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Assessing the potential impact of sugarcane varieties and predation on *Diatraea saccharalis* (F.) populations in southern Louisiana

Bessin, Ricardo Tomás, Ph.D.
The Louisiana State University and Agricultural and Mechanical Col., 1990

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

The Department of Entomology

by

Ricardo Tomás Bessin

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Abstract

To facilitate a better understanding of how varietal resistance and predation affect area-wide sugarcane borer populations, several studies were undertaken before the development of a simulation model. The first study was a 3-year investigation into the compatibility and contributions of varietal resistance, arthropod predation and insecticide toward sugarcane borer control. Insecticides were shown to be the predominant management factor preventing plant injury, but varietal resistance appeared nearly as important in terms of sugarcane borer population regulation in sugarcane. The next study assessed a moth production index in addition to the percentage of bored internodes as a tool for quantifying varietal resistance to the sugarcane borer. Resistance ratings based on the percentage of bored internodes were proven to be inadequate estimators of moth emergence due to differences in sugarcane borer survival after entry into the stalk. The third study investigated the fecundity of the sugarcane borer with larval development on four gramineous hosts. A single linear regression on female pupal weight was obtained to predict fecundity regardless of the host for larval development. The simulation model included processes of immature development, oviposition, host-dependent mortality and mortality due to arthropod predation. Varietal parameters in the model were obtained from small-plot varietal evaluations. Percentages
of bored internodes were used to compare survival of sugarcane borer eggs until establishment in the stalk among sugarcane cultivars with and without predator suppression. To estimate survival among cultivars, from establishment in the stalk until pupation, a relative survival index was utilized. Simulations showed that differences in moth emergence and total emergence were greatest when there was no exchange of adults among varieties. Simulations indicated that the impact of susceptible varieties on sugarcane borer populations can be mitigated if these varieties are properly dispersed among varieties with greater resistance. Relatively small differences observed in small plot varietal evaluations were magnified during the simulations when amount of adult redistribution among varieties was reduced (i.e. grown in larger continuous plantings). Thus, results obtained from small plot varietal resistance evaluations alone do not adequately address the potential role that varieties may have on pest populations when grown on larger acreages.
Introduction

Although the sugarcane borer, *Diatraea saccharalis* (F.), typically overwinters only in sugarcane (Kirst & Hensley 1974), it is a multi-host perennial pest that can build up to damaging levels on corn (*Zea mays* L.), rice (*Oryza sativa* L.), and sorghum (*Sorghum bicolor* (L.) Moench) when grown in agroecosystems containing sugarcane (Long & Hensley 1972). In addition to these cultivated hosts, *D. saccharalis* can also successfully develop on several gramineous weeds including johnsongrass (*Sorghum halepense* (L.) Persoon), sprangletop (*Letochola filiformis* (Lam.) Beauvios), dallisgrass (*Paspalum dilatatum* Poiret), hairy crabgrass (*Digitaria sanguinalis* (L.) Koeler), goosegrass (*Eleusine indica* (L.) Gaertner), junglerice (*Echinochloa colonum* (L.) Link), and annual ryegrass (*Lolium temulentum* L.).

Since the early 1960's, candidate sugarcane varieties have been evaluated for resistance to the sugarcane borer in replicated field tests (each plot 0.004 ha) conducted both at the Louisiana Agricultural Experiment Station and at the USDA station in Houma, Louisiana (Reagan & Martin 1988). These tests are extremely valuable when used as tools to obtain information comparing damage among sugarcane varieties under similar sugarcane borer populations. However, because these tests randomize varieties among small plots in the field, the potential impact a single variety may have when planted in larger acreages may be masked.
Typically, in south Louisiana there are four to five generations of the sugarcane borer per year. Any differences in survival until adulthood or fecundity due to varieties would not be manifested in these small plot tests, because adult sugarcane borers from each generation freely redistribute themselves among the varieties. For example, a variety allowing only a limited number of moths to emerge may be infested by moths from adjacent plots that are producing greater numbers of adults in these studies. It would be expected that this variety would appear more favorable in terms of sugarcane borer resistance when planted in larger acreages.

In order to better understand how host plant resistance and predation affect sugarcane borer populations on an areawide basis, a simulation model has been developed. Although there is insufficient data to model day-to-day sugarcane borer field populations accurately, there is sufficient information available to model the magnitudes of difference in sugarcane borer populations among sugarcane varieties.

In order to develop the simulation model, several fields studies were conducted. An initial three-year study to evaluate the contributions of arthropod predation, sugarcane varietal resistance, and insecticidal control toward sugarcane borer management helped to quantify the value of multiple control tactics in the management of this insect. This study identified possible interactions among these management components. Varietal evaluation studies
conducted to assess resistance to the sugarcane borer examined the effect of cultivars on area-wide pest populations in comparison to resistance to plant injury from pest attack. A separate study investigated the physiological quality of sugarcane borer moths, measured in terms of fecundity and pupal weights, when emerging from different gramineous host plants.

Results of the field studies were used as the basis for the formulation of the simulation model. Differences in survival and fecundity of the sugarcane borer under different field situations are the major inputs for the model.
Literature Review

*Diatraea saccharalis* (F.)

The sugarcane borer, *Diatraea saccharalis* (F.), has now been designated to the family Pyralidae, subfamily Crambinae, and Tribe Chilini (Hodges 1983). *Diatraea saccharalis* has had a confused taxonomic history in the literature. A quote from Box (1931) illustrates that confusion,

"The use of the name *saccharalis*, Fabr., for the present species has hitherto been largely arbitrary. No type is known to us, and the original description might be interpreted as being applicable not only to a number of different species of *Diatraea* but to other Crambine moths as well."

Exhaustive revisions of the genus *Diatraea* by Dyar & Heinrich (1927) and Box (1931) have cleared up much of the confusion concerning the identity of this species.

Fabricius first described this species as *Phalaena saccharalis* in 1794 from material collected from "Americae meridionalis" (Meyrick 1895, Fernald 1896, Dyar & Heinrich 1927 McDunnough 1938). Four years later, Fabricius redescribed this species *Crambus sacchari*, which became the first in a long list of synonyms. The genus *Diatraea* was erected in 1828 by Guilding who described as one of its members, *Diatraea saccharalis* (Box 1931). This too became a synonym for this species and *P. saccharalis* became the type species for *Diatraea*.
The family name Crambidae was adopted by Walker in 1863, and he placed this species in that family (Fernald 1896). In that publication Walker also described *Crambus leucaniellus* and *C. lineosellus* as new species which became two additional synonyms for the original Fabricius species. Excluding the appearance of three new synonyms, *D. obliterateella* Zeller, 1881, *D. striatalis* Snell, 1891, and *Chilo obliterateella* Zeller, 1863 (Fernald 1896, Box 1931), the status of this species remained the same until 1882 when Grote attempted to place this species in the genus *Diaraetria*. Meyrick (1895) did not follow Grote and maintained this Crambid in *Diatraea*. Dyar (1911) and Dyar & Heinrich (1927) redescribed *P. saccharalis* twice as *D. pedidocta* and *D. incomarella*, respectively.

In 1895, Hampson mistakenly considered *Chilo crambidoides* Grote to be equivalent to *D. saccharalis*. This mistake was followed by many authors and added to the confusion in the literature. Dyar & Heinrich (1927) retained the name as a synonym of *D. saccharalis*, but thought it an earlier name for *D. zeacolella*. *Chilo crambidoides* was determined to be distinct from *D. saccharalis* by Box in 1931. Dyar (1902) and McDunnough (1938) united many of the smaller families used by Meyrick (Pyraustidae, Crambidae, Galleriidae, Phycitidae, etc.) into the family Pyralidae. Considering the sugarcane borer's turbulent past, the taxonomic status of this species has changed little since the Dyar checklist of 1902 (Hodges
Box (1931) concluded *D. saccharalis* is not only numerically the most abundant species in the genus, but also the most widely distributed. The range of distribution has been reported to include the southern United States, Hawaii, the West Indies, Central America, and South America as far south as Argentina. Five other *Diatraea* have also been reported from Louisiana, seven others from the United States, and 47 others from the Americas (Hodges 1983). There are more than 90 species of *Diatraea* worldwide (Box 1931). There have been no reports of *D. saccharalis* occurring in the Old World. This species has been reported to be a pest in Louisiana as early as 1855 (Holloway & Loftin 1919), having been introduced in sugarcane from South America.

Host Plant Resistance Studies

For nearly 90 years, the differential response of sugarcane varieties to sugarcane borer attack has been studied (Stubbs & Morgan 1902; Holloway 1935; Mathes & Ingram 1942, 1944; Long et al. 1961; Mathes & Charpentier 1962). Several criteria have been used to assess resistance to the sugarcane borer, the primary criterion being the percentage of bored internodes obtained from varieties in replicated field tests (Holloway 1935; Mathes & Ingram 1942, 1944; Kyle & Hensley 1970; Reagan & Martin 1988). This serves as the criterion to quantify plant injury resulting
from sugarcane borer attack. Jaynes & Bynum (1941) demonstrated a high degree of association between bored internodes determined by external examination and those determined by splitting stalks. However, it has been demonstrated that sugar yields are affected not only by the amount of damage, but also the position of injury on the stalk (McGuire et al. 1965). Two physical mechanisms have been implicated as being responsible for causing differences in percentages of bored internodes among sugarcane varieties; the rate of sugarcane rind hardness development (Martin & Cochran 1975, Martin et al. 1975) and leaf sheath appression (Coburn & Hensley 1972). Screening sugarcane seedlings in the greenhouse has been investigated as a method of evaluating large numbers of varieties for sugarcane borer resistance (Pan & Hensley 1973), however, this technique is not currently employed. The degree of seedling elimination was closely correlated to the level of parental resistance.

Varietal resistance to the sugarcane borer has been an important tool in the management of this perennial pest during the past two decades (Hensley 1971), and has resulted in a substantial suppression of sugarcane borer populations (Reagan & Martin 1988). In 1986, 86% of the Louisiana sugarcane acreage incorporated sugarcane borer resistant sugarcane varieties (Fanguy & Fontenot 1987). During this same period, more than 70% of the sugarcane acreage was contracted for sugarcane borer scouting by private
consultants who stratify their sampling and scouting time according to varietal susceptibility (Reagan & Martin 1982, 1988). In south Louisiana, during the 1973-1975 period, a susceptible variety, CP 61-37, received an average of 3.3 insecticidal applications per year, while a resistant variety, NCo 310, averaged only 1.1 applications (Reagan & Martin 1982).

Arthropod Predation

Several studies have illustrated the value of predator and parasitoids for reducing sugarcane borer populations in southern Louisiana. Long et al. (1958) demonstrated a 48% increase in crop damage when heptachlor was applied to remove predators. More recent studies by Negm & Hensley (1967, 1969, 1972) identified a plethora of arthropod predators attacking sugarcane borer. In particular, the imported fire ant, Solenopsis invicta Buren, is considered a key beneficial insect attacking Diatraea saccharalis in the sugarcane agroecosystem (Charpentier et al. 1967, Reagan 1986). Cultural practices such as weed management (Ali & Reagan 1985b) and ratooning of sugarcane fields (White 1980) have been shown to exert a significant influence on the composition and numbers of predator and prey populations.

Differences in predation have also been noted among sugarcane and other Diatraea saccharalis hosts. Fuller & Reagan (1988) observed a 4-fold and 16-fold greater abundance of predators in sugarcane as compared to sweet
sorghum, *Sorghum bicolor* (L.) Moench, in 1985 and 1986, respectively. These innate differences between host crops were attributed to predator habitat disruption associated with differing cultivation practices. The perennial sugarcane receives minimal cultivation as compared with the annual crop of sweet sorghum.

**Modeling Insect Populations**

Getz & Gutierrez (1982) examined current systems analysis research as applied to pest management problems and noted three basic modeling approaches; (a) the simulation approach - where biological realism and modeling completeness are stressed in order to explore the structure and functioning of a system; (b) the analytical approach - in which sub-model structures (e.g. ovipositional rates, survival rates, dispersal rates, feeding rates, etc.) are emphasized to develop quantitative principles in ecology and resource management; and (c) the operations approach - to design models to address specific problems, and analysis is geared toward obtaining quantitative solutions.

Numerous models are currently available to depict insect populations including *Heliothis*, European corn borer, boll weevil, alfalfa weevil, Egyptian alfalfa weevil, cereal leaf beetle, aphids, Lygus bugs, winter moth, mosquitoes, grasshoppers, velvetbean caterpillar, mites, Mexican bean beetle, fall webworm, southern green stink bug, pecan nut casebearer, and several non-pest species (Ruesink 1976).
These models may be categorized as follows: Models that change with respect to time are considered "dynamic", whereas, those which do not move or progress are termed "static". Nearly all models developed for insects are dynamic. A model may also be "discrete" or "continuous". One that predicts an outcome for any instant in time is said to be continuous, as opposed to one in which there are fixed "windows" in time where the status of the system can be characterized. The static approach does not address population developments between windows.

Two other categories of models are "deterministic" (where probability plays no role) and "stochastic" (those containing probabilistic statements). The proposed model in this study will be dynamic, discrete, and stochastic. Oddson & Aggarwal (1985) used this model type to predict population changes of the navel orange worm, *Amyelosis transitella* (Walker), in almonds when different hypothetical management practices were implemented. Stinner et al. (1974) successfully used the HELSIM-2 model for *Heliothis zea* (Boddie) to improve upon it's management on several North Carolina crops. Gutierrez et al. (1976) developed a simulation model for alfalfa and the Egyptian alfalfa weevil, *Hypera brunneipennis* (Boheman), to predict year long population development based upon early season estimates for each and weather parameters. Discrepancies detected between simulated and observed results pinpointed areas of insufficient knowledge. The model's inadequacy
forced them to reexamine some biological assumptions pertinent to the weevil's biology. Haynes & Gage (1981) discussed the various cereal leaf beetle, *Oulema melanopus* (L.), models using information on life history, population dynamics, parasitoid interactions, alternate hosts, overwintering sites, and other environmental factors and how these models led to the concepts of regional on-line management for cereal leaf beetle populations. The components of this management scheme were (a) environmental monitoring; (b) biological monitoring (pest densities, physiological states, parasitism); (c) ecosystem modeling; and (d) a computer-based delivery system providing access to the information. This enabled identification of priorities for future research.
Chapter I

Integration of Control Tactics for Management of the Sugarcane Borer (Lepidoptera: Pyralidae) in Louisiana Sugarcane

The following chapter is modified from manuscript J89-090, which was accepted by the Journal of Economic Entomology and is currently in press.
Introduction

The sugarcane borer, *Diatraea saccharalis* (F.), is a serious pest of sugarcane, a complex hybrid of *Saccharum* spp., in Louisiana. More than 95% of the damage caused by insects to this crop is attributed to this species (Reagan et al. 1972). Varietal resistance to the sugarcane borer has been an important tool in the management of this perennial pest during the past two decades (Hensley 1971), and has resulted in substantial suppression of sugarcane borer populations (Reagan & Martin 1988). In 1986, 86% of the Louisiana sugarcane acreage incorporated sugarcane borer resistant sugarcane varieties (Fanguy & Fontenot 1987). During this same period, more than 70% of the sugarcane acreage was contracted for sugarcane borer scouting by private consultants who stratify their sampling and scouting time according to varietal susceptibility (Reagan & Martin 1982, 1988). In south Louisiana, during the 1973-1975 period, a susceptible variety, CP 61-37, received an average of 3.3 insecticidal applications per year, while a resistant variety, NCo 310, averaged only 1.1 applications (Reagan & Martin 1982). Arthropod predation on the sugarcane borer provides additional control throughout the season. The composition of the arthropod predator complex and its importance in the regulation of borer populations as influenced by numerous cultural and natural factors in sugarcane has been studied intensively (Negm & Hensley 1969, 1972, Reagan et al. 1972, Ali & Reagan 1985, Fuller & Reagan
Thus, other than the influences of weather and temperature, population regulation of *D. saccharalis* during the growing season relies on three principal components; varietal resistance, insecticidal control, and a complex of natural enemies. Furthermore, the impact of each of these management components, when combined, has the potential to be altered and/or to alter the effects of the other components to varying degrees. For example, it might be expected that the complex of natural enemies would be altered after an insecticide application, with a resultant decrease in the proportion of control contributed by natural enemies. Varietal resistance has been shown to be highly compatible with other pest management tactics (Kogan 1975), and additionally, it has been shown mathematically that even low levels of resistance can have profound effects on the efficiency of natural enemies (van Emden 1966).

The goal of this study was to determine the relative contributions of varietal resistance, arthropod predation, and insecticidal control in sugarcane borer management. Additionally, these tactics were combined to investigate their mutual compatibilities (i.e., antagonism, synergism, or additivity) in the sugarcane agroecosystem of southern Louisiana.

**Materials and Methods**

A 3-year study to evaluate the relative contribution
and compatibility of varietal resistance, arthropod predation, and insecticidal control of the sugarcane borer using a repeated measures split-split-plot design (4 replications) was located at the St. Gabriel Research Station of the Louisiana Agricultural Experiment Station. Because of the mobility of ants and spiders, main-plot treatments consisted of plots with and without predator suppression (chlordane applied to the soil surface at 1.12 kg [AI]/ha), with the sub-plot represented by three sugarcane varieties, CP 61-37 (sugarcane borer susceptible), CP 65-357 (moderately resistant), and CP 70-330 (resistant), each planted in eight-row plots (16x22 m). Fenvalerate insecticide was applied to one pair of outside rows in each sub-plot (0.14 kg [AI]/ha) while the other rows were left untreated, forming the sub-sub-plots. When sugarcane borer infestations exceeded the 5% economic threshold (Pollet et al. 1978) in CP 61-37 plots with insecticide and no predator suppression, insecticide was applied to all the insecticide sub-sub-plots.

Sugarcane borer infestations were monitored biweekly through the summer during 1985 (24 July-20 September), 1986 (9 July-1 October), and 1987 (7 July-16 September) using destructive sampling, which involved the dissection of 15 stalks per sub-plot. Two sampling methods were used to monitor the effectiveness of predator suppression treatments: pitfall traps using two 473 ml jars per sub-plot according to the method of Reagan et al. (1972), and peanut
oil-baited index cards, two per sub-plot, at biweekly intervals, put out near midday and collected after 40 min (Ali & Reagan 1986). Pitfalls provided continuous sampling of ground associated arthropods for the entire season.

To estimate sugarcane yield, sugarcane borer damage, and sugarcane borer moth production, three 15-stalk samples were harvested at random from each sub-sub-plot at the end of the season. Stalk density was estimated from a single 12 m sample of row in each sub-sub-plot. Stalks were stripped of leaves, weighed, and carefully inspected for characteristic sugarcane borer larval entrance and adult emergence holes. Sugarcane borer damage, as measured by percent bored internodes, was determined for each sample as a proportion of internodes bored to total internodes. Sugarcane borer adult production was determined as the product of the mean number of adult exit holes per stalk and stalk density. Stalk density was estimated within each sub-plot with two 12 m samples. Sugar yields, calculated as metric tons of sugar per ha, were determined according to the methods of Legendre & Henderson (1972).

Percent bored internodes were transformed using the logit function (Neter et al. 1985) for normalization of percentile data. Moth emergence data were subjected to a logarithmic transformation (Neter et al. 1985). No transformation was performed on yield data. Because sugarcane is grown as a perennial crop in Louisiana, treatments could not be re-randomized each year, so the data
were combined and treated as repeated measures. Data were subjected to analysis of variance.

Results

During 1985, the sugarcane borer infestation did not peak until late in the season, resulting in a mean of 30.0% infested stalks (Figure 1), whereas, the 1986 season was characterized by a large early season infestation and a seasonal mean of 31.1% infested stalks. Sugarcane borer infestations were greatest during the 1987 season with a mean of 51.4% stalks infested. Biweekly monitoring of sugarcane borer infestations indicated the need for three insecticidal applications during each year of the study: 2 August, 27 August, and 19 September in 1985; 11 July, 30 July, and 13 September in 1986; and 13 July, 5 August, and 7 September in 1987.

Peanut oil-baited index card data indicated means of 100.9 ± 16.4 and 2.4 ± 1.8 ants (±SE) collected per card per 40 min sample in predator and predator suppressed plots, respectively, for the 3-year period. Solenopsis invicta Buren, the red imported fire ant, constituted 97.9% of the ants collected on index cards. Pitfall data revealed similar relationships with respect to S. invicta (Table 1). The soil insecticide applied to these plots reduced the abundance of S. invicta while increasing the number of ground beetles (Carabidae). The different sugarcane cultivars had no detectable effects on the abundance of the
Figure 1. Mean percent *Diatraea saccharalis* infested sugarcane stalks (±SE) during 1985, 1986 and 1987 at the St. Gabriel Research Station.
Table 1. Effects of predator suppression on the abundance of selected insect and spider taxa in pitfall traps collected at 2-week intervals at the St. Gabriel Research Station during 1985, 1986 and 1987a

<table>
<thead>
<tr>
<th>Arthropod taxon</th>
<th>F</th>
<th>P&gt;F</th>
<th>Suppressionb</th>
<th>No suppression</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. invicta</td>
<td>50.85</td>
<td>&lt;0.01</td>
<td>3.53 ± 0.41</td>
<td>20.25c± 1.35</td>
</tr>
<tr>
<td>Other ants</td>
<td>4.10</td>
<td>0.14</td>
<td>0.35 ± 0.06</td>
<td>0.72 ± 0.13</td>
</tr>
<tr>
<td>Carabidae</td>
<td>27.33</td>
<td>0.01</td>
<td>1.48 ± 0.10</td>
<td>0.73c± 0.07</td>
</tr>
<tr>
<td>Dermaptera</td>
<td>8.30</td>
<td>0.06</td>
<td>0.27 ± 0.04</td>
<td>0.15 ± 0.04</td>
</tr>
<tr>
<td>Staphylinidae</td>
<td>0.25</td>
<td>0.65</td>
<td>2.12 ± 0.19</td>
<td>1.86 ± 0.17</td>
</tr>
<tr>
<td>Cicindellidae</td>
<td>0.48</td>
<td>0.54</td>
<td>0.20 ± 0.04</td>
<td>0.16 ± 0.04</td>
</tr>
<tr>
<td>Orthoptera</td>
<td>1.44</td>
<td>0.32</td>
<td>4.92 ± 0.26</td>
<td>3.98 ± 0.26</td>
</tr>
<tr>
<td>Spiders</td>
<td>6.67</td>
<td>0.08</td>
<td>5.87 ± 0.36</td>
<td>8.44 ± 0.41</td>
</tr>
<tr>
<td>Total predators</td>
<td>26.98</td>
<td>0.01</td>
<td>14.90 ± 0.69</td>
<td>36.05c± 1.61</td>
</tr>
</tbody>
</table>

a Degrees of freedom for F values = 1,3.
b Predator suppression was maintained with biannual chlordane applications (1.12 kg [AI]/ha) applied to the soil surface.
c Means are different by analysis of variance (P<0.05).
different predators ($F=0.11-2.01$, d.f.$=2,12$, $P=0.18-0.89$).

Highly significant differences ($P<0.01$) were detected in percent bored internodes among years. Sugarcane borer damage increased each year with means of 6.3, 11.1 and 19.2% bored internodes in 1985, 1986, and 1987, respectively. Each of the three management components caused highly significant ($P<0.01$) reductions in sugarcane borer injury to sugarcane as measured by percent bored internodes (Table 2). Over the 3-year duration of the study, arthropod predation and insecticidal applications contributed 1.9 and 7.3 fold decreases, reducing $D. saccharalis$ bored internodes from 21.7 to 13.4% and 29.8 to 4.8%, respectively. Varietal resistance contributed a 2.9 fold decrease in percent bored internodes when the susceptible, CP 61-37, and the resistant variety, CP 70-330, were compared. The moderately resistant variety, CP 65-357, was injured intermediate to that of the other varieties in 1985, when the infestation was the lowest, and similar to the susceptible variety in the subsequent two years, which resulted in a significant ($P<0.05$) year x varietal resistance interaction (Figure 2). There was a highly significant insecticide by year interaction ($P<0.01$). Fenvalerate applications reduced percent bored internodes by 90.0 and 87.1% in 1985 and 1986, respectively, but only 77.5% in 1987. Arthropod predation and varietal resistance, varietal resistance and insecticidal control, and arthropod predation and insecticidal control were not found to interact as measured
Table 2. Comparison of *Diatraea saccharalis* damage and adult emergence from sugarcane as determined by end-of-season stalk inspection during 1985, 1986 and 1987

<table>
<thead>
<tr>
<th>Management factor combination</th>
<th>Bored internodes (%)</th>
<th>Moth emergence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>d.f.</td>
<td>F</td>
</tr>
<tr>
<td>Predation (P)</td>
<td>1,3</td>
<td>71.0</td>
</tr>
<tr>
<td>Varietal resistance (HPR)</td>
<td>2,12</td>
<td>66.2</td>
</tr>
<tr>
<td>P * HPR</td>
<td>2,12</td>
<td>1.1</td>
</tr>
<tr>
<td>Fenvalerate (I)</td>
<td>1,18</td>
<td>759.9</td>
</tr>
<tr>
<td>P * I</td>
<td>1,18</td>
<td>1.4</td>
</tr>
<tr>
<td>HPR * I</td>
<td>2,18</td>
<td>0.5</td>
</tr>
<tr>
<td>P * HPR * I</td>
<td>2,18</td>
<td>0.7</td>
</tr>
<tr>
<td>Year (Y)</td>
<td>2,71</td>
<td>55.8</td>
</tr>
<tr>
<td>P * Y</td>
<td>2,71</td>
<td>1.5</td>
</tr>
<tr>
<td>HPR * Y</td>
<td>4,71</td>
<td>3.1</td>
</tr>
<tr>
<td>I * Y</td>
<td>2,71</td>
<td>10.2</td>
</tr>
<tr>
<td>P * HPR * Y</td>
<td>4,71</td>
<td>1.5</td>
</tr>
<tr>
<td>P * I * Y</td>
<td>2,71</td>
<td>1.3</td>
</tr>
<tr>
<td>HPR * I * Y</td>
<td>4,71</td>
<td>0.2</td>
</tr>
<tr>
<td>P * HPR * I * Y</td>
<td>4,71</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Figure 2. Mean *D. saccharalis* damage among three sugarcane cultivars at harvest in 1985, 1986 and 1987. The cultivars represent varying degrees of *D. saccharalis* resistance: susceptible (CP 61-37), moderately resistant (CP 65-357), and resistant (CP 70-330).
by percent bored internodes.

Moth emergence ranged from a mean of 110,400 moths per ha, on sugarcane borer susceptible sugarcane with predator suppression and no insecticidal control in 1986, to 300 moths per ha, on resistant sugarcane with predation and insecticidal control in 1986. Predation, varietal resistance (susceptible vs. resistant), and insecticidal control resulted in 1.7, 7.1, and 7.9 fold reductions, respectively, of adult emergence. Moth production, as measured by emergence holes, was significantly (P<0.05) reduced by both varietal resistance and insecticidal control (Table 2). Predation did not significantly (P>0.05) reduce adult production; however, a strong trend toward reduction was observed, i.e. 15,400, 35,100 and 30,300 moths per ha emerged from predator-suppressed sugarcane during 1985, 1986 and 1987, respectively, as opposed to 8500, 17,400 and 23,000 moths per ha from sugarcane with predation during those same years. Moth emergence from the moderately resistant variety was similar to that of the resistant variety in 1985, when early season infestations were low, but in 1986 and 1987, moth production in the moderately resistant variety was intermediate to that of the other varieties (Figure 3), resulting in a significant (P<0.05) varietal resistance x year interaction. A significant (P<0.05) interaction was observed between varietal resistance and insecticidal control influencing moth emergence. This relationship was antagonistic, indicating a
Figure 3. Mean *D. saccharalis* adult emergence among three sugarcane cultivars at harvest in 1985, 1986 and 1987. The cultivars represent varying degrees of *D. saccharalis* resistance: susceptible (CP 61-37), moderately resistant (CP 65-357), and resistant (CP 70-330).
greater insecticidal control of adult emergence occurring on the susceptible and the moderately resistant variety (86.4 and 79.1%, respectively) compared with the resistant variety (71.4%). While this antagonism affected magnitudes of control, increased control was always observed with the combination of these management factors (Figure 4).

Mean sugar yields differed significantly \( (F=121.63; \text{d.f.}=2,71; P<0.01) \) with resulting means of 6.70, 6.65, and 3.74 metric tons sugar per ha for 1985, 1986 and 1987, respectively. Mean stalk weight declined significantly \( (F=114.82; \text{d.f.}=2,71; P<0.01) \) during the study with yearly means of 1.09, 0.97 and 0.92 kg per stalk for the same three years, respectively. Varietal resistance and predation were not found to significantly \( (P>0.05) \) affect sugar yields individually; however, they were found to interact with insecticidal control in terms of sugar yields (Table 3). The insecticidal control x varietal resistance interaction was due to greater sugar yield reductions on varieties CP 61-37 (susceptible) and CP 65-357 (moderately resistant) than on CP 70-330 (resistant) when no insecticide was applied. The resistant variety sustained only a 0.61 metric ton per ha loss with the removal of insecticide, while the susceptible and moderately resistant varieties sustained losses of 1.51 and 1.16 metric ton per ha (Table 4), respectively. An insecticide x predation interaction was detected, and was due to greater increases in sugar yields when insecticides were applied to predator plots than to
Figure 4. Adult emergence of *D. saccharalis* among three sugarcane cultivars with and without arthropod predation and insecticidal control during 1985, 1986 and 1987
Table 3. Statistical analysis of management factor combinations in sugarcane on sugar yield, during 1985, 1986 and 1987 at the St. Gabriel Research Station, St. Gabriel, LA

<table>
<thead>
<tr>
<th>Management factor combination</th>
<th>Sugar yield (metric tons sugar per ha)</th>
<th>d.f.</th>
<th>F</th>
<th>P&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predation (P)</td>
<td></td>
<td>1,3</td>
<td>0.01</td>
<td>0.98</td>
</tr>
<tr>
<td>Varietal resistance (HPR)</td>
<td></td>
<td>2,12</td>
<td>2.78</td>
<td>0.10</td>
</tr>
<tr>
<td>P * HPR</td>
<td></td>
<td>2,12</td>
<td>0.02</td>
<td>0.98</td>
</tr>
<tr>
<td>Fenvalerate (I)</td>
<td></td>
<td>1,18</td>
<td>13.66</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>P * I</td>
<td></td>
<td>1,18</td>
<td>9.91</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>HPR * I</td>
<td></td>
<td>2,18</td>
<td>3.56</td>
<td>0.05</td>
</tr>
<tr>
<td>P * HPR * I</td>
<td></td>
<td>2,18</td>
<td>1.40</td>
<td>0.27</td>
</tr>
<tr>
<td>Year (Y)</td>
<td></td>
<td>2,71</td>
<td>121.63</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>P * Y</td>
<td></td>
<td>2,71</td>
<td>0.01</td>
<td>0.93</td>
</tr>
<tr>
<td>HPR * Y</td>
<td></td>
<td>4,71</td>
<td>7.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>I * Y</td>
<td></td>
<td>2,71</td>
<td>3.02</td>
<td>0.09</td>
</tr>
<tr>
<td>P * HPR * Y</td>
<td></td>
<td>4,71</td>
<td>0.05</td>
<td>0.96</td>
</tr>
<tr>
<td>P * I * Y</td>
<td></td>
<td>2,71</td>
<td>2.31</td>
<td>0.13</td>
</tr>
<tr>
<td>HPR * I * Y</td>
<td></td>
<td>4,71</td>
<td>0.81</td>
<td>0.45</td>
</tr>
<tr>
<td>P * HPR * I * Y</td>
<td></td>
<td>4,71</td>
<td>0.32</td>
<td>0.73</td>
</tr>
</tbody>
</table>
plots with predator suppression, 1.11 and 1.05 metric tons per ha, respectively. Insecticidal control had a significant effect (P<0.01) on sugar yields on sugar yields, mean yields were 5.15 in non treated plots and 6.24 tons sugar per ha in insecticide treated plots (Table 4). A significant (P<0.01) year x variety interaction was detected. CP 61-37 out yielded the other varieties in 1985, but was out yielded in 1986 and 1987 (Table 4).

The relative contribution of each management factor toward the overall sugarcane borer management is presented in Table 5. The 3-year means indicate that predation, varietal resistance, and insecticidal control contributed 15.7, 24.4, and 60.7% of sugarcane borer control as measured by percent bored internodes. The contributions of predation, varietal resistance and insecticidal control (on CP 70-330) were 13.7, 39.1, and 47.2% of the control of adult sugarcane borer production, respectively, as measured by numbers of exit holes.

Discussion

Peanut oil-baited index card data and the pitfall data on arthropod predation correspond well with that of other studies that have involved predator suppression in sugarcane (Fuller & Reagan 1988, Reagan et al. 1972). Soil surface applied insecticide reduced the abundance of S. invicta, the dominant insect species in non-chlordane treated sugarcane. Although reported as a serious pest in the southern United
Table 4. Comparison of sugar yields among three sugarcane varieties during 1985, 1986 and 1987 with and without *D. saccharalis* insecticidal control at the St. Gabriel Research Station, St. Gabriel, LA

<table>
<thead>
<tr>
<th>Variety</th>
<th>1985</th>
<th>1986</th>
<th>1987</th>
<th>Mean with insecticide</th>
<th>Mean without insecticide</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP 70-330</td>
<td>5.82</td>
<td>7.06</td>
<td>4.24</td>
<td>6.01</td>
<td>5.41</td>
</tr>
<tr>
<td></td>
<td>(0.47)</td>
<td>(0.49)</td>
<td>(0.27)</td>
<td>(0.43)</td>
<td>(0.39)</td>
</tr>
<tr>
<td>CP 65-357</td>
<td>6.86</td>
<td>6.65</td>
<td>3.50</td>
<td>6.24</td>
<td>5.08</td>
</tr>
<tr>
<td></td>
<td>(0.30)</td>
<td>(0.24)</td>
<td>(0.17)</td>
<td>(0.40)</td>
<td>(0.32)</td>
</tr>
<tr>
<td>CP 61-37</td>
<td>7.43</td>
<td>6.23</td>
<td>3.48</td>
<td>6.47</td>
<td>4.96</td>
</tr>
<tr>
<td></td>
<td>(0.41)</td>
<td>(0.34)</td>
<td>(0.21)</td>
<td>(0.47)</td>
<td>(0.33)</td>
</tr>
</tbody>
</table>
Table 5. Relative contributions of arthropod predation, varietal resistance, and fenvalerate in controlling sugarcane borer injury to sugarcane and adult moth production

<table>
<thead>
<tr>
<th>Control factor</th>
<th>1985</th>
<th>1986</th>
<th>1987</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control of bored internodes (%)^a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predation</td>
<td>11.9</td>
<td>13.8</td>
<td>18.0</td>
<td>15.7</td>
</tr>
<tr>
<td>Varietal resistance</td>
<td>15.9</td>
<td>26.4</td>
<td>26.6</td>
<td>24.4</td>
</tr>
<tr>
<td>Insecticidal control</td>
<td>72.2</td>
<td>59.9</td>
<td>55.3</td>
<td>60.7</td>
</tr>
<tr>
<td>Control of adult moth production (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predation</td>
<td>9.5</td>
<td>9.0</td>
<td>14.6</td>
<td>13.7</td>
</tr>
<tr>
<td>Varietal resistance</td>
<td>50.1</td>
<td>36.4</td>
<td>33.7</td>
<td>39.1</td>
</tr>
<tr>
<td>Insecticidal control (on CP 70-330)</td>
<td>40.4</td>
<td>54.6</td>
<td>51.7</td>
<td>47.2</td>
</tr>
</tbody>
</table>

^a Percentages do not sum to 100 due to rounding.
States (Adams 1986), *S. invicta* is considered an important beneficial insect in the sugarcane agroecosystem (Charpentier et al. 1967, Reagan 1986).

In 1986 and 1987, the sugarcane variety CP 65-357 (moderately resistant) sustained injury similar to that of the susceptible cultivar, CP 61-37. However, it has been regarded as more resistant to sugarcane borer injury for several years (Martin et al. 1975). Due to the nature of the study, sugarcane borer infestations were somewhat larger than typically encountered under normal pest management conditions, and this may have resulted in a breakdown in resistance to the sugarcane borer by CP 65-357 as opposed to the susceptible CP 61-37. Varietal resistance is typically thought to be density independent, operating equally at all levels of pest infestation. In this instance, the contribution of varietal resistance may have diminished at higher infestations in the moderately resistant variety; however, sugarcane borer densities were confounded with years. Other differences associated with the years of the study, such as rainfall and temperature, may affect plant resistance to insects.

In terms of preventing sugarcane borer injury to sugarcane during the active pest part of the season, insecticidal control, when applied in accordance with the 5% economic threshold, contributed more than any of the other individual management factors. However, by simply adjusting the threshold at which the decision to apply the insecticide
is made, it may be possible to alter the contribution received from insecticidal control over the season. While this may alter the contribution of insecticidal control, altering the economic threshold is economically unreasonable until quantitative studies show otherwise. Arthropod predation and varietal resistance also prevented borer injury, but their contributions were less than that of insecticidal control. In each of the three years of study, control of plant injury was substantially enhanced when management factors were combined, and the least injury was observed with all three factors functioning in combination.

Using sugarcane borer emergence holes as the seasonal record of adult emergence, it is possible to estimate the potential area-wide suppression or enhancement of populations resulting from these control factors (Bessin et al. 1990). Varietal resistance and insecticidal control resulted in similar levels of suppression of moth emergence. While CP 61-37 and CP 65-357 were injured similarly, the moth production from these varieties differed considerably. This suggests that after larvae penetrate into the stalks of CP 65-357, subsequent survival is less than that inside CP 61-37. Thus, given equal levels of sugarcane borer injury, the moderately resistant variety, CP 65-357, was shown not to enhance area-wide populations nearly as much as the susceptible CP 61-37.

Had the experimental units in this study been larger, each encompassing entire fields, larger differences between
these treatment combinations would have been expected. When conducting this experiment, treatment combinations that yielded little control of moth emergence supplied inoculum to maintain pressure on experimental units that had superior treatments. Thus, if those superior treatments had been kept farther apart from the inferior treatments providing little control of moth emergence, less plant injury would have been expected than that observed in the superior treatments.

Highly significant (P<0.01) interactions were detected in sugarcane borer control between varietal resistance and insecticidal control as measured by moth emergence. These interactions were found to be antagonistic, as the benefits received from insecticidal control on the susceptible variety, CP 61-37, were greater than those received on the resistant variety, CP 70-330. Differences in insecticidal efficacy on the sugarcane varieties could possibly be due to morphological differences between varieties. One important mechanism of sugarcane resistance to the sugarcane borer is leafsheath appression. Coburn & Hensley (1972) showed that leafsheath appression was at least partially responsible for the differential survival of larvae on a resistant sugarcane variety, NCo 310, compared with the susceptible variety, CP 44-101. Once larvae established and tunneled into stalks, similar development patterns on these varieties were observed. The resistant variety, CP 70-330, has a high degree of leafsheath appression, and the susceptible
variety, CP 61-37, has a leafsheath that loosens rapidly as
the internode matures (personal observation). These
differences in leafsheath appression may limit the
penetration of the non-systemic insecticide, fenvalerate,
into the leafsheath and its subsequent contact with the
larvae. In this sense, varietal resistance and insecticidal
control are not completely compatible when physical
characteristics of the plant may act as both resistance
mechanisms and barriers affecting insecticidal control.

No interaction ($P > 0.05$) was detected between arthropod
predation and insecticidal control in terms of plant injury
or adult emergence (Table 2). The contribution resulting
from predation was not diminished when the sugarcane was
treated with fenvalerate. An arthropod predation
insecticide interaction was expected; however, the small
size of the sub-sub-plots that were treated with insecticide
may have reduced the impact of the insecticide on the
predators. Only two out of eight rows in each sub-plot were
treated with fenvalerate. This buffered the acute effects
of the insecticide by increasing the amount of refugia for
the predators from the applications. However, when applying
insecticide uniformly on sugarcane fields, one would
expect alterations in the composition and abundance of
arthropod predators should occur.

Sugar yields were shown to be affected by the different
sugarcane borer management factor combinations. Arthropod
predation and varietal resistance did not significantly
(P>0.05) affect yields individually. But, they were found to interact with insecticidal control. The susceptible and moderately resistant varieties were shown to have a greater potential for yield loss with the removal of insecticidal control. Greater increases in sugar yields were detected when insecticidal control was used in combination with predation as compared to insecticidal control and predator suppression. Insecticidal control as a sole management factor was found to increase sugar yields by more than 1 metric ton per ha.

It is noted that the sugarcane varieties used in this study may have different yield potentials. Therefore, when assessing the role of varietal resistance, other agronomic characteristics of the varieties are confounded with sugarcane borer resistance, direct comparisons among varieties should be restricted to yield loss among management factor combinations. Even in the absence of Diatraea saccharalis these varieties may show yield differences.

Sugarcane borer control was measured by two different criteria. First, control was quantified by plant injury utilizing percentages of internodes bored. Control was also quantified in terms of population regulation and was determined by measuring moth emergence. Resultant effects of different management factors differed when analyzed by these two criteria. While varietal resistance contributed only 24% of the control of plant injury, it supplied nearly
40% of the suppression of moth emergence. Even moderate levels of varietal resistance were shown to substantially reduce sugarcane borer emergence. Insecticidal control was shown to be the predominant management factor in preventing plant injury, but varietal resistance appeared to be equally important in terms of population regulation in sugarcane.

While predation contributed less than the other factors studied, it is available at little cost to the grower. Both predation and varietal resistance provide effects that are cumulative over the entire season. When implementing an integrated pest management program to control the sugarcane borer in sugarcane, consideration should be given to how different management factors contribute to control and the compatibility of the management factors amongst themselves.
References Cited


Inc. Homewood, Ill. 1127pp.


Chapter II

A Moth Production Index for Evaluating Sugarcane Cultivars for Resistance to the Sugarcane Borer
(Lepidoptera: Pyralidae)

The following chapter is modified from manuscript J89-039, which was accepted by the Journal of Economic Entomology and is currently in press.
Introduction

Resistant sugarcane cultivars are a major component of the integrated pest management (IPM) of the sugarcane borer, *Diatraea saccharalis* (F.), in Louisiana sugarcane, a complex hybrid of *Saccharum* spp. A differential response of sugarcane cultivars to sugarcane borer attack has been recognized and studied for many years (Stubbs & Morgan 1902; Holloway 1935; Mathes & Ingram 1942, 1944; Long et al. 1961; Mathes & Charpentier 1962). Hensley & Long (1969) demonstrated that sugarcane borer resistant cultivars when incorporated into an IPM program would provide sufficient sugarcane borer control to reduce insecticide usage by 50%. Factors in sugarcane which may impart resistance to the sugarcane borer include those which discourage oviposition and survival of young larvae on leaves (Sosa 1988), leafsheath appression (Coburn & Hensley 1972), and rind hardness (Martin et al. 1975, Martin & Cochran 1975).

One approach to evaluate cultivar resistance has been to assign sugarcane borer susceptibility ratings based on the percentage yield increase resulting from sugarcane borer control (Long et al. 1961, Hensley & Long 1969). Currently, the selection of sugarcane cultivars for the Louisiana agroecosystem involves the evaluation of resistance to the sugarcane borer by determining the percentage of bored internodes (Holloway 1935; Mathes & Ingram 1942, 1944; Kyle & Hensley 1970). Until recently, this was a commonly used criteria for ranking cultivars for sugarcane borer
resistance before commercial release (Reagan & Martin 1988). Recently, White & Hensley (1987) reported inconsistencies in sugarcane resistance ratings to the sugarcane borer based on percent bored internodes. While they observed CP 70-321 to be more resistant than CP 65-357 in terms of percent bored internodes, they found CP 65-357 to be more resistant to yield loss. They showed that the resistance of CP 65-357 appeared to be based on its ability to minimize sugarcane weight loss due to sugarcane borer attack.

Percent bored internodes and rind hardness are useful indices for measuring sugarcane resistance to early sugarcane borer instars. Rating cultivar susceptibility or resistance according to the percent bored internodes criteria helps quantify the observed resistance to sugarcane borer larval stages prior to stalk penetration. Because these indices focus on resistance mechanisms operating against early sugarcane borer instars, the degree of internal damage to stalk tissues and ultimate survival of sugarcane borer larvae is not addressed.

Many sugarcane cultivar resistance studies have ignored the relationship of latter stages of the sugarcane borer to plant development. Successful completion of the larval cycle is characterized by the presence of a distinct exit hole in the stalk made for the adult moth. Information on exit holes serves as a seasonal record of adult emergence. Analyzing the survival of the larvae to adulthood may
ascertain whether or not there are resistance factors acting against the larvae (i.e., reducing survival) after entry into the stalk. The objectives of this study were to determine if an adult sugarcane borer emergence criterion could provide additional information for the evaluation of cultivar resistance to the sugarcane borer and to determine if use of such a criterion might be helpful in assessing the potential impact of a new cultivar on area-wide populations of the sugarcane borer.

Materials and Methods

Three sugarcane cultivars, CP 61-37 (sugarcane borer susceptible), CP 65-357 (moderately resistant), and CP 70-330 (highly resistant), were each planted in 0.032 ha plots (8-rows by 22 m) in a randomized complete block design with eight replicates at the St. Gabriel Research Station of the Louisiana Agricultural Experiment Station. In 1985, 1986, and 1987 three 15-stalk samples were randomly removed from each of the 24 plots at harvest, and the percentage of bored internodes and the number of sugarcane borer emergence holes were recorded.

In a separate study in 1987 at the Glendale Plantation near Edgard, Louisiana, 12 experimental sugarcane cultivars from the Louisiana Sugarcane Variety Development Program and four commercial cultivars (CP 61-37 [susceptible], CP 74-383 [susceptible], CP 65-357 [moderately resistant], and CP 70-321 [highly resistant]) were planted in single row 3 m
plots. The test was analyzed as a four-replicated incomplete block design. This field was left untreated for the sugarcane borer throughout the season. On 27 October 1987, 15 millable stalks were randomly removed from each plot and the percentage of bored internodes and number of moth exit holes per bored internode were recorded as in the first test. In plots that contained 15 or fewer millable stalks, all the stalks were removed (minimum = 9).

From this information a relative survival (RS) index was developed to estimate the survival of larvae in the stalks that emerged to adult moths.

\[
RS = \frac{\text{No. Exit holes}}{\text{No. Bored Internodes}}
\]

Relative survival was calculated for each 15 stalk sample, and was a measure of older instar survival (eg., low RS implies high resistance to older instars).

Moth production per hectare was calculated for each cultivar as the product of the number of adult exit holes and the stalk density per hectare. Due to the small plot size in the Edgard test, a density of 30,000 stalks per hectare for all cultivars was assumed.

Data on percent-bored internodes and RS were analyzed using analysis of variance (ANOVA) for the randomized complete block design \((P=0.05)\) and, where significant differences among treatments (cultivars) were detected, Duncan's multiple range test was used for mean separations.
Prior to these analyses, data on percent-bored internodes and relative survival were transformed using a probit function (Steel & Torrie 1980) and then weighted according to the number of stalks removed from each plot. In addition to the ANOVA and the Duncan's test, when differences among varieties were found with respect to RS, the statistical correlation (r) between RS and percent-bored internodes (transformed data) was determined. Data on moth production from each test were analyzed using least-squares ANOVA with a covariable, bored internodes, and Duncan's test was used to separate means.

Results

Results from the St. Gabriel test indicated the mean percent bored internodes varied from 12.0 on CP 70-330 in 1985, to 44.8 on CP 61-37 in 1987 (Table 1). The susceptible cultivar, CP 61-37, sustained more injury than the resistant cultivar, CP 70-330. The moderate cultivar, CP 65-357, was intermediate to the two other cultivars during the first ratoon year and was damaged similarly to CP 61-37 the following two years. In the Edgard test, differences were detected in percent bored internodes \((F=3.52, \, df=15,36, \, P=0.001)\) among varieties. The percentage of bored internodes ranged from 20.19 to 59.33\% (Table 2). Three cultivars exhibited less damage than the 27.26\% bored internodes sustained by the resistant commercial cultivar CP 70-321.
Table 1. Comparison of Diatraea saccharalis damage in three commercial sugarcane cultivars and survival of larvae inside the stalks during a three-year study on the St. Gabriel Research Station

<table>
<thead>
<tr>
<th>Commercial Cultivar</th>
<th>% bored internodes(^a)</th>
<th>Relative Survival(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP61-37</td>
<td>32.8a</td>
<td>39.9a</td>
</tr>
<tr>
<td>CP65-357</td>
<td>23.2b</td>
<td>38.6a</td>
</tr>
<tr>
<td>CP70-330</td>
<td>12.0c</td>
<td>12.4b</td>
</tr>
</tbody>
</table>

* * * * * * * * statistical analysis * * * * * * * * *

\(F\)\(^c\) 19.34 104.97 48.45 5.25 9.11 9.49

\(P>F\) <0.001 <0.001 <0.001 0.020 0.003 0.003

\(^a\) Means within the same column followed by the same letter are not significantly different \((P>0.05; \text{Duncan's [1955] multiple range test})\).

\(^b\) Based on a ratio of \(D.\) saccharalis exit holes to bored internodes.

\(^c\) Degrees of freedom for \(F\) values were \((2,14)\).
Table 2. Damage by *Diatraea saccharalis* and relative survival of larvae inside the stalk in four commercial and 12 experimental cultivars (1985 LCP series) on the Glendale Plantation, near Edgard, La. 1987

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>% Bored</th>
<th>Relative Survival</th>
<th>Production, Moths/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCP 85-341</td>
<td>20.19i</td>
<td>0.087ef</td>
<td>27,682h</td>
</tr>
<tr>
<td>LCP 85-358</td>
<td>23.33gh</td>
<td>0.274cd</td>
<td>51,668cdef</td>
</tr>
<tr>
<td>LCP 85-376</td>
<td>24.32ghi</td>
<td>0.065f</td>
<td>25,193h</td>
</tr>
<tr>
<td>CP 70-321</td>
<td>27.26fghi</td>
<td>0.326bcd</td>
<td>55,459bcde</td>
</tr>
<tr>
<td>LCP 85-352</td>
<td>30.19efgh</td>
<td>0.257cd</td>
<td>38,457fgh</td>
</tr>
<tr>
<td>LCP 85-336</td>
<td>30.43efgh</td>
<td>0.244cd</td>
<td>46,472defg</td>
</tr>
<tr>
<td>CP 65-357</td>
<td>32.31defg</td>
<td>0.184de</td>
<td>36,199gh</td>
</tr>
<tr>
<td>LCP 85-373</td>
<td>22.31defg</td>
<td>0.219cde</td>
<td>45,830defg</td>
</tr>
<tr>
<td>LCP 85-313</td>
<td>36.24cdef</td>
<td>0.273cd</td>
<td>43,269efg</td>
</tr>
<tr>
<td>CP 61-37</td>
<td>38.47bcde</td>
<td>0.567a</td>
<td>77,274a</td>
</tr>
<tr>
<td>LCP 85-316</td>
<td>40.35bcd</td>
<td>0.376abcd</td>
<td>67,196abc</td>
</tr>
<tr>
<td>LCP 85-307</td>
<td>41.61bcd</td>
<td>0.317bcd</td>
<td>53,396bcdef</td>
</tr>
<tr>
<td>CP 74-383</td>
<td>43.33bc</td>
<td>0.185de</td>
<td>34,757gh</td>
</tr>
<tr>
<td>LCP 85-298</td>
<td>44.56bc</td>
<td>0.414abc</td>
<td>63,491abcd</td>
</tr>
<tr>
<td>LCP 85-384</td>
<td>47.71b</td>
<td>0.550ab</td>
<td>68,724ab</td>
</tr>
<tr>
<td>LCP 85-360</td>
<td>59.33a</td>
<td>0.414abc</td>
<td>48,721cdefg</td>
</tr>
</tbody>
</table>

a Means within the same column followed by the same letter are not significantly different (P>0.05; Duncan's [1955])
Based on a ratio of *D. saccharalis* exit holes to bored internodes.

Calculated as the product of the mean number of exit holes per stalk and a stalk density of 30,000/ha, and adjusted for the number of bored internodes.
In terms of sugarcane borer relative survival in the St. Gabriel test, those infesting CP 61-37 showed significantly higher survival ($P<0.05$) than those on CP 70-330 (Table 1). Larval survival in CP 65-357 was intermediate when compared with that on other cultivars in 1985 and 1986; in 1987 the relative survival on this cultivar was not significantly different from the resistant cultivar, CP 70-330. In the Edgard test, significant differences were detected in relative survival ($F=1.99$, $df=15,36$, $P=0.045$) among varieties, and RS ranged from 6.5 to 56.7%. Ten out of 15 cultivars had lower levels of larvae surviving in the stalk than the 32.6% survival on the resistant CP 70-321 (Table 2).

When analyzed by plots in the Edgard test, the relationship between percent bored internodes and relative survival resulted in a low correlation ($r=0.253$). For example, cultivar CP 74-383 (susceptible) ranked thirteenth out of sixteen in susceptibility when using external damage as the ranking criteria. However, when relative survival was used as the criteria to rank this cultivar, it appeared to be more resistant than the other cultivars. Similarly, in the three-year St. Gabriel study, cultivar CP 70-330 was more damage-resistant than CP 65-357 in terms of bored internodes; however, these cultivars were not significantly different when analyzed for sugarcane borer relative survival in 1985 and 1987, but in 1986 relative survival was greater on CP 65-357.
Significant differences (P<0.05) were detected among cultivars in moth production after adjusting for bored internodes in the St. Gabriel test for two of the three years, and the adjusted seasonal moth production (Table 3) ranged from 15,053 on CP 65-357 in 1985, to 69,551 per hectare on CP 61-37 in 1986. In all three years, CP 61-37 produced significantly more (P<0.05) moths than the other cultivars. Throughout the study, moth production from CP 65-357 was similar to that of CP 70-330. In the Edgard test, significant differences (F=2.97, df=15,36, P=0.004) were also detected in moth production among cultivars after adjusting for bored internodes, and moth production ranged from 25,193 to 77,274 per hectare (Table 2). Two commercial cultivars, CP 70-321 (resistant) and CP 61-37 (susceptible), had high levels of moth production, 55,459 and 77,274 per hectare, respectively. The other two commercial cultivars, CP 65-357 (moderate) and CP 74-383 (susceptible), displayed low levels of moth production, 36,199 and 34,757 per hectare, respectively. Two cultivars from the breeding program, LCP 85-376 and LCP 85-341, had low levels of moth production, each less than 28,000, and also displayed less injury than the resistant cultivar CP 70-321.

Discussion

Because the relative survival index presented in this study is based on bored internodes rather than entrance holes, it does not reveal the actual survival of the larvae
Table 3. Comparison of *Diatraea saccharalis* adult emergence from three commercial sugarcane cultivars during a three-year study on the St. Gabriel Research Station

<table>
<thead>
<tr>
<th>Commercial Cultivar</th>
<th>Adult emergence per ha&lt;sup&gt;a&lt;/sup&gt;</th>
<th>1985&lt;sup&gt;b&lt;/sup&gt;</th>
<th>1986</th>
<th>1987</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP61-37</td>
<td></td>
<td>32,267 a</td>
<td>69,651 a</td>
<td>59,604 a</td>
</tr>
<tr>
<td>CP65-357</td>
<td></td>
<td>15,053 b</td>
<td>23,455 b</td>
<td>43,701 b</td>
</tr>
<tr>
<td>CP70-330</td>
<td></td>
<td>17,151 b</td>
<td>47,673 b</td>
<td>37,066 b</td>
</tr>
</tbody>
</table>

* ** *** *** *** statistical analysis ** *** *** *** *

| F<sup>c</sup> | 5.01 | 12.56 | 3.59 |
| P>F            | 0.024 | <0.001 | 0.055 |

<sup>a</sup> Estimated as the product of the mean number of exits per stalk and the number of stalks per hectare, and adjusted for the number of bored internodes.

<sup>b</sup> Means within the same column followed by the same letter are not significantly different (*P* > 0.05; Duncan's [1955] multiple range test).

<sup>c</sup> Degrees of freedom for *F* values were (2,14).
inside the stalk. It is not possible to determine the frequency of larvae which initially bored into the internode from the stalk information. One successful larva may create from one to several "entrance" holes, but will leave only one emergence hole, if surviving until pupation. Thus, if this ratio was based on the number of entrance holes, it would also create some bias because the number of entrance holes would overestimate the number of larvae penetrating into the stalks. Both techniques to assess sugarcane borer survival have some inherent bias; however, we feel the use of a relative ratio based both on bored internodes and adult emergence holes provides a more useful assessment.

If predictions were made concerning moth production based solely on percent bored internodes from the St. Gabriel test in 1986 and 1987, it would be expected that CP 65-357 and CP 61-37 should have had similar levels of moth production because of their similar levels of injury. However, this was not the case. Even when injury levels to CP 65-357 were similar to CP 61-37, moth production from CP 65-357 was considerably less than that from CP 61-37. The differences detected in moth production among cultivars after adjusting for bored internodes indicated that resistance ratings based on percent bored internodes do not adequately reflect the resultant levels of moth production due to the differences in larval survival after boring into the stalk.

Sugarcane borer exit holes serve as a seasonal record
of adult emergence, and thus delineate the cultivars' role in enhancement or suppression of area-wide populations. This measurement of moth production may be used to compare the potential impact that a cultivar may have on area-wide populations in this study, assuming that moths emerging from the different cultivars have equal fecundity. A comparison of the percent bored internodes with the relative survival data reveals sugarcane borer survival after boring into the stalk does not correspond well with the percent bored internode resistance ratings. For example, CP 70-321 is highly resistant to sugarcane borer penetration into the stalk (Table 2), but upon entry larvae appear to survive better than in most of the other cultivars in this study. Therefore, a resistance rating based on external evidence of sugarcane borer entry into the stalk did not adequately provide a relative comparison of the cultivars' impact on area-wide populations. This implies a weak association between resistance factors reducing sugarcane borer entry and those affecting relative survival in the stalk.

While cultivars CP 74-383 and CP 61-37 appear to have similar levels of resistance to sugarcane borer damage based on percent bored internodes, their relative survival rankings differ considerably. If greater numbers complete their development on CP 61-37 relative to CP 74-383, one might expect greater internal damage (i.e., amount of tunnelling) to result on CP 61-37 even though the percent bored internodes on the two cultivars is similar. White &
Hensley (1987) showed that CP 65-357 was more resistant to yield loss by the sugarcane borer than CP 70-321, even though CP 70-321 was more resistant to percent bored internodes. This suggests that with CP 65-357 there may be a lesser degree of internal damage associated with the sugarcane borer attack or a greater tolerance to attack. Further studies would be required to determine the relationship between relative survival and the degree of internal damage.

Moth production serves as an index to estimate the role of a cultivar in area-wide suppression or enhancement of sugarcane borer populations. Resistance ratings based on external injury may often be poor indicators of this resistance factor. In the Edgard test, only one of the commercial cultivars showed levels of moth production consistent with that of their injury ratings. When comparing alternate host crops of the sugarcane borer (i.e., corn and sweet sorghum), moth production is an important consideration to the development of management strategies (Flynn et al. 1984, Fuller et al. 1988). It has been suggested that the planting of resistant sugarcane cultivars adjacent to corn and sweet sorghum fields might help in the management of this mutual pest (Reagan & Flynn 1986). Yet, when rating sugarcane cultivars for sugarcane borer resistance, similar consideration has not been given to moth production. Results of this study indicate that differences exist and that this resistance factor along with resistance
Relative to insect pest problems in sugarcane, a grower's primary objective is to minimize economic loss. The approaches to reduce this economic impact are to minimize pest damage caused by the insect and to minimize the cost incurred controlling the pest. Use of high yielding resistant sugarcane cultivars provides a means of reducing pest damage at little or no cost to the grower.

Current sugarcane borer resistance rating schemes are focused on the prevention of damage, whereas in this study an additional criteria with long-term input reducing area-wide populations is proposed. Use of cultivars which have low moth production ratings should therefore assist in the area-wide suppression of sugarcane borer populations, and thus reduce the frequency of needed insecticide applications. Although selecting cultivars which are less likely to be damaged by the sugarcane borer should be a goal of the breeding program, selection of cultivars which slow the area-wide population buildup of this multi-generation multi-host crop pest should also be a major consideration in long term management.
References Cited


Chapter III

Sugarcane Borer, *Diatraea saccharalis* (F.) (Lepidoptera: Pyralidae), Fecundity as Affected by Larval Development on Gramineous Host Plants

The following chapter is modified from manuscript E89-087, which was accepted by Environmental Entomology and is currently in press.
Introduction

The sugarcane borer, *Diatraea saccharalis* (F.) is the key pest of sugarcane, a complex hybrid of *Saccharum* spp., and is responsible for more than 90% of the damage caused by insects in Louisiana (Reagan et al. 1972). The sugarcane borer typically overwinters on sugarcane and is, therefore, restricted to areas in the state where sugarcane is grown. However, this insect can build up to damaging levels on corn, *Zea mays* L., when grown in agroecosystems containing sugarcane (Flynn & Reagan 1984, Floyd et al. 1960). As early as 1927, Hinds & Spencer recommended corn as a trap crop for sugarcane borer control. Other cultivated hosts of the sugarcane borer include sweet sorghum, *Sorghum bicolor* (L.) Moench; rice, *Oryza sativa*, L.; and several gramineous weeds including johnsongrass, *Sorghum halapense* (L.) Persoon (Long & Hensley 1972). Differential survival of the sugarcane borer on varieties of sugarcane, corn, rice, and sorghum has been the subject of several studies (Flynn & Reagan 1984, Flynn et al. 1984, Floyd et al. 1960, Martin et al. 1975, Coburn & Hensley 1972). These investigations were primarily concerned with crop damage and did not address the effects of host plant on biological factors, such as fecundity.

Isa (1961) studied the biology of the sugarcane borer reared in plastic dishes on excised plant parts of corn and sugarcane. He noted differences in developmental rates, survival, and pupal weight. More recently, Reagan & Flynn...
(1986) collected 15, 11, and 10 pairs of sugarcane borer pupae from corn, sorghum, and sugarcane, respectively, and recorded the fecundity of these individuals in the laboratory. Trends were noted even among such small samples, though the authors suggested additional trials would be necessary to determine whether these observations represented actual differences.

Recently, corn acreage in southeastern Louisiana has been increasing. In order to better predict, prior to implementation, how this change in cropping practices will affect sugarcane pest management in Louisiana, precise information on the life histories of the sugarcane borer on these different host plants must be determined. Information concerning fecundity is needed to determine the growth rate of populations on different crops. Population growth is also dependent on the number of surviving females and their production of progeny. The objective of this two-year study was to compare the fecundity of the sugarcane borer collected from several hosts.

**Materials and Methods**

Sugarcane borer pupae were collected from two varieties of sugarcane, CP 61-37 (susceptible) and CP 65-357 (moderately resistant), hybrid corn, variety 'Merrit'; and johnsongrass on the St. Gabriel research station from 20 August through 20 September 1987 and from 2 August through 12 September 1988. These collection intervals corresponded
to the peak periods of sugarcane borer infestation (Bessin et al 1990). Plants from fields untreated with insecticide were examined for characteristic sugarcane borer exit holes. Regardless of the host, these exit holes are characteristically large, oval, and covered with a thin layer of dead leaf sheath that has been perforated by the larvae to allow for subsequent escape of the adult. In contrast, the normal feeding holes left by larvae entering or leaving stalks are round rather than oval and are smaller than the exit holes. Stalk sections containing exit holes were taken to the lab where pupae were carefully dissected from the stalks, sexed, and their weights, lengths, and diameters (at the first abdominal segment) recorded. One pupa of each sex, obtained from the same host, was placed in a 1.9-liter cardboard carton in which the lid was replaced with a single layer of cheese cloth. These cartons, which contained moist vermiculite and were lined with creased wax paper as an ovipositional substrate, were held in a growth chamber at a constant 27°C, ca. 90% RH, 14:10 L:D, until death of the females.

Data collected included the pupal physical characteristics, eggs laid per female, and sex of the pupae from the different hosts. In the 1988 study, egg viability from the different hosts, as estimated by the number of eggs that displayed embryonic development, was determined. Percent egg viability for 1988 was transformed by a logit function (Neter et al. 1985), and subjected to an analysis.
of variance. A Chi-square test of homogeneity was used to test for independence of sugarcane borer sex and host. Analysis of variance procedures were performed on the physical measurement data to test for differences among pupae of the same sex from different hosts. A stepwise regression technique (Neter et al. 1985) was used to determine the best set of physical variables that could be used to predict fecundity. An analysis of covariance (Neter et al. 1985) performed on sugarcane borer fecundity utilized the results of the stepwise regression and the host plant and year from which the pupae were collected. Product moment correlations (r) were determined among the pupal characteristics and fecundity. Fecundity differences among sugarcane borers collected from different hosts were determined by Duncan's (1955) multiple range test.

The maximum reproductive rate ($R_m$), potential rate of increase ($r_p$), and potential daily rate of increase were calculated for the sugarcane borer on the different hosts using the mean fecundity estimates and the assumptions and methods of Southwood (1969).

**Results**

A total of 256 and 351 pupae were obtained from the four hosts during the 1987 and 1988 collections. Sugarcane borer pupae were observed on several additional gramineous hosts, including sprangletop (*Leptochloa filiformis* (Lam.) Beauvios), hairy crabgrass (*Digitaria sanguinalis* (L.)
Koeler), goosegrass (Eleusine indica (L.) Gaertner), junglerice (Echinochloa colonum (L.) Link), and annual ryegrass (Lolium temulentum L.). The sex ratio of collected pupae was approximately 1:1 female to male, and a Chi-square test of homogeneity indicated independence between sex and host ($X^2=5.69; \text{d.f.}=3; P=0.128$). Biometric parameter estimates of sugarcane borer populations from the different hosts are presented in Table 1. Pupae from the four hosts displayed highly significant differences ($P<0.01$) in weight, length, and diameter for both sexes. Pupae obtained from johnsongrass were smaller ($P<0.05$) in all measured parameters than those from other hosts. Differences were not detected in length, diameter, or weight of pupae collected from the susceptible sugarcane variety (CP 61-37) and corn. The female pupae collected from the moderately resistant variety (CP 65-357) weighed less and were shorter ($P<0.05$) than those from CP 61-37 and corn. However, the male pupae collected from CP 65-357 pupae were similar in weight to those from CP 61-37 but were physically shorter and narrower ($P<0.05$).

Stepwise regression analysis indicated that the best model for predicting fecundity, as measured by total egg production, from pupal measurements was a simple linear regression containing pupal weight as the independent variable ($F=321.32; \text{d.f.}=1,163; P=0.0001$). The linear equation is:
Table 1. Comparison of lengths, diameters, and weights of sugarcane borer pupae collected from four gramineous hosts at the St. Gabriel Research Station during 1987 and 1988

<table>
<thead>
<tr>
<th>Host</th>
<th>Female</th>
<th></th>
<th>Male</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight</td>
<td>Length</td>
<td>Dia.</td>
<td>Weight</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>(mg)a</td>
<td>(cm)</td>
<td>(cm)</td>
</tr>
<tr>
<td>Corn</td>
<td>73</td>
<td>158.2a</td>
<td>1.78a</td>
<td>0.385a</td>
</tr>
<tr>
<td>CP 61-37b</td>
<td>74</td>
<td>160.6a</td>
<td>1.80a</td>
<td>0.386a</td>
</tr>
<tr>
<td>CP 65-357°</td>
<td>78</td>
<td>141.1b</td>
<td>1.71b</td>
<td>0.369a</td>
</tr>
<tr>
<td>Johnson-grass</td>
<td>54</td>
<td>95.8c</td>
<td>1.54c</td>
<td>0.321b</td>
</tr>
</tbody>
</table>

*************** Statistical Analysis ****************

| F   | 53.63 | 41.44 | 53.30 | 69.31 | 60.50 | 6.822 |
| d.f. | 3,275 | 3,275 | 3,275 | 3,324 | 3,324 | 3,324 |
| P>F | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |

a Means in the same column followed by the same letter are not significantly different (DMRT P > 0.05).
b A sugarcane borer-susceptible sugarcane variety.
c A sugarcane variety moderately resistant to the sugarcane borer.
where $F$ is the fecundity and $W$ is the female pupal weight in milligrams. This equation is based on weights ranging from 57 to 250 mg (Figure 1). There were high correlations between pupal physical characteristics (Table 2) indicating multicollinearity when more than one of these variables is included in the regression model. The regression model accounted for 66% of the variation in sugarcane borer fecundity.

Mean fecundity estimates from the different hosts were based only on data collected from females producing fertile eggs. Otherwise, it was assumed the paired pupae did not mate properly because one of the paired pupae in the carton never emerged as an adult, emerged early, or emerged too late, preventing successful mating. It was observed in this study that paired pupae needed to emerge as adults within 48 hours of each other in order to mate successfully.

An analysis of covariance performed on sugarcane borer fecundity indicated that the addition of the categorical variables; host from which the pupa was collected ($F=0.29$; d.f.$=3,160$; $P=0.83$), year of collection ($F=0.01$; d.f.$=1,159$; $P=0.93$), host-by-year interaction ($F=0.61$; d.f.$=3,156$; $P=0.61$), weight-by-year interaction ($F=0.89$; d.f.$=1,152$; $P=0.35$), the host-by-weight interaction ($F=0.33$; d.f.$=3,153$; $P=0.80$), or the host-by-year-by-weight interaction ($F=0.85$; d.f.$=3,149$; $P=0.47$) did not improve the regression model
Figure 1. Relationship of *D. saccharalis* fecundity (F) to female pupal weight (W) on johnsongrass (JOGR), two sugarcane varieties (CP 61-37 and CP65-357), and corn ($R^2=0.66$).
Table 2. Correlations among *D. saccharalis* fecundity and pupal physical characteristics collected from four gramineous hosts at the St. Gabriel Research Station during 1987 and 1988

<table>
<thead>
<tr>
<th></th>
<th>Pupal weight&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Pupal length</th>
<th>Pupal diameter&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fecundity</td>
<td>-</td>
<td>0.8116</td>
<td>0.7775</td>
</tr>
<tr>
<td></td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
</tr>
<tr>
<td>Pupal weight</td>
<td>0.8116</td>
<td>-</td>
<td>0.9560</td>
</tr>
<tr>
<td></td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
</tr>
<tr>
<td>Pupal length</td>
<td>0.7775</td>
<td>0.9560</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
</tr>
<tr>
<td>Pupal diameter</td>
<td>0.7569</td>
<td>0.9181</td>
<td>0.8614</td>
</tr>
<tr>
<td></td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Numbers in parentheses represent the probability of a $r$ assuming no relationship between the variables.

<sup>b</sup> Diameters were recorded at the first abdominal segment.
based on pupal weight alone. This indicates the need for only one intercept and one slope in the predictive model for all hosts during both years.

The maximum number of eggs obtained from a single female sugarcane borer was 1141, which was collected from the susceptible sugarcane variety CP 61-37. Females collected from corn and CP 61-37 laid an average of 714 and 708 eggs, respectively, which was significantly (P<0.05) more than the average egg production by females from other hosts (Table 3). Sugarcane borer pupae taken from johnsongrass yielded only 427 eggs per female, the least from any host, and females from CP 65-357 produced 605 eggs, intermediate to collections from females from the other hosts.

Results of the analysis of variance performed on the 1988 egg viability indicated no significant (P>0.05) differences in viability among the eggs from the different hosts. Overall mean egg viability was 95.1 %.

Maximum natality, potential rate of increase, and potential finite daily rate of increase for the sugarcane borer from the various hosts are presented in Table 4. Increased fecundity on corn and CP 61-37 led to subsequent increases in each of the sugarcane borer reproductive statistics.
Table 3. Comparison of the mean fecundity and egg viability of *D. saccharalis* collected from four gramineous hosts at the St. Gabriel Research Station during 1987 and 1988

<table>
<thead>
<tr>
<th>Host</th>
<th>N</th>
<th>eggs/female&lt;sup&gt;a&lt;/sup&gt;</th>
<th>% Egg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>41</td>
<td>714.2a</td>
<td>96.8a</td>
</tr>
<tr>
<td>CP 61-37</td>
<td>45</td>
<td>708.1a</td>
<td>93.5a</td>
</tr>
<tr>
<td>CP 65-357</td>
<td>39</td>
<td>604.9b</td>
<td>95.8a</td>
</tr>
<tr>
<td>Johnsongrass</td>
<td>40</td>
<td>427.1c</td>
<td>92.4a</td>
</tr>
</tbody>
</table>

*************** Statistical analysis **************

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>d.f.</th>
<th>P&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21.93</td>
<td>3,161</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>0.39</td>
<td>3.84</td>
<td>0.76</td>
</tr>
</tbody>
</table>

<sup>a</sup> Means in the same column followed by the same letter are not significantly different (DMRT P > 0.05).

<sup>b</sup> Determined from pupae collected in 1988.
Table 4. Reproductive statistics of the sugarcane borer collected from various hosts at the St. Gabriel Research Station during 1987 and 1988

<table>
<thead>
<tr>
<th>Host</th>
<th>Maximum natality $\left(R_m\right)^a$</th>
<th>Potential rate of increase (r_p)</th>
<th>Rate of increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>345.8</td>
<td>0.124</td>
<td>1.132</td>
</tr>
<tr>
<td>CP 61-37</td>
<td>332.9</td>
<td>0.124</td>
<td>1.132</td>
</tr>
<tr>
<td>CP 65-357</td>
<td>290.2</td>
<td>0.121</td>
<td>1.128</td>
</tr>
<tr>
<td>Johnsongrass</td>
<td>197.8</td>
<td>0.113</td>
<td>1.119</td>
</tr>
</tbody>
</table>

$^a$ Calculated according to the methods of Southwood (1969) assuming a 1:1 sex ratio on the various hosts.
Discussion

While johnsongrass is considered a pest of sugarcane, it also serves as a host to harbor and/or increase sugarcane borer populations, although pupae collected from this host were smaller, lighter, and subsequently produced fewer eggs than did those collected from other hosts. Corn and the susceptible sugarcane variety, CP 61-37, were found to be the optimal hosts for the sugarcane borer. These two hosts produced heavier pupae, which in turn led to a greater production of eggs per female. The fecundity-pupal weight regression equation obtained indicated that sugarcane borer fecundity increased at a rate of 4.3 viable eggs for each milligram increase in pupal weight, regardless of the host from which the female was collected. There is no biological interpretation of the equation's intercept, 10.9, and it is used only to improve the model's fit. The high correlation among pupal characteristics indicated that similar relationships would be noted with the other pupal characteristics and fecundity. However, only one pupal characteristics variable should be included in the regression to preclude multicollinearity. Pupal weight accounted for more variation in fecundity than the other measurements. This predictive model provides a simple tool for estimating fecundity of the sugarcane borer from different hosts without having to mate the moths and count the eggs. However, the use of this predictive model should be restricted to a pupal weight range from 57 to 250 mg.
Prebble (1941) warns against the indiscriminate use of the regression of fecundity on pupal or adult size outside the population on which the calculation is based.

The linear relationship of fecundity to body weight and/or size of the pupa has also been observed with other insects. Miller (1957) noted that spruce budworm, Choristoneura fumiferana Clemens, fecundity could be estimated on pupal weight or length, since both factors are related linearly, but chose to regress fecundity on an index of pupal size through a linear relationship. This method permitted estimation of spruce budworm fecundity from empty pupal cases collected in the field using the length of the first completely visible abdominal segment as the index of pupal length. Williams (1963) observed the correlation between pupal weight and fecundity to be greater than that between pupal length and fecundity with another sugarcane pest, Chilo sacchariphagus Bojer. He determined that fecundity increased at a linear rate of 3.15 eggs for each milligram increase in pupal weight with this insect.

Sugarcane varietal resistance not only affects sugarcane borer survival (Flynn & Reagan 1984, Coburn & Hensley 1972) but also negatively impacts upon the fecundity of the survivors, both components of the intrinsic rate of growth. Reagan & Flynn (1986) observed that the sugarcane borer from corn could produce more eggs than those from sugarcane, although they did not specify from which sugarcane varieties the pupae were collected. Isa (1961)
noted pupae reared from excised corn tissues to be larger than those from plant parts of a sugarcane borer-resistant sugarcane variety, NCo 310.

Values calculated for the sugarcane borer potential rate of increase and the potential finite daily rate of increase in this study were considerably larger than those obtained by Southwood (1969) for the sugarcane borer, 0.104 and 1.111, respectively. However, Southwood's values were based on a mean fecundity of 333 eggs per sugarcane borer female (Ingram & Bynum 1941), a conservative estimate of sugarcane borer fecundity even on a host such as johnsongrass.

Previous studies on the population dynamics and pest management of the sugarcane borer have considered only numbers or densities of this insect on various host plants that share similar growth potentials. Those studies were concerned primarily with the survival component of population growth and damage inflicted by these populations. Our investigation illustrates the need to also consider the physiological quality of those individuals occurring in the area of study. Populations developing on different hosts, while capable of intermixing, possess different biotic growth parameters.
References Cited


Chapter IV

Modeling Potential Impacts of Sugarcane Varieties and Predation on Sugarcane Borer (Lepidoptera: Pyralidae) Populations in Southern Louisiana

(Prepared for submission to Environmental Entomology)
Introduction

The sugarcane borer, *Diatraea saccharalis* (F.), is the key insect pest attacking sugarcane, a complex hybrid of *Saccharum* spp., in Louisiana, and is responsible for 90% of the total insect damage to this crop (Reagan et al. 1972). Although *D. saccharalis* typically overwinters only in sugarcane, it can build up to damaging levels on corn (*Zea mays* L.), rice (*Oryza sativa* L.), and sorghum (*Sorghum bicolor* (L.) Moench) when grown in agroecosystems containing sugarcane (Long and Hensley 1972). In addition to these cultivated hosts, Bessin & Reagan (1990) observed that *D. saccharalis* successfully develop on several gramineous weeds including johnsongrass (*Sorghum halepense* (L.) Persoon), sprangletop (*Letochola filiformis* (Lam.) Beauvios), dallisgrass (*Paspalum dilatatum* Poiret), hairy crabgrass (*Digitaria sanguinalis* (L.) Koeler), goosegrass (*Eleusine indica* (L.) Gaertner), junglerice (*Echinochloa colonum* (L.) Link), and annual ryegrass (*Lolium temulentum* L.).

There are many published studies concerning how various management and cropping practices affect the development of *D. saccharalis* populations and their level of damage to cultivated hosts. This paper describes a model which integrates the effects of varietal resistance and predation on *D. saccharalis* populations, providing insights into the area-wide enhancement and suppression of this key pest.
Currently, information is limited for precisely estimating day-to-day *D. saccharalis* field populations on different sugarcane varieties. However, there is extensive information on how certain varieties and predation impart differences in *D. saccharalis* population dynamics, and how these factors differentially affect pest population density and individual survival. With the use of data on *D. saccharalis* emergence holes, Bessin et al. (1990b) quantified the differential survival rates of *D. saccharalis* from entry into the stalk until adult emergence from different sugarcane cultivars. Differential survival of young (instars I-III) larvae among sugarcane cultivars was observed by Coburn & Hensley (1972). They found that establishment of *D. saccharalis* larvae of the first 2 instars was much lower on the resistant cultivar NCo 310 than on the susceptible CP 44-101. Bessin et al. (1990b) found a low correlation ($r=0.25$) between plant damage, measured as a percentage of bored internodes, and subsequent survival until adulthood. Thus, they noted the need to incorporate a cultivar's impact on build up (or reduction) of area-wide populations in addition to an assessment of cultivar sensitivity to insect attack when evaluating varieties for *D. saccharalis* resistance. When resistant sugarcane varieties are integrated into a pest management program, including properly timed insecticide applications
and effective use of naturally occurring predatory arthropods, resistant varieties have been shown to contribute nearly 40% of the overall control of moth emergence throughout the season (Bessin et al. 1990a).

Many studies have indicated the importance of predatory arthropods for the biological control of *D. saccharalis* (Negm & Hensley 1967, 1972; Reagan et al. 1972; Ali & Reagan 1985; Fuller & Reagan 1988). Bessin et al. (1990a) observed that naturally occurring arthropod predation can reduce *D. saccharalis* caused damage to sugarcane 1.9 fold and resultant pupal production by 1.7 fold. During the three year study, differences were not detected among predator abundance or control exerted by predators among the 3 different sugarcane cultivars.

The objective of this study was to model the current and potential roles that different sugarcane varieties and predation have on *D. saccharalis* populations. Output from simulations revealed magnitudes of differences in crop damage and moth production among the various field practices. This model is not intended to predict *D. saccharalis* populations on a daily basis, or to predict the timing of pesticide applications. Its primary value is to assist in the formulation of long term area-wide management strategies.

A simulation model similar to the one used in this
study for *D. saccharalis*, was developed by Wilkerson et al. (1986) for velvetbean caterpillar, *Anticarsia gemmatalis* Hübnner, populations in soybeans. That model was intended to simulate day-to-day velvetbean caterpillar densities within a single field, while the *D. saccharalis* simulation will be used to compare the effects of different management types on area-wide *D. saccharalis* populations.

**Materials and Methods**

**Model Description**

The model structure is an adaptation of the velvetbean caterpillar model (Wilkerson et al. 1986). The *D. saccharalis* populations have been divided into five developmental stages: eggs, small larvae, large larvae, pupae, and adults. The small larval size classes roughly correspond to larvae found in the sugarcane leafsheaths, instars I-III, and the large larval size class corresponds to the larvae found boring into the stalk, instars IV-VI. Within each developmental stage physiological age is calculated and stored. The change in the densities of individuals (*N_i*) is expressed as:

\[
\frac{\Delta N_i}{\Delta t} + \frac{\Delta N_i}{\Delta a} = E_i - m_{ij}N_i - T_iN_i, \quad (1)
\]

where \(m_{ij}\) is the host dependent age specific mortality, \(T_i\) is an inter-stage development function, and \(E_i\) is the number
entering a stage. $E_i$ can be calculated for all stages except eggs as:

$$E_i(0,t) = T_{i-1}N_{i-1} + I_i,$$  \hspace{1cm} (2)

$$E_i(a,t) = 0 \text{ if } a \neq 0,$$  \hspace{1cm} (3)

where $I_i$ is the immigration to the field and is zero except for the adult stage. For the egg stage $E_i$ can be calculated as:

$$E_i(0,t) = \sum_{j=1}^{k} f_j g(a,t) N_i(a,t),$$  \hspace{1cm} (4)

$$E_i(a,t) = 0 \text{ if } a \neq 0,$$  \hspace{1cm} (5)

where $\frac{1}{k}$ is the ratio of females to the total number of adults, $f_j$ is the host specific fecundity, 40 days is the maximum allowable chronological age for egg-laying adults, and $g(a,t)$ is the proportion of the maximum possible number of eggs which is laid by females of age $a$ at time $t$.

**Development**

The length of time required for an individual to advance to the next stage is temperature dependent. King et al. (1975) provide the basis for *D. saccharalis* development with respect to temperature. In that study, they investigated the development of *D. saccharalis* eggs, larvae, pupae, and adults at numerous (5 or more) different constant temperatures, respectively. In addition they reported the
minimum and maximum amount of time required by individuals to complete development within each stage at the different temperatures.

Variability among individuals is incorporated into the model by adapting a cumulative distribution function taken from Stinner et al. (1975):

\[ F(a_p) = (1-Z)^{c^k}, \quad (6) \]
\[ Z = (B - a_p)/(B - A), \quad (7) \]

where \( F \) is the proportion of individuals which has completed development by the time they reach physiological age \( a_p \), \( c \) and \( k \) are empirical constants, \( A \) is the minimum time required for the first individual to complete development, and \( B \) is the maximum time for the last individual to complete development. Stinner et al. (1975) found that a value of 2.0 for \( k \) worked well for a number of different insects. The value for \( c \) (2.1013) was calculated by solving equation \( 6 \) at the median development time and \( F(a_p) = 0.5 \).

**Fecundity and Oviposition**

*Diatraea saccharalis* fecundity has been shown to be host dependent (Bessin & Reagan 1990). Fecundity of moths collected from corn and a susceptible variety of sugarcane, CP 61-37, were greater than that of moths collected from a moderately resistant sugarcane cultivar, CP 65-357, or johnsongrass (Table 1). Regardless of host, fecundity \( f_j \)
was positively correlated ($r = 0.79$) with female pupal weight ($w_i$). Fecundity, thus, can be expressed as:

$$f_j = 10.9 + 4.305w_i,$$  \hspace{1cm} (8)

where the intercept is the result of regression analysis and has no biological interpretation. Female pupal weight is measured in milligrams.

The proportion of eggs laid by a female on a given day is a function of adult physiological age. Oviposition is expressed with a cumulative distribution function adapted from Stinner et al. (1975) similar to development previously described (Eq. 6).

**Mortality**

Percentage of bored internodes were used to compare survival of *D. saccharalis* eggs until establishment in the stalk among sugarcane cultivars. To estimate survival from establishment in the stalk until pupation among cultivars, a relative survival index was utilized (Bessin et al. 1990b). Survival of the pupae until adulthood was equal among all field types.

Overall mortality between the developmental stages can be expressed as:

$$S_{ij} = (1 - m_{Hij})(1 - m_{Pij}),$$  \hspace{1cm} (9)
where $s_{ij}$ is the age specific survival, $m_{Hij}$ is the developmental class-specific host-dependent mortality, $m_{pij}$ is the mortality due to predators. To compare field types, $m_{pij}$ for young larvae is estimated as the ratio of percentages of bored internodes in sugarcane with and without predators. Similarly, to estimate the effect of predators on survival of larger larvae, a ratio of the relative survival of larvae inside the stalk in sugarcane with and without predators was used.

Model Testing

The model was tested using data from a small plot (12x22 m) study involving two sugarcane varieties, CP 61-37 and CP 65-357, with and without predator suppression conducted during 1985 and 1986 at the St. Gabriel Research Station (Bessin et al. 1990a). Host specific, age dependent survivorship parameters for small larvae in the leafsheaths and larger larvae inside the stalk were estimated using the 1985 percentage of bored internode and relative survival data (Bessin et al. 1990b), and fecundity estimates for D. saccharalis on these hosts (Bessin & Reagan 1990). All simulations utilized these parameters and the 1986 minimum and maximum daily temperatures for the Ben Hur Research Station, but varied the redistribution of moths emerging from the four variety-by-predator field type combinations.
Emigrating moths from each field were pooled together at rates of 100, 80, 60, 40, 20 and 0 % emigration for the individual simulations. This migrant moth pool was then equally redistributed to all of the fields.

*Diatraea saccharalis* populations were simulated for 191 days (10 April–17 October). Simulated results were scaled to have an overall mean equal to that of the 1986 field estimates, and each field type was compared to the individual field estimates.

**Varietal Evaluations**

In a separate study in 1989 at the Glendale Plantation near Edgard, Louisiana, eight experimental sugarcane varieties from the seventh year of the Louisiana Sugarcane Variety Development Program (Table 1) and three commercial cultivars [CP 76-331 (susceptible), CP 74-383 (susceptible), and CP 70-321 (highly resistant)] were planted in single row 4.5 m plots. The test was analyzed as a four-replication, incomplete block design. This field was left untreated for *D. saccharalis* throughout the season. On 18 August 1989, 15 millable stalks were randomly removed from each plot and the percentage of bored internodes and numbers of moth exit holes per bored internode were recorded as in the first test. Relative survival was determined with the methods of Bessin et al. (1990b) and used to estimate survival of older
larvae.

Between 20 August and 20 September, a minimum of 20 *D. saccharalis* pupae were collected from each variety. To estimate the potential fecundity of these pupae, weights were compared proportionally to those of pupae collected from CP 65-357 (Bessin & Reagan 1990). A fecundity estimate was assigned to each variety based on the mean weight ratio with respect to CP 65-357.

*Diatraea saccharalis* populations were simulated for 191 days (10 April-17 October). Four different simulations were conducted utilizing rates of 60, 40, 20 and 0 % equal redistribution of moths emerging among varieties. Minimum and maximum temperatures were randomly generated based on the mean monthly properties and frequency of occurrence of eight synoptic weather types for the New Orleans area determined by Muller & Willis (1983).

**Results**

Survival estimates used for model testing are included in Table 2. Survival rates were greater on sugarcane variety CP 61-37 than on CP 65-357. The model testing exercises resulted in four simulated *D. saccharalis* generations. The 1986 field estimates and the results of the six simulations used to test the model are presented in Table 3. When the simulations used 40 % or more
Table 1. Stages in the Louisiana Sugarcane Varietal Development program of the Louisiana Agricultural Experiment Station

<table>
<thead>
<tr>
<th>Year</th>
<th>Stage</th>
<th>Number of varieties selected annually</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Crossing</td>
<td>80,000</td>
</tr>
<tr>
<td>1</td>
<td>Single stools, plant cane</td>
<td>5,000</td>
</tr>
<tr>
<td>2</td>
<td>Single stools, first ratoon</td>
<td>&lt;1,000</td>
</tr>
<tr>
<td>3</td>
<td>1st line trials, plant cane</td>
<td>&lt;500</td>
</tr>
<tr>
<td>4</td>
<td>2nd line trials, plant cane</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2nd line trials, first ratoon</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>Infield</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>Infield and exchange with USDA\textsuperscript{a}</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>Infield and introduce to outfield</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>Infield and plant in outfield</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>Outfield plant cane</td>
<td>4</td>
</tr>
<tr>
<td>11</td>
<td>Outfield first ratoon</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>Outfield second ratoon</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Release</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Evaluation of resistance to \textit{Diatraea saccharalis} begun in the seventh year.
Table 2. Parameter estimates incorporated into the simulation model based on the percentage of bored internodes and relative survival data collected during 1985 at the St. Gabriel Experiment Station

<table>
<thead>
<tr>
<th>Factor</th>
<th>Survival rate of instars I-III</th>
<th>Survival rate of instars IV-VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP 61-37</td>
<td>0.338</td>
<td>0.135</td>
</tr>
<tr>
<td>CP 65-357</td>
<td>0.241</td>
<td>0.067</td>
</tr>
<tr>
<td>Predation</td>
<td>0.602</td>
<td>0.972</td>
</tr>
<tr>
<td>Predator suppression</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>
redistribution of adults, the simulated means were within one standard error of the mean of the field estimates. As the redistribution of moths was reduced, the simulated means diverged more rapidly. Differences among the extreme field types, CP 61-37 with predator suppression and CP 65-357 with predation, was greatest when fields were isolated (i.e. no redistribution of adults).

The parameter estimates obtained from the Edgard test and used for the simulated varietal evaluations are presented in Table 4. The simulated results follow a similar pattern as did the model testing results. As the amount of adult redistribution was reduced among the varieties, the extreme varieties displayed greater divergence (Table 5). Additionally, as the redistribution was reduced, the total number of moths emerging in each simulation increased, with a 1.6-fold increase as the redistribution was reduced from 20 to 0 %. The scaled results for 60 % adult redistribution are similar to the actual field estimates, with only three of the eleven varieties, CP 74-383, LCP 87-018 and LCP 87-491, diverging by more than 10 % from the actual estimates.

Two candidate varieties, LCP 87-023 and LCP 87-472, appeared comparable in terms of moth emergence to the resistant commercial standard, CP 70-321. All three varieties producing less than 1000 pupae per ha when
Table 3. Comparison of 1986 field estimates and simulated *Diatraea saccharalis* (F.) moth emergence from four variety by predator field type combinations

<table>
<thead>
<tr>
<th>Variety</th>
<th>Predation</th>
<th>1986 field estimate ± SEM</th>
<th>100</th>
<th>80</th>
<th>60</th>
<th>40</th>
<th>20</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP 61-37</td>
<td>-</td>
<td>107.3 ± 9.7</td>
<td>104.0</td>
<td>104.5</td>
<td>107.0</td>
<td>114.9</td>
<td>136.4</td>
<td>181.3</td>
</tr>
<tr>
<td>CP 61-37</td>
<td>+</td>
<td>55.8 ± 8.9</td>
<td>61.1</td>
<td>61.0</td>
<td>60.4</td>
<td>58.5</td>
<td>52.3</td>
<td>37.8</td>
</tr>
<tr>
<td>CP 65-357</td>
<td>-</td>
<td>41.1 ± 9.6</td>
<td>36.9</td>
<td>36.6</td>
<td>35.6</td>
<td>32.1</td>
<td>22.9</td>
<td>3.5</td>
</tr>
<tr>
<td>CP 65-357</td>
<td>+</td>
<td>19.4 ± 3.9</td>
<td>21.7</td>
<td>21.5</td>
<td>20.6</td>
<td>18.1</td>
<td>12.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*a* Simulated results for each rate of redistribution were scaled to have an overall mean equal to the overall field mean.
Table 4. Parameter estimates incorporated into the simulation model based on the percentage of bored internodes, relative survival, and pupal weight data collected during 1989, Edgard, Louisiana

<table>
<thead>
<tr>
<th>Variety</th>
<th>Survival rate of instars I-III</th>
<th>Survival rate of instars IV-VI</th>
<th>Fecundity&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP 74-383</td>
<td>0.493</td>
<td>0.185</td>
<td>570</td>
</tr>
<tr>
<td>CP 76-331</td>
<td>0.510</td>
<td>0.079</td>
<td>587</td>
</tr>
<tr>
<td>CP 70-321</td>
<td>0.282</td>
<td>0.095</td>
<td>548</td>
</tr>
<tr>
<td>LCP 87-018</td>
<td>0.418</td>
<td>0.140</td>
<td>530</td>
</tr>
<tr>
<td>LCP 87-020</td>
<td>0.447</td>
<td>0.180</td>
<td>623</td>
</tr>
<tr>
<td>LCP 87-023</td>
<td>0.423</td>
<td>0.074</td>
<td>519</td>
</tr>
<tr>
<td>LCP 87-472</td>
<td>0.374</td>
<td>0.068</td>
<td>567</td>
</tr>
<tr>
<td>LCP 87-479</td>
<td>0.423</td>
<td>0.177</td>
<td>554</td>
</tr>
<tr>
<td>LCP 87-491</td>
<td>0.325</td>
<td>0.153</td>
<td>652</td>
</tr>
<tr>
<td>LCP 87-494</td>
<td>0.538</td>
<td>0.141</td>
<td>611</td>
</tr>
<tr>
<td>LCP 87-496</td>
<td>0.298</td>
<td>0.113</td>
<td>595</td>
</tr>
</tbody>
</table>

<sup>a</sup> Based on a ratio of pupal weights, with respect to sex, to those of pupae collected from CP 65-357 (Bessin & Reagan 1990).
Table 5. Comparison of simulated moth emergence of *Diatraea saccharalis* (F.) with varying levels of adult redistribution among 11 sugarcane varieties

<table>
<thead>
<tr>
<th>Variety</th>
<th>Actual moth emergence per ha</th>
<th>Simulated moth emergence per ha with % adult redistribution of emergence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>per ha</td>
<td>60 a</td>
</tr>
<tr>
<td>CP 74-383</td>
<td>20,700</td>
<td>23,477</td>
</tr>
<tr>
<td>CP 76-331</td>
<td>10,400</td>
<td>10,035</td>
</tr>
<tr>
<td>CP 70-321</td>
<td>5,800</td>
<td>6,609</td>
</tr>
<tr>
<td>LCP 87-018</td>
<td>18,900</td>
<td>14,702</td>
</tr>
<tr>
<td>LCP 87-020</td>
<td>19,400</td>
<td>20,668</td>
</tr>
<tr>
<td>LCP 87-023</td>
<td>8,000</td>
<td>7,731</td>
</tr>
<tr>
<td>LCP 87-472</td>
<td>6,600</td>
<td>6,270</td>
</tr>
<tr>
<td>LCP 87-479</td>
<td>18,300</td>
<td>19,038</td>
</tr>
<tr>
<td>LCP 87-491</td>
<td>15,100</td>
<td>12,516</td>
</tr>
<tr>
<td>LCP 87-494</td>
<td>17,800</td>
<td>19,395</td>
</tr>
<tr>
<td>LCP 87-496</td>
<td>7,800</td>
<td>8,356</td>
</tr>
<tr>
<td>Total</td>
<td>148,800</td>
<td>148,800</td>
</tr>
</tbody>
</table>

* a Simulated results for 60 % adult redistribution were scaled to have an overall mean equal to the overall field estimate.
isolated from the effects of the other fields. One candidate variety, LCP 87-020, appeared to be similar in moth emergence to the susceptible commercial standard, CP 74-383.

**Discussion**

This simulation model utilizes two assumptions in order to estimate host dependent age specific mortalities. First, by assuming no ovipositional preference of *D. saccharalis* and nearly equal egg deposition among sugarcane varieties in small plot tests, percentage of bored internodes can be used to compare survival among sugarcane cultivars, of *D. saccharalis* from egg to establishment in the stalk. To date, no ovipositional preference by *D. saccharalis* has been observed among any commercially grown sugarcane cultivar in the United States or any sugarcane hybrid in the Sugarcane World Germplasm Collection maintained by the U.S. Department of Agriculture in Miami, Fla (Sosa 1988). For example, assuming there are two varieties, A and B, in a replicated small-plot study and A has twice the injury as B. Therefore, survival until penetration into the stalk on the A is said to be twice that of B. Secondly, to estimate survival from establishment in the stalk until pupation among cultivars, a relative survival index is utilized (Bessin et al. 1990b).
The amount of redistribution of adults among sugarcane varieties was varied in these simulations. This was comparable to altering the level of influence certain varieties may have on other varieties. If varieties are assessed in much larger continuous acreages, as they are in commercial production, then it is expected the different varieties would exert less of an influence on each other. By varying the levels of adult redistribution, insights are gained into how these varieties may potentially impact area-wide D. saccharalis populations. To date, there is little information available to estimate the size of the acreages which would correspond to different levels of adult redistribution. More research into the dispersal of the adult D. saccharalis impacting upon oviposition is required.

These results indicate that small-plot varietal evaluations may not adequately address the impact that some varieties may have on area-wide D. saccharalis populations when planted on larger commercial acreages. Relatively small differences observed in small plot tests among varieties may translate into much larger differences when these varieties are grown commercially. Additionally, the simulations indicated that the impact of susceptible varieties on D. saccharalis populations may be reduced if these varieties are properly dispersed among varieties with greater resistance. A degree of stability is maintained
when acreages have at least 20% redistribution of adults.

Bessin et al. (1990a) found insecticidal control to interact with sugarcane host plant resistance when measuring moth emergence. While combining these control strategies always resulted in the greatest control of emergence, a lesser percentage of control due to insecticides on the resistant variety was observed. Such an interaction would require separate estimates of the effectiveness of insecticidal control on individual sugarcane varieties to incorporate insecticidal control into the simulation. The effects of varietal resistance and predation were found to be additive.

Seasonal *D. saccharalis* populations under normal management practices are unlikely to reach the levels depicted in these field studies or simulations. However, varieties which have the greatest potential for enhancing *D. saccharalis* populations will receive insecticide applications more frequently than more resistant varieties.

In order to predict the potential impact of different sugarcane varieties on area-wide *D. saccharalis* populations prior to commercial release, a simulation model has been developed. The model is constructed to facilitate more accurate prediction of the *D. saccharalis* population dynamics on various sugarcane varieties. A major aspect of the concept of pest management involves the separate
understanding of pest build-up on an area-wide basis as compared to pesticide treatment of an individual field (Reagan 1981). Thus, a reduction of pest populations through better crop management on an area-wide basis would lower pesticide usage and environmental contamination, and would enhance farm economics and permanency of production. This would result in a far greater savings to the industry and the region where the crop is produced than the simple reduction of 2-3 pesticide applications, annually.
References Cited


Summary

These studies have investigated various aspects of the relationship between the sugarcane borer and several of its cultivated hosts. Many previous investigations have studied this relationship in terms of differential damage caused by this insect under various management conditions or to different hosts. The studies presented here have focused on the effects different sugarcane varieties, predation, and insecticidal control have on sugarcane population dynamics.

Sugarcane host plant resistance has been shown to affect sugarcane borer populations quantitatively, in terms of survival, and qualitatively, measured in terms of fecundity. The effects of arthropod predation and varietal resistance on moth emergence were additive, but those of insecticidal control and varietal resistance were not. While insecticidal control was the predominant factor in preventing plant injury, varietal resistance was as important in terms of regulating sugarcane borer moth emergence.

Evaluation of the percentage of bored internodes has traditionally served as the primary criteria to quantify sugarcane resistance to sugarcane borers. Resistance ratings based on the percentage of bored internodes were inadequate estimators of moth emergence because of differences in sugarcane borer survival after entry into the stalk. A low correlation (r=0.253) was found between the percentage of bored internodes and the relative survival of
older larvae. A moth production index was proposed to be used in combination with percentages of bored internodes when rating sugarcane varieties for sugarcane borer resistance.

A practical method was found to predict sugarcane borer fecundity when larval development occurred on different gramineous hosts. A linear regression of sugarcane borer fecundity on pupal weight was obtained. Fecundity increased at a rate of 4.3 eggs for each milligram increase in pupal weight, regardless of the host on which larval development occurred. Differences in sugarcane borer fecundity were found when larval development occurred on different sugarcane varieties.

A simulation model was developed to predict the potential impact of sugarcane varieties on area-wide sugarcane borer populations. The model included processes of immature development, oviposition, host-dependent mortality, and mortality due to arthropod predation. Varietal parameters for the model were obtained from small-plot varietal evaluations. Percentages of bored internodes were used to compare survival among sugarcane cultivars, of sugarcane borer eggs until establishment in the stalk with and without predator suppression. To estimate survival from establishment in the stalk until pupation among cultivars, a relative survival index based on a ratio of exit holes to bored internodes was utilized.

Relatively small differences observed in small plot
varietal evaluations were magnified during the simulations when amount of adult redistribution among varieties was reduced (i.e., simulating varieties grown in larger continuous plantings). Simulations showed that differences in moth emergence and total emergence were greatest when there was no exchange of adults among varieties. Differences between extreme sugarcane varieties were greatest when varieties did not exert any influence on each other relative to the exchange of adult moths. Simulations indicated that impacts on sugarcane borer populations would be mitigated if the susceptible varieties are properly dispersed among varieties with greater resistance. This indicated that results obtained from small plot varietal resistance evaluations alone do not adequately address the potential impact varieties may have when grown on larger acreages. This study indicated the need for future research to study the dispersal of adult sugarcane borers relative to their oviposition rates.

Mathematical modeling of insect populations has generated skepticism from those who contend that the empirical approach does not adequately reflect the intrinsic field situation. Descriptive models have several important uses. First, the process of organizing existing knowledge regarding population dynamics into mathematical equations forces one to consider the system as a whole. The process of modeling will reveal gaps in knowledge concerning the system. Secondly, a model should contain all relevant
parameters impinging upon population dynamics. Thus, it may serve as an excellent teaching tool for a researcher who is unfamiliar with a particular pest and wishes to understand population dynamics expediently (Metcalf & Luckman 1975, Ruesink 1976). Models permit one to conceptualize the impact of a multiplicity of complex factors that affect the population flux of an organism. Additionally, they can have the value of determining the impact of changes in cultural and management practices prior to implementation. A systems model also can serve as a tool for generating hypotheses, subsequently to be tested in the field.
List of References


resistance to the sugarcane borer (Lepidoptera: Pyralidae) J. Econ. Entomol. (in press)


sugarcane varieties for susceptibility to the sugarcane borer in Louisiana. Sugar Bull. 39:175-178.


Appendices
Appendix A

Source code for the *Diatraea saccharalis* (F.)

Stochastic Simulation model
program simulation(input,output,wthrfile,result,pop);

const d1=31.2; d0=19.2;
        f1=20.87; f0=2.88;
        sexratio=0.5;
        fieldno=4;

type temp = array [1..365] of integer;
        cellarray = array [0..40,1..fieldno] of real;
        devrates = array [1..45] of real;
        fields = array [1..fieldno] of integer;
        fieldmort = array [1..fieldno] of real;
        shortarray = array [0..40] of real;

var day,lastday: integer;
        eggden,slvden,llvden,pupden,adtken :cellarray;
        eggage,slvage,llvage,pupage,adtage,migden,migfecn
                    :shortarray;
        wthrfilen,result,pop:text;
        mintemp,maxtemp:temp;
        rate:devrates;
        maxfecnuntiy,fieldtye:fields;
        m1,m2,m3,m4,m5,m6,bored,moths,NULL:fieldmort;
        o:char;
        r:real;

procedure initializearrays;
var i,j: integer;

begin

    for j:=1 to fieldno do begin
        m1[j]:=1.0;  { EGG TO SMALL LARVAE MORTALITY ARRAY }
        m2[j]:=1.0;  { SMALL TO LARGE LARVAE MORTALITY ARRAY }
        m3[j]:=1.0;  { LARGE LARVAE TO PUPAE MORTALITY ARRAY }
        m4[j]:=1.0;  { PUPA TO ADULT MORTALITY ARRAY }
        m5[j]:=1.0;  { PRE ENTRY PREDATION }
        m6[j]:=1.0;  { POST ENTRY PREDATION }
        moths[j]:=0; { MOTH PRODUCTION PER FIELD-TYPE }
        bored[j]:=0; { BORERS PENETRATING STALKS PER FIELD }
        null[j]:=0;

        for i:=0 to 40 do begin
            eggden[i,j]:=0;  { SETTING }
            slvden[i,j]:=0;  { DENSITY }
            llvden[i,j]:=0;  { ARRAYS }
            pupden[i,j]:=0;  { TO }
            adtden[i,j]:=0;  { ZERO }
        end; {for}
    end; {for fields}

    for i:=0 to 40 do begin
        eggage[i]:=0;  { SETTING }
        slvage[i]:=0;  { AGE }
        llvage[i]:=0;  { ARRAYS }
        pupage[i]:=0;  { TO }
        adtage[i]:=0;  { ZERO }
        migden[i]:=0;
    end; {for age}
procedure gettemperatures;
var i: integer;
begin
{ GETTING TEMPERATURE DATA }
assign(wthrfile,'a:weather'); { FROM FILE 'WEATHER' }
reset(wthrfile);
for i := 1 to 365 do begin
readln(wthrfile,mintemp[i],maxtemp[i]); { TO BE USED IF }
mintemp[i]:=round((mintemp[i]-32)*5/9); { TEMPERATURES }
maxtemp[i]:=round((maxtemp[i]-32)*5/9); { ARE IN CELCIUS }
end;
close(wthrfile);
end; {gettemperatures}

procedure addborers(var stageden:cellarray;
var stageage:shortarray);
var i,j: integer; {GETTING A }
begin {BORER COHORT}
readln(pop,j,fieldtype[j],i,stageden[i,j]); {FROM A FIELD}
stageage[i]:=0; write(result,j:10,fieldtype[j]:10,i:10);
writeln(stageden[i,j]:12:0);
end; {addborers}

procedure getdata;
var ch:char;  
    i:integer;  
begin  
    assign(pop,'a:borers');  
    reset(pop);  
    writeln(result);  
    write(result,'Initial borer populations inputed into ');  
    writeln(result,'the model');  
    write(result,' Stage Field Field Type Day');  
    writeln(result,' Density');  
    while not eof(pop) do begin  
        read(pop,ch);  
        write(result,ch:10);  
        case ch of  
            'e': addborers(eggden,eggage);  
            's': addborers(slvden,slvage);  
            'l': addborers(llvden,llvage);  
            'p': addborers(pupden,pupage);  
            'a': addborers(adtden,adtage)  
        end;  
    end;  
    close(pop);  
end;  
procedure startingdate;  
begin  
    writeln;
writeln('SUGARCANE PRODUCTION PRACTICE IMPACT MODEL');
writeln;
writeln('Enter starting date for the simulation');
readln(day);
writeln('Enter the ending date for the simulation');
readln(lastday);
writeln('Do you want long or short output? (1/s)');
readln(o);
write('What proportion of adults are to be redistributed?');
writeln(' (0-1.0)');
readln(r);
getdata;
end;

procedure fecundity(var maxfecundity : fields; var m1,m2,m3,m4,m5,m6: fieldmort);
var j: integer;

{ THIS PROCEDURE SUPPLIES THE }
{ INTERSTAGE SURVIVAL AND THE }
{ MAXIMUM AVERAGE FECUNDITY }
{ AMONG THE DIFFERENT FIELD }
{ TYPES }
{ m1[j]: SURVIVAL EGG TO 1-3 }
{ m2[j]: SURVIVAL 1-3 TO 4-6 }
{ m3[j]: SURVIVAL 4-6 TO pupae }
{ m4[j]: SURVIVAL PUPA TO ADULT }
{ m5[j]: PRE ENTRY PREDATION }
begin
  for j:= 1 to fieldno do begin
    case fieldtype[j] of
      1: begin maxfecundity[j]:=669;
        m1[j]:=0.2;
        m2[j]:=0.338;
        m3[j]:=0.135;
        m4[j]:=1.0;
        m5[j]:=1.0;
        m6[j]:=1.0;
      end; (61-37 NO PREDATION)
      2: begin maxfecundity[j]:=537;
        m1[j]:=0.2;
        m2[j]:=0.241; { ALL DATA BASED }
        m3[j]:=0.067; { ON 1985 RAW MEANS }
        m4[j]:=1.0;
        m5[j]:=1.0;
        m6[j]:=1.0;
      end; (65-357 NO PREDATION)
      3: begin maxfecundity[j]:=669;
        m1[j]:=0.2;
        m2[j]:=0.338;
        m3[j]:=0.135;
        m4[j]:=1.0;
        m5[j]:=1.0;
        m6[j]:=0.602;
    end;
end;
function distr(x1,x2,w1,w0:real): real;
  var x3,z1,z2,y1,y2 : real; {STINNER ET AL 1975 CUMMULATIVE}
  begin
    { DISTRIBUTION FUNCTION }
    x3 := x1-x2;
    z1 := (w1 - x1)/(w1 - w0);
    z2 := (w1 - x3)/(w1 - w0);
    if z1 >= 1 then y1 := 0;
    if z1 < 0 then y1 := 1;
    if z2 >= 1 then y2 := 0;
    if z2 < 0 then y2 := 1;
    if (z1 > 0) and (z1 < 1) then
      y1 := exp(2.1013*z1*z1*ln(1-z1));
    if (z2 > 0) and (z2 < 1) then
\[ y2 := \exp (2.1013 \cdot z2 \cdot z2 \cdot \ln (1 - z2)) \]

if \( y2 < 1 \) then \( \text{distr} := (y1 - y2) / (1 - y2) \) else \( \text{distr} := 1 \);

end; \{ \text{distr} \}

procedure setrates; \{ SETTING THE DEVELOPMENT RATES \}

\{ DIFFERENT TEMPERATURES \}

\{ BASED ON HOURLY RATES \}

begin

rate[16] := 0.01004; rate[17] := 0.01098; rate[18] := 0.01198;
rate[19] := 0.01305; rate[20] := 0.01419; rate[21] := 0.01539;
rate[22] := 0.01667; rate[23] := 0.01800; rate[24] := 0.01940;
rate[25] := 0.02086; rate[26] := 0.02237; rate[27] := 0.02392;
rate[28] := 0.02552; rate[29] := 0.02714; rate[30] := 0.02878;
rate[31] := 0.03044; rate[32] := 0.03210; rate[33] := 0.03077;
rate[34] := 0.02912; rate[35] := 0.02747; rate[36] := 0.02584;
rate[37] := 0.02424; rate[38] := 0.02268; rate[39] := 0.02116;
rate[40] := 0.01969; rate[41] := 0.01828; rate[42] := 0.01693;
rate[43] := 0.01564; rate[44] := 0.01442; rate[45] := 0.01327;

end; \{ \text{setrates} \}

procedure movetonextstage(mort, pred : fieldmort; stageaging: real; var stageden, nextstageden: cellarray; var total : fieldmort; stageage: shortarray);
var i,j: integer; { MOVING BORERS TO NEXT }
x,p: real; { LIFE STAGE }
begin { MORTALITIES WILL OCCUR }
for i:= 39 downto 0 do begin { ONLY BETWEEN LIFE STAGES }
p:=distr(stageage[i+1],stageaging,d1,d0);
for j:= 1 to fieldno do begin
x;=(mort[j]*pred[j]*p);
nextstageden[0,j]:=nextstageden[0,j]+x*stageden[i,j];
total[j]:=total[j] + x*stageden[i,j];
stageden[i+1,j]:=stageden[i ,j]*(1-p);
end; {for fields}
end; {for}
for j:= 1 to fieldno do stageden[0,j]:=0;
end; {movetonextstage}

procedure moveadults(var adtden:cellarray; var adtage:
shortarray; adtaging:real; var migden,
migfec:shortarray);
var i,j: integer;
p, test: real; { COLLECTING MIGRANTS AND }
begin { PARTITIONING THEM }
for i:= 39 downto 0 do begin { BETWEEN FIELDS }
p:=distr(adtage[i+1],adtaging,d1,d0);
migden[i+1]:= migden[i]*(1-p);
migfec[i+1]:= migfec[i];
for j:= 1 to fieldno do begin { 0% REDISTRIBUTION }
adtden[i+1,j]:= adtden[i,j]*(1-p)*(1-r);
if (adtden[i,j]*(l-p)*r > 0) or (migden[i+1] > 0)
then migfec[i+1] := (migfec[i+1]*migden[i+1]
+ r*adtden[i,j]*(l-p)*maxfecundity[j]) /
(migden[i+1] + adtden[i,j]*r*(1-p)) else
migfec[i+1] := 0;
migden[i+1] := migden[i+1] + adtden[i,j]*r*(1-p);
end;
end;
for j:=l to fieldno do adtden[0,j] := 0;
migden[0] := 0;
migfec[0] := 0;
end; {moveadults}

procedure oviposition(adtage, migden, migfec: shortarray;
adtden: cellarray; adtaging: real; var eggden: cellarray);
var p: real;
i, j: integer;
begin { EGG DEPOSITION IN THE FIELDS }
for j:=l to fieldno do eggden[0,j] := 0;
for i:=1 to 40 do begin
p := distr(adtage[i], adtaging, fl, f0);
for j:=l to fieldno do begin
eggden[0,j] := eggden[0,j] +
(p*maxfecundity[j]*sexratio*adtden[i,j]) +
(p*migfec[i]*sexratio*migden[i]/fieldno);
end; {for fields}
end; {for}
end;  (oviposition)

procedure updateages;
var tavg, i, j: integer;
    eggaging, slvaging, llvaging, pupaging, adtaging: real;
begin
    tavg := trunc((mintemp[day] + maxtemp[day]) / 2);
    eggaging := rate[tavg] * 7.299 * 24;
    slvaging := rate[tavg] * 3.8081 * 24;
    llvaging := rate[tavg] * 3.685 * 24;  \{ RECIPRICALS OF THE \}
    pupaging := rate[tavg] * 5.236 * 24;  \{ PROPORTION OF \}
    adtaging := rate[tavg] * 7.246 * 24;  \{ OVERALL DEVELOPMENT \}
for i := 39 downto 0 do begin
    eggage[i + 1] := eggage[i] + eggaging;
    slvage[i + 1] := slvage[i] + slvaging;  \{ ADVANCING \}
    llvage[i + 1] := llvage[i] + llvaging;  \{ THE \}
    pupage[i + 1] := pupage[i] + pupaging;  \{ AGE \}
    adtage[i + 1] := adtage[i] + adtaging;  \{ ARRAYS \}
end;  \{for\}
moveadults(adtden, adtage, adtaging, migden, migfec);
{  PARTIONING THE INDIVIDUALS  }
{  BETWEEN CURRENT &  }
{  NEXT LIFE STAGE  }
movetonextstage(m4, m4, pupaging, pupden, adtden, moths, pupage);
movetonextstage(m3, m6, llvaging, llvden, pupden, null, llvage);
movetonextstage(m2,m5,slvaging,slvden,llvden,bored,slvage);
movetonextstage(m1,m4,eggaging,eggden,slvden,null,eggage);
oviposition(adtage,migden,migfec,adtden,adtdaging,eggden);
end; {updateages}

procedure showpopulation;
var i,j: integer;
  eggs,slv,llv,pup,adt,tmoths,tbored,teggs,tslv,tllv,
  tpup,tadt: real;
begind
  write(result,'FIELD EGGS S.LARV. L.LARV. ');
  writeln(result,'PUPAE ADULTS BORED T.MOTHS');
  writeln(result);
  tslv:=0;
  teggs:=0;
  tpup:=0;
  tadt:=0;
  tllv:=0;
  tmoths:=0;
  tbored:=0;
  for j:=1 to fieldno do begin
    eggs:=0;
    slv:=0;
    llv:=0;
    pup:=0;
    adt:=0;
    for i:=0 to 40 do begin;
eggs := eggs + eggden[i,j];
slv := slv + slvden[i,j]; { CALCULATING DENSITIES }
llv := llv + llvden[i,j]; { IN EACH FIELD FOR EACH }
pup := pup + pupden[i,j]; { LIFE STAGE }
adt := adt + adtden[i,j] + migden[i]/fieldno;
end; {for}
write(result,j:4,eggs:9:0,slv:9:0,llv:9:0,pup:9:0);
writeln(result,adt:9:0,bored[j]:9:0,moths[j]:9:0);
teggs := teggs + eggs;
tllv := tllv + llv;
tslv := tslv + slv; { CALCULATING GRAND TOTALS OF }
tpup := tpup + pup; { INDIVIDUALS FOR EACH LIFE }
tadt := tadt + adt; { AMONG ALL FIELDS }
tmoths := tmoths + moths[j];
tbored := tbored + bored[j];
end; {for fields}
write(result,'  GT'^eggsigtO/tslvigtOjtllvigtOjtpupigtO);
writeln(result,adt:9:0,tbored:9:0,tmoths:9:0);
writeln(result);
end; {finalpopulation}

procedure showarrays(stageden:cellarray;stageage :
shortarray);
var i,j,k,l:integer;
begin { THIS PROCEDURE SHOWS THE }
for j := 1 to fieldno do begin {CELL VALUES FOR THE DIFF.}
i := 0; { ARRAYS AT THE END OF THE}
for k:=1 to 10 do begin { SIMULATION }
for l:=1 to 4 do begin
    write(result,i:5,stageden[i,j]:7:0,stageage[i]:7:2);
    i:=i+1;
end; {for}
writeln(result);
end; {for}
writeln(result);
writeln(result);
end; {for fields}
writeln(result);
writeln(result);
end; (showarrays)

begin (main)
    assign(result,'results.00');
    rewrite(result);
    gettemperatures;
    initializearrays;
    startingdate;
    septrates;
    fecundity(maxfecundity,m1,m2,m3,m4,m5,m6);
    showpopulation;
    while day <= lastday do begin { EACH RUN THRU}
        updateages; { THIS LOOP WILL}
        writeln(result,' **day=',day:1,'**'); { REPRESENT ONE}
        writeln(' **day=',day:1,'**'); { DAY IN THE }
day:=day+1;  \{ SIMULATION \}
writeln(result);
showpopulation;
end;  \{while\}
if o = '1' then begin
  showarrays(eggden,eggage);
  showarrays(slvdent,slvage);
  showarrays(llvdent,llvage);
  showarrays(pupden,pupage);
  showarrays(adtdden,adtage);
end;  \{long results\}
close(result);
end.  \{main\}
Appendix B

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November 22, 1989

Ric Bessin  
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Dear Mr. Bessin:

Permission is hereby granted for you to reproduce any material from the articles described on the attached sheet in your dissertation.

Sincerely,

Ray Everngam  
Managing Editor
Attachment


Vita

Ricardo Tomás Bessin was born on December 27, 1959, in Caracas, Venezuela. He moved to the San Francisco Bay area in 1962, where he attended school from the first through the twelfth grades. In 1977, he began four years of study at the University of California, Berkeley where he earned a B.S. with a major in Agricultural Pest Management. In 1982, he moved to Joumine, Tunisia to serve two years with the U.S. Peace Corps working as a Beekeeping Extension Agent with the Tunisian Ministry of Agriculture. After Peace Corps service, he remained in Tunisia for an additional 18 months as a private consultant to several large private beekeeping operations. In 1986, he married Susan Carol Stensrud, and later that year their first son Scott arrived. At Louisiana State University he worked in the sugarcane pest management laboratory studying sugarcane varietal resistance and modeling of sugarcane borer populations. Concurrently, he obtained a M. Ap. Stat. in 1989 while studying at Louisiana State University. In 1989, their second son, Sean, was born.
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March 5, 1990