 ha. The primary insect pest of sugarcane is the Mexican rice borer, *Eoreuma loftini* (Dyar) (Lepidoptera: Pyralidae). Since its entry into Texas in the early 1980s, *E. loftini* has replaced another stalkboring pyralid, the sugarcane borer, *Diatraea saccharalis* (F.), as the dominant pest of sugarcane (Meagher et al. 1994, Legaspi

et al. 1997b). Currently, *E. loftini* accounts for >95% of the sugarcane damage by stalkborers in Texas (Legaspi et al. 1997a, b). The effectiveness of insecticides against *E. loftini* is limited by the high plant biomass of sugarcane, prolonged insect activity, a benign climatic environment, and the cryptic lifestyle of the pest. Larvae bore tunnels within the stalk and pack them with frass, thereby obstructing the access of control agents. Growers in Texas have abandoned pesticides as a viable control measure, and they accept the stalkborer damage. Of the 18,200 ha cultivated in sugarcane in the 1996–1997 growing season, only ≈81 ha (<0.5%) were treated with insecticides. Recent surveys have documented that *E. loftini* damages ≈20% of the sugarcane internodes (Legaspi et al. 1997b). This level of damage would result in monetary losses of $575/ha, based on the yield loss estimates of Meagher et al. (1994). Over the entire Texas sugarcane region, losses would total $10–20 million annually (Legaspi et al. 1997b).

We quantified the relationships between the percentages of bored internodes on sugarcane yield and on various measures of sugarcane quality for 2 impor-

tant varieties grown in south Texas, NCo 310 and CP 70–321.

## Materials and Methods

**Sugarcane Varieties.** Seedling strains of the 'NCo' sugarcane series originated from Coimbatore, India, and were developed in Natal, South Africa. The variety NCo 310 was released by the USDA in 1954, and has long been used as the standard in classifying sugarcane for cold hardiness (Reeves 1975). In the mid-1970s, NCo 310 was the major variety under production in Texas, comprising ≈45% of acreage (Reeves 1975). However, the variety was found susceptible to smut (*Ustilago scitaminea* Sydow), and acreage was reduced in 1996. Currently, only ≈3% of acreage is planted to NCo 310. In the future, this variety will be phased out completely in favor of more tolerant varieties, such as CP 70–321. The 'CP' varieties are products of the USDA sugarcane breeding program at Canal Point, FL. CP 70–321 is an early maturing variety and was 1st released in 1979. Currently, ≈64% of acreage in Texas is planted to this variety. Some of this acreage will be planted to other varieties in the future.

**Bored Internodes.** Six fields were selected as experimental sites and were sampled from 1990 to 1995. The sites were on farms owned by the Rio Grande Valley Sugar Growers (Santa Rosa, TX), the Texas Agricultural Experiment Station (TAES), and local growers. In the TAES sugarcane breeding program, field plantings with 16–22 cultivars and clones have been evaluated yearly for stalkborer injury in plots with 4 rows (9.1 m long) on a 1.5-m row spacing. In this study, we selected the data only for NCo 310 and CP 70–321 because of their historical or current importance. Field layout was a randomized complete block design with 4 replications. A buffer crop (usually NCo 310) was planted around the experiment. Stalkborer injury was evaluated by removing 20 stalks from the outer 2 rows of each plot at harvest. Stalks were mechanically split longitudinally (using a Tilby stalk splitter, Intercane Systems, Windsor, ON, Canada) and examined. The total number of internodes injured was counted to calculate percentage of bored internodes. Stalkborer species injury was separated using the characteristics described by Pfannenstiel and Meagher (1991) and Legaspi et al. (1997a).

**Measures of Sugarcane Yield and Quality.** The methods and terminology used in the assessment of sugarcane yield and quality are standard to the industry and are described in Chen (1985). A section of 4 rows 9.1 m (30 feet) long are selected at harvest. Cane from the 2 centermost rows are harvested at ground level by a hydraulic grab loader. All extraneous plant material, such as leaves and litter, are removed. The weight of the sugarcane harvested, converted to a per acre basis, is called cane per acre and is expressed in tons of net or millable sugarcane per acre of field. From the sugarcane harvested, a subsample of 15 stalks is selected and weighed. The stalk weight (mean weight per stalk) is expressed as pounds per stalk. After a mechanical disintegration of the stalks, a hy-

draulic press is used to extract the juice. The remaining plant material is the bagasse, which is composed of water, a low percentage of sugar, impurities, and fiber, which is expressed as a percentage. Lime and diatomaceous earth are added to the juice, which is then allowed to settle. Filtration produces a clear juice for analysis with a polarimeter. The polarimeter measures the percentage of sucrose (pol) in the juice. Inorganic dissolved minerals, consisting primarily of potassium (ash), are expressed in mmho). The ratio of sucrose to all dissolved solids in the juice (juice purity) is expressed as a percentage. The amount of sucrose in the sample is then extrapolated to 1 ton of sugarcane, resulting in sugar per ton, which is expressed in pounds of sugar per ton of sugarcane. Further extrapolation on an acre basis results in sugar per acre, expressed in tons sugar (sucrose) per acre of sugarcane field.

**Statistical Analysis.** Data were pooled across year and location, and analyzed using Systat statistical software (SPSS, Chicago, IL; Wilkinson et al. 1992). Comparisons of yield and quality between the 2 sugarcane varieties were performed using independent $t$-tests ($P = 0.05$). Data reported as percentages (bored internodes, pol, juice purity, and fiber content) were transformed using the arcsine transformation before all statistical analyses but are presented as untransformed means. Percentage of bored internodes and sugarcane variety were analyzed for their effects on sugarcane yield and quality using a general linear model. Sugarcane variety was designated to be a categorical variable. Linear regressions were performed on measures of sugarcane yield and quality (dependent variables) as affected by percentage of bored internodes. When the general linear model analysis indicated no significant varietal effect on percentage of bored internodes, data were pooled. However, when the varietal effect was significant, separate regressions were performed for each variety. Presentation of the untransformed percentage data required fitting new regression lines to the untransformed data.

## Results and Discussion

**Comparisons Between NCo 310 and CP 70–321.** CP 70–321 generally displayed more favorable characteristics compared with NCo 310 (Table 1). NCo 310 suffered a significantly higher mean percentage of bored internodes (19.4%) than CP 70–321 (10.9%). CP 70–321 has shown resistance to bored internodes compared with NCo 310 in past sugarcane breeding evaluations (Pfannenstiel and Meagher 1991); however, over 5 field seasons, CP 70–321 had fewer bored internodes in only 28% of the comparisons (Meagher et al. 1996). Sugar per ton also was higher in CP 70–321 (216.0 lb [97.9 kg]) than in NCo 310 (190.9 lb [86.6 kg]); as were juice purity and pol. The other variables (sugar per acre, cane per acre, fiber, ash, and stalk weight) did not differ significantly between the 2 varieties.

Table 1. Comparison of damage, yield, and quality for 2 sugarcane varieties by t-test (means ± SD)

| Factor | Variety | | t | P |
|---|---|---|---|---|
| | NCo 310 (n = 39) | CP 70-321 (n = 31) | | |
| % bored internodes | 19.04 ± 11.2 | 10.89 ± 5.89 | 3.64 | <0.01 |
| Sugar/acre, t/acre | 3.56 ± 0.99 | 3.71 ± 1.07 | 0.60 | 0.55 |
| Cane/acre, t/acre | 37.51 ± 8.85 | 34.13 ± 8.22 | 1.65 | 0.1 |
| Sugar/ton, lb/t | 190.92 ± 28.64 | 215.97 ± 22.9 | 4.07 | <0.01 |
| % juice purity | 83.72 ± 3.88 | 85.69 ± 3.24 | 2.33 | 0.022 |
| % fiber | 12.38 ± 2.32 | 12.44 ± 2.38 | 0.01 | 0.99 |
| Ash, mmhos | 6.85 ± 3.03 | 5.98 ± 3.25 | 1.15 | 0.25 |
| % Pol | 14.54 ± 1.75 | 16.52 ± 1.25 | 5.46 | <0.01 |
| Stalk wt, lb/stalk | 2.5 ± 0.48 | 2.57 ± 0.49 | 0.60 | 0.55 |

General Linear Models for Effects of Damage and Variety. The general linear model analyses indicated that the percentage of bored internodes significantly affected all sugarcane variables measured except for fiber content (Table 2). Sugarcane variety significantly affected cane per acre, sugar per ton, and pol content. In both t-tests and general linear model analyses, factors that were not significantly affected by sugarcane variety were sugar per acre, fiber content, ash, and stalk weight. In both analyses, sugar per ton and pol content were significantly affected by sugarcane variety. The effect of variety on cane per acre was highly significant in the linear model but not in the t-test. Finally, juice purity was not significantly affected by variety in the linear model analysis but was significant in the t-tests. The explanation for differences in the effects of variety on these variables is likely due to the effect of damage in the linear analyses. In the t-tests, damage is analyzed as a dependent variable, whereas it is incorporated as an independent variable in the general linear models. In the case of juice purity for example, the t-test showed that CP 70-321 had significantly higher purity than NCo 310 (Table 1). However, the general model showed that the varietal effect was not significant (Table 2); the result was attributed to differences in damage between the varieties.

Regressions Using Percentage of Bored Internodes as the Independent Variable. Regression equations using untransformed data against percentage of bored internodes are plotted against the data in Figs. 1 and 2. Single regression lines were calculated for sugar per acre, juice purity, ash, and stalk weight because these variables were not affected by variety (Table 2). Sugar

per acre, juice purity, and stalk weight all were inversely related to percentage of bored internodes. Predictably, greater damage to the plant resulted in reductions in these measures of sugarcane yield and quality. The ash content was found to increase with damage (Fig. 1C), which is consistent with a plant displaying symptoms of stress.

Regression lines for cane per acre, sugar per ton and pol content were fitted separately by variety. Increasing damage resulted in decreasing yield and quality of the sugar (Fig. 2 A–C). Interestingly, the slopes of the regressions for CP 70–321 are steeper than those for NCo 310, perhaps suggesting that although CP 70–321 displays less damage than NCo 310 (Table 1), cane per acre, sugar per ton and pol content are affected more severely by greater intensity of borer damage. Because CP 70–321 has higher sugar content than NCo 310, it has more to lose by any borer incursions. Fiber content was not significantly affected by borer damage (Fig. 2D).

Similar regression analyses were performed by Ulloa et al. (1982) for *D. saccharalis* in Florida sugarcane. Based on their equations, sugar per ton averaged across all varieties declined from 118.3 (235.1) to 112.6 g/kg (223.81 lb/t) at 10% bored internodes. This represents a loss of 5.7 g/kg (11.3 lb/t). At 20% bored internodes, sugar per ton declined to 107.0 (212.5), representing a loss of 11.4 g/kg (22.6 lb/t). These losses are smaller than those we estimate for CP 70–321, but greater than those for NCo 310 (Fig. 2). At 10% bored internodes, sugar per ton of NCo 310 declines from 104.8 g/kg (208.3 lb/t) to 100.2 g/kg (199.2 lb/t), representing a loss of 4.6 g/kg (9.1 lb/t). At 20% bored internodes, yield declines to 95.6 g/kg (190.0

Table 2. Comparison of yield and quality as functions of borer damage (arcsine transformed % bored internodes) and sugarcane variety using the general linear model analysis

| Dependent variable | $R^2$ | Effect of bored internodes | | Effect of sugarcane variety | |
|---|---|---|---|---|---|
| | | F | P | F | P |
| Sugar/acre, t/acre | 0.37 | 39.16 | <0.01 | 3.18 | 0.08 |
| Cane/acre, t/acre | 0.23 | 16.54 | <0.01 | 10.7 | <0.01 |
| Sugar/ton, lb/t | 0.38 | 21.46 | <0.01 | 5.37 | 0.02 |
| % juice purity | 0.31 | 22.6 | <0.01 | 0.3 | 0.58 |
| % fiber | 0.004 | 0.29 | 0.59 | 0.04 | 0.85 |
| Ash, mmhos | 0.082 | 4.53 | 0.037 | 0.06 | 0.8 |
| % Pol | 0.42 | 15.24 | <0.01 | 14.42 | <0.01 |
| Stalk wt lb/stalk | 0.008 | 5.45 | 0.02 | 0.12 | 0.73 |

## A: Sugar per acre (t/ac) (kg/4.46 sq m)

$Y = 4.50539 - 0.0569x$
$(R^2 = 0.34; F = 35.4; P < 0.01)$

## B: Juice purity (%)

$Y = 87.33508 - 0.17778x$
$(R^2 = 0.30; F = 29.6; P \leq 0.01)$

## C: Ash (mmhos)

$Y = 5.14148 + 0.08586x$
$(R^2 = 0.08; F = 5.96; P = 0.02)$

## D: Stalk weight (lbs [= 0.45 kg]/stalk)

$Y = 2.77992 - 0.01611x$
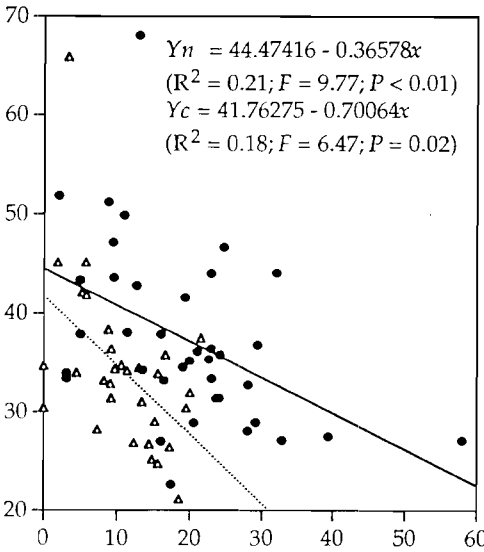$(R^2 = 0.08; F = 5.79; P = 0.02)$
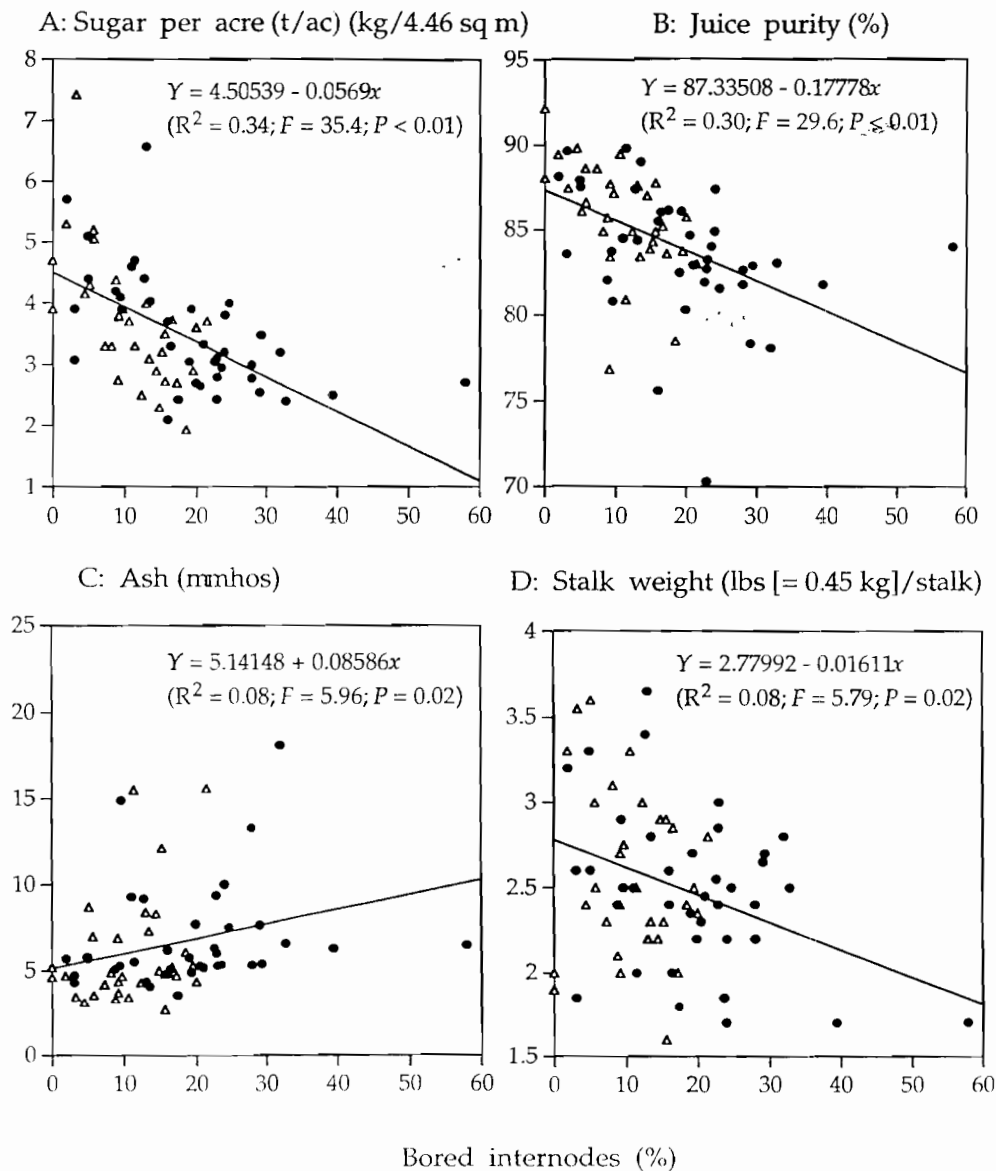
### Bored internodes (%)

Fig. 1. Pooled regression lines and data for percentage of bored internodes and A) sugar per acre, B) juice purity, C) ash, and D) stalk weight. Data are shown for NCo 310 (●), and CP 70–321 (△). Regression equations are indicated by the solid line ( - -), and shown with corresponding $R^2$, $F$, and $P$ values.

lb/t), representing a loss of 9.2 g/kg (18.3 lb/t). However, in the case of CP 70–321, yield declines from 121.2 g/kg (240.8 lb/t) to 109.8 g/kg (218.0 lb/t) at 10% bored internodes, representing a loss of 11.5 g/kg (22.8 lb/t). At 20% bored internodes, yield declines by 22.9 g/kg (45.5 lb/t) to 98.3 g/kg (195.2 lb/t).
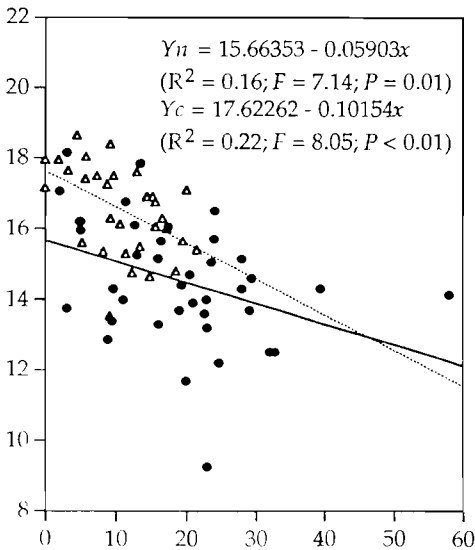
**Economic Analysis.** Much of the interest in quantification of the economic losses from stalkborer re-

lated internode damage is related to the implications of losses not only to sugarcane producers, but also to the sugar mill. In Texas, the typical sugarcane share agreement conveys ≈60% of raw sugar proceeds to the sugarcane grower with the raw sugar factory retaining ≈40% of the proceeds as compensation for milling. An added charge (based on both tonnage of cane harvested and weight of sugar produced) is then also
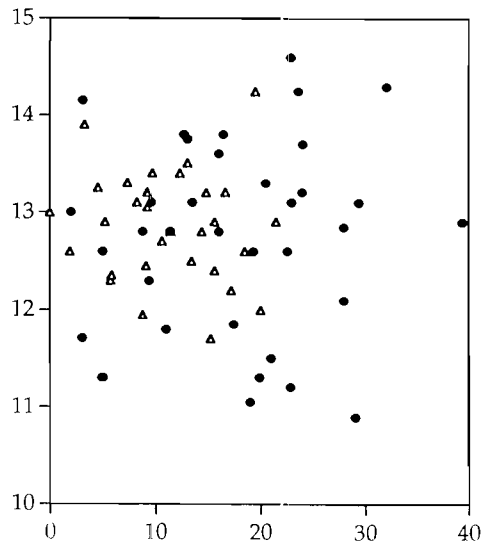
## A: Cane per acre (t/ac) (kg/4.46 sq m)

$Yn = 44.47416 - 0.36578x$
$(R^2 = 0.21; F = 9.77; P < 0.01)$
$Yc = 41.76275 - 0.70064x$
$(R^2 = 0.18; F = 6.47; P = 0.02)$

## B: Sugar per ton (lb/t) (g/2 kg)

$Yn = 208.32964 - 0.91428x$
$(R^2 = 0.17; F = 7.55; P < 0.01)$
$Yc = 240.75746 - 2.27698x$
$(R^2 = 0.42; F = 21.4; P < 0.01)$

## C: pol (%)

$Yn = 15.66353 - 0.05903x$
$(R^2 = 0.16; F = 7.14; P = 0.01)$
$Yc = 17.62262 - 0.10154x$
$(R^2 = 0.22; F = 8.05; P < 0.01)$
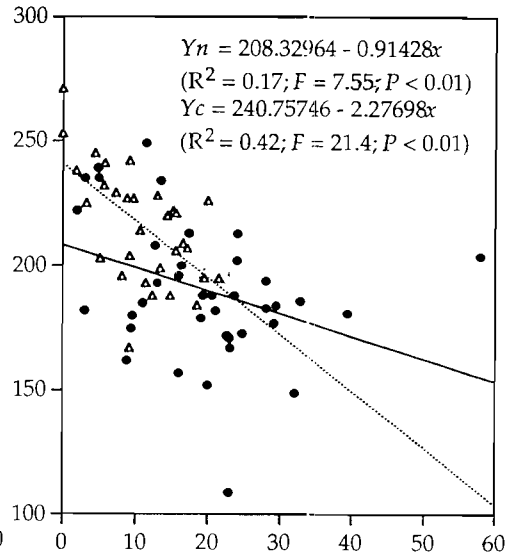
## D: Fiber (%)

Bored internodes (%)

Fig. 2. Regression lines (by variety) and data for percentage of bored internodes and A) cane per acre, B) sugar per ton, C) pol content, and D) fiber content. Data are shown for NCo 310 (●), and CP 70–321 (△). The regression equation for NCo 310 is given by $Yn$ and indicated by the solid line (—); that for CP 70–321 is given by $Yc$ and indicated by the dashed line (---). Analysis of fiber (D) indicated no significant statistical models. Regression statistics $R^2$, $F$, and $P$ for each equation are shown below the corresponding regressions.

levied against the sugarcane grower's share to pay for the sugarcane harvesting process which is collectively managed by the mill. An effect of this agreement is that only 60% of all economic losses due to damaged internodes actually accrue to the producer, whereas the remaining 40% of economic losses are absorbed by the mill. Further, if the sugarcane production occurs under the premises of a landlord/tenant land tenure agreement, then the grower's share of the economic losses accrue to both landlord and tenant in a ratio consistent with the land tenure share agreement (Johnson et al. 1995). Therefore, for all involved parties, economic losses from stalkborer internode damage result in a shortfall of potential revenues.

The effects of borer damage on revenue can be estimated by simply multiplying the regression equation of yield loss by the value of raw sugar. Assuming the value of raw sugar is $420 per ton (907.18 kg, $463 metric ton) or $0.21 per pound, then revenue loss is estimated as $Y = 420 \mid 4.50539 - (4.50539 - 0.0569x) \mid$. Using the above equation, the 20% level of bored internodes reported for Texas sugarcane (Meagher et al. 1993, Legaspi et al. 1997b) results in a loss of $1,181.04/ha ($477.96/acre). Meagher et al. (1994) reported losses at 20% bored internodes to be $575/ha, but used the sugar price paid to growers (60% of $420 per ton) in their calculation. Using the same equation as above and the regression equation of Meagher et al. (1994) ($Y = 3.54 - 0.0483x$), results in losses of $1,002.53/ha (or $405.72/acre). For average Texas sugarcane acreage (18,200 ha or 45,000 ac), total losses from our results would be approximately $21.5 M. As indicated earlier, ≈60% of these losses ($12.9 M) would accrue to sugarcane producers while 40% of the losses ($8.6 M) would be absorbed by the raw sugar mill.

Meagher et al. (1994) compared their results from *E. loftini* studies in Texas with historical results of injury due to *D. saccharalis* in Louisiana and the Caribbean. The average regression coefficient from the equations was approximately half of the coefficient calculated for *E. loftini*. However, differences in larval behavior and noninsect-related factors were offered as possible explanations for the apparent increased sugar yield loss due to *E. loftini* versus *D. saccharalis*. These factors included differences in tunneling behavior between the 2 species, sugarcane cultivars tested, age of cane when injured, and losses due to the occurrence of red rot fungus (Meagher et al. 1994). The results from our study show slightly higher loss in sugar yield to stalkborer injury compared with Meagher et al. (1994) (for 20% bored internodes: $477.96 versus $405.72, respectively). However, the design of both experiments was different, as were the sugarcane cultivars examined. Another important factor that has yet to be investigated fully is the effect of location of stalkborer injury on sugar loss. Preliminary results have shown that injury to the lower parts of a stalk decreases sugar yield more than injury to the upper parts of the stalk (R.L.M., unpublished data). Therefore, yield loss is probably affected by location

of the injury, but this has not been fully investigated experimentally and is beyond the scope of this paper.

Based on the assumption that the mean percentage of bored internodes due to stalkborer damage is ≈20%, then $20 M appears to be a conservative estimate of the economic loss incurred yearly by the Texas sugarcane industry. Despite these losses, there continues to be a satisfactory profit level inherent in sugarcane production. Current production practices allow sugarcane producers to earn returns above variable costs ranging from approximately $247–$988/ha ($100–$400/acre, respectively). These typical returns from sugarcane production consistently outperform other irrigated row crop alternatives grown in Texas, such as cotton, sorghum, and soybeans (TAES 1998). Therefore, the current and relative level of profitability and apparent lack of effective chemical controls have combined to lessen the incentive to recover losses in sugarcane production occurring from stalkborer damage. However, it is in the best interest of the sugarcane industry to explore opportunities to reduce damage to the crop. The ineffectiveness of insecticides, leading to their abandonment by sugarcane growers in Texas, makes it imperative that noninsecticidal alternatives, including resistant varieties and biological control agents, be investigated and supported to alleviate the economic losses.

## Acknowledgments

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