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Advanced management of the Mexican rice borer (Eoreuma loftini) in sugarcane

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ADVANCED MANAGEMENT OF THE MEXICAN RICE BORER (*EOREUMA LOFTINI*) IN SUGARCANE

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
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requirements for the degree of
Master of Science

in

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by
Blake E. Wilson
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ABSTRACT

Insecticide, greenhouse and varietal resistance experiments were conducted in Texas to develop management tactics for the Mexican rice borer, *Eoreuma loftini* (Dyar), sugarcane. A 3-treatment, large plot aerial application study was set up in 5 commercial sugarcane fields (35-84 acres) to evaluate the utilization of pheromone traps to improve chemical control strategies for *E. loftini* during 2009 and 2010 growing seasons. A threshold of 20-25 moths/trap/wk was used as an indicator to initiate monitoring for *E. loftini* larval infestations. Larval infestations were directly related to the no. of moths/trap/wk (R^2=0.71). Reductions in borer injury and adult emergence (60% and 40% for novaluron and β-cyfluthrin, respectively) were detected when a threshold of 5% of stalks with treatable larvae was used for timing an insecticide application. Data revealed novaluron treatments increased sugar production by 14%. A greenhouse study assessed the establishment and behavior of *E. loftini* neonates on two phenological stages of stalkborer resistant (HoCP 85-845) and susceptible (HoCP 00-950) cultivars. Approximately half (55%) of neonates on HoCP 00-950 and 28% on HoCP 85-845 tunneled inside the leaf mid-ribs within 1d of eclosion. Duration of neonate exposure ranged from 3.5 - 6.4 d. This research shows a short window of vulnerability of *E. loftini* to insecticide applications, and demonstrates the potential to use pheromone traps and new chemistries for enhancing chemical control. A 5-replication field test evaluated stalkborer resistance in 25 sugarcane cultivars. Differences were detected between cultivars in *E. loftini* injury which ranged from 1.0-20.3% bored. The resistant standard HoCP 85-845 and a South African cultivar, N-21, were the most resistant. HoCP 96-540, which represents the majority of sugarcane acreage in Louisiana, was among the most susceptible. Assessment of stalkborer resistance in sugarcane cultivars is needed as host plant resistance will continue to be important to *E. loftini* IPM.

CHAPTER 1

INTRODUCTION AND REVIEW OF LITERATURE

Introduction

Management of invasive species is a growing concern in the United States. Currently there are approximately 50,000 invasive species in the U.S. responsible for $137 billion in damages and control costs, annually (Pimentel *et al.* 2000). Of those species, approximately 1,000 are crop pests which account for $14.4 billion annually in damages (Pimentel *et al.* 2000). One invasive insect that has become established as a major pest of sugarcane and rice in Texas is the Mexican rice borer, *Eoreuma loftini* (Dyar). This species was first reported as a pest of sugarcane in the U.S. in the Lower Rio Grande Valley (LRGV) of Texas in 1980 (Johnson and Van Leerdam 1981), where it now accounts for >95% of the sugarcane stalkborer population (Legaspi *et al.* 1999a). It has since spread northeast through the Texas rice belt along the Gulf Coast (Reay-Jones *et al.* 2007a). Despite a 2005 quarantine designed to prevent movement of Texas sugarcane into Louisiana, *E. loftini* was discovered in Louisiana in December 2008 (Hummel *et al.* 2010). Based on its current 16.5 km/yr rate of expansion, *E. loftini* is predicted to infest the entire state by 2035 when it is projected to cause >$260 million in annual revenue loss to Louisiana agriculture (Reay-Jones *et al.* 2008). As *E. loftini* threatens Louisiana, the need to develop effective control tactics is of growing importance to Louisiana agriculture.

Management of *E. loftini* in sugarcane relies on a balance of multiple control tactics. Reay-Jones *et al.* (2005) showed that a combination of irrigation, cultivar resistance, and insecticide applications greatly reduced *E. loftini* injury. However, *E. loftini* control is complicated by the tunneling behavior of larvae limiting exposure to insecticides, beneficial insects, and other control tactics (Van Leerdam 1986, Meagher *et al.* 1994). Biological control has been largely unsuccessful against *E. loftini* in the LRGV (Legaspi *et al.* 1997, Meagher *et al.* 1998) despite releases of multiple parasitoids (Browning and Melton 1987). In addition, the efficacy of insecticide applications is often inadequate to improve subsequent sugar yields and chemical control of *E. loftini* in sugarcane is not economical (Meagher *et al.* 1994, Legaspi *et al*. 1997, Reay-Jones *et al*. 2005). The lack of adequate chemical *E. loftini* control in sugarcane is most often attributed to the insufficient exposure of larvae (Johnson *et al.* 1985, Meagher *et al.* 1994). Plant characteristics which affect larval establishment such as rind hardness and nutritional factors vary between cultivars (Posey *et al.* 2006, Reay-Jones *et al.* 2005, 2007b, Showler and Castro 2009) and phenological stage (Atkinson and Nuss 1989, Reay-Jones *et al.* 2007b). A better understanding of *E. loftini* neonate behavior, improved timing of insecticide applications, and varietal resistance could lead to the development of management strategies which effectively control larvae before they become protected within the stalk. This research attempts to evaluate: (1) the use of pheromone traps to improve chemical control of *E. loftini* by increasing scouting efficiency and enhancing the timing of insecticide applications; (2) the effect of a single aerial application of novaluron on borer injury and sugarcane yield in a commercial setting; (3) neonate establishment, feeding behavior, and exposure to control agents on different sugarcane cultivars and phenological growth stages, and (4) cultivar resistance to *E. loftini* among 25 commercial and experimental sugarcane varieties.

Literature Review

Eoreuma loftini was first reported in the U.S. in Arizona (Dyar 1917), but did not become established in the LRGV of Texas until 1980 (Johnson and Van Leerdam 1981). It has since become the dominant pest of sugarcane in the LRGV where it now accounts for >95% of the sugarcane stalkborer population (Legaspi *et al.* 1999a). Stalkborers are the primary pest of sugarcane in the LRGV and are responsible for damaging ~20% of sugarcane internodes annually (Legaspi *et al*. 1999a). *Eoreuma loftini* is a devastating pest of sugarcane responsible for >$10 million in annual revenue losses (Legaspi *et al.* 1997) and yield losses of 50-65% have been attributed to *E. loftini* infestations in the LRGV (Johnson 1984). Shortly after establishment, sugarcane was the source of 97% of all *E. loftini* collected in the LRGV (Johnson 1984). However, recent evidence suggests other crops including rice, corn, and sorghum as well as certain weed hosts may also be important to *E. loftini* ecology (Beuzelin *et al.* 2010b). The range of *E. loftini* has since expanded north-easterly through the Texas rice belt along the Gulf Coast (Reay-Jones *et al.* 2007a). Despite a 2005 quarantine preventing the entry of Texas sugarcane into Louisiana, *E. loftini* was discovered in the state in December of 2008 (Hummel *et al.* 2010). The continued spread of *E. loftini* will have serious economic consequences to Louisiana agriculture which emphasizes the need for effective area-wide population management. Based on the current rate of expansion, 16.5 km/yr, *E. loftini* is predicted to infest the entire Louisiana sugarcane industry by 2035 (Reay-Jones *et al.* 2008). Its establishment as an economic pest in Louisiana sugarcane is predicted to cause $220 million and $48 million in annual revenue loss for the sugarcane and rice industries, respectively, by 2035 (Reay-Jones *et al.* 2008). The need to develop *E. loftini* IPM strategies which reduce crop injury as well as area-wide populations is of critical importance to the state of Louisiana.

Inability to provide effective pest control of *E. loftini* in sugarcane can be attributed to the pest's biology which limits exposure to control tactics. Female *E. loftini* oviposit in sheltered sites on dried sugarcane leaves located on the lower portion of the plant, i.e. between the soil surface and 80 cm height (Van Leerdam *et al*. 1984, 1986, Showler and Castro 2010). The globular cream-colored eggs are usually laid in groups of 5 to 100. Temperature is directly related to total fecundity, with an average of 259 eggs per female at 20°C and 406 eggs at 26ºC. The oviposition rate varies from 29 eggs/d at 20°C to 64 eggs/d at 32°C (Van Leerdam 1986).

Oviposition peaks 2 d after female emergence. Increasing temperature appears to decrease the time between emergence and oviposition (Van Leerdam 1986). While oviposition is an important factor affecting *E. loftini* ecology, it is the larval characteristics which complicate pest management.

Extensive laboratory examination of *E. loftini* development was conducted by Van Leerdam (1986). Newly hatched *E. loftini* larvae disperse from dry leaves where the eggs are deposited to green parts of the plant where they mine into leaf sheaths and stalks, and become protected from beneficial insects and insecticides. *Eoreuma loftini* completes the egg stage in 14 d at 20°C and 5 d at 32°C when reared at constant temperatures (Van Leerdam 1986). In appearance, the larvae have an orange/brown head capsule and four dark broken lines that run the length of the light-colored body. Laboratory examination revealed developmental polymorphism, with five to seven instars occurring before pupation. The number of stadia is affected by sex, with a higher average for females (six) than for males (five) (Van Leerdam 1986). Temperature is inversely related to this number, with a six stadia larval development at 23°C, and five stadia at 29°C. The mean duration of each stadium decreases rapidly as temperature increases, with an average of 78 d at 20°C and 21 d at 32°C for completion of all larval stages (Van Leerdam 1986). Van Leerdam (1986) found that *E. loftini* larvae typically feed in the leaf sheath until becoming third instars when they enter the stalk and begin to feed internally. In addition, the average age of third instars reared on artificial diet is roughly 11 d. However, these studies were conducted under artificial laboratory conditions and may not be representative of *E. loftini* behavior on live sugarcane stalks. Once inside the stalk *E. loftini* larvae tunnel both vertically and horizontally (Legaspi *et al*. 1997). Mature larvae create an emergence window in the stalk prior to pupation which takes place in frass-packed tunnels. This behavior creates a protected chamber for development from stalk entry until adult emergence (Legaspi *et al.* 1997). The duration of the *E. loftini* pupal stage is also inversely related to temperature and lasts from 21 d (20°C) to 7 d at 32°C (Van Leerdam 1986). The developmental times of *E. loftini* on sugarcane stalk sections showed extended durations compared with those obtained from development on artificial diet, suggesting that sugarcane may be a less than optimal food source (Van Leerdam 1986). Variation in the duration of larval development between different cultivars (Kennedy and Kishaba 1976) may be related to nutritional content such as concentrations of free amino acids (FAA) (Reay-Jones *et al*. 2005) and other nutrients. Management in the LRGV is further complicated by overlapping generations which mean multiple life stages are present simultaneously. Studies have shown that *E. loftini* is active throughout the year in the LRGV, and active larval and adult stages have been observed throughout the winter (Johnson 1985, Van Leerdam *et al*. 1986, Beuzelin *et al.* 2010b).

The life stage of *E. loftini* targeted for chemical control is the neonate, which migrates from the oviposition site on dry leaves at the base of the plant to green parts of the plant (Meagher *et al*. 1994). Weekly applications of insecticides have reduced *E. loftini* injury, but the effect on sugarcane yield was rarely significant (Johnson 1985, Meagher *et al.* 1994, Legaspi *et al.* 1999b, Reay-Jones *et al.* 2005). Insecticides therefore are believed to have had such limited success in controlling *E. loftini* that most sugarcane growers in the LRGV have abandoned this control approach altogether (Legaspi *et al.* 1997). Similar to the sugarcane borer, *Diatraea saccharalis* F., *E. loftini* injury is most commonly expressed as a proportion of bored internodes. Key yield and quality parameters such as recoverable sugar, juice purity, and sucrose content are inversely related to percentage of bored internodes (White and Hensley 1987, Legaspi *et al.* 1999a). However, past failures to detect effects of insecticide treatments on yield despite a reduction in percentage of bored internodes (Johnson 1985, Meagher *et al.* 1994, Legaspi *et al.* 1999b, and Reay-Jones *et al.* 2005) may be the result of high variability of sugarcane yield studies and differential responses to injury between cultivars (Hensley and Long 1969).

The narrow temporal window during which *E. loftini* larvae are potentially exposed to insecticides reduces the impact of chemical control. The difficulty of applying pesticides to foliage in the lower parts of sugarcane further reduces the efficiency. The potential to improve chemical control may lie in the use of insect growth regulators, as well as an effort to achieve better insecticide application timing. Tebufenozide has shown excellent efficacy against sugarcane stalkborers in both laboratory (Rodriguez *et al.* 2001) and field tests (Rodriguez *et al.* 1995, Reay-Jones *et al.* 2005). Laboratory studies revealed that tebufenozide is toxic to *E. loftini*, even though it is slower acting than traditionally used pyrethroid insecticides (Legaspi *et al.* 1999b). However, even when multiple applications of tebufenozide are made, the effect on sugar yield has not been significant (Reay-Jones *et al.* 2005). In addition, laboratory studies have shown there is potential for development of insecticide resistance to tebufenozide which highlighted the need for alternative chemistries (Akbar *et al.* 2008b). A recently labeled ("section 3" for sugarcane) insect growth regulator, novaluron, is a promising new chemistry which has also been shown to be effective in controlling stalkborers in sugarcane (Akbar *et al.* 2008a, 2009, Beuzelin *et al.* 2005, 2010). However, *E. loftini* control with novaluron using aerial application technology in a commercial setting has not yet been evaluated.

In addition to new chemistries, control of *E. loftini* could be improved by more precise timing of insecticide applications. In order to maximize efficiency, insecticide applications should be made when high densities of larvae are exposed and feeding on the external surfaces of stalks. Well timed insecticide applications may not only improve efficacy, but also reduce the number of treatments needed. Insecticidal control of the sugarcane borer has been greatly improved by the utilization of scouting thresholds (Hensley 1971). Adapted from the sugarcane borer work in Louisiana, a treatment threshold of 5% of stalks with larvae present in the leaf sheaths (or exposed on the surface of the plant) has been used to trigger insecticide applications for control of *E. loftini* (Johnson *et al.* 1985, Meagher *et al.* 1994). However, scouting for *E. loftini* in sugarcane is labor intensive and requires a large number of stalks to be sampled to provide accurate estimations of larval infestations (Hall 1986, Meagher *et al.* 1996b). Previous studies (Meagher *et al.* 1996b) suggest that identification of relationships between adult population density estimations such as pheromone trap catches and larval injury might be used to improve early detection of pest population increases. In a small plot study (Reagan *et al.* 2001), the use of pheromone traps and treatment thresholds to direct insecticide applications showed potential to enhance chemical control of *E. loftini.*

Brown *et al.* (1988) were the first to provide evidence of the *E. loftini* female sex pheromone. The pheromone was subsequently synthesized (Shaver *et al.* 1988), and field experiments demonstrated the efficiency of pheromone-baited traps as a survey and monitoring tool (Shaver *et al.* 1990, 1991). Pheromone traps have been used to track the movement of *E. loftini* across the Texas rice production area (Reagan *et al.* 2005, Reay-Jones *et al.* 2007a) and provided the first detection of the invasive insect in Louisiana (Hummel *et al.* 2010). Pheromone traps are useful in monitoring population fluctuations and may provide improved early warning signs of pest outbreaks (Robacker and Landholt 2002). By monitoring adult population fluctuations, pheromone traps have potential to reduce scouting effort and improve insecticide application timing. The use of pheromone traps to assist scouting has yet to be evaluated in a commercial setting. However, even if chemical control of *E. loftini* is improved, management programs will not be able to rely solely on insecticide applications. The use of multiple control tactics is likely the only method to achieve adequate control of this destructive pest (Reay-Jones *et al.* 2005). The use of resistant cultivars may provide an important component of *E. loftini* IPM. In addition to reducing pest injury on an individual field basis, area-wide pest management aims to reduce population levels of the target organism over a large geographical area (Bessin *et al.* 1991).

Resistant cultivars have consistently shown reduced *E. loftini* injury when compared to susceptible cultivars (Pfannenstiel and Meagher 1991, Meagher *et al.* 1996a, Reay-Jones *et al.* 2003, 2005). Host plant resistance in *E. loftini* management can also aid in the reduction of area-wide populations. This led to the development of a moth production index based on adult emergence which compares the effects of treatments on area-wide populations (Bessin *et al.* 1990). Expansive acreage of susceptible varieties with elevated moth production increases endemic *E. loftini* populations and imposes additional pressure on the remaining acreage. Currently, the majority of sugarcane acreage in Louisiana is planted with *E. loftini* susceptible cultivars HoCP 96-540 and LCP 85-384 which had the greatest moth production in varietal resistance studies (Reay-Jones *et al.* 2003). In addition to reducing area-wide populations, resistant cultivars may improve the efficacy of other control tactics by impeding larval entry into the stalk. While host plant resistance has repeatedly been shown to be promising for *E. loftini* control, the mechanisms of resistance are not fully understood.

Host plant resistance to sugarcane stalkborers has been classified into four categories: (1) unattractiveness of plants to adults for oviposition, (2) plant characteristics unfavorable for larval establishment in the plant, (3) plant characteristics that inhibit or retard larval development, and (4) plant tolerance (Mathes and Charpentier 1969). While the importance of each component of resistance is continually being evaluated, the majority of work has been focused on *E. loftini* oviposition. Oviposition preference may play a role in resistance because *E. loftini* prefers folds in senescing leaves as oviposition sites (Van Leerdam 1986, Reay-Jones *et al.* 2007b, Showler and Castro 2010a,b). Plant vigor characteristics which minimize leaf senescence and attractiveness for egg laying may contribute to *E. loftini* resistance (Reay-Jones *et al.* 2005, 2007b, Showler and Castro 2010a,b). Showler and Castro (2010b) demonstrated *E. loftini* prefers folds in curled leaves as oviposition sites which further limit exposure of eggs and neonates. Oviposition preference may be linked to chemoreceptors which detect the presence/absence of primary or secondary compounds to assist females in accepting or rejecting a host plant (Ramaswamy 1988). FAA concentrations, which are elevated in drought stressed sugarcane (Reay-Jones *et al.* 2005, Showler and Castro 2010a), may be responsible for *E. loftini* oviposition preference. Reay-Jones *et al*. (2007b) demonstrated that a positive correlation exists between free essential amino acids concentrations and eggs per plant. *Eoreuma loftini* females have shown an oviposition preference for susceptible cultivars and drought stressed sugarcane containing elevated concentrations of essential FAAs (Reay-Jones *et al.* 2007b, Showler and Castro 2010a). Factors which may hinder larval establishment are physical characteristics such as rind hardness and leaf sheath appression, which impede stalk entry prolonging larval exposure on plant surfaces (Coburn and Hensley 1972). Premature rind hardness may also be a component of this relationship (Martin *et al.* 1975). This potential mechanism of resistance may provide a key component to *E. loftini* IPM because it has potential to enhance the efficacy of other management tactics such as chemical control by increasing the duration of larval exposure. In addition to physical factors, host plant concentrations of certain primary and secondary metabolites affect larval development. Differences in *E. loftini* larval weight and time to pupation may be linked to varying levels of allelochemicals among sugarcane cultivars (Meagher *et al.* 1996a). Evidence suggests that drought stress tolerance may be a factor in *E. loftini* resistance. Infestations of *E. loftini* are enhanced by plant stress which leads to an increase in FAA concentrations in sugarcane under drought stress (Reay-Jones *et al.* 2005, Showler and Castro 2010a). This increase in FAAs is less pronounced in resistant varieties compared to susceptible varieties indicating that drought tolerance might be a component of *E. loftini* resistance (Reay-Jones *et al.* 2005, Showler and Castro 2010a), but further research is needed before the roles of primary metabolites as well as other metabolic components in host plant resistance is fully understood. In addition, resistance mechanisms which impede entry into the stalk and may enhance the effects of other control tactics by prolonging the duration of larval vulnerability should be evaluated.

As *E. loftini* threatens to become established in Louisiana where it is expected to cause substantial economic losses (Reay-Jones *et al.* 2008), the need for effective management strategies is becoming more important. Because of the limited vulnerability of *E. loftini* larvae, continued examination of control tactics which target exposed neonates will contribute to development of improved *E. loftini* IPM programs. Potential control strategies highlighted by this research include the use of pheromone traps to assist scouting and improve application timing, utilization of new chemistries which are more effective against neonates, and the incorporation of resistant sugarcane varieties into *E. loftini* IPM.

CHAPTER 2

CHEMICAL CONTROL TACTICS THAT TARGET EXPOSED *E. LOFTINI* LARVAE IN SUGARCANE

Introduction

The Mexican rice borer, *Eoreuma loftini* (Dyar), is an invasive species originating from Mexico which became established in the Lower Rio Grande Valley (LRGV) of Texas in 1980 (Johnson and Van Leerdam 1981) and has since become the dominant pest of sugarcane in that area representing >95% of the sugarcane stalkborer population (Legaspi *et al.* 1999a) and causing >$10 million in annual revenue losses (Legaspi *et al.* 1997). The range of *E. loftini* has expanded across the rice production area in east Texas (Browning *et al.* 1989, Reay-Jones *et al.* 2007a), eventually reaching Louisiana in 2008 (Hummel *et al.* 2010). Based on its current 16.5 km/yr rate of expansion, *E. loftini* is predicted to infest the entire Louisiana sugarcane industry by 2035 and is projected to cause up to $268 million in annual revenue losses in sugarcane ($220 million) and rice ($48 million) (Reay-Jones *et al.* 2008).

While insecticide applications have been shown to reduce *E. loftini* injury, chemical control has rarely affected sugarcane yield (Johnson 1985, Meagher *et al.* 1994, Reay-Jones *et al.* 2005), and most LRGV producers abandoned insecticides as a means of management (Legaspi *et al.* 1997). However, new insecticide chemistries and improved scouting methods might enhance approaches to control. A recently labeled insect growth regulator, novaluron, is a promising new compound that was demonstrated to suppress *E. loftini* in sugarcane (Akbar *et al.* 2009).

Chemical control of *E. loftini* is inhibited because the larvae tunnel and pack it with frass, protecting them from exposure to topically applied insecticides. Thus, insecticide applications target neonates (1st to 3rd instars) not yet within tunnels. Overlapping generations in the LRGV result in multiple life stages of the pest simultaneously (Johnson 1985, Van Leerdam 1986, and Meagher *et al.* 1994).

Timing insecticide applications against stalkborers is dependent on scouting for treatable larval infestations. Modeled after sugarcane borer, *Diatraea saccharalis* F., work (Hensley 1971), a treatment threshold of 5% of stalks with *E. loftini* larvae on plant surfaces indicates the need for an insecticide application (Johnson *et al.* 1982). Scouting for *E. loftini* in sugarcane is labor intensive and it has been suggested that identification of a relationship between adult population density and larval injury could improve early detection of population increases (Meagher *et al.* 1996). Brown *et al.* (1988) studied the presence of the *E. loftini* female sex pheromone by examining male response to ovipositor extracts. Pheromone traps are effective at trapping male *E. loftini* (Shaver *et al.* 1990, 1991) and have been used to assist scouting by carefully timing insecticide applications (Reagan *et al.* 2001). In addition, a more thorough understanding of *E. loftini* larval behavior could lead to the development of control strategies which target vulnerable neonates.

Chemical *E. loftini* control is hindered by limited exposure of larvae. *Eoreuma loftini* shows a preference for oviposition on folds of dry leaf material (Van Leerdam 1984, Reay-Jones *et al.* 2007b, Showler and Castro 2010b), areas which are difficult to access with insecticides. After eclosion, early instars disperse and begin feeding on the green tissue of leaves and leaf sheaths before they enter the stalk and begin to feed internally (Van Leerdam 1986). Van Leerdam (1986) found larvae typically enter the stalk when they are third instars stalk and the average age of third instars reared on artificial diet is roughly 11d. Plant characteristics which affect larval establishment such as rind hardness and nutritional factors vary between cultivars (Posey *et al.* 2006, Reay-Jones *et al.* 2005, 2007b, Showler and Castro 2010a) and phenological growth stage (Atikinson and Nuss 1989, Reay-Jones *et al.* 2007b). The duration of larval feeding in the leaf sheath has been shown to be directly related to plant age (Van Leerdam 1986) and internodes

<70 d old are most susceptible to *E. loftini* injury (Ring *et al.* 1991) attributable to changes in physiology such as increasing rind hardness as internodes mature. Determination of the duration of leaf sheath feeding could improve the efficacy of scouting and action thresholds in *E. loftini* chemical control.

The objectives of this study are (1) to evaluate the use of pheromone traps to improve the timing of chemical control of *E. loftini* and enhance scouting efficiency, (2) to evaluate the efficacy of a single aerial application of novaluron on borer injury and sugarcane yield in a commercial setting, and (3) to determine the duration of *E. loftini* neonate exposure to control agents and to assess the effect of cultivar and phenological stage on neonate establishment, behavior, and survival.

Materials and Methods

Aerial Insecticidal Control. A 2009/2010 study was conducted using a randomized complete block experimental design with five replications (fields) in the LRGV (Cameron and Hidalgo Counties, TX). Insecticide treatments were assigned randomly to 4-ha plots in 5 commercial sugarcane fields ranging from 14-33 ha of variety CP 72-1210. Treatments were a single application of either novaluron (Diamond® 0.83EC, Makeshim Agan of North America Inc, Raleigh, NC) applied at 80 g (AI)/ha, β-cyfluthrin (Baythroid® XL, Bayer CropScience LP, Research Triangle Park, NC) applied at 25 g (AI) /ha, and another 5 plots were left as non-treated controls. Adult *E. loftini* population densities were monitored throughout the growing season with pheromone traps. Bucket type traps (one/field in 2009, two/field in 2010) baited with a synthetic *E. loftini* female sex pheromone lure (Luresept; Hercon Environmental, Emigsville, PA) attached to metal poles at a height of ≈1 m above the ground were placed on opposite edges of experimental sugarcane fields. An insecticidal strip (Vaportape II; Hercon

Environmental) was placed inside traps to kill all insects trapped. Pheromone lures were replaced every 2 wk and insecticidal strips were replaced every 4 wk.

Traps were checked weekly from 15 July to 14 October 2009 and from 1 June to 14 August 2010. The number of male *E. loftini* caught per trap per week was recorded. Trap catches of >20–25 moths/trap/week were used as a scouting threshold to initiate monitoring for larval infestations. This threshold was developed from pheromone trap catch numbers collected in a small plot insecticide trial (Reagan *et al.* 2001). Larval infestations exceeding the economic threshold of 5% of stalks with treatable larvae present on plant surfaces initiated insecticide applications in all fields made by fixed wing aircraft flying at 233 kph equipped with CP-03 nozzles at 96 L/ha with less than 8 kph wind the mornings of 21 August 2009 and 14 August 2010. In 2010 weekly larval scouting was conducted by careful examination of 10 stalks (1 June–6 July) or 20 (13 July–14 August) from two locations several rows in from trap sites in all fields. Prior to harvest (28 October, 2009 and 8 November, 2010) two 15-stalk samples were collected from each plot and the numbers of bored internodes and emergences holes were recorded. Treatments plots were harvested separately and each load was weighed to determine the total weight of cane from each plot. The number of loads taken from each plot was variable, and all plots were completely harvested. A core sample from each load was weighed and prepared for quality analysis. A hydraulic press was used to extract juice. Brix, percent soluble solids in juice, was recorded using a brix refractometer. Percent sucrose in juice (Pol) was measured with an automatic sucrolyser after clarifying the juice with acetate. The ratio of sucrose to all other dissolved solids (Brix) is referred to as juice purity and expressed as a percentage. Tons of cane per acre (TCA) was calculated by dividing the total weight of cane (tons) harvested from each plot by the plot size (acres). Commercially recoverable sugar (CRS) was recorded for each core sample and extrapolated to one ton of cane which is expressed as lbs of sugar/ton of cane. Yield was further extrapolated to tons of sugar per acre (TSA) calculated by the following: TSA= (Mean CRS* TCA)/2000. Data were analyzed with generalized linear mixed models (Proc GLIMMIX, SAS Institute 2006) with Gaussian distributions. Tukey's honestly significant difference (HSD) was used for mean separation for all analyses except for sugar/ha and cane/ha which were separated with Fisher's least significant difference (LSD) test due to low degrees of freedom. All reported means were converted to metric units after analysis.

The total number of internodes, bored internodes, and emergence holes from stalks were summed for each 15 stalk sample. Data from 2009 and 2010 were analyzed together with year, field, field X year, and field X yield X treatment as random effects (Appendix B). Injury data, proportion of bored internodes, and relative survival to adulthood were analyzed using a generalized linear mixed model (Proc GLIMMIX, SAS Institute 2006) with a binomial distribution. Numbers of adult emergence holes were analyzed using a generalized linear mixed model with a Poisson distribution (Poisson 1837). A relative index was used to estimate survival of larvae to adulthood (relative survival = no. emergence holes/no. bored internodes) (Bessin *et al.* 1990, Reay-Jones *et al.* 2003). For all models, the Kenward-Roger method (Kenward and Roger 1997) was used to compute denominator degrees of freedom for the test of fixed effects for all variables. In addition, a simple linear regression between the numbers of male *E. loftini*/trap/wk and the percentages of stalks infested with treatable larvae was performed.

Neonate Establishment and Behavior. A greenhouse study was conducted during the summer of 2010 at the USDA-ARS Kika de la Garza Subtropical Agricultural Research Center in Weslaco, TX to investigate *E. loftini* neonate establishment and feeding behavior on two phenological stages of a resistant sugarcane variety, HoCP 85-845, and a susceptible variety, HoCP 00-950 (Reay-Jones *et al.* 2005, Reagan *et al.* 2007). Twenty-four sugarcane nodes of each cultivar were obtained from Certis U.S.A. sugarcane tissue cultures. Plants were arranged on greenhouse tables in a completely randomized design with a 2 x 2 factorial, cultivar x phenological stage, with each of the four treatments representing 12 stalks. All stalks pieces were planted in late spring in 7.6 L pots in Sunshine mix no.1 nursery potting soil (~75% sphagnum peat moss, perlite, dolomitic limestone, and gypsum; Sungro Horticulture, Bellevue, Washington). Plants were kept well watered throughout their growth and 200 ml of Peters Professional (Scotts-Sierra Horticulture Products Company, Marysville, Ohio) water-soluble general purpose fertilizer was applied to the soil once plants reached the 2-leaf stage.

The experiment was conducted on immature cane once stalks had produced 6 nodes, 14 June – 2 July and on mature cane from 30 July–17 August once stalks had 12 nodes. *Eoreuma loftini* eggs were manually placed on sugarcane stalks in locations consistent with normal oviposition activity 15–25 cm from the stalk on the underside of sugarcane leaves which showed early signs of senescence to simulate natural *E. loftini* oviposition (Reay-Jones *et al.* 2007b, Showler and Castro 2010a,b). Eggs were obtained from a laboratory colony reared from *E. loftini* larvae collected from commercial sugarcane fields in Hidalgo County, TX on artificial diet (Martinez *et al.* 1988) at 25°C, 65% RH, and a photo period of 14:10 (L:D). After mating, eggs masses of 10-80 eggs were deposited by the *E. loftini* females on to ½-inch-wide paper strips. Eggs on each strip were counted prior to clipping strips to leaves with 1-inch paper clips.

Development of early instar larvae was examined by direct observation and stalk dissection. Egg strips were removed after hatching, 7 d after strips were clipped to leaves, and the numbers of unhatched eggs were counted under a microscope. The location of initial establishment was recorded as either sheath feeding or mid-rib entry. The number and position of mid-rib entry holes was recorded. All leaves and leaf sheaths on each plant were examined daily for the presence of *E. loftini* neonates, and the location of feeding sites (mid-rib or sheath), dispersal distance from oviposition sites, and time to stalk entry were recorded. The percentage of larvae that became established on each stalk was calculated by dividing the number of larvae observed feeding in leaves or sheaths by the number of hatched eggs. Dispersal of neonates, expressed as the number of internodes moved from oviposition sites, was recorded for all established larvae. Neonates which became established feeding within the leaf sheath were monitored daily by carefully checking between the stalk and sheath for the presence of larvae. Daily examination of each sheath was conducted until entry holes were observed or larvae were recorded as dead or vanished. Survival to stalk entry and duration of leaf sheath feeding (time from eclosion to stalk boring) were recorded. After allowing 4 wk for development, stalks were destructively sampled and the numbers and locations of entry holes and live larvae and pupa recorded. Data was analyzed using generalized linear mixed models (Proc GLIMMIX, SAS Institute 2006) (Appendix C). The proportion of larvae which became established on the stalk, the proportion which entered into the midrib of the leaf, and the proportion of larvae which survived to stalk entry were analyzed with binomial distributions because data are expressed as proportions of eclosed or established neonates. A Gaussian distribution was used to analyze data on the duration of larval exposure, and dispersal distance. Data were not transformed because response variables were dependent on the number of eggs pinned on each plant.

Results

Aerial Insecticidal Control. Pheromone trap catches in both 2009 and 2010 peaked in late August. Live larval infestations were sampled from ten stalks per plot and ranged from 5% to 32% with a mean of 13.8±1.8[SE] % of stalks with treatable larvae present on plant surfaces in various fields on 20 Aug 2009 just prior to insecticide applications and a steady decline in the mean number *E. loftini*/trap/wk followed (Fig. 2.1A). On 14 August 2010 larval infestations ranged from 5 to 22.5% with a mean of 11.25±1.5[SE] % of stalks with treatable larvae. Weekly monitoring of larval infestations in 2010 depicted the relationship between adult population density and larval infestation (Fig. 2.1B). Linear regression revealed a substantial correlation (F = 280.7; df = 1,114; $P < 0.0001$, r^2=0.71) between pheromone trap catches (x) and larval infestation (y) which can be summarized by the equation, y = 0.213x - 0.03833 where x is equal to the number of male *E. loftini*/trap/wk and y = percentage of stalks infested with treatable larvae on plant surfaces.

Insecticide treatments significantly reduced the probability of occurrence of a bored internode by an average of 40.3% and 60.2% over both years for β-cyfluthrin and novaluron, respectively (F = 11.41; df= 2,18.2; P = 0.0006) (Fig. 2.2A). Insecticide applications reduced emergence holes per stalk by 37.4 and 58.4% over both years for β-cyfluthrin and novaluron, respectively (F = 4.65; df = 2,17.2; P = 0.0244) (Fig. 2.2B). Novaluron provided the best control in both years reducing injury (proportion of bored internodes) by 2.2-fold and 3.5-fold, and moth emergence by 1.7-fold and 4.3-fold for 2009 and 2010, respectively. β-cyfluthrin reduced the proportion of bored internodes by only 1.4-fold and 2.4-fold and adult emergence by 1.7-fold and 1.9-fold in 2009 and 2010, respectively. Mean relative survival to adulthood ranged from 0.237-0.260, however, differences between treatments were not detected. Insecticide applications reduced *E. loftini* injury and moth production to a greater degree in 2010 than in 2009. The probability of occurrence of a bored internode was 1.2-fold greater in 2010 (0.140) than in 2009 (0.124).

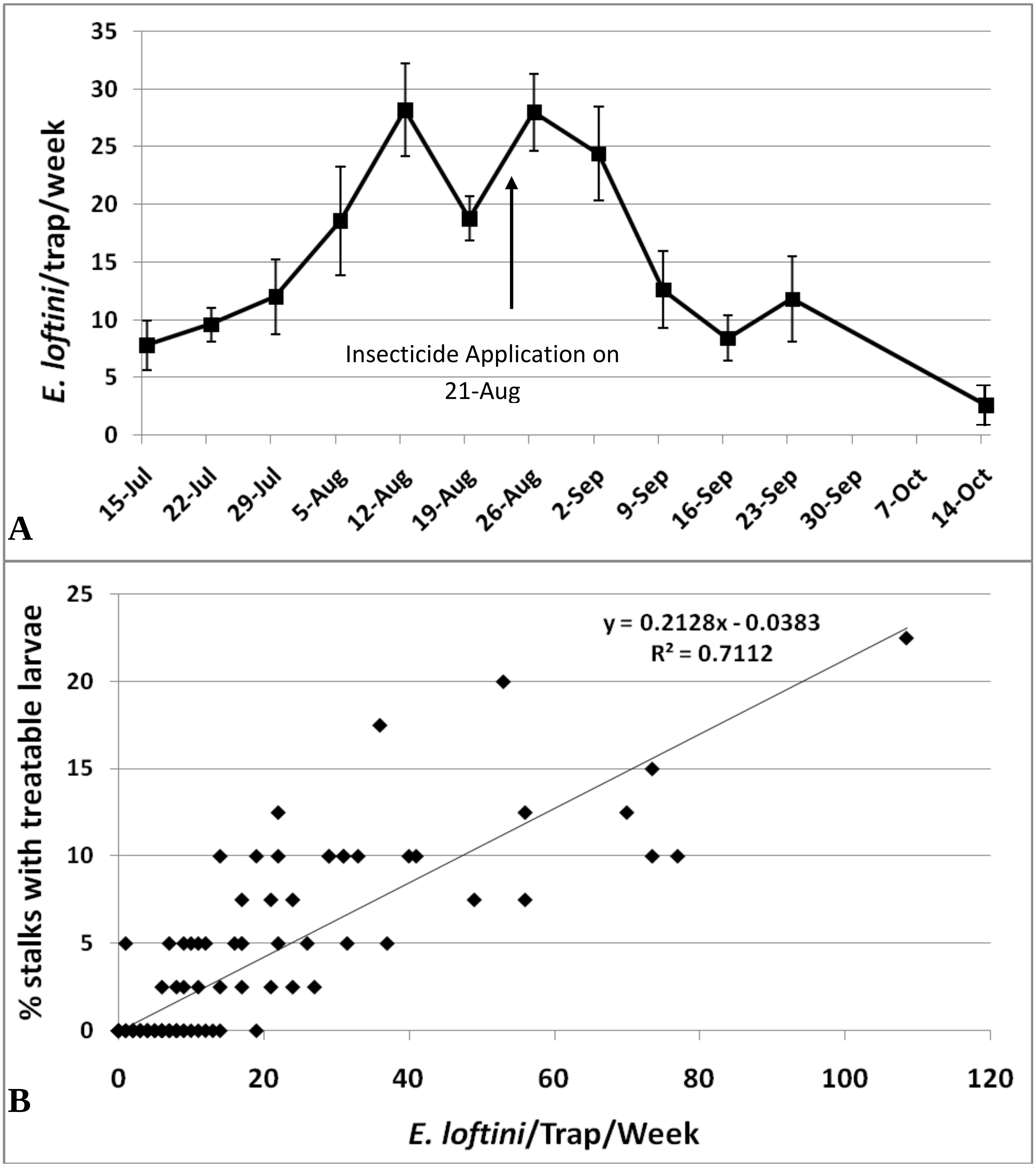

Fig. 2.1: Pheromone Trap Catch Results LRGV 2009 and 2010. (A) Average no. of male *E. loftini*/trap/wk through out the growing season. (B) The relationship between adult population densities (no. of male *E. loftini*/trap/wk) and larval infestation (percent of stalks infested with treatable larvae feeding in leaf sheaths), 2010.

Due to a late season crop killing freeze in the winter of 2009-2010, yield was not collected in 2 replications and 2009 sugar yield and quality data were not included in the analyses. Data from 2010 indicate that insecticide treatments improved juice purity, percentage sucrose, brix, and sugar/metric ton cane, metric tons of cane per acre, and recoverable sugar (tons of sugar/acre) (Table 2.1). A single application of novaluron increased sugar yield by 14% (7.29 metric tons sugar/ha) over untreated controls (6.39). β-cyfluthrin treated plots were only significantly different from untreated controls in terms of sugar yield per metric ton of cane.

Table 2.1: Sugar Yield and Quality as Affected by Insecticide Treatments
Cameron and Hildalgo Counties, TX. 2010

	Purity	**POL (% Sucrose)**	**Brix**	**Sugar (Kg/ tonne of cane)**	**Cane (tonnes/ha)**	**Sugar (tonnes/ha)**
Novaluron	85.3 (±0.4)A	14.5 (±0.17)A	17.0 (±0.2)A	104.07 (±1.85)A	70.1 (±4.2) A	7.29 (±0.48) A
Baythroid	85.0 (±0.4) AB	14.2 (±0.18)B	16.7 (±0.2)B	101.47 (±1.85)B	58.7 (±4.2) B	5.97 (±.48) B
Control	84.4 (±0.4)B	14.0 (±0.17)B	16.5 (±0.2)B	98.87 (±1.85)C	64.4 (±4.2) AB	6.39 (±.48) B
F	4.15[a]	13.94[a]	7.47[a]	16.03[a]	5.60[b]	6.78[b]
P >F	0.018	<0.0001	0.0009	<0.0001	0.03	0.019

*Means which share the same letter are not significantly different

[a] df= 2, 124; Means were separated with Tukey's HSD (α=0.05)

[b] df= 2,8 Means were separated with Fisher's LSD test

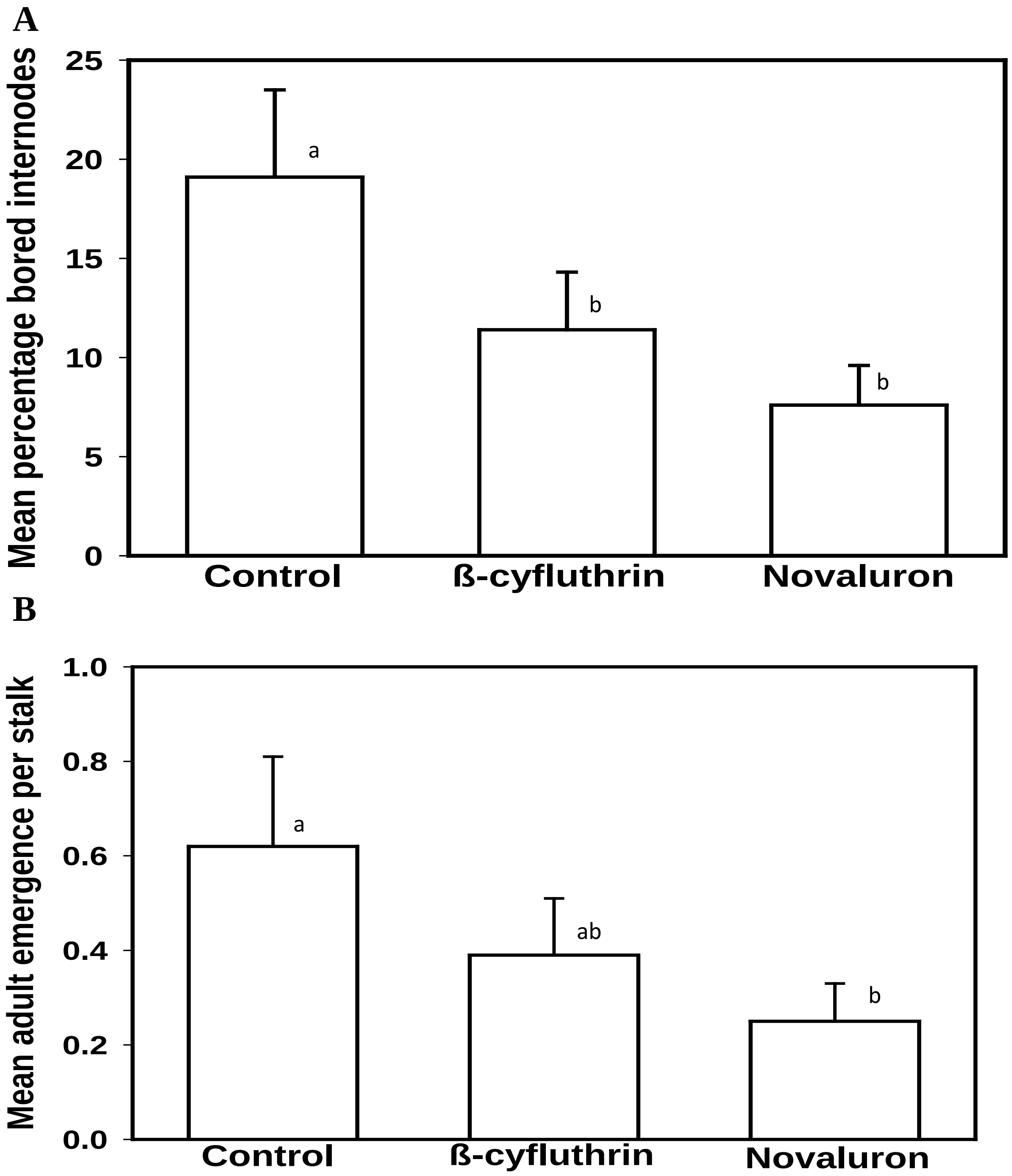

Fig. 2.2: *E. loftini* injury and emergence sugarcane aerial insecticde application experiment in Cameron and Hidalgo Counties, TX. (A) LS mean (±SE) probability of an *E. lofitini* bored internode (equivalnt to proportion of bored internodes) and (B) LS mean (±SE) number of moth emergence holes per stalk. Bars within each chart followed by the same letter are not significantly different (P > 0.05, Tukey's HSD).

Neonate Establishment and Behavior. Over all treatments and replications, establishment and behavior of a total of 277 larvae was monitored. On the first day after egg hatch, numerous entry holes in the mid-ribs of sugarcane leaves were observed indicating neonates had bored into leaves within one day of hatching. The percentage of larvae to enter the mid-rib within one day after eclosion ranged from 24.1–67.5%. The percentage of larvae surviving to stalk entry ranged from 27.4–72.4%, and mean duration of exposure ranged from 3.5–6.4 d. When all established larvae were considered, differences in dispersal distance were not detected between treatments; however, there was a trend for greater dispersal on HoCP 85-845 (resistant) compared to HoCP 00-950 (susceptible) and immature compared to mature cane (Table 2.2).

Over both phenological stages, the percentage of eclosed neonates (hatched eggs) which became established feeding on the stalk was 40% greater on susceptible cultivar HoCP 00-950 than on resistant HoCP 85-845 (Table 2.2). The proportion of established larvae which bored into the leaf mid-rib within one day was twice as high for HoCP 00-950 than HoCP 85-845 (Table 2.2). Average dispersal distance (no. of leaves/internodes from oviposition sites) was 19% greater on HoCP 85-845 than HoCP 00-950, but differences were not statistically significant. The duration of exposure of all established larvae was 40% longer on HoCP 85-845 than HoCP 00-950. When neonates that entered the mid-rib were excluded the mean duration of exposure over all treatments rose 34% and was 14.7% longer in HoCP 85-845 compared to HoCP 00-950 (Table 2.2).

Differences were detected between immature (6 nodes) and mature (12 nodes) sugarcane in the percentage of eclosed larvae which became established feeding on stalks, the proportion of established larvae to successfully enter the stalk, and duration of exposure. The percentage of eclosed larvae that established feeding was 60% greater on mature than immature stalks. The percentage of established larvae surviving to stalk entry was 90% greater on immature than mature stalks. Average dispersal distance was greater on immature (1.458 internodes from oviposition sites) than on mature sugarcane (1.153). All dispersal on immature cane was towards the top of the stalk while 21% of larvae moved down from oviposition sites on mature sugarcane. Duration of exposure was 20% greater on mature stalks than immature. Mean duration of exposure of all established larvae was 4.67 and 5.90 d compared to 6.37 and 7.79 d for sheath feeding larvae on immature and mature sugarcane, respectively. A significant interaction effect was detected between cultivar and phenological stage for the percentage of larvae entering the mid-rib within one day and the percentage of established larvae surviving to stalk entry. Larval vulnerability was least on immature HoCP 00-950 which had the greatest percentage of larvae entering the mid-rib within 1 d (67.5%) and a mean duration of exposure of only 3.5 d. Larval exposure was maximized on mature HoCP 85-845 having a mean exposure duration of 6.4 d.

Discussion

The use of pheromone traps to assist scouting for stalkborers in sugarcane demonstrated potential to reduce scouting effort and improve chemical control of *E. loftini*. Scouting for stalkborers in sugarcane is both time consuming and labor intensive because of the high number of stalks that must be examined in order to accurately determine larval infestations (Meagher *et al.* 1996). The use of an action threshold based on *E. loftini* pheromone trap catches could enhance scouting efficiency by focusing scouting efforts at more appropriate times when adult population densities are high. When directed by a moth threshold of 20-25 *E. loftini/*trap/week, only one incident of larval scouting was necessary to indicate the need for treatment in 2009.

Table 2.2: *E. loftini* neonate establishment and behavior on two phenological growth stages of sugarcane cultivars HoCP 84-845 and HoCP 00-950, Weslaco, TX, 2010

	Percent of eclosed larvae established feeding	**Percent of established larvae which entered midrib within 1 day**	**Percent of established larvae surviving to stalk entry**	**Mean dispersal distance (nodes from oviposition site)**	**Mean duration of exposure (days) all larvae**	**Mean duration of exposure (days) sheath feeding larvae**
Growth Stage						
Immature	16.02	44.84	64.17	1.46	4.676	6.367
Mature	26.15	37.58	33.89	1.15	5.895	7.786
F	15.43[a]	0.91[a]	16.77[a]	1.81[b]	4.23[c]	21.03[d]
P > F	0.0003	0.3447	0.0002	0.1815	0.0417	<0.0001
Cultivar						
HoCP 85-845	17.63	28.30	49.88	1.419	6.181	7.559
HoCP 00-950	23.99	55.36	47.98	1.193	4.391	6.593
F	5.08[a]	13.27[a]	0.06[a]	0.99[b]	9.13[c]	9.73[d]
P > F	0.0176	0.0007	.8047	0.3214	0.0038	0.0025
Growth Stage X Cultivar						
Immature						
HoCP 85-845	14.08	24.14	72.41	1.756	5.952	7.118
HoCP 00-950	18.18	67.50	55.00	1.161	3.400	5.615
Mature						
HoCP 85-845	21.86	32.88	27.40	1.082	6.409	8.000
HoCP 00-950	30.95	42.54	41.04	1.225	5.381	7.571
F	0.28[a]	5.42[a]	5.08[a]	2.65[b]	1.65[c]	3.01[d]
P > F	0.5990	0.0246	0.0293	0.1073	0.2006	0.0864

[a] df = 1,44
[b] df= 1, 159; considers all larvae
[c] df = 1,127; considers all larvae which survived until stalk entry
[d] df = 1,85; considers sheath feeding larvae which survived until stalk entry

Weekly larval scouting from June to mid-August in 2010 further revealed a strong positive relationship between the number of *E. loftini/*trap/wk and the percentage of stalks infested with treatable larvae on plant surfaces. Linear regression analysis indicated that a trap catch of 23.6 *E. loftini/*trap/wk corresponds to the treatment threshold of 5% of stalks infested with treatable larvae. This suggests that an action threshold of 20-25 *E. loftini/*trap/week is appropriate to initiate scouting and verify larval infestations. Therefore, pheromone trap assisted scouting could potentially be further evaluated by consultants and utilized on a commercial scale to increase efficiency of consultant monitoring. The Louisiana sugarcane industry is heavily dependent on consultant scouting for the sugarcane borer and the infrastructure is in place to employ pheromone trap assisted scouting when *E. loftini* becomes established as a major economic pest in Louisiana. Furthermore, this approach also seems feasible to assist LRGV growers in their efforts to achieve more efficient *E. loftini* control. Growers should be aware that the scouting threshold may not always be representative of larval infestations due to variation in pheromone trap catches.

When appropriately timed, a single insecticide application reduced *E. loftini* injury and adult emergence in both 2009 and 2010. Control tactics which reduce adult emergence could aide in reducing area-wide populations and slow the expansion of this invasive pest. The superior control of novaluron is likely the result of both longer residual activity and reduced mortality of beneficial insects (Beuzelin *et al.* 2010). Novaluron has been shown to have good residual activity, remaining effective for 10-30 d depending on environmental conditions (Ishauya *et al.* 2002). β-cyfluthrin has demonstrated longer residual activity relative to other pyrethroids (Athanassiou *et al.* 2003), but its residual toxicity is negatively correlated with temperature and is greatly reduced at temperatures exceeding 25°C (Arthur 1999) with less than 50% mortality one week after application. The negative relationship between pyrethroid residual activity and temperature (Toth and Sparks 1990) may be an important factor limiting pyrethroid efficacy in the LRGV where average summer temperatures are ~ 35°C (National Weather Service). Novaluron and other insect growth regulators have been shown to be less toxic to non-target arthropods than pyrethroid insecticides and better preserve natural pest suppression (Reagan and Posey 2001, Beuzelin *et al.* 2010). Novaluron, a benzoylphenyl urea insect growth regulator, is selective for larval stages because it inhibits chitin synthesis. Reduced predation in β-cyfluthrin treated plots likely also contributed to the superior control provided by novaluron.

Previous studies have shown that chemical control of *E. loftini* is inadequate to improve sugarcane yield even when multiple insecticide applications are made (Meagher *et al.* 1996, Reay-Jones *et al.* 2005). Because of the high input cost required with indefinite return, chemical control of *E. loftini* has often not been economical, and the use of insecticides against this pest has largely been abandoned in the LRGV (Meagher *et al.* 1994). However, our studies indicate that much of the difficulty may have been due to less efficient timing of the insecticidal control approach. The economics of *E. loftini* management could be greatly improved by reduction of input costs if effective control can be achieved with a single insecticide application. The large treatment plots (3.94 ha/plot) used in this study provided an accurate assessment of insecticide application effects on sugar yield and quality in a commercial setting. The two years of bored internode (insect damage) data helps to further substantiate the yield effects. The unavailability of 2009 yield and quality data from milling because of the hard freezes in December 2009 and Jan 2010 was due to the major rush for harvesting to prevent further deterioration of sugarcane yields across the LRGV. Insecticide treatments significantly reduced injury in 2009 and 2010 based on percent bored internodes.

Key yield and quality parameters such as sugar per acre, juice purity, and sucrose content have been documented (Legaspi *et al.* 1999) as being inversely related to percentage of bored internodes. We feel that some of the past failures to detect significant effects of insecticide treatments on yield despite a reduction in percentages of bored internodes (Johnson 1985, Meagher *et al.* 1994, Legaspi *et al.* 1999b, and Reay-Jones *et al.* 2005) may be the result of high variability of sugarcane yield studies, particularly as related to small plot studies. This study is the first to adequately replicate such large acreage (>20ha/treatment). A single application of novaluron enhanced sugar yield compared to untreated controls in 2010. Novaluron treated plots had substantially higher juice purity, percent sucrose, brix, sugar/ton cane, tons cane/ha, tons of sugar/ha compared to untreated plots. The 14% increase in tons of sugar /ha is consistent with the reduction in percent bored internodes as predicted by Legaspi *et al.* (1999a). Based on the current price of raw sugar of $706.80/ton, the novaluron treatment would be expected to increase revenue by $707.39 per ha. This provides the first clear evidence of insecticidal control of *E. loftini* resulting in a measurable increase in subsequent sugar yield and quality. Precisely timed applications of improved insecticide chemistries have potential to improve the economics of chemical control of *E. loftini.* In addition, the scouting methods and economic thresholds used to direct insecticide applications in this study are also expected to be useful in development of improved management practices of *E. loftini* as well as other stalk boring pests.

The importance of application timing and development of management tactics which target neonates is further supported by the greenhouse study which suggests the duration of larval feeding in the leaf sheaths is shorter than previously estimated (Van Leerdam 1986, Ring *et al.* 1999). Because larvae become protected once they bore into the stalk, the period of exposure while feeding on leaves and sheaths is the only time larvae are vulnerable to insecticides and biological control. In our study, the duration of larval exposure over all cultivars and phenological stages ranged from 3.5-6.4 d. In addition, results indicate as many as 67.5% (immature HoCP 00-950) of *E. loftini* neonates bore into the mid-rib within one day where they become protected from control agents such as insecticides and natural enemies. Prior to this research, larval entry into the mid-rib of sugarcane leaves and potential applications to *E. loftini* IPM had not been documented.

Differences in larval behavior between cultivars suggest resistant varieties which impede larval establishment have potential to improve efficacy of other control tactics. Total larval establishment (percent of eclosed larvae feeding on the plant) was greater on susceptible HoCP 00-950 than on resistant HoCP 85-845 which we believe is due to the greater percentage of larvae which borer into the mid-rib becoming protected within one day in HoCP 00-950. Mean duration of larval exposure was nearly 2 d longer on HoCP 85-845 compared to HoCP 00-950. When all established larvae were considered, mean dispersal was greater on the HoCP 85-845 than on HoCP 00-950. The increased duration of exposure on HoCP 84-845 could be due to the greater dispersal distance on the resistant cultivar as larvae search for more suitable feeding sites with higher nutrient quality.

When both cultivars were considered, a greater percentage of eclosed larvae became established on mature sugarcane than immature. This may be related to increased expression of phenolic compounds in immature sugarcane (Atkinson and Nuss 1989). Another possible explanation is the increased space available for larval establishment on larger mature sugarcane as crowded conditions may have limited establishment on young cane. However, once established, larval survival to stalk entry was nearly twice as great on immature than mature cane indicating young internodes are more susceptible to borer entry. Although more larvae became established feeding on the leaves and sheaths of immature cane, proportionately fewer successfully entered the stalk. In addition, mean duration of exposure (time to stalk entry) was greater on mature than immature cane. This suggests that physiological factors such as increased rind hardness of mature cane impede larval entry into the stalk. This is consistent with previous research (Van Leerdam 1986, Ring *et al.* 1990) which indicates that young internodes are more vulnerable to *E. loftini* injury.

Host plant characteristics which are unfavorable for larval establishment are a key component of host plant resistance to stalkborers (Mathes and Charpentier 1969). Resistance mechanisms which prolong larval exposure outside the stalk may enhance the efficacy of other control tactics such as insecticide applications or biological control. Improved efficacy of chemical control of stalkborers has been documented when insecticide applications are used in conjunction with host plant resistance (Posey *et al.* 2006).

Rapid neonate entry into the mid-rib and the short duration of sheath feeding strongly suggest that *E. loftini* larvae are protected from foliar applied contact insecticides. Thus, residual activity, ovicidal activity and sublethal effects of insecticides will likely contribute to improved chemical control. The residual activity of novaluron may be in part responsible for the superior control observed in field studies. Chemical control might also be improved by enhancing this residual activity through the use of surfactants. Other new insecticides which have demonstrated substantial residual activity should also be evaluated for *E. loftini* management in sugarcane. Novaluron has been shown to have significant ovicidal contact toxicity against the European corn borer, another Crambid pest (Boiteau and Noronha 2007). Sub-lethal effects of novaluron also include reduced egg viability following adult exposure (Lopez *et al.* 2008) and increased occurrence of morphological abnormalities such as malformations of the wing in emerging adults

(Cetin *et al.* 2006). Insecticides with translaminar properties may also better control larvae protected in leaf mid-ribs. Continued evaluation of new chemistries and application methods for control of *E. loftini* are necessary to improve chemical control of this devastating pest. In addition, future assessment of varietal resistance should emphasize identification of mechanisms which impede larval entry into the stalk. Resistant sugarcane varieties which prolong larval vulnerability would greatly improve the success of *E. loftini* IPM programs.

As *E. loftini* threatens to become established as an economic pest in Louisiana where it is expected to cause substantial revenue losses (Reay-Jones *et al.* 2008), the need for effective management strategies is becoming more important. Because of the limited vulnerability of *E. loftini* larvae which rapidly become protected within sugarcane leaves and stalks, continued examination of control tactics which target exposed neonates will contribute to development of improved *E. loftini* IPM programs. Potential control strategies highlighted by this research include the use of pheromone traps to assist scouting and substantially improved application timing, increased residual activity of insecticides, and resistant cultivars which impede larval entry into the stalk.

CHAPTER 3

FIELD EVALUATION OF 25 COMMERCIAL AND EXPERIMENTAL SUGARCANE CULTIVARS FOR *E. LOFTINI* RESISTANCE

Introduction

Host plant resistance is a vital component of sugarcane stalkborer IPM worldwide. Resistant cultivars have consistently shown reduced *E. loftini* injury when compared to susceptible cultivars (Pfannenstiel and Meagher 1991, Meagher *et al.* 1996a, Reay-Jones *et al.* 2005). The use of host plant resistance in stalkborer management can also aid in the reduction of area-wide populations (Bessin *et al.* 1991). Expansive hectarage of susceptible varieties with elevated moth production increases endemic stalkborer populations and imposes additional pressure on the remaining hectarage. Because the sugarcane borer, *D. saccharalis,* is adequately controlled through the use of insecticides, emphasis on development of stalkborer resistant sugarcane cultivars in Louisiana has declined. However, establishment of *E. loftini* in Louisiana will require multiple management tactics to reduce revenue losses (Reay-Jones *et al.* 2005). The importance of incorporating resistant varieties into *E. loftini* management programs is amplified by the insufficiency of insecticidal control. While host plant resistance has repeatedly been shown to be promising for *E. loftini* control, the mechanisms of resistance are not fully understood. Continued evaluation of commercial and experimental sugarcane cultivars is critical to the incorporation of resistant varieties into *E. loftini* IPM programs (Reay-Jones *et al.* 2003).

Unattractiveness for oviposition, impediment of larval establishment, hindrance of larval development and plant tolerance have all been cited as categories of stalkborer resistance (Mathes and Charpentier 1969, Reay-Jones *et al.* 2007b, Showler and Castro 2010a). However, the importance of each component of resistance is not well understood and is continually being evaluated. Oviposition preference may play a role in resistance because *E. loftini* is most attracted to folds in dry leaves as oviposition sites (Van Leerdam 1986, Reay-Jones *et al.* 2007b, Showler and Castro 2010b). Oviposition preference may be linked to chemoreceptors which detect the presence or absence of primary or secondary compounds which assist females in the behavioral and physiological responses necessary for accepting or rejecting a host plant in the insect-plant interaction process (Kogan 1994). Recent research has demonstrated a positive correlation exists between free essential amino acid concentrations and eggs laid per plant (Reay-Jones *et al.* 2007b, Showler and Castro 2010a,b). *Eoreuma loftini* females have shown oviposition preference for young sugarcane (5 nodes), susceptible cultivars, and drought stressed sugarcane which all contain heightened concentrations of free essential amino acids (Reay-Jones *et al.* 2007b, Showler and Castro 2010a,b). While reduced oviposition preference contributes to resistance, other studies (Meagher *et al.* 1996a) suggest plant characteristics which affect larvae may also be important to this relationship.

Of particular importance are factors which may hinder larval establishment including physical characteristics which impede boring such as fiber content, rind hardness and leaf sheath appression. As suggested in Chapter 2, these factors might enhance the efficacy of other management tactics by prolonging larval exposure to control agents such as insecticides or beneficial insects. Some varieties currently in development by the USDA with potential to impede stalk entry are the high-fiber cultivars US 93-25, US 01-40, and Ho 06-9610. Resistance characteristics which retard larval development may be critical to reducing areawide populations. Host plant concentrations of certain primary metabolites affect larval development in addition to influencing oviposition preference. Differences in *E. loftini* larval weight and time to pupation are thought to be linked to varying levels of allelochemicals between sugarcane cultivars (Meagher *et al.* 1996a). Reduced expression of essential nutrients may lead to decreased *E. loftini* survival to adulthood and subsequent moth production (Reay-Jones *et al.* 2005, Showler and Castro 2010a).

Assessment of cultivar resistance must not only examine resistance mechanisms, but also implications of potential widespread use of resistant cultivars. Bessin *et al.* (1990) developed a sugarcane resistance rating criteria for *D. saccharalis* which assesses borer injury as well as the ability of a cultivar to enhance or reduce area-wide populations. A relative survival index for stalkborers was developed which incorporates emergence hole counts as well as percentage bored internodes to provide a season-long record of resistance (Reay-Jones *et al*. 2003). Relative survival is a key factor in assessing the effects of varieties on area-wide population densities. Variety tests are critical to the incorporation of cultivar resistance into stalkborer IPM; hence, assessment of varietal resistance to sugarcane stalkborers must be continually conducted as new high yielding varieties emerge.

One commercial cultivar which has consistently demonstrated a high level of *E. loftini* resistance is HoCP 85-845, while susceptible cultivars include L 03-371, LCP 85-384, and HoCP 05-961. Several cultivars have been previously evaluated for *E. loftini* resistance: HoCP 00-950 and HoCP 05-902 are susceptible, L 01-299, HoCP 04-838, and HoCP 96-540 have intermediate levels of *E. loftini* and *D. saccharalis* resistance (Reagan *et al.*, 2003, 2007, 2008). HoCP 96-540 demonstrated resistance against *D. saccharalis*, but was among the more susceptible cultivars when tested for *E. loftini* resistance (Reagan *et al.* 2002). L 03-371 has been shown to be resistant under conditions of heavy rainfall, but was the most susceptible under drought conditions (Reagan *et al.* 2008). Experimental varieties which may have stalkborer resistance include high-fiber varieties, clones from recurrent selection for sugarcane borer resistance, and South African cultivars (Pfannenstiel and Meagher 1991, Ring *et al.* 1991, Conlong *et al.* 2004, Posey *et al.* 2006).

Research being conducted in South Africa on host plant resistance to other sugarcane stalkborer species has revealed promising new cultivars. These cultivars, developed by the South African Sugar Research Institute in KwaZulu-Natal (N-cultivars), have potential resistance to *E. loftini* because they have demonstrated varying levels of resistance to African stalk borers, *Eldana saccharina* Walker and *Chilo saccariphagus* Bojer (Nuss *et al.* 1991, Conlong *et al.* 2004) which share many characteristics with *E. loftini*. Drought tolerance is thought to be an important resistance mechanism to *E. saccharina* which, like the Mexican rice borer, prefers drought stressed conditions (Conlong *et al.* 2004, Showler and Castro 2010a). Of the South African cultivars, the most resistant is N-21 and the most susceptible is N-26 (Nuss *et al.* 1991, Conlong *et al.* 2004), but the levels of resistance to *E. loftini* have not been assessed.

Continued evaluation of commercial and experimental sugarcane cultivars for stalkborer resistance is critical to the area-wide pest management of *E. loftini*. In addition to reducing *E. loftini* injury on an individual field basis, area-wide pest management may help slow the spread of this invasive pest by reducing population levels across a large geographical area. The objectives of this research were to evaluate *E. loftini* resistance under natural field conditions among 25 commercial and experimental sugarcane cultivars based on plant injury as well as suppression of adult production. Cultivars in this experiment may be incorporated into sugarcane breeding programs or considered for commercial releases in Texas and Louisiana.

Materials and Methods

A field study was conducted at the Texas A&M AgriLife Research and Extension Center at Beaumont, Texas to assess cultivar resistance to sugarcane stalkborers, *E. loftini* and *D. saccharalis,* among 25 commercial and experimental sugarcane cultivars. The varieties evaluated include five in commercial use (HoCP 85-845, HoCP 96-540, HoCP 00-950, L 01-

299, and L 03-371), eleven experimental clones (HoCP 05-902, HoCP 05-961, HoCP 04-838, Ho 06-563, Ho 07-613, Ho 07-604, Ho 07-617, Ho 07-612, Ho 06-537, L 07-68, and L 07-57), three clones bred for high fiber content (Ho 06-9610, US 93-15, and US 01-40), two clones from recurrent selection for *D. saccharalis* resistance (US 08-9001 and US 08-9003), and four South African cultivars (N-17, N-21, N-24, N-27).

A randomized complete block design five replicates was used. Block replicates had one-row plots (3.66 m long, 1.60 m row spacing and 1.22 m alleys) of each of the 25 varieties planted on 21 October 2009, (Appendix A). Only four plots were used for L-07-57 and US 93-15 because stalks failed to emerge in one replication of each variety. Beds were pulled on 20 October and opened just prior to planting in a field of Morey silt loam soil. All stalks were heat-treated prior to planting. Herbicides pendimethalin (Prowl®) 3.3EC at 9.615L/ha and atrazine (Atrex®) 4L at 9.615L/ha were applied on 21 October 2009 with a 3 nozzle spray boom (110º04 nozzles with 50 mesh screens) for pre-emergence control of grasses and broadleaves, respectively. Also, Mocap was applied at 11.5kg/ha with a hand-held gandy on non-buffer rows. Fields were exposed to natural stalkborer infestations for the remainder of the growing season. On 7-9 September 2010 ten stalk samples were collected from each plot with leaf sheaths removed for assessment of borer injury. Stalks were inspected externally for borer injury (entry and emergence holes). In addition, a stalk splitter was used to open stalks for internal examination. The number of bored internodes used in analysis included all internodes with either internal or external evidence of injury. The total number of internodes, bored internodes, and moth emergence holes were recorded for each stalk and summed for each plot. Relative survival was calculated as the no. emergence holes/no. bored internodes. Data was analyzed using generalized linear mixed models (Proc GLIMMIX, SAS Institute 2006) (Appendix D). The Kenward-Roger method

(Kenward and Roger 1997) was used to compute denominator degrees of freedom for the test of fixed effects for all variables. The proportion of bored internodes and relative survival data was analyzed with a binomial distribution and least square means are reported and separated with Tukey's HSD (α=0.05) when differences among treatments were detected. Average emergence per stalk was calculated for each plot as the total no. emergence holes divided by the number of stalks. Emergence per stalk was analyzed with a Gaussian distribution.

Results

Differences were detected in the proportion of bored internodes between cultivars (F = 17.68; df= 24, 94; P <0.0001). Injury ranged from 1.0-20.3% bored internodes (Table 3.1). *Eoreuma loftini* was responsible for >99% of bored internodes with *D. saccharalis* accounting for <1% of injury. Of the commercial varieties, HoCP 85-845 and L 01-299 were the most resistant, while L 03-371 and HoCP 96-540 were the most susceptible. HoCP 85-845 was the most resistant in terms of both injury and adult emergence (Table 3.1). HoCP 96-540, which is currently the most widely planted cultivar in Louisiana (Gravois *et al.* 2009), experienced nearly 8-fold more damage than the resistant cultivars, however, adult emergence for this cultivar was only 0.08 emergence holes/stalk. The experimental cultivars, Ho 06-563 and HoCP 05-902, were the most susceptible of all cultivars tested. All of the South African cultivars showed some level of resistance with N-21 (1.0 % bored) being the most resistant of all cultivars examined. The *D. saccharalis* resistant cultivars, US 08-9001 and US 08-9003, were also among the more resistant varieties at 5.2 and 2.6% bored, respectively. High fiber cultivars had a similar range of susceptibility (1.2 -5.8% bored) with US 93-15 being the most resistant. Adult emergence data followed the same trend as percent bored internodes (Table 3.1) however, differences in emergence between cultivars were not detected at α=0.05 (F=1.57, df= 24, 94, P=0.065) . The commercial cultivar HoCP 96-540 had relatively low moth production, despite being among the most susceptible based on the proportion of bored internodes. Adult emergence ranged from < 0.01 to 0.38 emergence holes/stalk. Ho 06-463, HoCP 05-902, and L 07-57 were the most susceptible in terms of moth production with >0.30 emergence holes per stalk. Analysis of relative survival data did not converge and is not reported.

Discussion

This study demonstrates the importance evaluating commercial and experimental sugarcane cultivars for stalk borer resistance. The levels of resistance reported in this study are consistent with previous findings. Since its commercial release in 1993, HoCP 85-845 has consistently demonstrated a high level of resistance to both *E. loftini* and *D. saccharalis* (Reagan *et al.* 2003, 2004, 2005, Reay-Jones *et al.* 2003). It is a relatively high fiber cultivar and has pith (W. H. White, pers. comm.). Our findings indicate that HoCP 85-845 should continue to be viewed as a standard for stalk borer resistant sugarcane cultivars. However, Reay-Jones *et al.* (2003) found that under severe *E. loftini* pressure the level of resistance in this cultivar was reduced relative to other cultivars. One of the most susceptible cultivars evaluated in this study, HoCP 96-540, is currently the most widely planted cultivar in Louisiana representing >50% of planted acreage (Gravois *et al.* 2009). Sugarcane producers often opt to grow the highest yielding varieties, regardless of the level of stalkborer resistance.

While HoCP 96-540 has demonstrated intermediate levels of resistance to *D. saccharalis* (Reagan *et al.* 2005), it is considerably more susceptible to *E. loftini*. This appears to be due to differences in oviposition preferences between the two pest species. Despite having high levels of injury, adult emergence was relatively low for HoCP 96-540 which indicates this cultivar may be attractive for oviposition, but is among the more resistant in terms of larval development.

Table 3.1: Mean percent bored internodes and emergence per stalk. Evaluation of varietal resistance to sugarcane stalkborers. Beaumont, Texas. 2010

Variety	**% Bored Internodes**	**Emergence per Stalk**
Ho 06-563	20.3 A	0.38
HoCP 05-902	14.4 AB	0.32
HoCP 04-838	10.9 BC	0.20
Ho 07-612	10.0 BCD	0.18
L 03-371	9.5 BCD	0.14
HoCP 96-540	7.8 BCDE	0.08
L 07-57	7.1 CDEF	0.32
Ho 07-604	6.3 CDEF	0.04
US 01-40	5.8 CDEFG	0.06
N-27	5.7 CDEFG	0.12
Ho 06-537	5.7 CDEFG	0.19
Ho 07-613	5.4 CDEFG	0.02
N-17	5.4 DEFG	0.08
HoCP 05-961	5.2 DEFG	0.12
US 08-9001	5.2 DEFG	0.04
Ho 06-9610	4.9 DEFG	0.04
HoCP 00-950	4.5 DEFGH	0.04
L 07-68	4.0 EFGH	0.12
Ho 07-617	3.9 EFGH	0.06
US 08-9003	2.6 FGH	0.06
N-24	2.4 FGH	<0.01
L 01-299	2.2 FGH	0.04
US 93-15	1.2 GH	0.01
HoCP 85-845	1.0 H	<0.01
N-21	1.0 H	<0.01

***Means which share a letter are not significantly different (Tukey's HSD, α=0.05).**
LS means: F=17.68; df=24, 94; P < 0.0001
SE = 8.52 for all cultivars except L 07-57 and US93-15 (SE=9.51)

Although not currently planted on a large portion of sugarcane acreage in Louisiana, L 01-299 may offer a high yielding, stalkborer resistant variety which could be incorporated into *E. loftini* IPM programs.

Additionally, this research evaluated *E. loftini* resistance among several experimental cultivars in various levels of the sugarcane breeding programs. The two varieties which have been identified as having antibiosis to *D. saccharalis*, Ho 08-9001 and Ho 08-9003 (W. H. White, pers. comm.), demonstrated moderate to high levels of resistance despite *E. loftini* accounting for the vast majority of injury. These two cultivars are currently in the process of being registered with Crop Science as resistant germplasms and may be incorporated into future breeding programs. The high fiber cultivars, US 93-15, US 01-40 and Ho 06-9610, had varying levels of susceptibility indicating high fiber content alone may not be adequate to provide resistance to *E. loftini*. However, the high fiber cultivar US 93-15 was among the most resistant of the varieties evaluated. Fiber content is often negatively associated with cane yield (Gravois *et al.* 2009) and widespread commercial planting of high fiber cultivars may not be economical for Louisiana sugarcane growers. However, if high fiber cultivars demonstrate potential to impede larval entry into the stalk, they may be used to enhance efficacy of other control tactics, especially for energy canes (those developed for biomass). Of the experimental cultivars, only HoCP 05-961, HoCP 04-838, L 07-57 and Ho 07-613 remain in the Louisiana variety program. HoCP 05-961 demonstrated moderate levels of resistance while HoCP 04-838, L 07-57, and Ho 07-613 were among the more susceptible varieties. HoCP 04-838 was previously thought to be resistant, but our results indicate it is highly susceptible to *E. loftini.* The varieties developed by the South African Sugar Research Institute all demonstrated some level of stalkborer resistance. N-21 was as resistant as HoCP 85-845 both in terms of injury and adult emergence.

Identification of these varieties as resistant may lead to their incorporation into the Louisiana breeding programs as resistant germplasms. N-21 shows resistance to a broad range of sugarcane stalkborers and could potentially be used in both *E. loftini* and *D. saccharalis* variety development programs.

Continued assessment of varietal resistance to sugarcane stalkborers is critical to the development of effective IPM programs. Research examining the mechanisms behind resistance, particularly the role of free amino acids, could lead to the development of a non biological assay for assessing stalkborer resistance. In addition, identification of resistant cultivars which prolong larval exposure by impeding stalk entry may lead to development of improved *E. loftini* IPM. Evaluation of cultivar resistance in conjunction with insecticide applications is necessary to assess the effects of resistant cultivars on efficacy of chemical control. Cultivar resistance has the potential to keep low to moderate *E. loftini* infestations suppressed below economic injury levels as well as to reduce area-wide populations. The use of resistant cultivars on a commercial basis could slow the spread of *E. loftini*. Due to the severe pest history of *E. loftini* in sugarcane, stakeholders in Louisiana cannot afford to wait until this insect becomes an economic pest before developing resistant cultivars. Continued assessment of resistance, improved understanding of resistance mechanisms and increased emphasis on stalkborer resistance by sugarcane breeding institutions are critical to *E. loftini* IPM.

CHAPTER 4

SUMMARY AND CONCLUSIONS

Since its establishment in the Lower Rio Grande Valley (LRGV) in 1980, the Mexican rice borer, *Eoreuma loftini* (Dyar), has been the dominant pest of sugarcane in that area, where it is responsible for major revenue losses (Johnson and Van Leerdam 1981, Legaspi *et al.* 1999a). The species has since expanded its range across the Texas rice production area, reaching Louisiana in 2008 (Reay-Jones *et al.* 2007a, Hummel *et al.* 2010). Development of effective control tactics is critical to Louisiana agriculture as the invasive species is predicted to cause as much as $220 million and $48 million in annual revenue losses for sugarcane and rice, respectively, by 2035 (Reay-Jones *et al.* 2008).

Management of *E. loftini* in sugarcane is based on a balance of control tactics including irrigation and host plant resistance supplemented by insecticide applications (Reay-Jones *et al.* 2005). These efforts are often not able to reduce infestations below economic injury levels. Chemical control of *E. loftini* is limited by the sheltered nature of larvae which restricts their exposure to insecticides. Chemical and biological control agents target neonates which have not yet become protected within the stalk. This research investigated potential management strategies which may improve *E. loftini* management by focusing control tactics on vulnerable larvae.

A two-year aerial insecticide application study using commercial sugarcane fields conducted in the LRGV revealed chemical control strategies which both reduced *E. loftini* injury and improved subsequent sugar yield. This study highlighted the potential use of pheromone traps to increase scouting efficiency and enhance timing of insecticide applications. Regression analysis indicated that an action threshold of 20-25 male *E. loftini*/trap/wk is appropriate to initiate scouting for larval infestations. As with many similar pheromone trap studies, the attractive properties of *E. loftini* pheromone lures, dispersion distances and other behavioral relationships are not well understood and need further examination. Over both years the insect growth regulator novaluron provided superior control compared to β-cyfluthrin and untreated plots. When applied as advised by thresholds, a single application of novaluron reduced *E. loftini* injury (proportion of bored internodes) by 60%, adult emergence by 58% and led to a 14% increase in sugar yield. The superior control of novaluron compared to pyrethroids is likely due to longer residual activity; by remaining on plant surfaces, novaluron can control neonates as soon as they eclose. Novaluron has been shown to have good residual activity remaining effective for 10–30 days depending on environmental conditions (Ishauya *et al.* 2002). β-cyfluthrin has demonstrated longer residual activity relative to other pyrethroids (Athanassiou *et al.* 2003), but its residual toxicity is negatively correlated with temperature and is greatly reduced at temperatures exceeding 25°C (Arthur 1999) with < 50% mortality one week after application. This study highlights management strategies utilizing pheromone traps to direct a single insecticide application and the improvement of chemical control of *E. loftini* in sugarcane. With the global price of sugar rising, yield reductions due to insect pests can lead to substantial decreases in revenue. The efficient chemical control demonstrated in this study has potential to greatly reduce revenue losses from *E. loftini* infestations in the LRGV.

A greenhouse study was conducted at the USDA-ARS Kika de la Garza Subtropical Agricultural Research Center in Weslaco, Texas on *E. loftini* neonate establishment and feeding behavior on two phenological stages of resistant (HoCP 85-845) and susceptible (HoCP 00-950) sugarcane cultivars. A substantial portion (42 ± 6.3%) of neonates mine into the mid-rib of sugarcane leaves within one day of eclosion where they become protected from insecticides, predators and parasitoids. The mean duration of exposure (time to stalk entry) was longer on the resistant cultivar HoCP 85-845 compared to HoCP 00-950 and on mature compared to immature plants. This research shows the limited exposure time of *E. loftini* larvae to foliar-applied insecticides, and indicates that residual activity of insecticides may improve the efficacy of chemical control. In addition, results from this study suggest that resistant cultivars which impede stalk entry and prolong larval exposure on plant surfaces may be able to enhance the effects of other control tactics. Because neonate larvae are the target of *E. loftini* control strategies, additional research on neonate establishment could lead to the development of advanced management tactics. Continued research in this area should investigate neonate behavior on a diverse range of sugarcane cultivars and examine the relationships between larval establishment and physical characteristics of host plants. Host plant resistance will likely become more important to *E. loftini* management as it has potential to both mitigate revenue losses and reduce areawide populations.

A small plot field study was conducted at the Texas A&M AgriLife Research and Extension Center at Beaumont, Texas, which assessed relative stalkborer resistance among 25 commercial and experimental sugarcane cultivars. Although both *E. loftini* and *D. saccharalis* are present in Beaumont, *E. loftini* accounted for 99% of the infestations in this study. Differences in *E. loftini* injury were detected between cultivars. Consistent with previous findings (Reay-Jones *et al.* 2003, 2005, Reagan *et al.* 2005) the commercial cultivar HoCP 85-845 was the least injured variety examined. South African cultivars N-21 and N-24 and the high fiber cultivar US 93-15 also demonstrated high levels of resistance. The most widely planted cultivar in Louisiana, HoCP 96-540, was among the most susceptible varieties evaluated. Sugarcane breeding institutions should place more emphasis on selecting for stalkborer resistant cultivars. While *D. saccharalis* is largely controlled through the use of insecticides, the sheltered nature of *E. loftini* larvae will likely require a balance of multiple management tactics to achieve adequate control

(Reay-Jones *et al.* 2005). Host plant resistance will provide a critical element of *E. loftini* IPM programs because it may be used in conjunction with other management strategies and has the potential to slow the spread of this invasive species by reducing areawide populations. However, future research is necessary to better understand the mechanisms of *E. loftini* resistance in sugarcane. Investigation of nutritional factors which influence both *E. loftini* oviposition and larval behavior may lead to the development of a non-biological assay to evaluate levels of resistance. Examination of host plant characteristics which impede larval entry into the stalk can help identify cultivars with potential to enhance efficacy of *E. loftini* chemical control.

This research indicates that *E. loftini* management could be improved by development of control strategies which target the exposed neonate stage. The use of pheromone traps to improve timing of insecticide applications and the recently labeled novaluron both demonstrated potential to improve *E. loftini* chemical control. However, due to the extremely limited exposure time of *E. loftini* larvae, resistant cultivars should also be incorporated into management programs. Future *E. loftini* IPM programs should use a balance of irrigation (Reay-Jones *et al.* 2005, Showler and Castro 2010a), improved chemical control strategies, and host plant resistance.

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APENDIX A

VARIETAL RESISTANCE TEST PLOT PLAN

	US 02-9010 (3 rows)			HoCP 91-552 (2 rows)		US 07-9027 (2 rows)	
V	US 04-9076	US 08-9003	Ho 06-563	HoCP 05-961	L07-57	HoCP 05-902	US 07-9019
		HoCP 85-845	Ho 07-604	Ho 07-612	US 08-9001	Ho 06-537	
		HoCP 04-838	L 03-371	Ho 06-9610	N-24	N-27	
		L 01-299	Ho 07-613	HoCP 00-950	HoCP 96-540	N-17	
		N-21	US 01-40	L 07-68	Ho 07-617	US 93-15	
IV	US 07-9612	HoCP 05-902	Ho 07-612	US 01-40	HoCP 05-961	Ho 07-604	HoCP 04-838
		US 93-15	Ho 07-613	L 01-299	US 08-9003	US 08-9001	
		L 07-57	L 07-68	HoCP 85-845	Ho 06-563	N-24	
		HoCP 00-950	L 03-371	HoCP 04-838	N-21	Ho 07-617	
		N-17	HoCP 96-540	N-27	Ho 06-537	Ho 06-9610	
III	US 07-9015	Ho 06-563	Ho 07-612	HoCP 05-961	US 08-9003	L 07-57	US 02-113
		Ho 06-9610	HoCP 00-950	N-21	HoCP 04-838	HoCP 96-540	
		Ho 07-617	N-24	N-17	US 93-15	N-27	
		HoCP 85-845	Ho 07-613	L 03-371	HoCP 05-902	US 01-40	
		US 08-9001	L 01-299	Ho 07-604	L 07-68	Ho 06-537	
II	US 07-9014	Ho 07-617	HoCP 04-838	HoCP 85-845	N-27	L 03-371	US 07-9017
		N-17	Ho 07-613	N-21	Ho 06-9610	HoCP 00-950	
		L 01-299	US 93-15	US 01-40	HoCP 96-540	N-24	
		Ho 06-563	Ho 06-537	Ho 07-612	US 08-9001	L 07-68	
		Ho 07-604	HoCP 05-961	US 08-9003	L 07-57	HoCP 05-902	
I	CP 44-155	HoCP 05-902	US 01-40	Ho 07-612	Ho 06-537	L 03-371	L 01-299
		L 07-57	L 07-68	HoCP 00-950	HoCP 85-845	US 08-9003	
		Ho 06-563	HoCP 04-838	N-17	HoCP 05-961	US 08-9001	
		L 01-299	N-21	N-27	HoCP 96-540	Ho 07-604	
		Ho 06-9610	N-24	US 93-15	Ho 07-617	Ho 07-613	
	HoCP 85-845 (7 rows)						

↓
N

Plot size = 1 row, 5.25 ft row width, 12 ft long with 4 ft alley
Shaded plots = Seed increase as buffer

APENDIX B: AERIAL APPLICATION STUDY STATISTICAL ANALYSIS

INJURY AND EMERCENCE

```
dm'output;clear;log;clear';
Title1'LRGV All by Sample';
data data1;
data data1;
input Year$ Trt$ field$ Pos$ Bored Tot Emerg ;
cards;
2009  B     4     F     6     180   1
2009  B     5     B     31    205   8
2009  B     4     B     9     209   2
2009  B     5     F     24    192   4
2009  B     2     F     47    207   22
2009  B     1     F     36    174   10
2009  B     3     B     35    195   9
2009  B     3     F     36    192   14
2009  B     2     B     31    230   16
2009  B     1     B     33    231   3
2009  C     4     B     23    181   2
2009  C     5     F     27    220   11
2009  C     5     B     51    193   30
2009  C     2     F     27    207   12
2009  C     4     F     19    244   6
2009  C     3     B     17    207   1
2009  C     2     B     72    175   24
2009  C     3     F     24    219   3
2009  C     1     F     24    207   2
2009  C     1     B     42    188   11
2009  D     4     B     5     226   2
2009  D     5     B     23    219   14
2009  D     5     F     21    216   18
2009  D     2     B     30    202   8
2009  D     4     F     9     233   0
2009  D     2     F     66    209   27
2009  D     3     F     25    213   12
2009  D     3     B     11    199   0
2009  D     1     F     10    218   1
2009  D     1     B     9     220   2
2010  B     1     F     36    200   7
2010  B     1     B     38    222   16
2010  D     1     B     46    198   5
2010  D     1     F     46    219   4
2010  C     1     B     41    206   8
2010  C     1     F     76    185   14
2010  B     2     F     51    177   9
2010  B     2     B     39    189   8
2010  D     2     B     12    200   0
2010  D     2     F     14    187   2
2010  C     2     B     73    191   18
2010  C     2     F     139   363   36
2010  B     3     F     14    235   5
2010  B     3     B     7     197   1
```

```
2010  D     3     F     6     232   1
2010  D     3     B     22    233   7
2010  C     3     B     56    212   11
2010  C     3     F     42    222   9
2010  B     4     B     14    179   3
2010  B     4     F     4     202   0
2010  D     4     B     5     203   0
2010  D     4     F     6     220   2
2010  C     4     B     27    188   3
2010  C     4     F     39    200   12
2010  B     5     B     17    180   6
2010  B     5     F     16    209   2
2010  D     5     B     10    191   3
2010  D     5     F     13    205   1
2010  C     5     F     44    382   6
2010  C     5     B     39    188   8
;
proc glimmix data=data1 ;
class Year Trt field Pos;
model Bored/Tot  = Trt  / htype=3 ddfm=kr dist=binomial ;
random year field field*year field*year*trt;
lsmeans Trt / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data1 ;
class Year Trt Field Pos;
model Emerg = Trt  / htype=3 ddfm=kr dist=poisson ;
random year Field Field*year Field*year*trt ;
lsmeans Trt / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data1 ;
class Year Trt Field Pos;
model Emerg/Bored  = Trt  / htype=3 ddfm=kr dist=binomial ;
random year Field Field*year Field*year*trt;
lsmeans Trt / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data1 ;
class Year Trt Field Pos;
```

```
model Bored/Tot  = Trt|year  / htype=3 ddfm=kr dist=binomial ;
random year Field Field*year Field*year*trt;
lsmeans Trt|year / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
                         LRGV All        10:02 Thursday, March 31, 2011  10

                       The GLIMMIX Procedure

                 Probability of a Bored Internode
                         Model Information
              Data Set                       WORK.DATA1
              Response Variable (Events)     Bored
              Response Variable (Trials)     Tot
              Response Distribution          Binomial
              Link Function                  Logit
              Variance Function              Default
              Variance Matrix                Not blocked
              Estimation Technique           Residual PL
              Degrees of Freedom Method      Kenward-Roger
              Fixed Effects SE Adjustment    Kenward-Roger

                     Class Level Information
                     Class    Levels    Values
                     Year          2    2009 2010
                     Trt           3    B C D
                     Field           5    1 2 3 4 5
                     Pos           2    B F

                Number of Observations Read          60
                Number of Observations Used          60
                Number of Events                   1815
                Number of Trials                  12626

                            Dimensions
                    G-side Cov. Parameters        4
                    Columns in X                  4
                    Columns in Z                 47
                    Subjects (Blocks in V)        1
                    Max Obs per Subject          60


                   Optimization Information
            Optimization Technique        Dual Quasi-Newton
            Parameters in Optimization    4
            Lower Boundaries              4
            Upper Boundaries              0
            Fixed Effects                 Profiled
            Starting From                 Data
```

```
                                     Iteration History
                                                 Objective                            Max
       Iteration    Restarts    Subiterations     Function          Change       Gradient
               0           0                5  187.02253872      0.11651819     41.77246
               1           0                4  194.55097319      0.00527579     41.66498
               2           0                2   194.8166387      0.00015906      41.6576
               3           0                1  194.81735269      0.00004300     41.65712
               4           0                1  194.81735262      0.00000582     41.65724
               5           0                1  194.81735028      0.00000917     41.65713
               6           0                1  194.81735109      0.00000683     41.65723
               7           0                1  194.81735027      0.00000476     41.65716
               8           0                1   194.8173512      0.00000491     41.65723
               9           0                1  194.81735058      0.00000353     41.65717
              10           0                1  194.81735125      0.00000361     41.65723
              11           0                1   194.8173508      0.00000260     41.65719
              12           0                1   194.8173513      0.00000266     41.65723
              13           0                1  194.81735096      0.00000189      41.6572
              14           0                1  194.81735132      0.00000195     41.65722
              15           0                1  194.81735108      0.00000141      41.6572
              16           0                1  194.81735134      0.00000145     41.65722
              17           0                1  194.81735116      0.00000302     41.65718
              18           0                1  194.81735173      0.00000279     41.65722
              19           0                0  194.81735132      0.00000000     41.65722

                      Convergence criterion (PCONV=1.11022E-8) satisfied.

                          Estimated G matrix is not positive definite.

                                        Fit Statistics
                             -2 Res Log Pseudo-Likelihood      194.82
                             Generalized Chi-Square            180.70
                             Gener. Chi-Square / DF              3.17

                                Covariance Parameter Estimates
                                                           Standard
                               Cov Parm        Estimate       Error

                               Year                   0           .
                               Field             0.2650      0.2318
                               Year*Field       0.03268     0.07646
                               Year*Trt*Field    0.2193     0.08169

                               Type III Tests of Fixed Effects
                                     Num      Den
                           Effect         DF       DF    F Value    Pr > F

                           Trt             2     18.2      11.41    0.0006

------------------------ Effect=Trt   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---

                                              Standard
                  Standard           Error of                                  Lower    Upper Letter
   Obs Trt Estimate  Error       Mean   Mean     Alpha     Lower     Upper      Mean     Mean Group

     1   C   -1.4435   0.2826   0.1910  0.04366   0.05  -2.1353   -0.7518   0.1057    0.3204   A
```

```
  2   B   -2.0463   0.2848   0.1144  0.02886   0.05  -2.7384  -1.3542  0.06074   0.2052   B
  3   D   -2.5000   0.2866  0.07586  0.02010   0.05  -3.1925  -1.8075  0.03945   0.1409   B
```

```
                               The GLIMMIX Procedure

                                    Emergence
                                Model Information
                   Data Set                       WORK.DATA1
                   Response Variable              Emerg
                   Response Distribution          Poisson
                   Link Function                  Log
                   Variance Function              Default
                   Variance Matrix                Not blocked
                   Estimation Technique           Residual PL
                   Degrees of Freedom Method      Kenward-Roger
                   Fixed Effects SE Adjustment    Kenward-Roger

                              Class Level Information
                          Class    Levels    Values
                          Year          2    2009 2010
                          Trt           3    B C D
                          Field           5    1 2 3 4 5
                          Pos           2    B F

                    Number of Observations Read          60
                    Number of Observations Used          60

                                  Dimensions
                         G-side Cov. Parameters         4
                         Columns in X                   4
                         Columns in Z                  47
                         Subjects (Blocks in V)         1
                         Max Obs per Subject           60

                             Optimization Information
                  Optimization Technique        Dual Quasi-Newton
                  Parameters in Optimization    4
                  Lower Boundaries              4
                  Upper Boundaries              0
                  Fixed Effects                 Profiled
                  Starting From                 Data

                                 Iteration History
                                              Objective                        Max
     Iteration    Restarts    Subiterations     Function          Change    Gradient

             0           0                7    162.77438672      0.21549969    6.129949
             1           0                5    180.08778862      0.04645105     6.25878
             2           0                3    182.65464661      0.00529663    6.247226
             3           0                2    182.73745635      0.00018619    6.245641
             4           0                1     182.7375978      0.00007154    6.245852
             5           0                1    182.73762526      0.00001618    6.245808
             6           0                1    182.73759444      0.00001097    6.245846
```

```
                 7           0                1     182.73760536      0.00000588    6.245835
                 8           0                1     182.73759365      0.00000450    6.245851
                 9           0                1     182.73759797      0.00000230    6.245846
                10           0                1     182.73759333      0.00000179    6.245852
                11           0                1     182.73759502      0.00000090    6.245851
                12           0                0     182.73759318      0.00000000    6.245851

                        Convergence criterion (PCONV=1.11022E-8) satisfied.

                            Estimated G matrix is not positive definite.

                                           Fit Statistics
                              -2 Res Log Pseudo-Likelihood      182.74
                              Generalized Chi-Square            115.11
                              Gener. Chi-Square / DF              2.02

                                   Covariance Parameter Estimates
                                                         Standard
                                Cov Parm        Estimate       Error
                                Year            8.03E-19           .
                                Field             0.2170      0.2777
                                Year*Field        0.1412      0.1834
                                Year*Trt*Field    0.3418      0.1489

                                  Type III Tests of Fixed Effects
                                        Num      Den
                          Effect         DF       DF    F Value    Pr > F

                          Trt             2    17.17       4.65    0.0244

-------------------------- Effect=Trt   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---

                                             Standard
                    Standard          Error of                                     Lower    Upper Letter
   Obs Trt Estimate  Error        Mean   Mean   Alpha    Lower    Upper     Mean     Mean Group

    1   C    2.2296   0.3131   9.2959   2.9106   0.05   1.4842   2.9750   4.4112  19.5894   A
    2   B    1.7611   0.3194   5.8188   1.8583   0.05   1.0120   2.5102   2.7512  12.3069   AB
    3   D    1.3125   0.3288   3.7155   1.2218   0.05   0.5564   2.0686   1.7444   7.9138   B

                                          LRGV All by stalk        10:02 Thursday, March 31, 2011
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                                        The GLIMMIX Procedure

                                         Relative Survival
                                          Model Information

                            Data Set                       WORK.DATA1
                            Response Variable (Events)     Emerg
                            Response Variable (Trials)     Bored
                            Response Distribution          Binomial
                            Link Function                  Logit
                            Variance Function              Default
                            Variance Matrix                Not blocked
```

```
              Estimation Technique           Residual PL
              Degrees of Freedom Method      Kenward-Roger
              Fixed Effects SE Adjustment    Kenward-Roger

                        Class Level Information
                     Class    Levels    Values
                     Year          2    2009 2010
                     Trt           3    B C D
                     Field           5    1 2 3 4 5
                     Pos           2    B F

                Number of Observations Read          60
                Number of Observations Used          60
                Number of Events                    482
                Number of Trials                   1815

                               Dimensions
                    G-side Cov. Parameters         4
                    Columns in X                   4
                    Columns in Z                  47
                    Subjects (Blocks in V)         1
                    Max Obs per Subject           60

                          Optimization Information
            Optimization Technique        Dual Quasi-Newton
            Parameters in Optimization    4
            Lower Boundaries              4
            Upper Boundaries              0
            Fixed Effects                 Profiled
            Starting From                 Data

                              Iteration History
                                               Objective                            Max
Iteration    Restarts    Subiterations          Function           Change      Gradient

        0           0               13       145.1021998       1.85589123      4.276594
        1           0                5      149.91541795       0.08559157      4.218059
        2           0                3      150.18429711       0.00136691      4.214693
        3           0                1      150.18842522       0.00002217      4.214747
        4           0                1      150.18849276       0.00001862      4.214536
        5           0                1       150.1884777       0.00000549      4.214612
        6           0                1      150.18848604       0.00000119       4.21461
        7           0                1      150.18848422       0.00000086      4.214627
        8           0                1      150.18848701       0.00000150        4.2146
        9           0                1      150.18848311       0.00000092      4.214616
       10           0                0      150.18848533       0.00000000      4.214616

          Convergence criterion (PCONV=1.11022E-8) satisfied.

              Estimated G matrix is not positive definite.

                             Fit Statistics
                -2 Res Log Pseudo-Likelihood      150.19
                Generalized Chi-Square             77.49
                Gener. Chi-Square / DF              1.36
```

```
                                   Covariance Parameter Estimates
                                                            Standard
                                Cov Parm        Estimate       Error

                                Year             0.08162      0.1866
                                Field             3.45E-20           .
                                Year*Field          0.1135      0.1224
                                Year*Trt*Field      0.2391      0.1168

                                  Type III Tests of Fixed Effects
                                        Num      Den
                          Effect         DF       DF    F Value    Pr > F

                          Trt             2    18.65       0.11    0.8949

------------------------ Effect=Trt   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---

                                      Standard
                    Standard          Error of                                     Lower    Upper Letter
   Obs Trt Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group

    1   B   -1.0464   0.2998   0.2599  0.05768   0.05  -2.4184   0.3256  0.08178   0.5807   A
    2   D   -1.1237   0.3125   0.2453  0.05786   0.05  -2.3563   0.1088  0.08657   0.5272   A
    3   C   -1.1706   0.2900   0.2367  0.05240   0.05  -2.7014   0.3602  0.06289   0.5891   A

                                         LRGV All by stalk        10:02 Thursday, March 31, 2011
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                                       The GLIMMIX Procedure

                         Probability of a Bored Internode Year*Treatment

                                         Model Information

                            Data Set                       WORK.DATA1
                            Response Variable (Events)     Bored
                            Response Variable (Trials)     Tot
                            Response Distribution          Binomial
                            Link Function                  Logit
                            Variance Function              Default
                            Variance Matrix                Not blocked
                            Estimation Technique           Residual PL
                            Degrees of Freedom Method      Kenward-Roger
                            Fixed Effects SE Adjustment    Kenward-Roger

                                      Class Level Information
                                   Class    Levels    Values

                                   Year          2    2009 2010
                                   Trt           3    B C D
                                   Field           5    1 2 3 4 5
                                   Pos           2    B F

                              Number of Observations Read          60
                              Number of Observations Used          60
```

```
           Number of Events                  1815
           Number of Trials                 12626

                          Dimensions
               G-side Cov. Parameters         4
               Columns in X                  12
               Columns in Z                  47
               Subjects (Blocks in V)         1
               Max Obs per Subject           60

                       Optimization Information
           Optimization Technique        Dual Quasi-Newton
           Parameters in Optimization    4
           Lower Boundaries              4
           Upper Boundaries              0
           Fixed Effects                 Profiled
           Starting From                 Data

                            Iteration History

                                           Objective                        Max
Iteration    Restarts    Subiterations       Function          Change    Gradient

        0           0                5    184.50505566      0.24271646    1.283E-6
        1           0                4    192.05945964      0.00875641    0.000041
        2           0                3    192.32627574      0.00017295    5.047E-6
        3           0                1    192.32691833      0.00000090    5.942E-6
        4           0                0    192.32691882      0.00000000    5.901E-6

           Convergence criterion (PCONV=1.11022E-8) satisfied.

               Estimated G matrix is not positive definite.

                            Fit Statistics
               -2 Res Log Pseudo-Likelihood      192.33
               Generalized Chi-Square            178.31
               Gener. Chi-Square / DF              3.30

                    Covariance Parameter Estimates
                                              Standard
             Cov Parm        Estimate       Error

             Year                   0           .
             Field             0.2515      0.2341
             Year*Field       0.06898      0.1017
             Year*Trt*Field    0.1895     0.07637

                   Type III Tests of Fixed Effects
                          Num      Den
           Effect          DF       DF    F Value    Pr > F

           Trt              2    16.09      12.88    0.0005
           Year             1    4.088       0.02    0.8981
           Year*Trt         2    16.09       2.21    0.1414

                      LRGV All by stalk        10:02 Thursday, March 31, 2011
```

```
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------------------------- Effect=Trt   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---
                                         Standard
                       Standard          Error of                             Lower    Upper
Letter
 Obs Year Trt Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean
Group

   1       C   -1.4473   0.2789   0.1904  0.04300   0.05  -2.1383  -0.7563   0.1054   0.3195   A
   2       B   -2.0471   0.2812   0.1143  0.02848   0.05  -2.7382  -1.3560  0.06075   0.2049   B
   3       D   -2.4996   0.2830  0.07589  0.01985   0.05  -3.1909  -1.8082  0.03951   0.1409   B

------------------------- Effect=Year   Method=Tukey-Kramer(P<.05)   Set=2 ----------------------
---
                                         Standard
                       Standard          Error of                             Lower    Upper
Letter
 Obs Year Trt Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean
Group

   4 2010      -1.9818   0.2806   0.1211  0.02987   0.05  -2.6783  -1.2853  0.06427   0.2167   A
   5 2009      -2.0142   0.2803   0.1177  0.02911   0.05  -2.7107  -1.3177  0.06234   0.2112   A

----------------------- Effect=Year*Trt   Method=Tukey-Kramer(P<.05)   Set=3 --------------------
---
                                         Standard
                       Standard          Error of                             Lower    Upper
Letter
 Obs Year Trt Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean
Group

   6 2010  C   -1.1836   0.3234   0.2344  0.05804   0.05  -1.9093  -0.4579   0.1291   0.3875   A
   7 2009  C   -1.7110   0.3256   0.1530  0.04220   0.05  -2.4388  -0.9832  0.08026   0.2723   AB
   8 2009  B   -1.9097   0.3274   0.1290  0.03679   0.05  -2.6395  -1.1799  0.06664   0.2351   AB
   9 2010  B   -2.1845   0.3294   0.1011  0.02995   0.05  -2.9164  -1.4526  0.05135   0.1896   B
  10 2009  D   -2.4219   0.3306  0.08152  0.02475   0.05  -3.1551  -1.6888  0.04089   0.1559   B
  11 2010  D   -2.5772   0.3325  0.07062  0.02182   0.05  -3.3125  -1.8419  0.03515   0.1368   B
```

LINEAR REGRESSION

PHEROMONE TRAP CATCH VS LARVAL INFESTATION

```
dm'output;clear;log;clear';
Title1'Catch vs Larval Infestation';
data data1;
input DATE$ FIELD$ Trap$      CATCH Infst;
cards;
1-Jun        1      A      3      0           1-Jun        4      A      2      0
1-Jun        1      B      1      0           1-Jun        4      B      1      5
1-Jun        2      A      2      0           1-Jun        5      A      0      0
1-Jun        2      B      0      0           1-Jun        5      B      0      0
1-Jun        3      A      0      0           8-Jun        1      A      2      0
1-Jun        3      B      0      0           8-Jun        1      B      1      0
```

```
8-Jun       2     A     2     0
8-Jun       2     B     5     0
8-Jun       3     A     1     0
8-Jun       3     B     4     0
8-Jun       4     A     0     0
8-Jun       4     B     0     0
8-Jun       5     A     0     0
8-Jun       5     B     2     0
15-Jun      1     A     1     0
15-Jun      1     B     2     0
15-Jun      2     A     2     0
15-Jun      2     B     4     0
15-Jun      3     A     5     0
15-Jun      3     B     3     0
15-Jun      4     A     2     0
15-Jun      4     B     0     0
15-Jun      5     A     1     0
15-Jun      5     B     5     0
22-Jun      1     A     4     0
22-Jun      1     B     6     0
22-Jun      2     A     5     0
22-Jun      2     B     4     0
22-Jun      3     A     7     0
22-Jun      3     B     8     0
22-Jun      4     A     3     0
22-Jun      4     B     4     0
22-Jun      5     A     2     0
22-Jun      5     B     6     0
29-Jun      1     A     8     0
29-Jun      1     B     7     0
29-Jun      2     A     6     0
29-Jun      2     B     4     0
29-Jun      3     A     6     0
29-Jun      3     B     8     0
6-Jul       1     A     5     0
6-Jul       1     B     8     0
6-Jul       2     A     6     0
6-Jul       2     B     3     0
6-Jul       3     A     6     0
6-Jul       3     B     4     0
6-Jul       4     A     2     0
6-Jul       4     B     3     0
6-Jul       5     A     3     0
6-Jul       5     B     4     0
13-Jul      1     A     9     5
13-Jul      1     B     7     5
13-Jul      2     A     8     2.5
13-Jul      2     B     11    2.5
13-Jul      3     A     12    5
13-Jul      3     B     16    5
13-Jul      4     A     6     0
13-Jul      4     B     4     0
13-Jul      5     A     3     0
13-Jul      5     B     7     0
20-Jul      1     A     11    5
20-Jul      1     B     9     0
20-Jul      2     A     8     0
20-Jul      2     B     14    10
20-Jul      3     A     19    10
20-Jul      3     B     22    10
20-Jul      4     A     7     0
20-Jul      4     B     10    0
20-Jul      5     A     6     2.5
20-Jul      5     B     8     0
27-Jul      1     A     17    2.5
27-Jul      1     B     13    0
27-Jul      2     A     10    5
27-Jul      2     B     29    10
27-Jul      3     A     31    10
27-Jul      3     B     17    5
27-Jul      4     A     12    0
27-Jul      4     B     9     2.5
27-Jul      5     A     14    2.5
27-Jul      5     B     19    0
4-Aug       1     A     21    7.5
4-Aug       1     B     29    10
4-Aug       2     A     31    10
4-Aug       2     B     11    0
4-Aug       3     A     24    2.5
4-Aug       3     B     37    5
4-Aug       4     A     17    5
4-Aug       4     B     21    2.5
4-Aug       5     A     9     0
4-Aug       5     B     24    7.5
11-Aug      1     A     33    10
11-Aug      1     B     17    7.5
11-Aug      2     A     22    12.5
11-Aug      2     B     41    10
11-Aug      3     A     53    20
11-Aug      3     B     36    17.5
11-Aug      4     A     22    5
11-Aug      4     B     27    2.5
11-Aug      5     A     14    0
11-Aug      5     B     26    5
13-Aug      1     A     56    12.5
13-Aug      1     B     40    10
13-Aug      2     A     31.5  5
13-Aug      2     B     77    10
13-Aug      3     A     108.5 22.5
13-Aug      3     B     73.5  15
13-Aug      4     A     49    7.5
13-Aug      4     B     73.5  10
13-Aug      5     A     56    7.5
13-Aug      5     B     70    12.5
;
proc reg data=data1;
model Infst = catch;
```

```
run;

    Catch vs Larval Infestation
                                                                      10:02 Thursday, March 31,
2011

                                         The REG Procedure
                                           Model: MODEL1
                                    Dependent Variable: Infst

                              Number of Observations Read         116
                              Number of Observations Used         116

                                        Analysis of Variance
                                               Sum of           Mean
           Source                   DF        Squares         Square    F Value    Pr > F

           Model                     1     1896.74901     1896.74901     280.74    <.0001
           Error                   114      770.22297        6.75634
           Corrected Total         115     2666.97198

                        Root MSE              2.59930    R-Square     0.7112
                        Dependent Mean        3.08190    Adj R-Sq     0.7087
                        Coeff Var            84.34081

                                        Parameter Estimates
                                     Parameter       Standard
                Variable     DF       Estimate          Error    t Value    Pr > |t|

                Intercept     1       -0.03833        0.30483      -0.13      0.9002
                CATCH         1        0.21278        0.01270      16.76      <.0001
```

2010 YIELD AND QUALITY

SUGAR PER ACRE

```
dm'output;clear;log;clear';
Title1'LRGV 2010 Yield';
data data1;
input  field$ trt$ Pur Fib Brix POL CRS TCA TSA;

cards;
1     D     86.98 17.48 16.64 14.47 208   28.14 2.93
1     C     85.92 18.12 16.77 14.40 204   29.69 3.04
1     B     85.45 17.64 17.34 14.82 211   28.79 3.04
2     D     84.78 18.92 17.25 14.62 205   27.19 2.79
2     C     81.43 18.71 16.58 13.51 185   21.40 1.99
2     B     84.67 18.71 16.48 13.95 195   18.12 1.77
4     D     84.94 15.39 17.22 14.63 211   34.51 3.65
4     C     84.54 15.36 16.65 14.07 203   31.36 3.19
4     B     85.34 15.01 16.47 14.05 204   30.53 3.13
5     D     84.82 14.99 17.56 14.90 216   28.24 3.06
5     C     84.21 15.87 17.13 14.42 207   27.59 2.86
5     B     85.11 15.59 16.71 14.22 206   25.84 2.66
```

```
3     D     84.85 17.34 16.52 14.02 199   33.90 3.38
3     C     85.14 19.30 15.65 13.32 186   29.59 2.76
3     B     84.77 18.06 16.40 13.90 196   24.01 2.36
;
proc glimmix data=data1 ;
class  Field Trt ;
model TSA  = Trt  / htype=3 ddfm=kr dist=Gaussian ;
random Field ;
lsmeans Trt / ilink diff cl ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;


proc glimmix data=data1 ;
class  Field Trt ;
model TCA  = Trt  / htype=3 ddfm=kr dist=Gaussian ;
random Field ;
lsmeans Trt / ilink diff cl ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
LRGV 2010 Yield         10:02 Thursday, March 31, 2011  25
                                      The GLIMMIX Procedure

                                            Sugar/Acre

                                        Model Information

                    Data Set                       WORK.DATA1
                    Response Variable              TSA
                    Response Distribution          Gaussian
                    Link Function                  Identity
                    Variance Function              Default
                    Variance Matrix                Not blocked
                    Estimation Technique           Restricted Maximum Likelihood
                    Degrees of Freedom Method      Kenward-Roger
                    Fixed Effects SE Adjustment    Kenward-Roger

                                     Class Level Information
                                  Class    Levels    Values

                                  field           5    1 2 3 4 5
                                  trt           3    B C D

                             Number of Observations Read          15
                             Number of Observations Used          15

                                           Dimensions
```

```
                                      G-side Cov. Parameters         1
                                      R-side Cov. Parameters         1
                                      Columns in X                   4
                                      Columns in Z                   5
                                      Subjects (Blocks in V)         1
                                      Max Obs per Subject           15

                                         Optimization Information

                              Optimization Technique        Dual Quasi-Newton
                              Parameters in Optimization    1
                              Lower Boundaries              1
                              Upper Boundaries              0
                              Fixed Effects                 Profiled
                              Residual Variance             Profiled
                              Starting From                 Data

                                              Iteration History

                                                          Objective                         Max
                Iteration    Restarts    Evaluations        Function          Change    Gradient

                        0           0              4    14.120093624       .            1.89E-15

                            Convergence criterion (ABSGCONV=0.00001) satisfied.

                                               Fit Statistics
                                    -2 Res Log Likelihood         14.12
                                    AIC  (smaller is better)      18.12
                                    AICC (smaller is better)      19.45
                                    BIC  (smaller is better)      17.34
                                    CAIC (smaller is better)      19.34
                                    HQIC (smaller is better)      16.02
                                    Generalized Chi-Square         0.75
                                    Gener. Chi-Square / DF         0.06

                                       Covariance Parameter Estimates
                                                              Standard
                                      Cov Parm    Estimate       Error

                                      field         0.1520      0.1228
                                      Residual     0.06283     0.03141

                                      Type III Tests of Fixed Effects

                                            Num      Den
                              Effect         DF       DF    F Value    Pr > F

                              trt             2        8       6.78    0.0190


------------------------------ Effect=trt   Method=LSD(P<.05)   Set=1 ---------------------------
---

                                                     Standard
                        Standard          Error of                              Lower    Upper Letter
```

```
     Obs trt Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group

      1   D    3.1620   0.2073   3.1620   0.2073   0.05   2.6547   3.6693   2.6547   3.6693   A
      2   C    2.7680   0.2073   2.7680   0.2073   0.05   2.2607   3.2753   2.2607   3.2753   B
      3   B    2.5920   0.2073   2.5920   0.2073   0.05   2.0847   3.0993   2.0847   3.0993   B


                                       LRGV 2010 Yield        10:02 Thursday, March 31, 2011
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                                              Cane/acre
                                        The GLIMMIX Procedure
                                          Model Information

                        Data Set                      WORK.DATA1
                        Response Variable             TCA
                        Response Distribution         Gaussian
                        Link Function                 Identity
                        Variance Function             Default
                        Variance Matrix               Not blocked
                        Estimation Technique          Restricted Maximum Likelihood
                        Degrees of Freedom Method     Kenward-Roger
                        Fixed Effects SE Adjustment   Kenward-Roger

                                       Class Level Information
                                    Class    Levels    Values

                                    field           5    1 2 3 4 5
                                    trt           3    B C D

                               Number of Observations Read          15
                               Number of Observations Used          15

                                              Dimensions
                                   G-side Cov. Parameters         1
                                   R-side Cov. Parameters         1
                                   Columns in X                   4
                                   Columns in Z                   5
                                   Subjects (Blocks in V)         1
                                   Max Obs per Subject           15

                                      Optimization Information
                            Optimization Technique        Dual Quasi-Newton
                            Parameters in Optimization    1
                            Lower Boundaries              1
                            Upper Boundaries              0
                            Fixed Effects                 Profiled
                            Residual Variance             Profiled
                            Starting From                 Data

                                          Iteration History
                                                     Objective                         Max
                Iteration    Restarts    Evaluations        Function          Change    Gradient

                        0           0              4    67.161408321       .            8.33E-16
```

```
                     Convergence criterion (ABSGCONV=0.00001) satisfied.

                                    Fit Statistics
                         -2 Res Log Likelihood         67.16
                         AIC  (smaller is better)      71.16
                         AICC (smaller is better)      72.49
                         BIC  (smaller is better)      70.38
                         CAIC (smaller is better)      72.38
                         HQIC (smaller is better)      69.06
                         Generalized Chi-Square        65.26
                         Gener. Chi-Square / DF         5.44

                            Covariance Parameter Estimates
                                                  Standard
                           Cov Parm    Estimate       Error

                           field          11.4373      9.4130
                           Residual      5.4385      2.7193

                           Type III Tests of Fixed Effects
                                 Num      Den
                     Effect         DF       DF    F Value    Pr > F

                     trt             2        8       5.60    0.0301

------------------------------ Effect=trt   Method=LSD(P<.05)   Set=1 ---------------------------
---
                                            Standard
                     Standard               Error of                                   Lower    Upper Letter
   Obs trt Estimate  Error        Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group

     1   D   30.3960   1.8372  30.3960   1.8372   0.05  25.9446  34.8474  25.9446  34.8474   A
     2   C   27.9260   1.8372  27.9260   1.8372   0.05  23.4746  32.3774  23.4746  32.3774   AB
     3   B   25.4580   1.8372  25.4580   1.8372   0.05  21.0066  29.9094  21.0066  29.9094   B
```

QUALITY PARAMETERS

```
dm'output;clear;log;clear';
Title1'LRGV 2010 Yield Quality';
data data1;
input  field$ trt$ Pur Brix POL CRS ;

cards;
5     D     86.58 17.80 15.42 228
5     D     86.17 17.03 14.68 212
5     D     86.00 17.87 15.37 227
5     D     84.92 17.68 15.01 219
5     D     82.06 17.78 14.59 210
5     D     84.47 17.63 14.89 214
5     D     84.78 17.46 14.80 216
5     D     83.59 17.23 14.40 208
5     C     83.76 17.73 14.85 213
5     C     82.74 17.34 14.35 203
5     C     84.00 17.67 14.84 216
5     C     84.08 17.42 14.64 210
```

5	C	84.04	17.13	14.39	205
5	C	85.09	17.26	14.69	211
5	C	84.41	16.37	13.82	197
5	C	82.70	16.97	14.03	201
5	C	84.63	17.13	14.50	210
5	C	82.45	17.11	14.10	203
5	C	83.96	16.64	13.97	199
5	C	87.47	17.17	15.01	222
5	C	85.35	16.70	14.25	205
5	B	85.45	15.51	13.26	191
5	B	85.02	17.04	14.49	211
5	B	85.27	16.93	14.44	209
5	B	85.71	16.65	14.27	203
5	B	84.31	17.30	14.59	211
5	B	84.89	16.80	14.26	211
4	D	85.11	18.26	15.54	226
4	D	85.02	17.62	14.98	215
4	D	86.66	17.23	14.93	218
4	D	85.77	16.55	14.19	204
4	D	86.16	17.20	14.82	214
4	D	83.35	17.12	14.27	207
4	D	84.09	16.64	13.99	204
4	D	83.33	17.14	14.29	206
4	C	82.60	17.90	14.79	215
4	C	83.06	17.26	14.34	207
4	C	84.71	16.52	13.99	203
4	C	85.62	16.16	13.83	201
4	C	85.64	16.11	13.80	199
4	C	85.60	15.94	13.65	197
4	B	85.61	16.50	14.13	205
4	B	84.58	16.23	13.73	198
4	B	84.76	16.45	13.94	203
4	B	83.45	17.00	14.18	209
4	B	83.52	15.65	13.07	186
4	B	87.02	16.60	14.44	213
4	B	86.42	16.63	14.37	213
4	B	85.19	16.88	14.38	207
4	B	86.66	16.36	14.18	206
4	B	86.17	16.35	14.09	208
3	D	84.61	16.20	13.71	197.00
3	D	85.12	17.12	14.57	210.00
3	D	85.76	17.01	14.59	211.00
3	D	85.45	16.21	13.85	198.00
3	D	85.62	16.56	14.18	204.00
3	D	85.27	16.77	14.30	204.00
3	D	83.69	16.03	13.41	189.00
3	D	83.49	17.24	14.39	205.00
3	D	83.61	16.57	13.85	195.00
3	D	84.82	15.97	13.54	187.00
3	D	85.91	16.04	13.78	196.00
3	C	85.41	15.81	13.51	192.00
3	C	85.43	15.35	13.11	180.00
3	C	85.80	15.61	13.40	189.00
3	C	83.18	16.59	13.80	194.00
3	C	83.06	16.55	13.74	197.00

3	C	83.86	15.84	13.28	190.00
3	C	83.22	15.15	12.61	173.00
3	C	84.12	15.07	12.67	175.00
3	C	87.73	14.86	13.04	177.00
3	C	86.58	16.16	13.99	196.00
3	C	87.23	14.77	12.89	176.00
3	C	86.07	16.06	13.82	197.00
3	B	82.94	16.23	13.46	189.00
3	B	86.42	16.58	14.33	204.00
3	B	85.65	16.45	14.09	197.00
3	B	84.05	16.34	13.73	197.00
2	C	84.30	17.06	14.38	202
2	C	79.84	15.44	12.33	164
2	C	80.81	15.87	12.82	174
2	C	82.64	17.08	14.12	197
2	C	82.72	17.17	14.20	198
2	C	78.25	16.88	13.21	179
2	D	82.95	17.50	14.51	196
2	D	85.07	16.73	14.23	197
2	D	84.24	16.70	14.07	197
2	D	83.53	16.28	13.60	189
2	D	86.03	17.25	14.84	211
2	D	86.80	17.05	14.80	211
2	D	85.00	18.13	15.41	219
2	D	84.52	18.33	15.49	219
2	D	83.99	17.52	14.71	204
2	D	85.70	16.99	14.56	207
2	B	85.14	16.62	14.15	195
2	B	85.77	16.20	13.90	195
2	B	84.69	16.12	13.65	192
2	B	84.36	16.33	13.78	196
2	B	84.95	16.16	13.72	192
2	B	83.08	17.46	14.51	204
1	D	85.97	17.23	14.81	214
1	D	84.42	16.64	14.04	199
1	D	85.60	17.04	14.59	210
1	D	88.30	16.06	14.18	201
1	D	87.71	16.57	14.54	210
1	D	87.98	17.15	15.09	223
1	D	88.34	17.07	15.08	220
1	D	86.40	17.03	14.71	214
1	D	85.97	16.44	14.14	203
1	D	89.07	15.20	13.54	189
1	C	88.42	16.16	14.29	206
1	C	87.73	16.25	14.25	204
1	C	86.08	16.51	14.21	198
1	C	88.50	15.71	13.90	199
1	C	84.75	16.68	14.13	203
1	C	84.15	16.75	14.09	202
1	C	85.25	16.46	14.03	201
1	C	84.23	17.42	14.67	204
1	C	84.05	17.53	14.73	205
1	C	86.08	18.24	15.70	224
1	B	86.48	17.28	14.95	210
1	B	85.11	17.67	15.04	213

```
1     B     86.40 18.23 15.75 229
1     B     86.00 17.31 14.89 211
1     B     83.22 17.89 14.88 214
1     B     86.91 17.50 15.21 220
1     B     84.92 16.83 14.29 203
1     B     85.55 17.20 14.72 210
1     B     84.75 16.63 14.09 197
1     B     85.17 16.87 14.37 206
;
ODS HTML FILE='C:\Documents and Settings\treagan\Desktop\Blake Wilson\LRGV
2010 Yield Quality.html' style = minimal
;
proc glimmix data=data1 ;
class  Field Trt ;
model Pol  = Trt  / htype=3 ddfm=kr dist=Gaussian ;
random Field ;
lsmeans Trt / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
proc glimmix data=data1 ;
class  Field Trt ;
model Pur  = Trt  / htype=3 ddfm=kr dist=Gaussian ;
random Field ;
lsmeans Trt / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
proc glimmix data=data1 ;
class  Field Trt ;
model brix  = Trt  / htype=3 ddfm=kr dist=Gaussian ;
random Field ;
lsmeans Trt / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
proc glimmix data=data1 ;
class  Field Trt ;
model CRS  = Trt  / htype=3 ddfm=kr dist=Gaussian ;
random Field ;
lsmeans Trt / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
```

```
run;
```

```
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                             The GLIMMIX Procedure
                            Percent Sucrose (POL)
                               Model Information

                 Data Set                      WORK.DATA1
                 Response Variable             POL
                 Response Distribution         Gaussian
                 Link Function                 Identity
                 Variance Function             Default
                 Variance Matrix               Not blocked
                 Estimation Technique          Restricted Maximum Likelihood
                 Degrees of Freedom Method     Kenward-Roger
                 Fixed Effects SE Adjustment   Kenward-Roger

                            Class Level Information
                         Class    Levels    Values

                         field           5    1 2 3 4 5
                         trt           3    B C D

                      Number of Observations Read         130
                      Number of Observations Used         130

                                  Dimensions
                        G-side Cov. Parameters         1
                        R-side Cov. Parameters         1
                        Columns in X                   4
                        Columns in Z                   5
                        Subjects (Blocks in V)         1
                        Max Obs per Subject          130

                           Optimization Information
                    Optimization Technique        Dual Quasi-Newton
                    Parameters in Optimization    1
                    Lower Boundaries              1
                    Upper Boundaries              0
                    Fixed Effects                 Profiled
                    Residual Variance             Profiled
                    Starting From                 Data

                              Iteration History
                                          Objective                       Max
     Iteration    Restarts    Evaluations         Function          Change    Gradient

             0           0              4    209.65163212       .             0.786074
             1           0              3    209.62438108      0.02725105     0.27281
             2           0              2    209.62176364      0.00261744    0.087835
             3           0              2    209.62150377      0.00025987    0.006761
             4           0              2    209.62150217      0.00000160    0.000153
             5           0              2    209.62150216      0.00000000     2.74E-7

                     Convergence criterion (GCONV=1E-8) satisfied.
```

```
                                           Fit Statistics
                                -2 Res Log Likelihood         209.62
                                AIC  (smaller is better)      213.62
                                AICC (smaller is better)      213.72
                                BIC  (smaller is better)      212.84
                                CAIC (smaller is better)      214.84
                                HQIC (smaller is better)      211.53
                                Generalized Chi-Square         32.67
                                Gener. Chi-Square / DF          0.26

                                   Covariance Parameter Estimates
                                                          Standard
                                  Cov Parm    Estimate       Error
                                  field           0.1244     0.09467
                                  Residual      0.2573     0.03280

                                  Type III Tests of Fixed Effects
                                        Num      Den
                          Effect         DF       DF    F Value    Pr > F
                          trt             2    123.6      13.94    <.0001


------------------------- Effect=trt   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---

                                      Standard
                    Standard          Error of                             Lower    Upper Letter
   Obs trt Estimate  Error       Mean   Mean    Alpha    Lower    Upper      Mean    Mean Group

    1   D   14.5192   0.1743  14.5192   0.1743   0.05  14.0749  14.9634  14.0749  14.9634   A
    2   B   14.1965   0.1796  14.1965   0.1796   0.05  13.7530  14.6400  13.7530  14.6400   B
    3   C   13.9637   0.1748  13.9637   0.1748   0.05  13.5194  14.4081  13.5194  14.4081   B

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                                       The GLIMMIX Procedure
                                          Juice Purity

                                         Model Information

                    Data Set                       WORK.DATA1
                    Response Variable              Pur
                    Response Distribution          Gaussian
                    Link Function                  Identity
                    Variance Function              Default
                    Variance Matrix                Not blocked
                    Estimation Technique           Restricted Maximum Likelihood
                    Degrees of Freedom Method      Kenward-Roger
                    Fixed Effects SE Adjustment    Kenward-Roger

                                      Class Level Information
                                   Class    Levels    Values
                                   field         5    1 2 3 4 5
                                   trt         3    B C D
```

```
                 Number of Observations Read         130
                 Number of Observations Used         130

                              Dimensions
                     G-side Cov. Parameters         1
                     R-side Cov. Parameters         1
                     Columns in X                   4
                     Columns in Z                   5
                     Subjects (Blocks in V)         1
                     Max Obs per Subject          130

                        Optimization Information
             Optimization Technique        Dual Quasi-Newton
             Parameters in Optimization    1
             Lower Boundaries              1
             Upper Boundaries              0
             Fixed Effects                 Profiled
             Residual Variance             Profiled
             Starting From                 Data

                             Iteration History
                                          Objective                       Max
   Iteration    Restarts    Evaluations    Function          Change    Gradient

           0           0              4    477.68892338       .           0.433986
           1           0              4    477.68602878      0.00289460    0.020752
           2           0              2     477.6860228      0.00000598    0.001662
           3           0              2    477.68602276      0.00000004    5.776E-6

              Convergence criterion (GCONV=1E-8) satisfied.

                              Fit Statistics
                   -2 Res Log Likelihood        477.69
                   AIC  (smaller is better)     481.69
                   AICC (smaller is better)     481.78
                   BIC  (smaller is better)     480.90
                   CAIC (smaller is better)     482.90
                   HQIC (smaller is better)     479.59
                   Generalized Chi-Square       273.67
                   Gener. Chi-Square / DF         2.15

                      Covariance Parameter Estimates
                                            Standard
                     Cov Parm    Estimate      Error
                     field         0.6233     0.5003
                     Residual      2.1549     0.2748

                     Type III Tests of Fixed Effects
                           Num      Den
             Effect         DF       DF    F Value    Pr > F
             trt             2    123.9       4.15    0.0180


------------------------ Effect=trt   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---
```

```
                                      Standard
                    Standard          Error of                                Lower    Upper Letter
   Obs trt Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group

    1   D   85.2887   0.4133  85.2887   0.4133   0.05  84.2698  86.3077  84.2698  86.3077   A
    2   B   85.0371   0.4317  85.0371   0.4317   0.05  84.0127  86.0615  84.0127  86.0615   AB
    3   C   84.4252   0.4151  84.4252   0.4151   0.05  83.4049  85.4455  83.4049  85.4455   B
```

```
                                       The GLIMMIX Procedure
                                              Brix
                                         Model Information

                    Data Set                       WORK.DATA1
                    Response Variable              Brix
                    Response Distribution          Gaussian
                    Link Function                  Identity
                    Variance Function              Default
                    Variance Matrix                Not blocked
                    Estimation Technique           Restricted Maximum Likelihood
                    Degrees of Freedom Method      Kenward-Roger
                    Fixed Effects SE Adjustment    Kenward-Roger

                                      Class Level Information
                                   Class    Levels    Values
                                   field           5    1 2 3 4 5
                                   trt           3    B C D

                              Number of Observations Read         130
                              Number of Observations Used         130

                                             Dimensions
                                  G-side Cov. Parameters         1
                                  R-side Cov. Parameters         1
                                  Columns in X                   4
                                  Columns in Z                   5
                                  Subjects (Blocks in V)         1
                                  Max Obs per Subject          130

                                     Optimization Information
                          Optimization Technique        Dual Quasi-Newton
                          Parameters in Optimization    1
                          Lower Boundaries              1
                          Upper Boundaries              0
                          Fixed Effects                 Profiled
                          Residual Variance             Profiled
                          Starting From                 Data

                                            Iteration History
                                                      Objective                          Max
                Iteration    Restarts    Evaluations        Function          Change    Gradient

                        0           0              4    255.41715996       .            0.774658
                        1           0              3    255.39806588      0.01909407    0.036456
```

```
                  2           0              2    255.39803462      0.00003126    0.008119
                  3           0              2    255.39803302      0.00000161    0.000066
                  4           0              2    255.39803302      0.00000000    1.183E-7

                           Convergence criterion (GCONV=1E-8) satisfied.

                                           Fit Statistics
                                -2 Res Log Likelihood        255.40
                                AIC  (smaller is better)     259.40
                                AICC (smaller is better)     259.49
                                BIC  (smaller is better)     258.62
                                CAIC (smaller is better)     260.62
                                HQIC (smaller is better)     257.30
                                Generalized Chi-Square        47.12
                                Gener. Chi-Square / DF         0.37

                                   Covariance Parameter Estimates
                                                       Standard
                                  Cov Parm    Estimate       Error
                                  field           0.1477      0.1142
                                  Residual      0.3710     0.04730

                                  Type III Tests of Fixed Effects
                                        Num      Den
                          Effect         DF       DF    F Value    Pr > F
                          trt             2    123.7       7.47    0.0009


------------------------- Effect=trt   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---
                                      Standard
                 Standard             Error of                              Lower    Upper Letter
   Obs trt Estimate  Error        Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group

     1   D   17.0267   0.1936  17.0267   0.1936   0.05  16.5393  17.5141  16.5393  17.5141   A
     2   B   16.6949   0.2004  16.6949   0.2004   0.05  16.2074  17.1825  16.2074  17.1825   B
     3   C   16.5469   0.1943  16.5469   0.1943   0.05  16.0593  17.0346  16.0593  17.0346   B

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                                       The GLIMMIX Procedure
```

CRS

```
                                         Model Information

                 Data Set                       WORK.DATA1
                 Response Variable              CRS
                 Response Distribution          Gaussian
                 Link Function                  Identity
                 Variance Function              Default
                 Variance Matrix                Not blocked
                 Estimation Technique           Restricted Maximum Likelihood
                 Degrees of Freedom Method      Kenward-Roger
                 Fixed Effects SE Adjustment    Kenward-Roger

                                      Class Level Information
```

```
                         Class    Levels    Values
                         field           5    1 2 3 4 5
                         trt           3    B C D

                    Number of Observations Read         130
                    Number of Observations Used         130

                                   Dimensions
                        G-side Cov. Parameters         1
                        R-side Cov. Parameters         1
                        Columns in X                   4
                        Columns in Z                   5
                        Subjects (Blocks in V)         1
                        Max Obs per Subject          130

                           Optimization Information
                Optimization Technique        Dual Quasi-Newton
                Parameters in Optimization    1
                Lower Boundaries              1
                Upper Boundaries              0
                Fixed Effects                 Profiled
                Residual Variance             Profiled
                Starting From                 Data

                                Iteration History
                                           Objective                         Max
Iteration    Restarts    Evaluations        Function          Change    Gradient

        0           0              4    937.43470262       .             0.09258
        1           0              4    937.43405478      0.00064784    0.004957
        2           0              2      937.434053      0.00000178    0.000183

                 Convergence criterion (GCONV=1E-8) satisfied.

                                 Fit Statistics
                      -2 Res Log Likelihood         937.43
                      AIC  (smaller is better)      941.43
                      AICC (smaller is better)      941.53
                      BIC  (smaller is better)      940.65
                      CAIC (smaller is better)      942.65
                      HQIC (smaller is better)      939.34
                      Generalized Chi-Square       9957.28
                      Gener. Chi-Square / DF         78.40


                         Covariance Parameter Estimates
                                                Standard
                        Cov Parm    Estimate       Error
                        field          55.5866     41.4728
                        Residual     78.4038      9.9975


                        Type III Tests of Fixed Effects
                              Num      Den
                Effect         DF       DF    F Value    Pr > F
                trt             2    123.4      16.03    <.0001
```

```
------------------------ Effect=trt   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---
                                    Standard
                   Standard         Error of                                   Lower    Upper Letter
  Obs trt Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group

    1  D    208.24   3.5771   208.24   3.5771   0.05   198.90   217.58   198.90   217.58   A
    2  B    202.99   3.6556   202.99   3.6556   0.05   193.70   212.29   193.70   212.29   B
    3  C    197.79   3.5847   197.79   3.5847   0.05   188.46   207.13   188.46   207.13   C
```

APENDIX C

NEONATE ESTABLISHMENT STATISTICAL ANALYSIS

```
Dm 'output;clear;log;clear';
Title1'GH by plant';
data data1;
input Age$ Var$ Rep$ Eggs Hatch Midrib Vis Est Entry Surv;
cards;
I 950 1 39  18    2 1   3     3 1       M 950 1 73  56    7 11  18    8 0
I 950 2 22  12    2 1   3     1 1       M 950 2 37  34    6 14  20    13 1
I 950 3 46  31    11 1  12    2 1       M 950 3 86  51    4 6   10    1 0
I 950 4 35  19    2 0   2     1 1       M 950 4 20  20    6 8   14    5 0
I 950 5 24  16    1 2   3     3 2       M 950 5 43  19    5 7   12    4 0
I 950 6 47  22    1 3   4     3 1       M 950 6 77  58    8 6   14    8 0
I 950 7 14  8     1 0   1     1 1       M 950 7 64  39    4 4   8     3 0
I 950 8 14  13    1 2   3     3 1       M 950 8 37  22    2 6   8     1 0
I 950 9 24  15    2 0   2     1 1       M 950 9 48  33    5 4   9     0 0
I 950 10 42 26    1 1   2     2 1       M 950 10 63 51    4 2   6     2 0
I 950 11 47 26    1 1   2     2 1       M 950 11 41 17    3 2   5     1 0
I 950 12 20 14    2 1   3     2 0       M 950 12 40 33    3 7   10    9 0
I 845 1 29  27    1 4   5     2 1       M 845 1 70  59    0 9   9     3 0
I 845 2 20  16    1 2   3     2 0       M 845 2 50  27    2 4   6     1 0
I 845 3 27  13    0 1   1     1 0       M 845 3 48  41    0 3   3     1 0
I 845 4 26  21    2 1   3     2 1       M 845 4 45  34    4 4   8     2 0
I 845 5 23  16    2 0   2     1 0       M 845 5 32  19    3 4   7     2 0
I 845 6 18  9     0 1   1     1 1       M 845 6 30  16    1 3   4     0 0
I 845 7 22  6     0 2   2     2 1       M 845 7 49  29    3 5   8     2 0
I 845 8 27  17    0 2   2     2 2       M 845 8 29  21    1 3   4     1 0
I 845 9 54  26    0 2   2     2 1       M 845 9 36  27    0 3   3     1 0
I 845 10 20 19    0 3   3     2 1       M 845 10 48 28    6 4   10    4 0
I 845 11 26 21    0 3   3     3 2       M 845 11 34 10    1 3   4     1 0
I 845 12 22 15    1 1   2     1 0       M 845 12 38 23    3 4   7     2 0
;proc glimmix data=data1 ;
class Age Var Rep;
model Midrib/est = Age|Var  / htype=3 ddfm=kr dist=binomial ;
lsmeans Age|Var / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
;%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data1 ;
class Age Var Rep;
model Est/Hatch  = Age|Var  / htype=3 ddfm=kr dist=binomial ;
lsmeans Age|Var / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
;%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
proc glimmix data=data1 ;
class Age Var Rep;
model Entry/Est = Age|Var  / htype=3 ddfm=kr dist=binomial ;
lsmeans Age|Var / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
;%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

Proc glimmix data=data1 ;
class Age Var Rep;
model Surv/Est = Age|Var  / htype=3 ddfm=kr dist=binomial ;
lsmeans Age|Var / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
;%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data1 ;
class Age Var Rep;
model Entry/Hatch = Age|Var  / htype=3 ddfm=kr dist=binomial ;
lsmeans Age|Var / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
;%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
GH by plant          10:02 Thursday, March 31, 2011  43
                                The GLIMMIX Procedure
                                    Midrib Entry
                                  Model Information
                          Data Set                     WORK.DATA1
                          Response Variable (Events)   Midrib
                          Response Variable (Trials)   Est
                          Response Distribution        Binomial
                          Link Function                Logit
                          Variance Function            Default
                          Variance Matrix              Diagonal
                          Estimation Technique         Maximum Likelihood
                          Degrees of Freedom Method    Residual


                               Class Level Information
                           Class    Levels    Values
                           Age           2    I M
                           Var           2    845 950
                           Rep          12    1 10 11 12 2 3 4 5 6 7 8 9

                              Number of Observations Read         48
                              Number of Observations Used         48
```

```
                              Number of Events                    115
                              Number of Trials                    276

                                             Dimensions
                                  Columns in X                   9
                                  Columns in Z                   0
                                  Subjects (Blocks in V)         1
                                  Max Obs per Subject           48

                                      Optimization Information
                            Optimization Technique        Newton-Raphson
                            Parameters in Optimization    4
                            Lower Boundaries              0
                            Upper Boundaries              0
                            Fixed Effects                 Not Profiled

                                          Iteration History
                                                     Objective                         Max
          Iteration    Restarts    Evaluations        Function          Change    Gradient
                  0           0              4    65.067131257       .            1.489971
                  1           0              3    64.831676436      0.23545482    0.029752
                  2           0              3    64.831579122      0.00009731    0.000018
                  3           0              3    64.831579122      0.00000000    5.72E-12

                           Convergence criterion (GCONV=1E-8) satisfied.

                                           Fit Statistics
                                -2 Log Likelihood             129.66
                                AIC  (smaller is better)      137.66
                                AICC (smaller is better)      138.59
                                BIC  (smaller is better)      145.15
                                CAIC (smaller is better)      149.15
                                HQIC (smaller is better)      140.49
                                Pearson Chi-Square             47.21
                                Pearson Chi-Square / DF         1.07

                                  Type III Tests of Fixed Effects
                                        Num      Den
                          Effect         DF       DF    F Value    Pr > F

                          Age             1       44       0.91    0.3447
                          Var             1       44      13.27    0.0007
                          Age*Var         1       44       5.42    0.0246

------------------------ Effect=Age   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---
                                        Standard
                      Standard          Error of                             Lower    Upper Ltter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group
  1   I       -0.2071   0.2749   0.4484  0.06799   0.05  -0.7611   0.3469   0.3184   0.5859   A
  2   M       -0.5073   0.1522   0.3758  0.03569   0.05  -0.8139  -0.2006   0.3071   0.4500   A

------------------------ Effect=Var   Method=Tukey-Kramer(P<.05)   Set=2 -----------------------
---

                                        Standard
```

```
                      Standard         Error of                             Lower    Upper
Letter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group

  3      950   0.2151   0.1901   0.5536  0.04697   0.05  -0.1680   0.5981   0.4581   0.6452   A
  4      845  -0.9294   0.2502   0.2830  0.05077   0.05  -1.4337  -0.4252   0.1925   0.3953   B

---------------------- Effect=Age*Var   Method=Tukey-Kramer(P<.05)   Set=3 --------------------
---
                                        Standard
                      Standard         Error of                             Lower    Upper Ltter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group

  5   I  950   0.7309   0.3376   0.6750  0.07406   0.05  0.05054   1.4112   0.5126   0.8040   A
  6   M  950  -0.3008   0.1747   0.4254  0.04271   0.05  -0.6529  0.05139   0.3423   0.5128   B
  7   M  845  -0.7138   0.2491   0.3288  0.05498   0.05  -1.2159  -0.2116   0.2287   0.4473   B
  8   I  845  -1.1451   0.4339   0.2414  0.07946   0.05  -2.0197  -0.2706   0.1172   0.4328   B

                                       The GLIMMIX Procedure
                                       Percent Established
                                         Model Information
                          Data Set                      WORK.DATA1
                          Response Variable (Events)    Est
                          Response Variable (Trials)    Hatch
                          Response Distribution         Binomial
                          Link Function                 Logit
                          Variance Function             Default
                          Variance Matrix               Diagonal
                          Estimation Technique          Maximum Likelihood
                          Degrees of Freedom Method     Residual

                                    Class Level Information
                           Class    Levels    Values
                           Age           2    I M
                           Var           2    845 950
                           Rep          12    1 10 11 12 2 3 4 5 6 7 8 9


                               Number of Observations Read          48
                               Number of Observations Used          48
                               Number of Events                    276
                               Number of Trials                   1193

                                           Dimensions
                                   Columns in X                9
                                   Columns in Z                0
                                   Subjects (Blocks in V)      1
                                   Max Obs per Subject        48

                                    Optimization Information
                            Optimization Technique        Newton-Raphson
                            Parameters in Optimization    4
                            Lower Boundaries              0
                            Upper Boundaries              0
                            Fixed Effects                 Not Profiled
```

```
                                          Iteration History
                                                     Objective                         Max
          Iteration    Restarts    Evaluations        Function          Change    Gradient

                  0           0              4    117.40174713       .             13.5412
                  1           0              3    116.92037584      0.48137129    0.251043
                  2           0              3    116.92013648      0.00023935    0.000143
                  3           0              3    116.92013648      0.00000000    7.39E-11

                           Convergence criterion (GCONV=1E-8) satisfied.

                                           Fit Statistics
                                -2 Log Likelihood             233.84
                                AIC  (smaller is better)      241.84
                                AICC (smaller is better)      242.77
                                BIC  (smaller is better)      249.33
                                CAIC (smaller is better)      253.33
                                HQIC (smaller is better)      244.67
                                Pearson Chi-Square             87.92
                                Pearson Chi-Square / DF         2.00

                                  Type III Tests of Fixed Effects
                                        Num      Den
                          Effect         DF       DF    F Value    Pr > F

                          Age             1       44      15.43    0.0003
                          Var             1       44       6.08    0.0176
                          Age*Var         1       44       0.28    0.5990

------------------------- Effect=Age   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---
                                        Standard
                      Standard          Error of                                             Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group

  1   M       -1.0383  0.08417   0.2615  0.01625   0.05  -1.2080  -0.8687   0.2301   0.2955   A
  2   I       -1.6565   0.1329   0.1602  0.01789   0.05  -1.9244  -1.3886   0.1274   0.1996   B

------------------------- Effect=Var   Method=Tukey-Kramer(P<.05)   Set=2 -----------------------
---
                                        Standard
                      Standard          Error of                                             Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group
  3      950  -1.1533   0.1017   0.2399  0.01854   0.05  -1.3583  -0.9484   0.2045   0.2792   A
  4      845  -1.5415   0.1201   0.1763  0.01744   0.05  -1.7834  -1.2995   0.1439   0.2143   B

----------------------- Effect=Age*Var   Method=Tukey-Kramer(P<.05)   Set=3 ---------------------
---
                                        Standard
                      Standard          Error of                                             Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group
  5   M  950  -0.8026   0.1040   0.3095  0.02222   0.05  -1.0121  -0.5931   0.2666   0.3559   A
  6   M  845  -1.2741   0.1324   0.2186  0.02261   0.05  -1.5409  -1.0072   0.1764   0.2675   B
  7   I  950  -1.5041   0.1748   0.1818  0.02600   0.05  -1.8564  -1.1518   0.1351   0.2402   B
  8   I  845  -1.8089   0.2003   0.1408  0.02423   0.05  -2.2126  -1.4051  0.09863   0.1970   B
```

```
                             The GLIMMIX Procedure
                       Percent Surviving to Stalk Entry
                               Model Information
                Data Set                      WORK.DATA1
                Response Variable (Events)    Entry
                Response Variable (Trials)    Est
                Response Distribution         Binomial
                Link Function                 Logit
                Variance Function             Default
                Variance Matrix               Diagonal
                Estimation Technique          Maximum Likelihood
                Degrees of Freedom Method     Residual

                            Class Level Information
                 Class    Levels    Values
                 Age           2    I M
                 Var           2    845 950
                 Rep          12    1 10 11 12 2 3 4 5 6 7 8 9

                    Number of Observations Read          48
                    Number of Observations Used          48
                    Number of Events                    120
                    Number of Trials                    276

                                   Dimensions
                        Columns in X                   9
                        Columns in Z                   0
                        Subjects (Blocks in V)         1
                        Max Obs per Subject           48


                            Optimization Information
                  Optimization Technique        Newton-Raphson
                  Parameters in Optimization    4
                  Lower Boundaries              0
                  Upper Boundaries              0
                  Fixed Effects                 Not Profiled

                                Iteration History
                                           Objective                        Max
Iteration    Restarts    Evaluations        Function         Change    Gradient
        0           0              4    73.452876663       .           2.368632
        1           0              3    73.362663278     0.09021339    0.005842
        2           0              3    73.362657543     0.00000574    1.215E-6

              Convergence criterion (ABSGCONV=0.00001) satisfied.

                                 Fit Statistics
                      -2 Log Likelihood            146.73
                      AIC  (smaller is better)     154.73
                      AICC (smaller is better)     155.66
                      BIC  (smaller is better)     162.21
                      CAIC (smaller is better)     166.21
                      HQIC (smaller is better)     157.55
                      Pearson Chi-Square            61.92
                      Pearson Chi-Square / DF        1.41
```

```
                                  Type III Tests of Fixed Effects
                                        Num      Den
                          Effect         DF       DF    F Value    Pr > F
                          Age             1       44      19.47    <.0001
                          Var             1       44       0.01    0.9318
                          Age*Var         1       44       3.65    0.0626

------------------------ Effect=Age   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---
                                        Standard
                      Standard          Error of                                      Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean   Alpha    Lower    Upper     Mean     Mean Group
   1  I        0.6853   0.2631   0.6649  0.05861   0.05   0.1551   1.2154   0.5387   0.7713   A
   2  M       -0.6683   0.1579   0.3389  0.03537   0.05  -0.9865  -0.3501   0.2716   0.4133   B


------------------------ Effect=Var   Method=Tukey-Kramer(P<.05)   Set=2 -----------------------
---
                                        Standard
                      Standard          Error of                                      Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean   Alpha    Lower    Upper     Mean     Mean Group
   3      950  0.02168   0.1837   0.5054  0.04592   0.05  -0.3486   0.3919   0.4137   0.5967   A
   4      845 -0.00474   0.2457   0.4988  0.06143   0.05  -0.4999   0.4904   0.3776   0.6202   A

---------------------- Effect=Age*Var   Method=Tukey-Kramer(P<.05)   Set=3 ---------------------
---
                                        Standard
                      Standard          Error of                                      Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean   Alpha    Lower    Upper     Mean     Mean Group
   5  I   845   0.9651   0.4155   0.7241  0.08300   0.05   0.1277   1.8024   0.5319   0.8584   A
   6  I   950   0.4055   0.3227   0.6000  0.07746   0.05  -0.2450   1.0559   0.4391   0.7419   AB
   7  M   950  -0.3621   0.1756   0.4104  0.04249   0.05  -0.7160 -0.00819   0.3283   0.4980   BC
   8  M   845  -0.9746   0.2624   0.2740  0.05220   0.05  -1.5034  -0.4457   0.1819   0.3904   C




                                      The GLIMMIX Procedure
                                  Percent Surviving to Pupation
                                         Model Information
                          Data Set                      WORK.DATA1
                          Response Variable (Events)    Surv
                          Response Variable (Trials)    Est
                          Response Distribution         Binomial
                          Link Function                 Logit
                          Variance Function             Default
                          Variance Matrix               Diagonal
                          Estimation Technique          Maximum Likelihood
                          Degrees of Freedom Method     Residual

                                      Class Level Information
                           Class    Levels    Values


                           Age           2    I M
```

```
                 Var           2    845 950
                 Rep          12    1 10 11 12 2 3 4 5 6 7 8 9

                    Number of Observations Read          48
                    Number of Observations Used          48
                    Number of Events                     23
                    Number of Trials                    276

                                   Dimensions
                        Columns in X                   9
                        Columns in Z                   0
                        Subjects (Blocks in V)         1
                        Max Obs per Subject           48

                            Optimization Information
                  Optimization Technique        Newton-Raphson
                  Parameters in Optimization    4
                  Lower Boundaries              0
                  Upper Boundaries              0
                  Fixed Effects                 Not Profiled

                                Iteration History
                                           Objective                         Max
Iteration    Restarts    Evaluations        Function          Change    Gradient
        0           0              4    31.487305762       .            4.877972
        1           0              3    29.465963171      2.02134259    1.198385
        2           0              3     28.93929815      0.52666502    0.322946
        3           0              3    28.777136788      0.16216136    0.094843
        4           0              3      28.7185603      0.05857649    0.034036
        5           0              3    28.697037756      0.02152254    0.012518
        6           0              3    28.689123509      0.00791425    0.004605
        7           0              3    28.686212488      0.00291102    0.001694
        8           0              3    28.685141646      0.00107084    0.000623
        9           0              3    28.684747714      0.00039393    0.000229
       10           0              3    28.684602796      0.00014492    0.000084
       11           0              3    28.684549483      0.00005331    0.000031
       12           0              3    28.684529871      0.00001961    0.000011
       13           0              3    28.684522656      0.00000722    4.199E-6

              Convergence criterion (ABSGCONV=0.00001) satisfied.
                                 Fit Statistics
                      -2 Log Likelihood              57.37
                      AIC  (smaller is better)       65.37
                      AICC (smaller is better)       66.30
                      BIC  (smaller is better)       72.85
                      CAIC (smaller is better)       76.85
                      HQIC (smaller is better)       68.20
                      Pearson Chi-Square             27.76
                      Pearson Chi-Square / DF         0.63

                        Type III Tests of Fixed Effects
                              Num      Den
                Effect         DF       DF    F Value    Pr > F
                Age             1       44       0.00    0.9674
                Var             1       44       0.00    0.9812
                Age*Var         1       44       0.00    0.9805
```

```
------------------------ Effect=Age   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---
                                        Standard
                      Standard          Error of                             Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group
  1   I       -0.7446   0.2606   0.3220  0.05690   0.05  -1.2698  -0.2193   0.2193   0.4454   A
  2   M      -10.7807   244.01 0.000021 0.005074   0.05  -502.54   480.98 561E-221   1.0000   A


------------------------ Effect=Var   Method=Tukey-Kramer(P<.05)   Set=2 -----------------------
---
                                        Standard
                      Standard          Error of                             Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group
  3      950   -2.8688   0.5307  0.05372  0.02698   0.05  -3.9384  -1.7993  0.01911   0.1419   A
  4      845   -8.6565   244.00 0.000174  0.04244   0.05  -500.42   483.10  47E-219   1.0000   A


---------------------- Effect=Age*Var   Method=Tukey-Kramer(P<.05)   Set=3 ---------------------
---
                                        Standard
                      Standard          Error of                             Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group
  5   I   845   -0.6419   0.3907   0.3448  0.08826   0.05  -1.4292   0.1455   0.1932   0.5363   A
  6   I   950   -0.8473   0.3450   0.3000  0.07246   0.05  -1.5427  -0.1519   0.1761   0.4621   A
  7   M   950   -4.8903   1.0038 0.007463 0.007435   0.05  -6.9133  -2.8674 0.000994  0.05379   B
  8   M   845  -16.6711   488.01 5.752E-8 0.000028   0.05 -1000.19   966.85        0   1.0000   AB

                                      The GLIMMIX Procedure
                                   Percent (Hatch) Stalk Entry
                                         Model Information
                          Data Set                       WORK.DATA1
                          Response Variable (Events)     Entry
                          Response Variable (Trials)     Hatch
                          Response Distribution          Binomial
                          Link Function                  Logit
                          Variance Function              Default
                          Variance Matrix                Diagonal
                          Estimation Technique           Maximum Likelihood
                          Degrees of Freedom Method      Residual
                                      Class Level Information
                           Class    Levels    Values
                           Age           2    I M
                           Var           2    845 950
                           Rep          12    1 10 11 12 2 3 4 5 6 7 8 9

                               Number of Observations Read          48
                               Number of Observations Used          48
                               Number of Events                    120
                               Number of Trials                   1193
                                             Dimensions
                                   Columns in X                9
                                   Columns in Z                0
                                   Subjects (Blocks in V)      1
                                   Max Obs per Subject        48
```

```
                                      Optimization Information
                            Optimization Technique        Newton-Raphson
                            Parameters in Optimization    4
                            Lower Boundaries              0
                            Upper Boundaries              0
                            Fixed Effects                 Not Profiled

                                          Iteration History
                                                     Objective                         Max
          Iteration    Restarts    Evaluations        Function          Change    Gradient
                  0           0              4    92.609074526       .             20.9784
                  1           0              3    90.182780032      2.42629449    1.546366
                  2           0              3    90.163709811      0.01907022    0.014015
                  3           0              3    90.163707878      0.00000193    1.442E-6

                        Convergence criterion (ABSGCONV=0.00001) satisfied.

                                           Fit Statistics
                                -2 Log Likelihood             180.33
                                AIC  (smaller is better)      188.33
                                AICC (smaller is better)      189.26
                                BIC  (smaller is better)      195.81
                                CAIC (smaller is better)      199.81
                                HQIC (smaller is better)      191.16
                                Pearson Chi-Square             65.47
                                Pearson Chi-Square / DF         1.49

                                  Type III Tests of Fixed Effects
                                        Num      Den
                          Effect         DF       DF    F Value    Pr > F
                          Age             1       44       0.95    0.3362
                          Var             1       44       4.68    0.0360
                          Age*Var         1       44       3.24    0.0788

------------------------- Effect=Age   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---
                                        Standard
                      Standard          Error of                             Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group
  1   I       -2.1379   0.1580   0.1055  0.01490    0.05  -2.4563  -1.8196  0.07898   0.1395   A
  2   M       -2.3406   0.1360  0.08781  0.01090    0.05  -2.6148  -2.0665  0.06819   0.1124   A
------------------------- Effect=Var   Method=Tukey-Kramer(P<.05)   Set=2 -----------------------
---
                                        Standard
                      Standard          Error of                             Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group
  3      950  -2.0138   0.1300   0.1178  0.01351    0.05  -2.2758  -1.7518  0.09315   0.1478   A
  4      845  -2.4647   0.1629  0.07837  0.01177    0.05  -2.7931  -2.1363  0.05770   0.1056   B

----------------------- Effect=Age*Var   Method=Tukey-Kramer(P<.05)   Set=3 ---------------------
---
                                        Standard
                      Standard          Error of                             Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean     Mean Group
  5   M  950  -1.9276   0.1443   0.1270  0.01600    0.05  -2.2184  -1.6367  0.09811   0.1629   A
```

```
 6   I  950  -2.1001   0.2163   0.1091  0.02102   0.05  -2.5359  -1.6642  0.07338   0.1592   AB
 7   I  845  -2.1758   0.2303   0.1019  0.02108   0.05  -2.6399  -1.7118  0.06661   0.1529   AB
 8   M  845  -2.7537   0.2306  0.05988  0.01298   0.05  -3.2184  -2.2889  0.03848  0.09205   B
```

DISPERSAL AND EXPOSURE (ALL LARVAE)

```
dm'output;clear;log;clear';
Title1'GH All Larvae';
data data1;
input Age$ Var$ Rep$ Midrib Stalk Exp Disp AbsDisp Surv;
cards;
I 845 1     1     1     1     0     0     1
I 845 2     1     1     1     0     0     0
I 845 4     1     1     1     0     0     1
I 845 5     1     1     1     0     0     0
I 950 1     1     1     1     0     0     0
I 950 1     1     1     1     1     1     0
I 950 3     1     1     1     0     0     1
I 950 5     1     1     1     0     0     1
I 950 6     1     1     1     0     0     1
I 950 7     1     1     1     0     0     1
I 950 8     1     1     1     0     0     0
I 950 9     1     1     1     0     0     1
I 950 9     1     0     1     0     0     0
I 950 10    1     1     1     0     0     0
I 950 11    1     1     1     1     1     1
I 950 12    1     1     1     0     0     0
M 845 2     1     1     1     0     0     0
M 845 4     1     1     1     0     0     0
M 845 10    1     1     1     0     0     0
M 845 10    1     1     1     0     0     0
M 845 10    1     1     1     0     0     0
M 950 2     1     1     1     0     0     0
M 950 2     1     1     1     0     0     0
M 950 2     1     1     1     0     0     0
M 950 4     1     1     1     0     0     0
M 950 4     1     1     1     0     0     0
M 950 4     1     1     1     0     0     0
M 950 5     1     1     1     0     0     0
M 950 5     1     1     1     0     0     0
M 950 5     1     1     1     0     0     0
M 950 6     1     1     1     0     0     0
M 950 6     1     1     1     0     0     0
M 950 6     1     1     1     0     0     0
M 950 6     1     1     1     0     0     0
M 950 6     1     1     1     0     0     0
M 950 7     1     1     1     0     0     0
M 950 7     1     1     1     0     0     0
M 950 10    1     1     1     0     0     0
M 950 11    1     1     1     0     0     0
M 950 12    1     1     1     0     0     0
M 950 12    1     1     1     0     0     0
M 950 12    1     1     1     0     0     0
I 950 3     0     1     4     3     3     0
I 950 5     0     1     4     1     1     0
I 950 6     0     1     4     1     1     0
I 950 10    0     1     4     3     3     1
I 950 11    0     1     4     4     4     0
I 845 10    0     1     5     5     5     0
I 950 5     0     1     5     3     3     1
M 950 1     0     1     5     -1    1     0
M 950 4     0     1     5     0     0     0
M 950 12    0     1     5     -1    1     0
I 845 10    0     1     6     1     1     1
I 845 1     0     1     6     1     1     0
I 845 9     0     1     6     1     1     1
I 950 2     0     1     6     3     3     1
I 950 8     0     1     6     2     2     0
M 845 5     0     1     6     1     1     0
M 950 1     0     1     6     -3    3     0
M 950 1     0     1     6     -2    2     0
M 950 2     0     1     6     -2    2     0
M 950 2     0     1     6     -1    1     0
M 950 2     0     1     6     0     0     0
M 950 6     0     1     6     0     0     0
M 950 7     0     1     6     -1    1     0
I 845 9     0     1     7     5     5     0
I 845 11    0     1     7     0     0     0
I 845 11    0     1     7     5     5     1
I 845 12    0     1     7     2     2     0
I 845 6     0     1     7     0     0     1
I 845 8     0     1     7     0     0     1
I 845 8     0     1     7     2     2     1
I 950 1     0     1     7     4     4     1
I 950 4     0     1     7     4     4     1
I 950 6     0     1     7     3     3     0
I 950 12    0     1     7     4     4     0
M 845 1     0     1     7     -1    1     0
M 845 7     0     1     7     1     1     0
M 845 9     0     1     7     0     0     0
M 845 11    0     1     7     2     2     0
M 845 12    0     1     7     0     0     0
M 950 1     0     1     7     -4    4     0
M 950 2     0     1     7     -2    2     0
M 950 2     0     1     7     -1    1     0
```

```
M 950 4     0     1     7     -2    2     0
M 950 5     0     1     7     2     2     0
M 950 5     0     1     7     3     3     0
M 950 6     0     1     7     1     1     0
M 950 12    0     1     7     -2    2     0
M 950 12    0     1     7     0     0     0
M 950 12    0     1     7     1     1     0
I 845 2     0     1     8     6     6     0
I 845 3     0     1     8     0     0     0
I 845 4     0     1     8     4     4     0
I 845 7     0     1     8     0     0     1
I 845 7     0     1     8     3     3     0
I 950 8     0     1     8     5     5     1
M 845 1     0     1     8     0     0     0
M 845 3     0     1     8     0     0     0
M 845 8     0     1     8     0     0     0
M 845 10    0     1     8     0     0     0
M 845 10    0     1     8     1     1     0
M 845 12    0     1     8     -1    1     0
M 950 1     0     1     8     -5    5     0
M 950 1     0     1     8     -5    5     0
M 950 1     0     1     8     -3    3     0
M 950 2     0     1     8     1     1     0
M 950 2     0     1     8     1     1     0
M 950 2     0     1     8     3     3     0
M 950 4     0     1     8     3     3     0
M 950 5     0     1     8     4     4     0
M 950 8     1     0     8     0     0     0
M 950 10    0     1     8     1     1     0
M 950 12    0     1     8     -2    2     0
M 950 12    0     1     8     1     1     0
I 845 11    0     1     9     1     1     1
M 845 1     0     1     9     -2    2     0
M 845 2     0     1     9     0     0     0
M 845 5     0     1     9     5     5     0
M 845 7     0     1     9     3     3     0
M 950 1     0     1     9     -3    3     0
M 950 2     0     1     9     -2    2     0
M 950 2     0     1     9     3     3     0
M 950 4     0     1     9     -2    2     0
M 950 5     0     1     9     2     2     0
M 950 6     0     1     9     -3    3     0
M 950 3     0     1     10    2     2     0
M 950 4     0     1     10    3     3     0
M 950 6     0     1     10    3     3     1
M 845 4     0     1     11    5     5     0
M 950 8     0     1     11    3     3     0
I 845 10    0     0     .     3     3     0
I 845 12    1     0     .     0     0     0
I 845 1     0     0     .     2     2     0
I 845 1     0     0     .     3     3     0
I 845 1     0     0     .     5     5     0
I 845 2     0     0     .     2     2     0
I 845 4     1     0     .     0     0     0
I 845 5     1     0     .     0     0     0
I 950 2     1     0     .     0     0     0
I 950 2     1     0     .     0     0     0
I 950 3     1     0     .     0     0     0
I 950 3     1     0     .     0     0     0
I 950 3     1     0     .     0     0     0
I 950 3     1     0     .     0     0     0
I 950 3     1     0     .     0     0     0
I 950 3     1     0     .     0     0     0
I 950 3     1     0     .     0     0     0
I 950 3     1     0     .     0     0     0
I 950 3     1     0     .     0     0     0
I 950 3     1     0     .     0     0     0
I 950 4     1     0     .     0     0     0
I 950 6     0     0     .     4     4     0
I 950 12    1     0     .     0     0     0
M 845 4     1     0     .     0     0     0
M 845 4     1     0     .     0     0     0
M 845 1     0     0     .     -3    3     0
M 845 1     0     0     .     -2    2     0
M 845 1     0     0     .     1     1     0
M 845 1     0     0     .     2     2     0
M 845 1     0     0     .     2     2     0
M 845 1     0     0     .     3     3     0
M 845 2     0     0     .     -1    1     0
M 845 2     0     0     .     1     1     0
M 845 2     0     0     .     4     4     0
M 845 2     1     0     .     0     0     0
M 845 3     0     0     .     -2    2     0
M 845 3     0     0     .     1     1     0
M 845 4     0     0     .     -1    1     0
M 845 4     0     0     .     2     2     0
M 845 4     0     0     .     3     3     0
M 845 4     1     0     .     0     0     0
M 845 5     0     0     .     1     1     0
M 845 5     0     0     .     2     2     0
M 845 5     1     0     .     0     0     0
M 845 5     1     0     .     0     0     0
M 845 5     1     0     .     0     0     0
M 845 6     0     0     .     -1    1     0
M 845 6     0     0     .     0     0     0
M 845 6     0     0     .     2     2     0
M 845 6     1     0     .     0     0     0
M 845 7     0     0     .     -2    2     0
M 845 7     0     0     .     -1    1     0
M 845 7     0     0     .     0     0     0
M 845 7     1     0     .     0     0     0
M 845 7     1     0     .     0     0     0
M 845 7     1     0     .     0     0     0
M 845 8     0     0     .     -1    1     0
M 845 8     0     0     .     1     1     0
M 845 8     1     1     .     0     0     0
M 845 9     0     0     .     2     2     0
M 845 9     0     0     .     3     3     0
M 845 10    0     0     .     2     2     0
M 845 10    0     0     .     5     5     0
M 845 10    1     0     .     0     0     0
M 845 10    1     0     .     0     0     0
M 845 10    1     0     .     0     0     0
M 845 11    1     0     .     0     0     0
M 845 11    0     0     .     0     0     0
M 845 11    0     0     .     3     3     0
M 845 12    0     0     .     -2    2     0
M 845 12    0     0     .     1     1     0
```

```
M 845 12    1     0     .     0     0     0
M 845 12    1     0     .     0     0     0
M 845 12    1     0     .     0     0     0
M 950 1     0     0     .     0     0     0
M 950 1     0     0     .     2     2     0
M 950 1     0     0     .     3     3     0
M 950 1     1     0     .     0     0     0
M 950 1     1     0     .     0     0     0
M 950 1     1     0     .     0     0     0
M 950 1     1     0     .     0     0     0
M 950 1     1     0     .     0     0     0
M 950 1     1     0     .     0     0     0
M 950 1     1     0     .     0     0     0
M 950 2     0     0     .     -3    3     0
M 950 2     0     0     .     2     2     0
M 950 2     0     0     .     4     4     0
M 950 2     0     0     .     6     6     0
M 950 2     1     0     .     0     0     0
M 950 2     1     0     .     0     0     0
M 950 2     1     0     .     0     0     0
M 950 3     0     0     .     -2    2     0
M 950 3     0     0     .     -1    1     0
M 950 3     0     0     .     0     0     0
M 950 3     0     0     .     1     1     0
M 950 3     0     0     .     4     4     0
M 950 3     1     0     .     0     0     0
M 950 3     1     0     .     0     0     0
M 950 3     1     0     .     0     0     0
M 950 3     1     0     .     0     0     0
M 950 4     0     0     .     -1    1     0
M 950 4     0     0     .     1     1     0
M 950 4     0     0     .     2     2     0
M 950 4     1     0     .     0     0     0
M 950 4     1     0     .     0     0     0
M 950 4     1     0     .     0     0     0
M 950 5     0     0     .     1     1     0
M 950 5     0     0     .     6     6     0
M 950 5     0     0     .     7     7     0
M 950 5     1     0     .     0     0     0
M 950 5     1     0     .     0     0     0
M 950 6     0     0     .     -2    20
M 950 6     0     0     .     2     2     0
M 950 6     1     0     .     0     0     0
M 950 6     1     0     .     0     0     0
M 950 6     1     0     .     0     0     0
M 950 7     0     0     .     -2    2     0
M 950 7     0     0     .     0     0     0
M 950 7     0     0     .     2     2     0
M 950 7     0     0     .     5     5     0
M 950 7     1     0     .     0     0     0
M 950 7     1     0     .     0     0     0
M 950 8     0     0     .     -1    1     0
M 950 8     0     0     .     0     0     0
M 950 8     0     0     .     1     1     0
M 950 8     0     0     .     2     2     0
M 950 8     0     0     .     5     5     0
M 950 8     1     0     .     0     0     0
M 950 9     0     0     .     -1    1     0
M 950 9     0     0     .     0     0     0
M 950 9     0     0     .     1     1     0
M 950 9     0     0     .     4     4     0
M 950 9     1     0     .     0     0     0
M 950 9     1     0     .     0     0     0
M 950 9     1     0     .     0     0     0
M 950 9     1     0     .     0     0     0
M 950 9     1     0     .     0     0     0
M 950 10    0     0     .     -2    2     0
M 950 10    1     0     .     0     0     0
M 950 10    1     0     .     0     0     0
M 950 10    1     0     .     0     0     0
M 950 11    0     0     .     -2    2     0
M 950 11    0     0     .     1     1     0
M 950 11    1     0     .     0     0     0
M 950 11    1     0     .     0     0     0
M 950 12    0     0     .     3     3     0
      ;
      proc glimmix data=data1 ;
      class Age Var Rep ;
      model AbsDisp = Age|Var  / htype=3 ddfm=kr dist=Gaussian ;
      random Rep(Age*Var) ;
      lsmeans Age|Var / ilink diff cl adjust=tukey;
      ods output diffs=ppp lsmeans=mmm;
      ods listing exclude diffs lsmeans;
      run;
      ;%include 'E:\Stats\pdmix800.sas';
      %pdmix800(ppp,mmm,alpha=.05,sort=yes);
      run;
      proc glimmix data=data1 ;
      class Age Var Rep ;
      model Exp = Age|Var  / htype=3 ddfm=kr dist=Gaussian ;
      random Rep(Age*Var) ;
      lsmeans Age|Var / ilink diff cl adjust=tukey;
      ods output diffs=ppp lsmeans=mmm;
      ods listing exclude diffs lsmeans;
      run;
      ;%include 'E:\Stats\pdmix800.sas';
```

```
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
                              The GLIMMIX Procedure
                                    Dispersal
                                Model Information
               Data Set                      WORK.DATA1
               Response Variable             AbsDisp
               Response Distribution         Gaussian
               Link Function                 Identity
               Variance Function             Default
               Variance Matrix               Not blocked
               Estimation Technique          Restricted Maximum Likelihood
               Degrees of Freedom Method     Kenward-Roger
               Fixed Effects SE Adjustment   Kenward-Roger

                           Class Level Information
                    Class    Levels    Values
                    Age           2    I M
                    Var           2    845 950
                    Rep          12    1 10 11 12 2 3 4 5 6 7 8 9

                      Number of Observations Read         277
                      Number of Observations Used         277

                                  Dimensions
                        G-side Cov. Parameters         1
                        R-side Cov. Parameters         1
                        Columns in X                   9
                        Columns in Z                  48
                        Subjects (Blocks in V)         1
                        Max Obs per Subject          277

                          Optimization Information
                  Optimization Technique        Dual Quasi-Newton
                  Parameters in Optimization    1
                  Lower Boundaries              1
                  Upper Boundaries              0
                  Fixed Effects                 Profiled
                  Residual Variance             Profiled
                  Starting From                 Data

                                Iteration History
                                                 Objective                        Max
        Iteration    Restarts    Evaluations      Function         Change    Gradient
                0           0              4    1037.610061         .         3.612149
                1           0              5   1037.6071724     0.00288868    0.054904
                2           0              2   1037.6071717     0.00000064    0.001855

                    Convergence criterion (GCONV=1E-8) satisfied.

                                 Fit Statistics
                      -2 Res Log Likelihood       1037.61
                      AIC  (smaller is better)    1041.61
                      AICC (smaller is better)    1041.65
                      BIC  (smaller is better)    1045.35
                      CAIC (smaller is better)    1047.35
```

```
                                HQIC (smaller is better)     1043.02
                                Generalized Chi-Square        670.82
                                Gener. Chi-Square / DF          2.46

                                   Covariance Parameter Estimates
                                                            Standard
                                Cov Parm        Estimate       Error
                                Rep(Age*Var)     0.01189     0.07124
                                Residual          2.4572      0.2194

                                  Type III Tests of Fixed Effects
                                        Num      Den
                          Effect         DF       DF    F Value    Pr > F
                          Age             1    88.76       1.81    0.1815
                          Var             1    88.76       0.99    0.3214
                          Age*Var         1    88.76       2.65    0.1073
------------------------- Effect=Age   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---
                                        Standard
                    Standard            Error of                                     Lower     UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean      Mean Group
   1   I       1.4584   0.1942   1.4584   0.1942   0.05   1.0744   1.8424   1.0744   1.8424   A
   2   M       1.1531   0.1172   1.1531   0.1172   0.05   0.9151   1.3910   0.9151   1.3910   A

------------------------- Effect=Var   Method=Tukey-Kramer(P<.05)   Set=2 -----------------------
---
                                        Standard
                    Standard            Error of                                     Lower     UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean      Mean Group
   3       845   1.4188   0.1740   1.4188   0.1740   0.05   1.0746   1.7631   1.0746   1.7631   A
   4       950   1.1927   0.1454   1.1927   0.1454   0.05   0.9011   1.4843   0.9011   1.4843   A

----------------------- Effect=Age*Var   Method=Tukey-Kramer(P<.05)   Set=3 ---------------------
---
                                        Standard
                    Standard            Error of                                     Lower     UpperLetter
 Obs Age Var Estimate  Error       Mean   Mean    Alpha    Lower    Upper     Mean      Mean Group
   5   I  845   1.7560   0.2934   1.7560   0.2934   0.05   1.1773   2.3347   1.1773   2.3347   A
   6   M  950   1.2245   0.1409   1.2245   0.1409   0.05   0.9282   1.5208   0.9282   1.5208   A
   7   I  950   1.1609   0.2544   1.1609   0.2544   0.05   0.6551   1.6667   0.6551   1.6667   A
   8   M  845   1.0817   0.1872   1.0817   0.1872   0.05   0.7066   1.4568   0.7066   1.4568   A

                                        The GLIMMIX Procedure
```

Duration of Exposure

```
                                          Model Information
                    Data Set                      WORK.DATA1
                    Response Variable             Exp
                    Response Distribution         Gaussian
                    Link Function                 Identity
                    Variance Function             Default
                    Variance Matrix               Not blocked
                    Estimation Technique          Restricted Maximum Likelihood
                    Degrees of Freedom Method     Kenward-Roger
                    Fixed Effects SE Adjustment   Kenward-Roger

                                       Class Level Information
```

```
                 Class    Levels    Values
                 Age           2    I M
                 Var           2    845 950
                 Rep          12    1 10 11 12 2 3 4 5 6 7 8 9

                    Number of Observations Read         277
                    Number of Observations Used         131

                                   Dimensions
                        G-side Cov. Parameters         1
                        R-side Cov. Parameters         1
                        Columns in X                   9
                        Columns in Z                  48
                        Subjects (Blocks in V)         1
                        Max Obs per Subject          131

                           Optimization Information
                Optimization Technique        Dual Quasi-Newton
                Parameters in Optimization    1
                Lower Boundaries              1
                Upper Boundaries              0
                Fixed Effects                 Profiled
                Residual Variance             Profiled
                Starting From                 Data

                              Iteration History
                                           Objective                         Max
Iteration    Restarts    Evaluations        Function          Change    Gradient
        0           0              4    658.83161216       .                   0

              Convergence criterion (ABSGCONV=0.00001) satisfied.

                  Estimated G matrix is not positive definite.

                                 Fit Statistics
                      -2 Res Log Likelihood        658.83
                      AIC  (smaller is better)      660.83
                      AICC (smaller is better)      660.86
                      BIC  (smaller is better)      662.70
                      CAIC (smaller is better)      663.70
                      HQIC (smaller is better)      661.54
                      Generalized Chi-Square       1197.13
                      Gener. Chi-Square / DF          9.43

                         Covariance Parameter Estimates
                                                  Standard
                      Cov Parm        Estimate       Error
                      Rep(Age*Var)           0           .
                      Residual          9.4262      1.1829

                        Type III Tests of Fixed Effects
                              Num      Den
                Effect         DF       DF    F Value    Pr > F
                Age             1      127       4.23    0.0417
                Var             1      127       9.13    0.0030
                Age*Var         1      127       1.65    0.2006
```

```
------------------------ Effect=Age   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---
                                                  Standard
                     Standard                     Error of                                      Lower      UpperLetter
 Obs  Age  Var  Estimate     Error        Mean       Mean    Alpha      Lower      Upper      Mean       Mean  Group
   1    M            5.8950    0.3802    5.8950    0.3802     0.05    5.1428    6.6473    5.1428    6.6473    A
   2    I            4.6762    0.4544    4.6762    0.4544     0.05    3.7770    5.5754    3.7770    5.5754    B

------------------------ Effect=Var   Method=Tukey-Kramer(P<.05)   Set=2 -----------------------
---
                                                  Standard
                     Standard                     Error of                                      Lower      UpperLetter
 Obs  Age  Var  Estimate     Error        Mean       Mean    Alpha      Lower      Upper      Mean       Mean  Group
   3         845    6.1807    0.4683    6.1807    0.4683     0.05    5.2540    7.1075    5.2540    7.1075    A
   4         950    4.3905    0.3629    4.3905    0.3629     0.05    3.6724    5.1085    3.6724    5.1085    B

---------------------- Effect=Age*Var   Method=Tukey-Kramer(P<.05)   Set=3 ---------------------
---
                                                  Standard
                     Standard                     Error of                                      Lower      UpperLetter
 Obs  Age  Var  Estimate     Error        Mean       Mean    Alpha      Lower      Upper      Mean       Mean  Group
   5    M   845    6.4091    0.6546    6.4091    0.6546     0.05    5.1138    7.7044    5.1138    7.7044    A
   6    I   845    5.9524    0.6700    5.9524    0.6700     0.05    4.6266    7.2781    4.6266    7.2781    A
   7    M   950    5.3810    0.3868    5.3810    0.3868     0.05    4.6155    6.1464    4.6155    6.1464    A
   8    I   950    3.4000    0.6140    3.4000    0.6140     0.05    2.1849    4.6151    2.1849    4.6151    B
```

EXPOSURE: SHEATH LARVAE

```
dm'output;clear;log;clear';
Title1'GH Sheath Larvae';
data data1;
input Age$ Var$   Rep$ Stalk Exp ;
cards;
I      845    10     1      5              I      845    6      1      7
I      845    10     1      6              I      845    8      1      7
I      845    9      1      7              I      845    8      1      7
I      845    11     1      7              I      845    2      1      8
I      845    11     1      7              I      845    3      1      8
I      845    12     1      7              I      845    4      1      8
I      845    11     1      9              I      845    7      1      8
I      950    3      1      4              I      845    7      1      8
I      950    5      1      4              M      845    5      1      6
I      950    6      1      4              M      845    1      1      7
I      950    10     1      4              M      845    7      1      7
I      950    11     1      4              M      845    9      1      7
I      950    5      1      5              M      845    11     1      7
I      950    2      1      6              M      845    12     1      7
I      950    8      1      6              M      845    1      1      8
I      950    1      1      7              M      845    3      1      8
I      950    4      1      7              M      845    8      1      8
I      950    6      1      7              M      845    10     1      8
I      950    12     1      7              M      845    10     1      8
I      950    8      1      8              M      845    12     1      8
I      845    1      1      6              M      845    1      1      9
I      845    9      1      6              M      845    2      1      9
```

M	845	5	1	9
M	845	7	1	9
M	845	4	1	11
M	950	1	1	5
M	950	4	1	5
M	950	12	1	5
M	950	1	1	6
M	950	1	1	6
M	950	2	1	6
M	950	2	1	6
M	950	2	1	6
M	950	6	1	6
M	950	7	1	6
M	950	1	1	7
M	950	2	1	7
M	950	2	1	7
M	950	4	1	7
M	950	5	1	7
M	950	5	1	7
M	950	6	1	7
M	950	12	1	7
M	950	12	1	7
M	950	12	1	7
M	950	1	1	8
M	950	1	1	8
M	950	1	1	8
M	950	2	1	8
M	950	2	1	8
M	950	2	1	8
M	950	4	1	8
M	950	5	1	8
M	950	8	1	8
M	950	10	1	8
M	950	12	1	8
M	950	12	1	8
M	950	1	1	9
M	950	2	1	9
M	950	2	1	9
M	950	4	1	9
M	950	5	1	9
M	950	6	1	9
M	950	3	1	10
M	950	4	1	10
M	950	6	1	10
M	950	8	1	11

```
;
proc glimmix data=data1 ;
class Age Var Rep ;
model Exp = Age|Var  / htype=3 ddfm=kr dist=Gaussian ;
random Rep(Age*Var)  ;
lsmeans Age|Var / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
;%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
                                      The GLIMMIX Procedure
                                         Model Information
                    Data Set                       WORK.DATA1
                    Response Variable              Exp
                    Response Distribution          Gaussian
                    Link Function                  Identity
                    Variance Function              Default
                    Variance Matrix                Not blocked
                    Estimation Technique           Restricted Maximum Likelihood
                    Degrees of Freedom Method      Kenward-Roger
                    Fixed Effects SE Adjustment    Kenward-Roger

                                      Class Level Information
                           Class    Levels    Values
                           Age           2    I M
                           Var           2    845 950
                           Rep          12    1 10 11 12 2 3 4 5 6 7 8 9

                              Number of Observations Read          89
                              Number of Observations Used          89

                                             Dimensions
                                  G-side Cov. Parameters          1
                                  R-side Cov. Parameters          1
                                  Columns in X                    9
                                  Columns in Z                   42
                                  Subjects (Blocks in V)          1
                                  Max Obs per Subject            89

                                     Optimization Information
                          Optimization Technique        Dual Quasi-Newton
                          Parameters in Optimization    1
                          Lower Boundaries              1
                          Upper Boundaries              0
                          Fixed Effects                 Profiled
                          Residual Variance             Profiled
                          Starting From                 Data

                                       The GLIMMIX Procedure
                                          Iteration History
                                                   Objective                        Max
          Iteration    Restarts    Evaluations       Function          Change    Gradient

                  0           0              4    300.97128996           .              0
```

```
                  Convergence criterion (ABSGCONV=0.00001) satisfied.

                      Estimated G matrix is not positive definite.

                                 Fit Statistics
                      -2 Res Log Likelihood         300.97
                      AIC  (smaller is better)      302.97
                      AICC (smaller is better)      303.02
                      BIC  (smaller is better)      304.71
                      CAIC (smaller is better)      305.71
                      HQIC (smaller is better)      303.61
                      Generalized Chi-Square        149.13
                      Gener. Chi-Square / DF          1.75

                         Covariance Parameter Estimates
                                                  Standard
                      Cov Parm        Estimate       Error
                      Rep(Age*Var)           0           .
                      Residual          1.7544      0.2691


                        Type III Tests of Fixed Effects
                                Num      Den
                  Effect         DF       DF    F Value    Pr > F
                  Age             1       85      21.03    <.0001
                  Var             1       85       9.73    0.0025
                  Age*Var         1       85       3.01    0.0864


------------------------- Effect=Age   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---
                                        Standard
                    Standard            Error of                                 Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean    Mean   Alpha    Lower    Upper     Mean     Mean Group
   1  M        7.7857   0.1904   7.7857   0.1904   0.05   7.4072   8.1642   7.4072   8.1642   A
   2  I        6.3665   0.2440   6.3665   0.2440   0.05   5.8814   6.8517   5.8814   6.8517   B

------------------------- Effect=Var   Method=Tukey-Kramer(P<.05)   Set=2 -----------------------
---
                                        Standard
                    Standard            Error of                                 Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean    Mean   Alpha    Lower    Upper     Mean     Mean Group
   3      845   7.5588   0.2272   7.5588   0.2272   0.05   7.1072   8.0105   7.1072   8.0105   A
   4      950   6.5934   0.2102   6.5934   0.2102   0.05   6.1755   7.0113   6.1755   7.0113   B

----------------------- Effect=Age*Var   Method=Tukey-Kramer(P<.05)   Set=3 ---------------------
---
                                        Standard
                    Standard            Error of                                 Lower    UpperLetter
 Obs Age Var Estimate  Error       Mean    Mean   Alpha    Lower    Upper     Mean     Mean Group
   5  M  845   8.0000   0.3213   8.0000   0.3213   0.05   7.3613   8.6387   7.3613   8.6387   A
   6  M  950   7.5714   0.2044   7.5714   0.2044   0.05   7.1651   7.9778   7.1651   7.9778   A
   7  I  845   7.1176   0.3213   7.1176   0.3213   0.05   6.4789   7.7564   6.4789   7.7564   A
   8  I  950   5.6154   0.3674   5.6154   0.3674   0.05   4.8850   6.3458   4.8850   6.3458   B
```

APENDIX D

VARIETAL RESISTANCE TEST
STATISTICAL ANALYSIS

PERCENT BORED INTERNODES

```
dm'output;clear;log;clear';
Title1'Variety Test by Plot';
data data1;
input  VAR$ rep$ tot bored Emerg;
cards;
US9315      1     102   0     0
US9315      5     74    1     0
US9315      3     112   0     0
US9315      4     125   5     0
L0768 1     149   28    4
L0768 2     165   1     0
L0768 3     143   0     0
L0768 4     146   2     0
L0768 5     119   3     2
N21   1     118   0     0
N21   2     121   0     0
N21   3     130   3     0
N21   4     124   4     0
N21   5     117   0     0
HO07617     1     130   14    1
HO07617     2     102   6     1
HO07617     3     123   6     1
HO07617     4     125   1     0
HO07617     5     124   0     0
US089001    1     124   12    0
US089001    2     126   6     0
US089001    3     112   17    2
US089001    4     127   1     0
US089001    5     121   0     0
HO07613     1     124   27    1
HO07613     2     135   5     0
HO07613     3     113   4     0
HO07613     4     131   2     0
HO07613     5     108   0     0
HoCP05902   1     96    15    0
HoCP05902   2     109   12    6
HoCP05902   3     98    40    10
HoCP05902   4     109   6     0
HoCP05902   5     108   7     0
L03371      1     126   28    0
L03371      2     98    5     1
L03371      3     125   5     1
L03371      4     128   15    1
L03371      5     115   10    4
N17   1     135   18    2
N17   2     130   0     0
N17   3     131   14    2
N17   4     124   4     0
N17   5     124   4     0
HoCP96540   1     120   17    0
HoCP96540   2     126   17    2
HoCP96540   3     142   11    1
HoCP96540   4     122   11    1
HoCP96540   5     133   0     0
L01299      1     107   6     0
L01299      2     114   0     0
L01299      3     98    5     2
L01299      4     87    2     0
L01299      5     75    0     0
Ho07612     1     103   21    0
Ho07612     2     107   17    5
Ho07612     3     131   9     1
Ho07612     4     116   12    3
Ho07612     5     109   3     0
HoCP00950   1     113   20    0
HoCP00950   2     115   2     0
HoCP00950   3     100   3     0
HoCP00950   4     129   2     1
HoCP00950   5     115   2     1
L0757 1     132   13    0
L0757 2     135   16    8
L0757 3     135   3     0
L0757 5     119   15    5
Ho069610    1     116   21    1
Ho069610    2     122   7     0
Ho069610    3     107   2     0
Ho069610    4     109   2     1
Ho069610    5     113   0     0
HoCP04838   1     153   37    0
HoCP04838   2     127   7     0
HoCP04838   3     132   26    7
HoCP04838   4     152   10    2
HoCP04838   5     127   5     1
Ho07604     1     128   15    0
Ho07604     2     120   16    2
Ho07604     3     116   6     0
Ho07604     4     111   1     0
Ho07604     5     118   5     0
N27   1     133   11    0
```

```
N27    2       120     5       4
N27    3       143     6       2
N27    4       130     9       0
N27    5       101     11      0
HoCP85845      1       117     0       0
HoCP85845      2       123     1       0
HoCP85845      3       131     0       0
HoCP85845      4       117     3       0
HoCP85845      5       114     3       0
Ho06563        1       153     74      0
Ho06563        2       139     48      10
Ho06563        3       131     17      2
Ho06563        4       146     0       0
Ho06563        5       146     17      7
H0CP05961      1       143     14      1
H0CP05961      2       135     9       0
H0CP05961      3       121     5       1
H0CP05961      4       120     3       1
H0CP05961      5       118     8       3
US089003       1       110     5       1
US089003       2       157     6       0
US089003       3       143     7       2
US089003       4       144     1       0
US089003       5       131     1       0
N24    1       91      6       0
N24    2       88      0       0
N24    3       87      3       0
N24    4       83      3       0
N24    5       71      0       0
Ho06537        1       130     9       0
Ho06537        2       113     8       5
Ho06537        3       131     13      3
Ho06537        4       132     9       1
Ho06537        5       120     2       0
US0140         1       127     12      2
US0140         2       134     11      1
US0140         3       128     14      0
US0140         4       117     2       0
US0140         5       120     3       0
;
ODS HTML FILE='C:\Documents and Settings\treagan\Desktop\Blake Wilson\Variety
Test by plot.html' style = minimal
;
proc glimmix data=data1 ;
class Var rep;
model Bored/Tot = Var  / htype=3 ddfm=kr dist=binomial ;
random Rep ;
lsmeans var / ilink diff cl adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
                           The GLIMMIX Procedure
                      Probability of a bored internode
                             Model Information

              Data Set                       WORK.DATA1
              Response Variable (Events)     bored
              Response Variable (Trials)     tot
              Response Distribution          Binomial
              Link Function                  Logit
              Variance Function              Default
              Variance Matrix                Not blocked
              Estimation Technique           Residual PL
              Degrees of Freedom Method      Kenward-Roger
              Fixed Effects SE Adjustment    Kenward-Roger

                          Class Level Information
     Class     Levels    Values
     VAR           25    HOCP0596 HO07613 HO07617 Ho06537 Ho06563
                         Ho069610 Ho07604 Ho07612 HoCP0095 HoCP0483
```

```
                    HoCP0590 HoCP8584 HoCP9654 L01299 L03371
                    L0757 L0768 N17 N21 N24 N27 US0140 US089001
                    US089003 US9315
rep           5     1 2 3 4 5


             Number of Observations Read         123
             Number of Observations Used         123
             Number of Events                   1057
             Number of Trials                  14898

                          Dimensions
                 G-side Cov. Parameters         1
                 Columns in X                  26
                 Columns in Z                   5
                 Subjects (Blocks in V)         1
                 Max Obs per Subject          123

                    Optimization Information
         Optimization Technique        Dual Quasi-Newton
         Parameters in Optimization    1
         Lower Boundaries              1
         Upper Boundaries              0
         Fixed Effects                 Profiled
         Starting From                 Data

                         Iteration History
                                     Objective                       Max
Iteration    Restarts    Subiterations     Function         Change    Gradient
        0           0                4    410.88103698      2.00000000    0.000017
        1           0                3    514.45822984      0.49515945    0.000079
        2           0                2    541.27249692      0.09674837    2.933E-7
        3           0                1    543.41936418      0.00246621    5.978E-9
        4           0                0    543.44404146      0.00000084    1.086E-6
        5           0                0    543.44404706      0.00000000    1.086E-6

        Convergence criterion (PCONV=1.11022E-8) satisfied.

                          Fit Statistics
             -2 Res Log Pseudo-Likelihood      543.44
             Generalized Chi-Square            467.51
             Gener. Chi-Square / DF              4.77

                      Covariance Parameter
                           Estimates
                   Cov                  Standard
                   Parm    Estimate       Error
                   rep       0.3903      0.2804

                 Type III Tests of Fixed Effects
                        Num      Den
         Effect          DF       DF    F Value    Pr > F
         VAR             24       98      17.68    <.0001

------------------------ Effect=VAR   Method=Tukey-Kramer(P<.05)   Set=1 -----------------------
---
```

```
                                             Standard
                           Standard          Error of                                        Lower     Upper
Letter
 Obs VAR         Estimate   Error        Mean     Mean     Alpha     Lower     Upper       Mean      Mean
Group

   1 Ho06563     -1.3689   0.2947    0.2028   0.04765    0.05   -2.1361   -0.6016    0.1056    0.3540 A
   2 HoCP0590    -1.7838   0.3060    0.1438   0.03768    0.05   -2.5465   -1.0210   0.07266    0.2648 AB
   3 HoCP0483    -2.1023   0.3037    0.1089   0.02946    0.05   -2.8655   -1.3391   0.05388    0.2077 BC
   4 Ho07612     -2.2005   0.3114   0.09970   0.02795    0.05   -2.9631   -1.4379   0.04912    0.1919 BCD
   5 L03371      -2.2599   0.3109   0.09450   0.02660    0.05   -3.0225   -1.4974   0.04642    0.1828 BCD
   6 HoCP9654    -2.4665   0.3136   0.07824   0.02262    0.05   -3.2293   -1.7037   0.03808    0.1540 BCDE
   7 L0757       -2.5778   0.3203   0.07058   0.02101    0.05   -3.3423   -1.8133   0.03415    0.1402 CDEF
   8 Ho07604     -2.7068   0.3225   0.06257   0.01892    0.05   -3.4722   -1.9415   0.03011    0.1255 CDEF
   9 US0140      -2.7824   0.3231   0.05828   0.01773    0.05   -3.5480   -2.0169   0.02798    0.1174CDEFG
  10 N27         -2.8020   0.3232   0.05722   0.01743    0.05   -3.5676   -2.0364   0.02745    0.1154CDEFG
  11 Ho06537     -2.8028   0.3240   0.05717   0.01747    0.05   -3.5688   -2.0369   0.02742    0.1154CDEFG
  12 HO07613     -2.8587   0.3271   0.05424   0.01678    0.05   -3.6261   -2.0912   0.02593    0.1100CDEFG
  13 N17         -2.8708   0.3249   0.05361   0.01648    0.05   -3.6372   -2.1045   0.02565    0.1087 DEFG
  14 US089001    -2.9075   0.3293   0.05179   0.01617    0.05   -3.6761   -2.1388   0.02470    0.1054 DEFG
  15 HOCP0596    -2.9077   0.3260   0.05177   0.01600    0.05   -3.6746   -2.1408   0.02473    0.1052 DEFG
  16 Ho069610    -2.9648   0.3348   0.04904   0.01561    0.05   -3.7370   -2.1926   0.02327    0.1004 DEFG
  17 HoCP0095    -3.0543   0.3395   0.04503   0.01460    0.05   -3.8300   -2.2786   0.02125   0.09291DEFGH
  18 L0768       -3.1744   0.3313   0.04014   0.01276    0.05   -3.9443   -2.4046   0.01900   0.08282 EFGH
  19 HO07617     -3.2171   0.3432   0.03853   0.01271    0.05   -3.9958   -2.4384   0.01806   0.08029 EFGH
  20 US089003    -3.6077   0.3609   0.02640  0.009277    0.05   -4.4040   -2.8114   0.01208   0.05671 FGH
  21 N24         -3.7114   0.4062   0.02386  0.009461    0.05   -4.5673   -2.8556   0.01028   0.05440 FGH
  22 L01299      -3.7891   0.3978   0.02212  0.008603    0.05   -4.6327   -2.9455  0.009635   0.04995 FGH
  23 US9315      -4.3926   0.4988   0.01222  0.006020    0.05   -5.4013   -3.3839  0.004491   0.03280 GH
  24 HoCP8584    -4.6005   0.4728  0.009947  0.004656    0.05   -5.5637   -3.6372  0.003820   0.02565 H
  25 N21         -4.6073   0.4727  0.009881  0.004625    0.05   -5.5705   -3.6441  0.003794   0.02548 H
```

EMERGENCE PER STALK

```
dm'output;clear;log;clear';
Title1'Variety Test by Plot';
data data1;
input  VAR$ rep$ emer Emerg;
cards;
US9315      1     0     0.0001
US9315      5     0     0.0001
US9315      3     0     0.0001
US9315      4     0     0.0001
L0768 1     0.4   0.4001
L0768 2     0     0.0001
L0768 3     0     0.0001
L0768 4     0     0.0001
L0768 5     0.2   0.2001
N21   1     0     0.0001
N21   2     0     0.0001
N21   3     0     0.0001
N21   4     0     0.0001
N21   5     0     0.0001
Ho07617     1     0.1   0.1001
Ho07617     2     0.1   0.1001
Ho07617     3     0.1   0.1001
Ho07617     4     0     0.0001
Ho07617     5     0     0.0001
US089001    1     0     0.0001
US089001    2     0     0.0001
US089001    3     0.2   0.2001
US089001    4     0     0.0001
US089001    5     0     0.0001
HO07613     1     0.1   0.1001
HO07613     2     0     0.0001
HO07613     3     0     0.0001
HO07613     4     0     0.0001
HO07613     5     0     0.0001
HoCP05902   1     0     0.0001
HoCP05902   2     0.6   0.6001
HoCP05902   3     1     1.0001
HoCP05902   4     0     0.0001
HoCP05902   5     0     0.0001
```

```
L03371      1     0     0.0001
L03371      2     0.111111
      0.111211
L03371      3     0.1   0.1001
L03371      4     0.1   0.1001
L03371      5     0.4   0.4001
N17   1     0.22222222  0.22232222
N17   2     0     0.0001
N17   3     0.2   0.2001
N17   4     0     0.0001
N17   5     0     0.0001
HoCP96540   1     0     0.0001
HoCP96540   2     0.2   0.2001
HoCP96540   3     0.1   0.1001
HoCP96540   4     0.1   0.1001
HoCP96540   5     0     0.0001
L01299      1     0     0.0001
L01299      2     0     0.0001
L01299      3     0.2   0.2001
L01299      4     0     0.0001
L01299      5     0     0.0001
Ho07612     1     0     0.0001
Ho07612     2     0.5   0.5001
Ho07612     3     0.1   0.1001
Ho07612     4     0.3   0.3001
Ho07612     5     0     0.0001
HoCP00950   1     0     0.0001
HoCP00950   2     0     0.0001
HoCP00950   3     0     0.0001
HoCP00950   4     0.1   0.1001
HoCP00950   5     0.1   0.1001
L0757 1     0     0.0001
L0757 2     0.8   0.8001
L0757 3     0     0.0001
L0757 5     0.5   0.5001
Ho069610    1     0.1   0.1001
Ho069610    2     0     0.0001
Ho069610    3     0     0.0001
Ho069610    4     0.1   0.1001
Ho069610    5     0     0.0001
HoCP04838   1     0     0.0001
HoCP04838   2     0     0.0001
HoCP04838   3     0.7   0.7001
HoCP04838   4     0.2   0.2001
HoCP04838   5     0.1   0.1001
Ho07604     1     0     0.0001
Ho07604     2     0.2   0.2001
Ho07604     3     0     0.0001
Ho07604     4     0     0.0001
Ho07604     5     0     0.0001
N27   1     0     0.0001
N27   2     0.4   0.4001
N27   3     0.2   0.2001
N27   4     0     0.0001
N27   5     0     0.0001
```

```
HoCP85845   1     0     0.0001
HoCP85845   2     0     0.0001
HoCP85845   3     0     0.0001
HoCP85845   4     0     0.0001
HoCP85845   5     0     0.0001
Ho06563     1     0     0.0001
Ho06563     2     1     1.0001
Ho06563     3     0.2   0.2001
Ho06563     4     0     0.0001
Ho06563     5     0.7   0.7001
H0CP05961   1     0.090909091
      0.091009091
H0CP05961   2     0     0.0001
H0CP05961   3     0.1   0.1001
H0CP05961   4     0.1   0.1001
H0CP05961   5     0.3   0.3001
US089003    1     0.1   0.1001
US089003    2     0     0.0001
US089003    3     0.2   0.2001
US089003    4     0     0.0001
US089003    5     0     0.0001
N24   1     0     0.0001
N24   2     0     0.0001
N24   3     0     0.0001
N24   4     0     0.0001
N24   5     0     0.0001
Ho06537     1     0     0.0001
Ho06537     2     0.555555556
      0.555655556
Ho06537     3     0.3   0.3001
Ho06537     4     0.1   0.1001
Ho06537     5     0     0.0001
US0140      1     0.2   0.2001
US0140      2     0.090909091
      0.091009091
US0140      3     0     0.0001
US0140      4     0     0.0001
US0140      5     0     0.000
```

```
proc glimmix data=data1 ;
class Var rep;
model Emerg = Var  / htype=3 ddfm=kr ;
random Rep ;
lsmeans var / ilink diff cl ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'E:\Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.1,sort=yes);
run;
```

```
                             The GLIMMIX Procedure
                                  Emergence
                               Model Information
          Data Set                       WORK.DATA1
          Response Variable              Emerg
          Response Distribution          Gaussian
          Link Function                  Identity
          Variance Function              Default
          Variance Matrix                Not blocked
          Estimation Technique           Restricted Maximum Likelihood
          Degrees of Freedom Method      Kenward-Roger
          Fixed Effects SE Adjustment    Kenward-Roger
                            Class Level Information
        Class    Levels    Values
        VAR          25    HOCP0596 HO07613 Ho06537 Ho06563 Ho069610
                           Ho07604 Ho07612 Ho07617 HoCP0095 HoCP0483
                           HoCP0590 HoCP8584 HoCP9654 L01299 L03371
                           L0757 L0768 N17 N21 N24 N27 US0140 US089001
                           US089003 US9315
        rep           5    1 2 3 4 5
                    Number of Observations Read         123
                    Number of Observations Used         123

                                   Dimensions
                        G-side Cov. Parameters         1
                        R-side Cov. Parameters         1
                        Columns in X                  26
                        Columns in Z                   5
                        Subjects (Blocks in V)         1
                        Max Obs per Subject          123

                           Optimization Information
                Optimization Technique        Dual Quasi-Newton
                Parameters in Optimization    1
                Lower Boundaries              1
                Upper Boundaries              0
                Fixed Effects                 Profiled
                Residual Variance             Profiled
                Starting From                 Data
                                Iteration History
                                           Objective                         Max
Iteration    Restarts    Evaluations        Function          Change    Gradient
        0           0              4    -9.073056736       .            0.619005
        1           0              5    -9.073545369      0.00048863    0.019953
```

```
                         2           0              2    -9.073545899      0.00000053    0.000614
                         3           0              2      -9.0735459      0.00000000     6.33E-7
                                  Convergence criterion (GCONV=1E-8) satisfied.

                                                Fit Statistics
                                       -2 Res Log Likelihood          -9.07
                                       AIC  (smaller is better)       -5.07
                                       AICC (smaller is better)       -4.95
                                       BIC  (smaller is better)       -5.85
                                       CAIC (smaller is better)       -3.85
                                       HQIC (smaller is better)       -7.17
                                       Generalized Chi-Square          3.36
                                       Gener. Chi-Square / DF          0.03
                                          Covariance Parameter Estimates
                                                              Standard
                                         Cov Parm    Estimate      Error
                                         rep         0.002046    0.002458
                                         Residual     0.03428    0.005001

                                         Type III Tests of Fixed Effects
                                               Num      Den
                                 Effect         DF       DF    F Value    Pr > F
                                 VAR            24    94.01       1.56    0.0671
----------------------------- Effect=VAR   Method=LDS(P<.1)   Set=1 -----------------------------
--
                                              Stand
                          Standard            Err of                                     Lower    UpperLetter
 Obs VAR      Estmate  Errr        Mean   Mean    Alpha    Lower      Upper     Mean      Mean Group

   1 Ho06563    0.3801  0.08523   0.3801  0.08523   0.05   0.2108    0.5494   0.2108   0.5494 A
   2 HoCP0590   0.3201  0.08523   0.3201  0.08523   0.05   0.1508    0.4894   0.1508   0.4894 AB
   3 L0757      0.3175  0.09514   0.3175  0.09514   0.05   0.1286    0.5063   0.1286   0.5063 ABC
   4 HoCP0483   0.2001  0.08523   0.2001  0.08523   0.05  0.03080    0.3694  0.03080   0.3694 ABCD
   5 Ho06537    0.1912  0.08523   0.1912  0.08523   0.05  0.02191    0.3605  0.02191   0.3605ABCDE
   6 Ho07612    0.1801  0.08523   0.1801  0.08523   0.05  0.01080    0.3494  0.01080   0.3494 BCDE
   7 L03371     0.1423  0.08523   0.1423  0.08523   0.05 -0.02698    0.3116 -0.02698   0.3116 BCDE
   8 N27        0.1201  0.08523   0.1201  0.08523   0.05 -0.04920    0.2894 -0.04920   0.2894 CDE
   9 L0768      0.1201  0.08523   0.1201  0.08523   0.05 -0.04920    0.2894 -0.04920   0.2894 CDE
  10 HOCP0596   0.1183  0.08523   0.1183  0.08523   0.05 -0.05102    0.2876 -0.05102   0.2876 CDE
  11 N17       0.08454  0.08523  0.08454  0.08523   0.05 -0.08476    0.2538 -0.08476   0.2538 DE
  12 HoCP9654  0.08010  0.08523  0.08010  0.08523   0.05 -0.08920    0.2494 -0.08920   0.2494 DE
  13 US089003  0.06010  0.08523  0.06010  0.08523   0.05  -0.1092    0.2294  -0.1092   0.2294 DE
  14 Ho07617   0.06010  0.08523  0.06010  0.08523   0.05  -0.1092    0.2294  -0.1092   0.2294 DE
  15 US0140    0.05828  0.08523  0.05828  0.08523   0.05  -0.1110    0.2276  -0.1110   0.2276 DE
  16 Ho07604   0.04010  0.08523  0.04010  0.08523   0.05  -0.1292    0.2094  -0.1292   0.2094 DE
  17 Ho069610  0.04010  0.08523  0.04010  0.08523   0.05  -0.1292    0.2094  -0.1292   0.2094 DE
  18 HoCP0095  0.04010  0.08523  0.04010  0.08523   0.05  -0.1292    0.2094  -0.1292   0.2094 DE
  19 L01299    0.04010  0.08523  0.04010  0.08523   0.05  -0.1292    0.2094  -0.1292   0.2094 DE
  20 US089001  0.04010  0.08523  0.04010  0.08523   0.05  -0.1292    0.2094  -0.1292   0.2094 DE
  21 HO07613   0.02010  0.08523  0.02010  0.08523   0.05  -0.1492    0.1894  -0.1492   0.1894 DE
  22 US9315    0.01179  0.09514  0.01179  0.09514   0.05  -0.1771    0.2007  -0.1771   0.2007 DE
  23 N24      0.000100  0.08523 0.000100  0.08523   0.05  -0.1692    0.1694  -0.1692   0.1694 E
  24 HoCP8584 0.000100  0.08523 0.000100  0.08523   0.05  -0.1692    0.1694  -0.1692   0.1694 E
  25 N21      0.000100  0.08523 0.000100  0.08523   0.05  -0.1692    0.1694  -0.1692   0.1694 E
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VITA

Blake Emerson Wilson was born into a loving family in 1987 in Tulsa, Oklahoma. He spent the early years of his life in Austin, Texas, and Shreveport, Louisiana, before landing in Mandeville, Louisiana, at the age of 9. He graduated from Mandeville High School in 2005. He received his Bachelor of Science degree in biology from LSU in 2009. While an undergraduate, Blake held student worker positions in various fields of biology before becoming an assistant in Dr. Reagan's sugarcane entomology lab. It was during his final semester as an undergraduate that he developed an interest in entomology. With help and encouragement from Dr. Reagan, Blake enrolled in a master's program in entomology at Louisiana State University.

Under the guidance of Dr. Reagan and Dr. Showler, Blake conducted his thesis research in the Lower Rio Grande Valley during the summer of 2010. Blake plans to continue to reside in Baton Rouge, Louisiana, and continue to be active in the scientific community. Blake hopes to continue to conduct entomological research and aspires to make meaningful contributions to agriculture in Louisiana.