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This issue mailed June 28, 1991

ANNOUNCEMENT 74TH ANNUAL MEETING FLORIDA ENTOMOLOGICAL SOCIETY

The 74th annual meeting of the Florida Entomological Society will be held August 4-7, 1991 at the Ritz Carlton Hotel, 280 Vanderbilt Beach Road, Naples, Florida 33963; telephone (813 598-3300. Registration forms and information will be mailed to members and will appear in the Newsletter.

David F. Williams, Chairman
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Medical and Veterinary Entomology Research Laboratory
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FORUM

BALSAM WOOLLY ADELGID (HOMOPTERA: ADELGIDAE) AND SPRUCE-FIR DECLINE IN THE SOUTHERN APPALACHIANS: ASSESSING PEST RELEVANCE IN A DAMAGED ECOSYSTEM

ROBERT G. HOLLINGSWORTH AND FRED P. HAIN
Dept. of Entomology, Box 7626
North Carolina State University
Raleigh, N.C. 27695

ABSTRACT

Research on tree decline has shown that the proportion of sapwood area to heartwood area is an important measure of tree health. Infestation by the balsam woolly adelgid (BWA), *Adelges piceae* (Ratz.), causes the formation of abnormal wood, which is thought to conduct sap poorly. BWA infestation is also associated with lower (more negative) xylem pressure potentials and increased areas of heartwood. We hypothesize that lower pressure potentials (a consequence of abnormal wood production) increase the rate of cavitation (gas-filling) of sapwood tracheids, thereby accelerating heartwood formation. If this hypothesis is correct, adelgid attack causes loss of functional sapwood both directly and indirectly.

There is evidence that the balsam woolly adelgid is an important factor causing the decline of Fraser fir, *Abies fraseri* (Pursh) Poiret, in the southern Appalachians. However adelgid damage is probably interacting with many other environmental factors to cause reductions in per cent sapwood area. Determining the relevance of this pest to tree decline can be accomplished by examing the relationship that exists between adelgid infestation, increment growth, and per cent sapwood area.

RESUMEN

En investigaciones se ha demostrado que la proporción alburduramen es una medida que se relaciona con la sanidad y vigor de arboles en decadencia. Infestaciones de el adelgido algodonoso del balsamo (BWA), *Adelges piceae* (Ratz.), causan la formación de madera anormal y disminuyen la conducción de la savia. La infestacion de BWA también se asocia con presion potencial baja (negativa) del xylema y con el incremento del duramen. Nosotros sostenemos la hipotesis de que presiones potenciales bajas (a consecuencia de la producción anormal de madera) incrementan la tasa de cavitación (llenado de gases) de las traqueidas del albur, causando la aceleración de formación del duramen. Si esta hipotesis es correcta, el ataque del adelgido causa una perdida directa e indirecta del albur.

Hay evidencia de que el adelgido algodonoso del balsamo es un factor importante para el declive de pino Fraser, *Abies fraseri* (Pursh) Parret, en el sur de los Apalaches. Probablemente el daño del adelgido esta interactuando con otros factores del medio ambiente, lo cual causa reducciones en un porcentaje del area de albur. Para determinar la importancia de esta plaga en el declive del árbol, se puede examinar la relación que existe entre las infestaciones de adelgidos, incremento del crecimiento y el porcentaje del area de albur.

There is little doubt that the balsam woolly adelgid (BWA), *Adelges piceae* (Ratz.), qualifies as an important pest of Fraser fir, *Abies fraseri* (Pursh) Poiret. Aerial photographs taken in 1960 near Mount Mitchell, N.C. revealed that approximately 200,000 fir trees had already been killed just five years after BWA was detected in this area (Amman & Speers 1965, Amman 1966). By 1966, 90% of all Fraser fir stems over 8 feet tall in the Mt. Mitchell area had been killed by this insect (Witter & Ragenovich 1986). Today in the Black Mountains surrounding Mt. Mitchell, an estimated 49% of standing Fraser fir trees are dead (Dull et al. 1988). Now that BWA has spread throughout the Black Mountains, it is no longer possible to compare the condition of infested trees with the condition of nearby trees which have never been infested. Thus it is difficult to separate the effects of BWA injury from the effects of other environmental factors.

Much research in the southern Appalachians is directed towards assessing the possible role of atmospheric pollutants in causing a growth decline of both Fraser fir and red spruce [*Picea rubra* (Du Roi) Link] (Bruck 1984, Zedaker et al. 1987). Although most researchers recognize that BWA is an important component of the decline problem, it is not clear to what degree this insect is continuing to cause decline symptomology. In order to assess the importance of BWA, we must consider how BWA damage to fir trees might be interacting with other environmental factors which have been hypothesized to cause tree decline. This paper reviews some of the factors that might be important to this interaction.

Background and History

BWA is thought to be native to the silver fir forests of central Europe (Pschorn-Walcher & Zwolfer 1958). This insect, in the family Adelgidae, seldom causes serious injury to fir trees (*Abies* sp.) within its native range (Varty 1956, p. 39). It was first discovered in the southern Appalachians in 1955 (Amman 1966). Although BWA attacks other North American fir species (*Abies* sp.), Fraser fir is one of the most susceptible (Mitchell 1966). BWA does not attack spruce.

Fraser fir is thought to represent a glacial remnant from the Pleistocene (Buell 1945, Cain 1944, Witter & Ragenovich 1986). It occurs in six discrete areas of high altitude in the southern Appalachians. Although not important as a timber source, Fraser fir forests are valuable for their recreational use, and also serve as a seed source for the Christmas tree industry.

Most tree mortality has occurred in the southern portion of Fraser fir's range, from the Black Mountains surrounding Mount Mitchell to the Great Smoky Mountains. Fraser fir trees at Mount Rogers, Virginia have suffered considerably less mortality, despite evidence that BWA has been present at this location since at least 1962 (Haneman et al. 1981). Individual trees at Mount Rogers do become heavily infested, just as they do in other areas where Fraser fir grows (personal observation). Therefore the relatively low mortality of trees in infested areas at Mount Rogers is probably not related to the degree with which trees become infested.

The life cycle of the BWA is comprised of the egg, three nymphal instars, and the adult female, which is wingless and parthenogenic. The first nymphal instar is termed a "crawler." Only this stage is mobile. After it finds a suitable place to feed, it inserts its stylet into the bark and feeds in that particular spot throughout its life. As an adult it measures approximately 0.80 mm in length, and is covered with white strands of wax which make the insect appear "woolly" (Balch 1952). BWA completes two or three generations per year in North Carolina (Arthur & Hain 1984). The adelgids feed primarily on the main stem of the tree. Trees that do not recover from infestation generally die within two to five years after initial attact (Amman & Speers 1965).

Host Reactions

Adelgid attack causes chemical and structural changes within the bark of susceptible hosts. Balch (1952) has described these changes in detail for balsam fir (*Abies balsamea* [L.] Mill.). Initially the number and size of bark parenchyma cells increase within the feeding zone (the area surrounding the insect's stylets). Within one year, the feeding zone becomes surrounded by purplish cork cells. The parenchyma cells within this zone then disintegrate, and the area becomes infiltrated with resin.

The bark of a Fraser fir tree is bounded exteriorly by a persistent periderm layer. As a result, the bark of most trees is comprised almost entirely of inner (living) bark (personal observation; also see Chang 1954). However, beneath areas of bark which are heavily-infested, a secondary periderm layer is formed at a depth of two or more millimeters. This process leaves behind a superficial layer of dead cells (outer bark) which physically prevents feeding by future generations of adelgids (Balch 1952). Areas of bark which are heavily-infested during one insect generation might support few (if any) insects during the subsequent generation (personal observation).

Although BWA feeds only from the bark of fir trees, infestations on North American firs typically induce the formation of altered xylem tissue which conducts water very poorly (Balch 1952, Mitchell 1967). In cross-section this wood is evidenced by enlarged growth rings which appear to contain a high proportion of latewood. Because of its color, it is termed "rotholz," a German word meaning "red wood." Microscopic examination shows that rotholz is anatomically similar to compression wood (Balch 1952), having thick-walled tracheids which are circular (as opposed to rectangular) in cross-section (Doerksen & Mitchell 1965, Timell 1986). Rotholz forms only in the vicinity of adelgid attack (Balch 1952; Doerksen & Mitchell 1965). Even low populations of BWA are sufficient to cause its occurrence beneath infested bark (Balch 1952, and personal observation). It has not been reported as occuring in any of the European fir species (Balch 1952, p. 74).

Mechanism of Injury

The bulk of available evidence suggests that the primary damage caused by BWA infestation to North American firs results from the production of abnormal wood. Mitchell (1967) injected acid fuchsin dye into the stems of grand and subalpine firs (*Abies grandis* (Dougl.) Lindl. and *Abies lasiocarpa* (Hook.) Nutt., respectively] to investigate the effect of BWA infestation on water uptake by the sapwood. Compared with uninfested controls, infested trees absorbed less dye and transported the dye in fewer growth rings. Dye did not move through areas containing rotholz. Dye uptake experiments have also been conducted on infested and uninfested balsam fir with similar results (Balch 1952, p. 63).

Figure 1 shows the relative positions of the various wood types discussed above in a stem section of a Fraser fir Christmas tree which had been lightly infested for three years.

In general, decline symptoms are similar for all species of North American fir that are infested primarily on the main stem. Differences which do exist apparently result from host sensitivity as well as the spatial pattern of BWA colonization (Mitchell 1966). Symptoms shown by grand and subalpine fir include drooping leaders (Mitchell 1966), positive sap pressures in mid-summer, and water-soaked appearance of heartwood (Mitchell 1967). The crown of grand fir usually dies over a period of years, beginning with the lower limbs and proceeding upwards. Amman (1967) observed a similar pattern for Fraser fir growing on Mount Mitchell. In contrast, the crown of subalpine fir usually

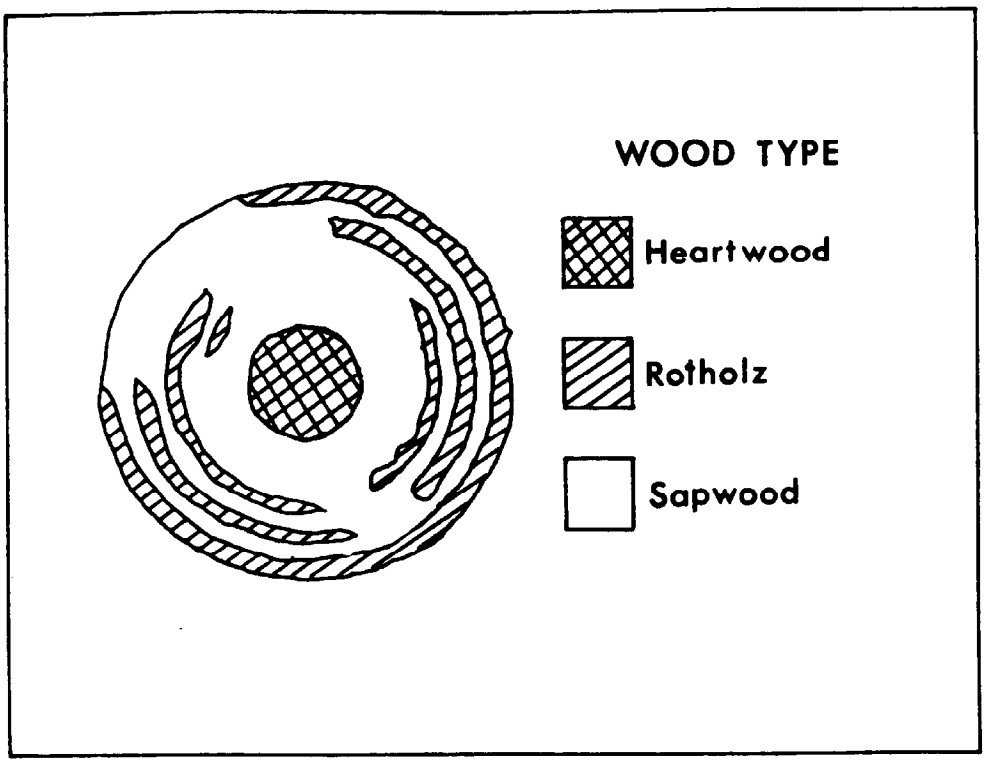

Fig. 1. Cross-section of a previously-infested Fraser fir stem.

begins dying from the top (Mitchell 1966). All of these symptoms are consistent with the hypothesis that BWA-induced damage impedes water transport in the sapwood.

For some heavily-infested trees, bark and cambial death apparently precede crown deterioration. This has been observed for balsam fir (Balch 1952) and Fraser fir (personal observation). In these cases, death of the bark and cambial tissues effectively "girdle" the trees. Within a year's time, the foliage of the entire crown becomes chlorotic, then changes to a russet red color. Balch suspected that this rapid tree death was the direct result of damage to the bark and cambium. To test this hypothesis, he selected four healthy balsam fir trees and, for each tree, removed a band of bark tissue by cutting with a scalpel. The depth of the cut and the width (height) of the band was varied between trees. The tree which received the most bark injury (5-foot-wide band, 3 mm deep) exhibited symptoms identical to those trees which were naturally "girdled" by BWA. Considering the rapid nature of decline symptoms, we believe that disturbance of water transport (not interruption of the phloem) is likely to be the proximal cause of tree death. Some girdled trees live for many years before dying (Zimmermann 1983, p. 121; Noel 1970). Perhaps in the case of fir, drying out of bark and cambial tissues leads to cavitation (gas-filling) of sapwood tracheids, thereby increasing resistance to sap ascent. It is unclear what proportion of Fraser fir succumbing to BWA follow this rapid pattern of decline.

Although rotholz production is a common occurrence in infested trees of North American fir species (including Fraser fir), not all infested trees produce rotholz. However the xylem of infested trees can be altered even when rotholz is not produced. Heavily-infested grand fir trees, grown as exotics in Scotland, were found to contain no rotholz, yet the "sapwood" of these trees (wood adjacent to the cambium) was only one-twentieth as permeable as sapwood sampled from nearby uninfested trees. This adelgid-altered

wood stained the same color as heartwood (Puritch 1971). Follow-up studies determined that the reduced permeability was most likely due to a combination of tracheid pit membrane encrustation and increased volume of air in the sapwood (a consequence of accelerated cavitation, or gas-filling of tracheids) (Puritch & Johnson 1971, Puritch & Petty 1971). A subsequent trial using grand fir from British Columbia found that BWA infestation was associated with an increase in both heartwood area and number of heartwood rings. Within an infested tree, the amount of heartwood was greater adjacent to areas of bark supporting higher BWA populations (Puritch 1977). Based on these results, Puritch and Johnson (1971) advanced the hypothesis that infestation by BWA caused the formation of "premature heartwood."

Pressure chamber measurements on cut shoots of Fraser fir add additional evidence that infestation interferes with water transport through the sapwood. Measurements taken in June showed that infested trees at Mount Mitchell and Roan Mountain, N.C., had lower xylem pressure potentials (an indication of poorer water status) than uninfested controls, while the infested and uninfested trees at Mt. Rogers, Virginia did not differ from one another. In mid-summer, there were no significant differences at any site. In September however, infested trees showed lower water potentials at all locations (Arthur 1985). As September is traditionally a low-rainfall month in the southern Appalachians, these results indicate that the physiological effects of BWA damage are more severe during periods of low rainfall.

In summary, the most important consequence of BWA infestation is a reduction of effective sapwood area leading to increased flow resistance in the sapwood.

Having established the probable mechanism of BWA injury, we can now consider how other environmental factors suspected to cause tree decline might be interacting with effects caused by the Balsam Woolly Adelgid. By so doing we hope to devise a reasonable method for determining the relevance of BWA in the context of a damaged spruce-fir ecosystem. We will use the Black Mountains of North Carolina as a case in point.

Tree Decline

Approximately 7200 acres of spruce-fir forest are contained within the rugged Black Mountains of North Carolina. The peaks stretch along a single twelve-mile long ridge with a north-south orientation. The percentage of Fraser fir in the stand component increases with elevation, up to 66% at elevations above 6000 feet. Approximately 11% of the spruce-fir type in the Southeast is within this region (Dull et al. 1987, Dull et al. 1988).

Disturbance by humans has been intense in this area (Pyle & Schafale 1988). Most notable is the logging and associated slash fires with subsequent erosion and windthrow problems. The majority of the logging operations occurred between 1912 and 1922, but salvage logging of windthrown trees continued until at least 1929. Other man-made disturbances resulted from grazing, tourism, and fires set by hunters prior to commercial logging.

Within the Black Mountains, both red spruce and Fraser fir are now declining, as evidenced by crown condition, growth increment, and mortality data. The decline has been most severe at the higher elevations, which also contain the highest proportion of fir (Bruck 1984, Bruck & Robarge 1988, Dull et al. 1988, Zedaker et al. 1987). From Mount Mitchell there is evidence that acidic cloud water is responsible for leaching of both calcium and magnesium from the forest canopy (Robarge et al. 1987).

The incidence of Fraser fir mortality is highly correlated with the presence of BWA (Zedaker et al. 1987). However it should be noted that the highest elevations, where fir dominates over spruce, probably receive greater inputs of atmospheric pollutants

due to higher precipitation and frequent cloud immersion (Dull et al. 1987). In this context, Hain and Arthur (1985) hypothesized that atmospheric pollutants may either lower the tolerance of Fraser fir to BWA, or add a final, lethal stress to trees already heavily stressed by BWA.

There is a growing concensus in Europe that pollution-induced deficiencies of soil nutrients are responsible for much of the forest decline observed there (Pitelka & Raynal 1989). Blank et al. (1988) summarized current hypotheses regarding pollutant effects in Europe, and emphasized that no single hypothesis explains all of the observed "decline types." One common type of decline exhibited by Norway spruce, *Picea abies* L. Karst, at high altitudes in Germany is defined by the yellowing and subsequent loss of older, magnesium-deficient needles. Blank et al. suggested that naturally low levels of magnesium in the soil predispose the spruce to deficiency caused by the leaching action of excess inputs of nitrogen and sulphur. The loss of needles would be expected to reduce the growth potential of the cambium.

Shortle & Smith (1988) hypothesized that calcium deficiency, induced by excess aluminum in the soil solution, is responsible for the red spruce decline in the northeastern United States. They noted that calcium is incorporated at a constant rate in the production of sapwood (regardless of tree vigor), and they used this fact to argue that calcium availability is a limiting factor for cambial growth. Because the demand for calcium per unit of cambial area is constant, the need for calcium (which is not recovered from the heartwood) increases exponentially as the tree grows. Calcium-deficient trees will have reduced sapwood area, leading to crown thinning and susceptibility.

Although the mechanism causing decline differs between these two scenarios, both scenarios result in reduced annual increment, which is evidenced by narrow growth rings. These narrow growth rings are associated with reduced sapwood area. Shortle & Bauch (1986) found this to be the case for declining balsam fir in the U.S. and silver fir (*Abies alba* Mill.) in West Germany. Their results indicated that trees with less than 25% basal area of sapwood become highly vulnerable to death from secondary pathogens and insects. The vulnerability occurs because less sapwood is available for defense, food storage, and water conduction (Shortle & Bauch 1986, Shortle & Smith 1988).

A reduced proportion of sapwood area results from a reduced rate of sapwood production, an accelerated rate heartwood formation. According to Huber, the loss of water from the tracheids is the "beginning of a chain of events which we call heartwood formation" (Zimmermann & Brown 1971, p. 212). Loss of water from the tracheids occurs when the tracheids cavitate. As sapwood ages, the proportion of tracheids which are cavitated gradually increases (Zimmermann 1983, p. 46). This is a least part of the reason why inner sapwood is generally less permeable than outer sapwood (Puritch 1971).

Interaction of BWA Damage with other Environmental Factors

As previously discussed, trees infested by BWA contain poorly-conducting sapwood rings and a greater proportion of heartwood. A reduction in effective sapwood area caused by BWA may lead to a lower (more negative) xylem pressure potential in the stem of an infested tree. According to Darcy's Law, the flow rate of a liquid through a porous material is equal to: [cross-sectional conducting area × permeability × pressure difference] ÷ [viscosity × specimen length] (Puritch 1971). For a given rate of sapwood flow, loss of sapwood area should cause pressure differences in the main stem to increase, assuming all other factors are held constant. Thus negative xylem pressures in the stems may became more negative in response to sapwood loss. Trees might compensate for lost sapwood area by dropping foliage or reducing transpiration. However there is experimental evidence (as discussed in the Introduction) that pre-dawn xylem pressure potentials are in fact lower (more negative) in infested versus uninfested trees. This indicates that compensation, if it occurs, is incomplete.

As pressure in the main stem becomes more negative, the relative frequency of cavitation (gas-filling) of sapwood tracheids is expected to increase (see Zimmermann 1983, p. 46). As previously mentioned, the loss of water from sapwood tracheids may initiate the process of heartwood formation (Zimmermann & Brown, 1971, p. 212). Thus we suggest that BWA damage accelerates heartwood formation by increasing the rate of cavitation of sapwood tracheids. If BWA attacks a tree whose cambial growth potential has already been reduced by other environmental factors, then per cent sapwood area may be reduced to the point that the tree succumbs to insects, disease, or drought.

Research Directions

If BWA interacts with other environmental factors to cause an reduction in per cent sapwood area, studying the interaction fully will require knowing the infestation history for each tree. Reasonably accurate infestation histories can be constructed by examining tree rings for the presence of rotholz.

Rotholz can usually be distinguished from true compression wood because the latter is seldom formed on both sides of the tree simultaneously. The presence of rotholz in a tree ring can be determined by examining wood cores collected from opposite sides of a tree. Unfortunately our experience suggests that heartwood-sapwood boundaries cannot be reliably determined from Fraser fir wood cores. Apparently the cores do not provide enough surface area for perceiving the generally slight color differences between sapwood and heartwood which occur when Fraser fir wood is reacted with 40% perchloric acid (following the method of Eades 1958). Assessing heartwood/sapwood boundaries may require cutting down a limited number of sample trees from protected areas. Data on rotholz histories and per cent sapwood areas could be used for testing the hypothesis that BWA infestation accelerates the formation of heartwood. In addition, it could be used to test for an interaction of BWA injury and tree decline (as measured by growth increment data) for Fraser fir growing in the Black Mountains of North Carolina.

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FALL ARMYWORM SYMPOSIUM

Preface

NOTE: Reprints of each paper of the Fall Armyworm Symposium are available from the respective authors.

The Fall Armyworm Symposium, held during the annual meetings of the Southeastern Branch of the Entomological Society of America since 1978, has served as a forum for scientific exchange of information on this pest of importance in the Americas. The papers presented have elucidated aspects of fall armyworm systematics, seasonal habitats and dynamics, migration, host plant resistance, biological and chemical control, to name a few.

The fall armyworm is a serious pest on corn, sorghum, and related grasses but attacks other crops as well when conditions are favorable. The extensive area of occurrence of this pest at damaging levels presents a challenge to entomologists throughout the Americas in developing practical and economical control measures. Dispersal of this insect from potential source areas has not been defined clearly. Migration into areas where it cannot survive is of international importance. Aspects of systematics of the species, spread of insecticidal resistance, development of resistant crop plants, and impact of chemical and biological control present a veritable smorgasbordd of research opportunities for collaborative research among scientists in the Americas. Projects in these areas provide information essential to the development of integrated pest management programs at different levels of crop production technology.

The papers presented here were part of the Fall Armyworm Symposium at the 64th Annual Meeting of the Southeastern Branch of the Entomological Society of America in Orlando, Florida, February 8, 1990. As in previous symposia on the fall armyworm, these papers represent current research on this pest. This symposium is dedicated to a scientist who has made many valuable contributions to management of this insect: Dr. John R. Young.

HENRY N. PITRE
Department of Entomology
Mississippi State University
Mississippi State, MS 39762

DR. JOHN R. YOUNG - ECONOMIC ENTOMOLOGIST

B. R. WISEMAN AND H. R. GROSS
USDA-ARS-IBPMRL
Tifton, GA 31793-0748

ABSTRACT

Dr. John R. Young, USDA-ARS-IBPMRL (retired), developed chemical and autocidal strategies for controlling the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) in corn and sorghum. Dr. Young's career spanned 30+ years with USDA during which time he published more than 100 articles in professional and/or popular journals. Dr. Young was one of the founders of the Fall Armyworm Conference, from which 133 recorded presentations and 57 articles by conferees have been published. Dr. Young pioneered principles and methodologies for the safe, economical, and efficient management of economic insect species through "insectigation"—the application of pesticides in irrigation water. John has been one of the discipline's true "Economic Entomologists."

RESUMEN

El Dr. John R. Young, jubilado del USDA-ARS-IBPMRL, desarrolló metodos autocidas y quimicos para control del cogollero del maíz, *Spodoptera frugiperda* (J. E. Smith) en maíz y sorgo. La carrera del Dr. Young abarca mas de 30 años con el USDA. Durante este tiempo publicó mas de 100 articulos en revistas profesionales y populares. El Dr. Young fue uno de los fundadores de la Conferencia del Cogollero, en la cual se han efectuado 133 presentaciones y se han publicado 57 articulos. El Dr. Young fué un pionero en los principios y metodologías para un manejo seguro, economico y eficiente de las especies de insectos a traves de la 'insectigacion'-aplicación de insecticidas en el agua de irrigación. John ha sido un entomologo economico verdadero.

Dr. John R. Young was born on August 6, 1932 at Perry, FL where he grew up, and remained through high school. John's interest in entomology began while he served in the Armed Forces in Korea as a medical laboratory technician from 1949 to 1951. After returning from Korea, John began his undergraduate study at the University of Maryland, where he received his B.S. in Bacteriology - Chemistry and Zoology in 1957. He also completed graduate work at the University of Maryland, receiving his M.S. in Entomology in 1959 and a Ph.D degree in Entomology, with a minor in Statistics, in 1964.

Following graduation, he relocated to Tifton, GA where he became a research entomologist with the U.S. Department of Agriculture's Agricultural Research Service, Grain and Forage Insects Branch, at the Southern Grain Insects Laboratory (SGIRL) (currently Insect Biology and Population Management Research Laboratory [IBPMRL]) under the direction of Dr. H C Cox. During his 30+ year career, Dr. Young served under two additional laboratory directors, Drs. A. N. Sparks and Charlie Rogers.

Dr. Young is married to the former Ilene Carpenter. They have two children, Jim and Malinda, and two grandchildren.

Dr. Young first formulated the idea of a conference on the fall armyworm around 1976. He discussed with several colleagues his concepts of an informal conference followed on alternate years by a formal symposium. The first fall armyworm symposium was held in January, 1977 as an informal conference at the Francis Marion Hotel in Charleston, SC, with Dr. Young as moderator. There were 38 participants discussing topics of: Resistance to Insecticides, Application Methods, Migration, Parasites, Rearing,

Pheromones, Light Traps, Host Plant Resistance, Hosts, and Economic Importance. The beginning of this important conference occurred before the devastating "outbreak" of fall armyworm in the summer of 1977. The second conference was held in January, 1978 at Gainesville, FL with Dr. E. R. Mitchell as the moderator. There were six presentations. The second conference had its proceedings published in 1979 in the Florida Entomologist. Editors of the Florida Entomologist agreed to publish all subsequent proceedings, which now have abstracts in both English and Spanish.

Since that first meeting of interested participants, there have been seven informal and five formal fall armyworm conferences, which have resulted in a total of 133 recorded presentations and 57 published articles. These impressive records must be at least partially credited to Dr. Young for his vision of developing better manangement systems for the fall armyworm through the formal exchange of information among interested scientists, producers, and industry representatives.

As a research entomologist at the IBPMRL, Dr. Young's mission was to gain new knowledge on the insect biology/ecology and population dynamics of pest species of field crops (with emphasis on the fall armyworm) and to apply this information toward the development of chemical and autocidal strategies for control. Dr. Young pioneered principles and methodologies for the economical, efficient, and environmentally sound strategies of management of economic insect species.

To date, Dr. Young's research career spans 30+ years, during which time he has authored or co-authored over 100 publications and made over 70 presentations, 27 of which were invitational. The following are but a few of Dr. Young's many accomplishments over the expanse of his career. Dr. Young and coworkers developed the concept of inducing sterility in the fall armyworm with chemosterilants. Chemosterilant feeders were designed, effective chemicals were identified, and criteria were developed for assessing sterility, thus introducing a safe and efficient technology for managing fall armyworm populations with minimum contamination of the environment.

Dr. Young found that adults of fall armyworm could also be sterilized with gamma irradiation. He identified the effective radiation dose and established the most susceptible developmental stage. Dr. Young found that the production of substerility in the F_1 fall armyworm with gamma irradiation was a viable approach for inducing sterility in subsequent generations. Because of reduced somatic damage, substerile fall armyworm were more competitive in nature than fully sterile insects and, thus, suppressed the wild population by infusion of deleterious genes.

One of Dr. Young's more important accomplishments was his work on the SGIRL corn earworm colony. He conceived the criteria for colony characterization, established the mating regimes to insure retention of heterozygosity, and conducted the trials that verified the rearing procedures. This colony has been utilized by the entire laboratory staff for achieving reproducible laboratory and field results.

Dr. Young developed a control strategy for fall armyworm that allowed production of multiple crops of field and/or sweet corn in the Southeast. He identified plant growth stages, based on leaf development, where damage by and control of the fall armyworm had the greatest effect on grain and forage yields. John found that the second crop of field corn produced its greatest returns for management cost when it was harvested as silage.

Dr. Young will probably be remembered most for the research conducted during the last ten years of his USDA career. Dr. Young observed the early expansion of irrigation usages in the southeastern U.S. and envisioned with it a means for the safe, economical, and efficient delivery of agricultural chemicals, including pesticides, to their target. John pioneered the introduction of chemigation, the application of agricultural chemicals (i.e., pesticides, fertilizers, and growth regulators) in irrigation water and demonstrated the practicality of this control strategy.

Dr. Young convened a group of interested scientists in Atlanta in 1982 that became the "Chemigation Information Exchange Group." This group has met annually to exchange information on chemigation, insectigation, and fertigation. He has since taken a lead role in the founding and promotion of this innovative technology, including helping to organize and serving as editor on "National Symposia on Chemigation" in 1981 and 1982.

Dr. Young successfully integrated irrigation and insect control into a cost-effective approach for grain production. Early studies with emulsifiable formulations of insecticides revealed that they were diluted to ineffective levels when applied in irrigation water. Subsequent efforts by Dr. Young revealed that insecticides formulated in oils (without emulsifiers) would remain intact during transport in irrigation water, but would penetrate the plant canopy, and separate from the water phase when it impinged upon the plant or insect surfaces. In studies involving the use of specific insecticides in non-emulsifiable petroleum or seed oils, control of corn earworm and fall armyworm was equal or superior to that achieved with conventional methodology.

As we conclude this dedicatory address on Dr. John R. Young, what more befitting things could be said than those of his peers, as follows:

"Dr. Young was able to put together a truly multidisciplined program aimed squarely at the limiting factor for corn production in the area, the fall armyworm *Spodoptera frugiperda* (J. E. Smith). It was in this regard that we at Dow first came to work with John and I emphasize *work*. He is a hard man to keep up with. John needed a material with excellent fall armyworm activity and low solubility. Our LORSBAN* product turned out to be well suited to John's uses. Unfortunately our emulsifiable formulation was not. Thus began a series of studies on various adjuvants and formulations designed to optimize the activity of the material. That activity continues to this day; and through it all, John's ideas have figured prominently in our development and labeling process. In the last few years John has carried word of this new application technique throughout the country. As an ambassador for chemigation, he has organized symposia, spoken at a multitude of crop clinics, and been a tireless inspiration to those trying the method for the first time. The fact that in 1983 chemigation in corn jumped from less than 1% to around 10% of the foliar market is a tribute to the fit of the method. John has acted as a catalyst, especially when he speaks to consultant organizations and irrigation workshops throughout the country. He gets people excited by talking about the basic benefits of the method. John most definitely is an independent thinker. He has pressured us for years to develop a non-emulsified LORSBAN formulation for chemigation. Finally, in 1984 we had one for him to test." (L. L. Larson, Agric. Products Dept., DOW Chemical USA, Midland, MI).

"I credit Dr. Young's efforts as being the single most important factor in establishing the credibility, practicality and validity of chemigation as an economically effective technique for the control of insects, particularly with respect to corn. At a time a few years ago when practically all scientists discounted chemigation as a practical means of applying pesticides whose efficacy depended upon their remaining on the plant foliage, Dr. Young maintained that the technique did have promise. He intensified his research efforts on chemigation, working diligently on basic studies of chemical formulations for chemigation, application techniques and the resulting efficacy in field studies. His diligence in pursuing this research with industry, other scientists and farmer cooperators was, in my opinion, the

driving force which elevated the application of insecticides via chemigation to the current level of acceptance. As you know, chemigation is now receiving widespread interest in not only the scientific community but also in industry and by farmers. Dr. Young's role in establishing this technology is manifested not only by his publications but also by the numerous requests which he receives for presentations to regional, national and international scientific meetings, industry and grower groups." (E. Dale Threadgill; Prof. and Head, Agric. Engineering Dept., University of GA, Athens, GA).

"During the past several years, Dr. Young, using imaginative and innovative research approaches, persuasion, and perseverance has become a nationally and internationally recognized authority on applying chemicals—specifically insecticides—through irrigation systems (chemigation). This research has developed new parameters on effectiveness of selected insecticides in relationship to formulations, carriers, deposition on target organisms, potential dilution effects, and safety during application with irrigation systems. Dr. Young's research on chemigation has proven that this technique is a viable and economically sound procedure that can be used in irrigated agriculture. His research has made late season crops of field corn and sweet corn feasible by effectively controlling insects with timely application of insecticides through irrigation. This application technology has a significant economic advantage over conventional application methods and can be used in a timely, effective, integrated pest management program." (Clyde C. Dowler, Res. Agronomist, USDA-ARS, Tifton, GA).

"As a practitioner of IPM in the cropping systems of the central great plains, where irrigation is a way of life, I know of no single research worker who has contributed so widely to a practical approach to controlling many insect pests of corn, milo, field beans, potatoes, soybeans and alfalfa. Dr. Young's insectigation research, particularly the addition of oil to insecticide application through sprinkler irrigation, has and is revolutionizing insecticide application to this area. Previous to his work with vegetable additives, insectigation was limited to applications using minimal amounts of water. This was frequently impossible due to the necessity to continue irrigating; the crop water needed. With the added oil, farmers can insectigate with irrigation amounts of water. This does not break the irrigation cycle nor reduce the insecticide's effectiveness." (Earle S. Raun, Ph.D. R.P.E., Pest Management Co., Lincoln, NE).

"Dr. Young has been the leader of several multidiscipline research teams involved in applying insecticides through overhead sprinkler irrigation systems for controlling insects on many crops. This innovative means of applying pesticides resulted in three National Symposia on Chemigation held at the Rural Development Center, Tifton, GA in 1981, 1982, and 1985. Dr. Young was a leader in planning and organizing the symposia. The new technology generated by Dr. Young has resulted in label amendments for two major insecticides for broader use on many crops. In addition, he has been active in transferring technology from his research program to various user groups. For example, with fewer insecticide applications than required with conventional methods, he has consistently demonstrated greater than 99% control of the corn earworm on sweet corn, a high value crop in the United States. Much of Dr. Young's research results in maximizing insect control, minimizing use of insecticides, and reducing unit production costs." (A. W. Johnson, Supervisory Res. Plant Pathologist, USDA-ARS, Tifton, GA).

"My association with John relates to his pioneering research injecting insecticides through overhead center pivot irrigation systems. Insectigation is a rapidly advancing new technology of pest control and is a process that is being accepted by a growing number of producers of irrigated crops. John's foresight in developing the research program on insectigation and his involvement in disseminating his research information through public meetings and other media has put him in a position of being a national leader in economic entomology." (John F. Witkowski, Ext. Entomol., University of Nebraska, Lincoln, NE).

"I have had the distinct pleasure of working with John for a number of years, both in small plot testing, lab trials and, of course, chemigation. I found John to be a very innovative, enthusiastic, dedicated and seemingly tireless researcher. John's work on fall armyworm, on corn, his work with R. B. Chalfant on vegetable insects, his work with A. W. Johnson on nematicides, and his numerous other consultations with researchers and growers have, I feel, played a major role in the development of insectigation as a viable, practical approach to insect control that offers the grower a number of advantages over conventional methods including ease of application, more uniform coverage, lower application costs, etc. I feel his discovery that activity of foliar insecticides was significantly enhanced by the addition of vegetable oil was the most important. This discovery allows the use of lower rates of insecticides which is beneficial to the grower, the consumer and the environment. As a result of his discovery and subsequent work to explain this phenomenon, I believe it will only be a short time before there will be a significant number of foliar insecticides, herbicides and fungicides formulated specifically as oil formulations for use in chemigation systems." (William S. Hurt, Project Manager, Agric. Prod. Res., Rohm and Haas Co., Spring House, PA).

"From having worked with John for the past several years, I know of no other entomologist more deserving of this recognition than Dr. Young. John has always shown outstanding enthusiasm and dedication to the field of chemigation for pest management. I and my colleagues consider Dr. John Young to be the outstanding researcher and pioneer in this field of research." (J. C. La Prade, Field Development Representative, Rhone-Poulenc Ag. Products Co., Dothan, AL).

"Dr. Young has not worked in isolation and through his enthusiasm has attracted researchers in other agricultural fields to study crop production holistically. John was instrumental in the direction and success of the R. K. Mellon Foundation ($2 million) Irrigated Crop Production Project." (Richard B. Chalfant, Professor, Dept. of Entomology, CPES, Univ. of GA, Tifton, GA).

"John is one of those individuals who refuses to take no for an answer. His concepts and ideas go beyond where others have stopped. John has single-handedly changed the concepts of the farmer and brought chemigation into a new era." (James M. [Jim] Rice, M. L. Bull Co., Inc., Norcross, GA).

The aforementioned comments by several of John's peers exemplify his work, his dedication, and many of his accomplishments. Dr. Young has certainly been interdisciplinary in his research. Dr. Young is truly deserving of the recognition by this conference. Therefore, it is a sincere and distinct pleasure for us to have been able to bring this dedicatory address to honor "Dr. John R. Young – Economic Entomologist."

FALL ARMYWORM (LEPIDOPTERA: NOCTUIDAE) HOST STRAIN REPRODUCTIVE COMPATIBILITY

S. S. QUISENBERRY
Department of Entomology
Louisiana Agricultural Experiment Station,
Louisiana State University Agricultural Center,
Baton Rouge, Louisiana 70803

ABSTRACT

The reproductive compatibility between fall armyworm, *Spodoptera frugiperda* (J. E. Smith), host strains (corn and rice) and the impact of colony age on reproductive potential were evaluated. Incompatibilities in interstrain matings were not observed and strains successfully mated in both directions. The number of fertile intrastrain and interstrain females ranged from 50 to 100% and 80 to 100%, respectively. Egg mass numbers were greater when colony age of corn females was older (25+ yr). Colony age of corn or rice males in the intrastrain and interstrain matings was less important in the number of egg masses produced than colony age of the corn females. In contrast, the number of egg masses oviposited was greater when colony age of rice females was younger (< yr and 1 yr). Regardless of strain, the younger the colony age the greater the number of viable eggs. Fewer viable eggs were produced as the period of colonization was extended, particularly period of colonization of females.

RESUMEN

Se evaluó la compatibilidad reproductiva entre el cogollero, *Spodotera frugiperda* (J. E. Smith), las líneas del hospedero (maíz y arroz), y el impacto de la edad de la colonia en el potencial reproductivo. No se observaron incompatibilidades en el apareamiento de razas entrecruzadas, y las razas se aparearon con exito en ambas direcciones. El numero de entrerazas fertiles y hembras entrerazadas varió desde 50 a el 100% y de 80 al 100% respectivamente. El número de posturas de huevos ovipositadas fue mayor cuando la colonia de las hembras criadas en maíz alcanzó mayor edad (25+ años). La edad de la colonia de machos criados en maíz o arroz fue menos importante que la edad de las hembras criadas en maíz en los apareamientos entre raciales e interraciales en lo relacionado con el numero de posturas producidas. En contraste, el numero de posturas fue mayor cuando la edad de la colonia de hembras criadas en arroz, era mas joven (< año y 1 año). Entre mas joven fue la colonia, mas grande fue el número de huevos producidos, sin que importara la raza. En la misma proporción que la edad de la colonia aumentaba se produjeron menos huevos viables, particularmente en el periodo de colonizacion de hembras.

Two strains (corn and rice) of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), have been identified (Pashley et al. 1985, Pashley 1986) that differ at allozyme loci (Pashley 1986) and in their mitochondrial DNA (mtDNA) restriction enzyme profiles (Pashley 1989). Numerous biological differences have been detected since their discovery. Physiological (i.e., development) differences exist between strains reared on each other's host plants (Pashley 1988a, Whitford et al. 1988), on artificial diets (Quisenberry & Whitford 1988, Whitford et al. 1988), and on selected bermudagrass genotypes (Lynch et al. 1983, Pashley et al. 1987a b, Quisenberry & Whitford 1988). Pashley et al. (1987b) also reported dissimilarity between strains in insecticidal resistance. In addition, ovipositional preferences were found to differ (Whitford et al. 1988).

Studies of interstrain hybridization and compatibility have been conducted to ascertain the taxonomic status of the strains. Pashley & Martin (1987) reported undirectional reproductive incompatibilities in interstrain matings. In no choice matings, rice females mated with corn males but corn females did not mate with rice males. Furthermore, F_1 hybrid females did not mate but males did. However, Whitford et al. (1988) found strains successfully mated in both directions. Pashley (1988) suggested the reproductive compatibilities reported by Whitford et al. (1988) may be due to altered behavioral characteristics that accompanies the selection process of colonization. Pashley & Martin (1987) used first and second or fourth and fifth generation fall armyworm while Whitford et al. (1988) used colonies at least 3 yr-old.

The objectives of this study were to determine the reproductive compatibility between fall armyworm host strains and to evaluate the impact of colony age on reproductive potential.

Materials and Methods

Six fall armyworm laboratory colonies were used. Colonies were previously identified electrophoretically as the corn and rice strains (Mason et al. 1987, Pashley et al. 1987a, D. P. Pashley unpublished). Corn strain 1 (C1) and corn strain 2 (C2) colonies were field collected from corn and maintained in the laboratory for 3 generations and 1 yr, respectively. Corn strain 3 (C3) was originally collected on bermudagrass but was supplemented with larvae from an unidentified (probably corn) source (Burton 1967, Perkins 1979) and maintained in the laboratory for 25+ yr. Rice strain 1 (R1), rice strain 2 (R2), and rice strain 3 (R3) colonies were field collected from bermudagrass and maintained in the laboratory for 2 generations, 1 yr, and 4+ yr, respectively. C2 was obtained from the USDA-ARS, Crop Science Research Laboratory, Mississippi State, Mississippi, and the C3 from the USDA-ARS, Insect Biology and Population Management Research Laboratory, Tifton, Georgia. Colonies were maintained individually according to procedures by Perkins (1979) at 26.7 ± 0.5°C, 14:10 (L:D) photoperiod, and > 50% relative humidity. Larvae were reared on a modified pinto bean diet (Quisenberry & Whitford 1988).

Pupae from the corn and rice strain colonies were sexed and placed individually in polystyrene cups (29.7 ml) and capped with a waxed lid which had an attached pad of moistened cellulose wadding (2.54 × 2.54 cm). At emergence, intrastrain and interstrain pairs of virgin adults were placed in oviposition containers (1.89 liter) containing vermiculite and an ovipositional substrate (cheesecloth top). Each container was provided a wicked polystyrene cup (29.7 ml) containing adult diet (honey-beer-ascorbic acid). Ovipositional containers were checked daily and egg masses removed when present for a total of 4 ovipositional days per mated female. Egg masses were held individually until hatch at 26.7 ± 0.5°C, 14:10 (L:D) photoperiod, and > 50% relative humidity. Females were dissected after successful oviposition or death for the presence of spermatophores to determine if mating had occurred.

The experiment was arranged in a completely randomized design with 36 total mating types and 10 replicates per mating type, for a total of 360 individual pairings. All possible combinations of colony mating types were examined. Data were subjected to analysis of variance and significant ($P < 0.05$) means separated by least-squares means (SAS Institute 1985).

Results

The colonies used in this study were identified electrophoretically as different fall armyworm strains (corn or rice). The influence of colony age on reproductive compatibility (i.e., number of egg masses oviposited and number of females with spermatophores)

varied between strains and according to mating type (significant strain by colony age interaction; $P < 0.003$) and required that data be analyzed within each strain by mating type (Table 1).

The crossing results indicated the strains successfully mated in both directions (Table 1). Dissections of females showed that spermatophores had been transferred in 80-100% of the matings, except for intrastrain (C2 ♀ × C2 ♂) corn matings where only 50% of the females had spermatophores.

The number of egg masses oviposited by females in corn matings was greater when the colony age of females was older (25+ yr). Thus, the colony age of corn females was more important in the number of egg masses produced than colony age of corn or rice

TABLE 1. FALL ARMYWORM INTRASTRAIN AND INTERSTRAIN REPRODUCTIVE COMPATIBILITY.

Strain	Colony age	Cross ♀	Cross ♂	No. of pairs	No. egg masses	No. with Spermatophores
Corn	25+ Yr × 25+ Yr	C3 ×	C3	10	11.4 a	10 a
	25+ Yr × 1 Yr	C3 ×	C2	10	10.9 a	10 a
	1 Yr × 25+ Yr	C2 ×	C3	10	10.0 a	10 a
	25+ Yr × < Yr	C3 ×	C1	10	8.3 ab	10 a
	1 Yr × < Yr	C2 ×	C1	10	5.2 bc	8 b
	< Yr × 1 Yr	C1 ×	C2	10	3.2 c	9 ab
	< Yr × < Yr	C1 ×	C1	10	2.5 c	8 b
	< Yr × 25+ Yr	C1 ×	C3	10	2.4 c	8 b
	1 Yr × 1 Yr	C2 ×	C2	10	1.9 c	5 c
Corn hybrid	25+ Yr × 1 Yr	C3 ×	R2	10	13.0 a	10 a
	25+ Yr × < Yr	C3 ×	R1	10	12.1 a	10a
	25+ Yr × 4+ Yr	C3 ×	R3	10	11.2 a	9 ab
	1 Yr × < Yr	C2 ×	R1	10	5.2 b	10 a
	1 Yr × 4+ Yr	C2 ×	R3	10	4.1 b	9 ab
	1 Yr × 1 Yr	C2 ×	R2	10	3.9 b	9 a
	< Yr × 1 Yr	C1 ×	R2	10	2.8 b	10 ab
	< Yr × 4+ Yr	C1 ×	R3	10	2.8 b	9 a
	< Yr × < Yr	C1 ×	R1	10	2.4 b	8 b
Rice	1 Yr × 1 Yr	R2 ×	R2	9	12.3 a	10 a
	1 Yr × 4+ Yr	R2 ×	R3	10	9.2 ab	10 a
	1 Yr × < Yr	R2 ×	R1	10	8.6 ab	10 a
	< Yr × 1 Yr	R1 ×	R2	10	6.1 b	10 a
	4+ Yr × 1 Yr	R3 ×	R2	10	5.8 b	10 a
	4+ Yr × < Yr	R3 ×	R1	10	5.7 b	10 a
	< Yr × < Yr	R1 ×	R1	10	5.4 b	10 a
	4+ Yr × 4 Yr	R3 ×	R3	10	5.3 b	10 a
	< Yr × 4 Yr	R1 ×	R3	10	5.3 b	10 a
Rice hybrid	1 Yr × 25+ Yr	R2 ×	C3	10	10.9 a	10 a
	1 Yr × 1 Yr	R2 ×	C2	10	9.7 ab	10 a
	1 Yr × < Yr	R2 ×	C1	10	9.1 ab	10 a
	< Yr × 25+ Yr	R1 ×	C3	10	6.6 bc	10 a
	4+ Yr × 25+ Yr	R3 ×	C3	10	4.8 c	10 a
	< Yr × 1 Yr	R1 ×	C2	10	4.5 c	10 a
	< Yr × < Yr	R1 ×	C1	10	4.4 c	9 a
	4+ Yr × < Yr	R3 ×	C1	10	4.4 c	10 a
	4+ Yr × 1 Yr	R3 ×	C2	10	3.4 c	10 a

Means within a column (strain or hybrid by length of colonization) followed by the same letter are not significantly different ($P > 0.05$); least-squares means test).

males in matings. In contrast, the number of egg masses produced by rice female matings was greater when female colony age was younger (< yr and 1 yr).

Colony age significantly influenced the number of viable eggs produced (Table 2). The younger the colony age, regardless of strain, the greater the number of viable eggs and thus, reproductive potential. Conversely, the older the colony age of the female the fewer the number of viable eggs.

Discussion

Incompatibilities reported in interstrain matings by Pashley & Martin (1987) were not found in this study (Table 1). Results are in agreement with Whitford et al. (1988) who found strains successfully mated in both directions. Colony age did not affect repro-

TABLE 2. Effect of colony age on fall armyworm egg viability.

Colony age	Cross ♀	Cross ♂	No. of pairs	No. viable eggs
< Yr × 1 Yr	C1	C2	40	391 a
	C1	R2		
	R1	R2		
	R1	C2		
< Yr × < Yr	C1	C1	40	375 a
	C1	R1		
	R1	R1		
	R1	C1		
1 Yr × < Yr	C2	C1	40	331 a
	C2	R1		
	R2	R1		
	R2	C1		
< Yr × 25+/4+ Yr	C1	C3	40	310 ab
	C1	R3		
	R1	R3		
	R1	C3		
1 Yr × 25+/4+ Yr	C2	C3	40	259 abc
	C2	R3		
	R2	R3		
	R2	C3		
1 Yr × 1 Yr	C2	C2	39	199 bc
	C2	R2		
	R2	R2		
	R2	C2		
25+/4+ Yr × 1 Yr	C3	C2	40	169 bc
	C3	R2		
	R3	R2		
	R3	C2		
25+/4+ Yr × < Yr	C3	C1	40	151 c
	C3	R1		
	R3	R1		
	R3	C1		
25+/4+ Yr × 25+/4+ Yr	C3	C3	40	121 c
	C3	R3		
	R3	R3		
	R3	C3		

Means followed by the same letter are not significantly different ($P > 0.05$; least-squares means test).

ductive compatibility as suggested by Pashley (1988); however, colony age, particularly of females, had a significant impact on the number of viable eggs produced. Extended colonization of fall armyworms resulted in production of fewer viable eggs (Table 2).

The corn and rice fall armyworm strains differ in a number of physiological (Lynch et al. 1983, Pashley et al. 1987a b, Pashley 1988, Quisenberry & Whitford 1988, Whitford et al. 1988) and behavioral (Whitford et al. 1988) traits; however, the status of reproductive isolating mechanisms between strains is not clear because matings in both directions occur (Table 1; Whitford et al. 1988). A prereproductive isolating mechanism between strains is not strongly fixed. This study and Pashley & Martin (1987) did not give females a choice between males of the two strains. However, preliminary studies reported by Pashley (1988b) indicated cross-attraction of strains occurs in the field even though males are preferentially attracted to females of their own strain. Pashley (unpublished) also reported that corn females did not mate with rice males but rice females accepted corn males. Studies must be conducted to further evaluate cross-attraction and mating in the field. In addition, extensive mate choice experiments should be performed to determine if mate preference serves as an isolating mechanism between strains.

Pashley (unpublished) suggests that temporal isolation by way of differences in mating times may be the primary isolating mechanism between strains. Corn strain mating occurs during the first part of the night while rice strain mate the last third. Thus, mating behavior and hybrid presence must be evaluated to establish if reproductive isolating mechanisms between fall armyworm strains exist.

In addition to fall armyworm strain differences influencing reproductive parameters, colonization of insects may cause changes in phenotypes (Mason et al. 1987). Phenotypic changes caused by random genetic drift, founder effects, nonrandom mating, or selection during colonization may influence reproductive behavior, fertility, and rates of reproduction (Dame et al. 1964, Fye & LaBrecque 1966, Raulston 1975, Economopoulos et al. 1976). Thus, inherent fall armyworm differences and colonization of insects potentially influenced the differences in reproduction observed in this study.

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FALL ARMYWORM (LEPIDOPTERA: NOCTUIDAE) OUTBREAK ORIGINATING IN THE LOWER RIO GRANDE VALLEY, 1989

S. D. PAIR,[1] J. R. RAULSTON,[2] J. K. WESTBROOK,[1]
W. W. WOLF,[1] AND S. D. ADAMS[1]
[1]Insect Biology and Population Management Research Laboratory Agric. Res. Serv., USDA, Tifton, GA 31793.
[2]Subtropical Agricultural Research Laboratory, Subtropical Cotton Insects Unit, 2413 East Highway 83, Weslaco, TX 78596.

ABSTRACT

Ecological, meteorological, and radar evidence indicated that 200,000 ha of irrigated corn grown in the Lower Rio Grande Valley (LRGV) of Texas and northeastern Mexico served as a primary source of migrant fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), that severely impacted crops at Corpus Christi and on the High Plains of Texas during the summer of 1989. Based on soil samples taken in 100 corn fields in the region which yielded an average of 3.97 pupae/m^2 of soil, an estimated 7.94 billion FAW adults were available for transport from the LRGV during late June and early July. A similar study conducted in 40 fields of 16,200 ha of corn grown 400 km NNW of the LRGV near Uvalde, Texas yielded populations averaging 0.39 pupae/m^2 which likely produced approximately 0.06 billion FAW adults. In the LRGV 15.9% of the adults had emerged during June 5-13 while no FAW adults had emerged at Uvalde June 19-21, thus indicating that the major FAW emergence events in the LRGV preceded those at Uvalde. Large numbers of FAW were captured in pheromone traps at Uvalde on the night of June 21 in the absence of local emergence, suggesting an influx of migrants from the LRGV.

Concurrently, pheromone traps indicated large influxes of FAW on the Texas High Plains. Subsequent reports indicated unusually early FAW infestations at Ankeny, Iowa and at Columbia, Missouri. Ground-based and airborne RADARS detected the maximum aerial density of insects emanating from the LRGV on the night of June 20. Calculated trajectories indicated that weather transport systems were available for displacement of passive objects to the High Plains (1000 km) and to Ankeny, Iowa (1900 km). This study constitutes the first reported evidence of long-distance FAW migration from a defined source area to directly impact crops in remote areas. Mature corn in the LRGV is proposed as a major contributory source of migrant FAW in the Central U.S.

RESUMEN

Evidencia ecologica y metereologica suministrada por el radar indicó que 20,000 has. de maíz de irrigación en el Valle del Río Grande (LRGV) de Texas y en el noreste de Mexico, sirvieron como las fuentes primarias para el cogollero migrador (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), el cual hizo un gran impacto en Corpus Cristi y en High Plain en Texas, durante el verano de 1989. Basados en las muestreos de suelos tomadas en 100 campos de maíz en esta región, las cuales tenian un promedio de 3.97 pupas/m^2 de suelo, se estimó que 7.94 billones de adultos de FAW podían estar disponibles para ser transportados desde LRGV durante el final de Junio y a comienzos de Julio. Un estudio similar realizado en 40 campos de 16,200 has de maíz cultivado a 400 kilometros al norte del LRCV cerca a Uvalde, Texas, brindaron un promedio poblacional de 0.30 pupas/m^2 el cual produjo aproximadamente 0.06 kilos de adultos del FAW. En el LRGV 15.9% de los adultos emergieron durante Junio 5-13 mientras que no hubo emergencia de adultos en Uvalde en Junio 19-21, indicando que la mayor emergencia de adultos en LRGV precedía a aquella de Uvalde. Tanto el gran numero de FAW capturados en trampas con feromona localizadas en Uvalde en la noche

del 21 de Junio y tanto la ausencia de emergencia en esa localidad, sugiri un influjo de migradores desde LRGV. Al mismo tiempo, las trampas de feromonas indicaron grandes migraciones de FAW en Texas, High Plains. Otros reportes indicaron unas infestaciones tempranas de FAW en Ankeny, Iowa y en Columbia, Missouri. Radares terrestres y aereos detectaron la mayor densidad de insectos provenientes desde LRGV en la noche del 20 de Junio. Las trayectorias calculadas indicaron que el desplazamiento de los sistemas de transportes de objetos pasivos hacia High Plains (1,000 km) y hacia Ankeny, Iowa (1900 km). Este estudio constituye la primera evidencia de migración a larga distancia del FAW desde una fuente definida haciendo un impacto directo en campos localizados. El maíz pre-cosecha en le LRGV es propuesto como la mayor fuente de migración del FAW hacia el centro de los Estados Unidos.

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), is a sporadic but often severe pest of many row crops and forages throughout much of South and North America and in the West Indies (Sparks 1979, Mitchell 1979). Because they lack a diapause mechanism, FAW are unable to survive winter in temperate zones and are believed to overwinter primarily in the southernmost portions of Florida and Texas (Luginbill 1928, Hinds & Dew 1915, Vickery 1929, Pair et al. 1986, Raulston et al. 1986b). Each spring, FAW populations (varying in magnitude from year to year) migrate from overwintering source areas to reinvade more northerly habitats. Luginbill (1928) noted several reports of FAW outbreaks, with particularly severe devastation occurring in 1899 and in 1912 when crops were almost completely devastated east of the Rocky Mountains. Heavy spring floods across the South during each of those years resulted in late-planted forage and grain crops, which were believed to contribute directly to subsequent outbreaks of FAW (Hinds & Dew 1915, Vickery 1929). Although other outbreaks have occurred irregularly, and most are poorly documented, none seem to match the severity of 1977 when losses due to FAW amounted to $137.5 million in Georgia alone (Sparks 1979).

The abiotic and biotic processes predisposing outbreaks of FAW are only partially understood. Luginbill (1928) associated the propagation of FAW populations in overwintering areas with periods of cool weather and abundant rainfall that is believed detrimental to its natural mortality agents. Under favorable conditions, FAW increase to damaging population levels and migrate before natural enemies can increase and regulate their populations. Substantial evidence suggests that drought promotes outbreaks of a multitude of insect pests (Mattson & Haack 1987) including FAW (Luginbill 1928). The outbreak of 1977 was characterized in the Southeast by record-breaking cold winter temperatures followed by an abnormally warm and dry spring and summer (Westbrook & Sparks 1986). Pair et al. (1986) suggested that the amounts of corn planted, favorable production practices, and synchronous FAW emergence from overwintering areas may largely determine the magnitude of populations arriving at northerly locations from the Southeastern U.S.

In 1989, the Insect Migration Unit of this laboratory and personnel of the USDA-ARS Subtropical Cotton Insects Laboratory, Weslaco, TX conducted field studies to document the production and movement of corn earworm (CEW), *Heliothis zea* Boddie, populations from irrigated corn in the Lower Rio Grande Valley (LRGV). Strong circumstantial evidence indicated this region as a primary source for migrant CEW and FAW populations capable of impacting more northerly areas (Raulston et al. 1986abc, Sparks et al. 1986, 1989, Pair et al. 1987). Favorable meteorological conditions occur on an interannual basis during the spring and early summer which are highly conducive to long-range transport of noctuids (Westbrook et al. 1985). While conducting field studies on the southern edge of the irrigated corn-growing region located in northeastern Tamaulipas, Mexico, we observed FAW populations destroying ear stage corn. The severity of the

localized FAW outbreak prompted efforts to document the magnitude and subsequent dispersal of the emerging population from a known source area. The results of those studies are reported herein.

Description of Source Areas

Raulston et al. (1986b) reported on the seasonal population dynamics of FAW in the Texas-Mexico Gulf Coast area during 1984-1985. A northerly temporal sequence of FAW population movement was observed in the state of Tamaulipas, and FAW populations were generally higher in the southern portions, particularly in irrigated corn grown near Abasolo (Fig. 1). Raulston and Houghtaling (1986) described the climatological, geographical, and agricultural characteristics of the LRGV (Fig. 2). The area (ca. 65 km long by 65 km wide centered at N25 30′ W98 00′) lies in northern Tamaulipas, Mexico and in southern Texas in a region described by Correll & Johnston (1970) as the Tamaulipan brushlands. The area is semi-arid tropical and typically receives ca. 680 mm of rainfall annually. The LRGV (15,000 km^2) is an area of intensive agriculture and ca. 200,000 ha of irrigated corn are planted in late February each year (170,000 in Mexico and 30,000 in Texas). Non-irrigated areas south of the LRGV are primarily devoted to dryland sorghum (500,000 ha) and to livestock production on native rangeland. Also, an additional 15,000 ha of irrigated corn are grown near Abasolo, situated ca 200 km south of the LRGV. Because of intensive agriculture and its geographical features, the LRGV is a natural corridor and/or primary source area for several economically important noctuid pests including FAW, CEW, and tobacco budworm, *H. virescens* F. (Raulston et al. 1986a, Sparks et al. 1989) that may impact crops in more northern areas.

A portion of the 1989 study was conducted ca. 470 km NNW and downwind of the LRGV at the Winter Garden area near Uvalde, TX. This area is at the northern edge of the Tamaulipan brushlands and ca. 16,200 ha of irrigated corn are planted in March. This site was selected to delineate the extent of FAW infestations in the proposed source area because it lies in the route for insects emigrating from the LRGV to more northerly areas such as the Texas High Plains.

Methodology

The potential production of FAW was studied in corn fields in the LRGV from June 5-13, 1989. To determine pupal production from maturing corn, two 1-m^2 soil samples were excavated to a depth of 8-10 cm in each of 100 fields in the LRGV (80 in Mexico and 20 fields in the U.S). On corn rows adjacent to each soil sample, 25 ears (total of 100/field) were inspected and the number of damaged and/or infested ears and the number of medium and large FAW larvae remaining in the ears were counted and recorded. At Uvalde, 40 fields were sampled on June 15-19, 1989 in the same manner as previously described. All noctuid life stages, i.e., prepupae, pupae, and pupal exuviae recovered from the soil samples were collected and identified to species. Calculations of the mean number of FAW produced per unit area were based on the total number of live prepupae and pupae and exuviae encountered in each sample. A portion of the live FAW pupae collected from the soil samples in the LRGV was held in an insectary to estimate emergence periods of FAW adults.

Pheromone traps (International Pheromone Systems, Merseyside, England) were used to index adult FAW populations in the LRGV, Uvalde and Lubbock, TX, and at Lane, OK. Two traps at each location were positioned at Uvalde (June 21), Lubbock (June 19), and at Lane, OK (June 18). Pheromone traps were already positioned in the LRGV (10 locations) and in Crowley, LA as part of an ongoing monitoring system. In all cases, traps were baited with a synthetic FAW pheromone (Terochem Laboratories Ltd, Alberta, Canada) that was changed every two weeks.

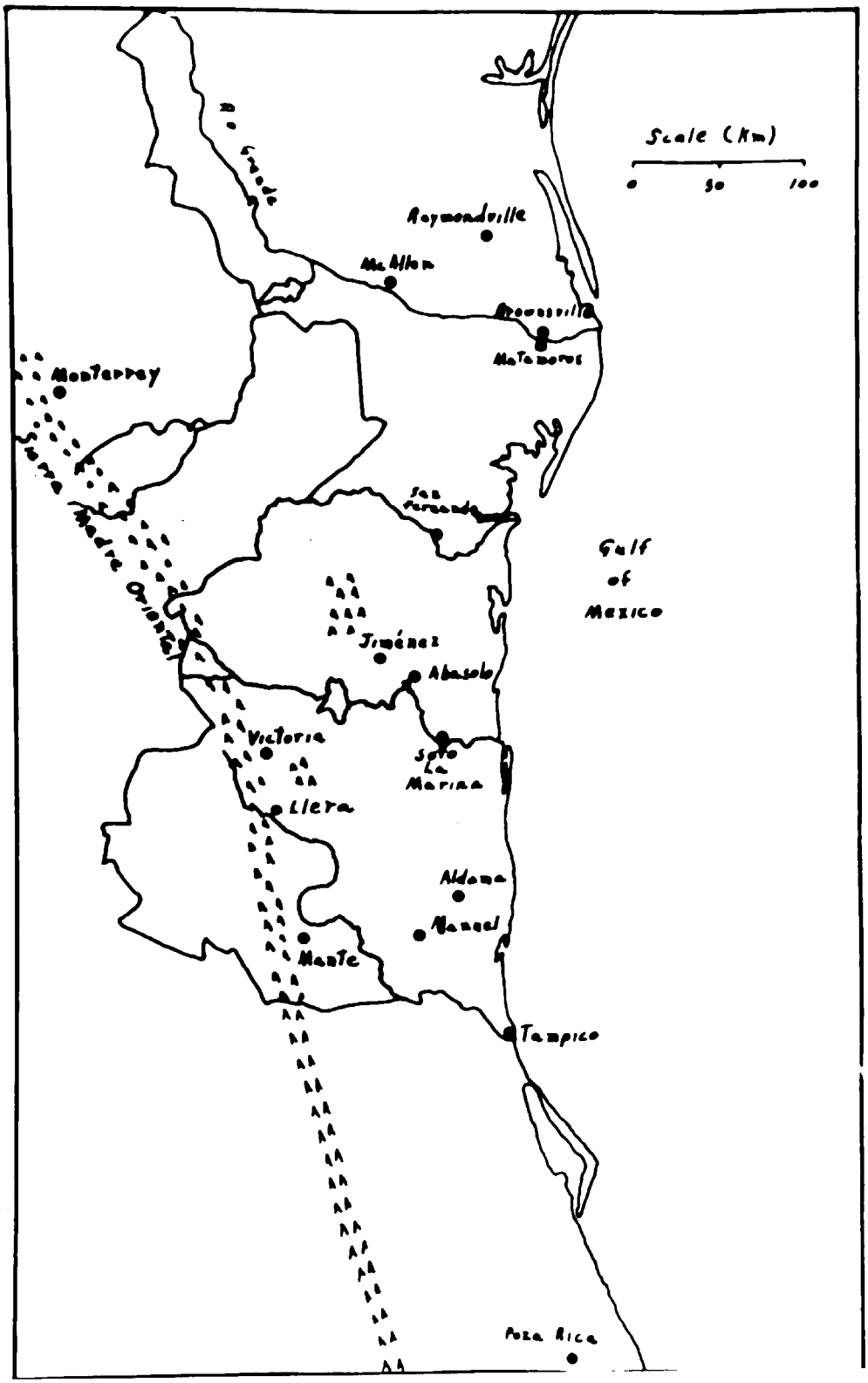

Fig. 1. Map of the Lower Rio Grande Valley of Texas and the State of Tamaulipas, Mexico (from Raulston and Houghtaling 1986).

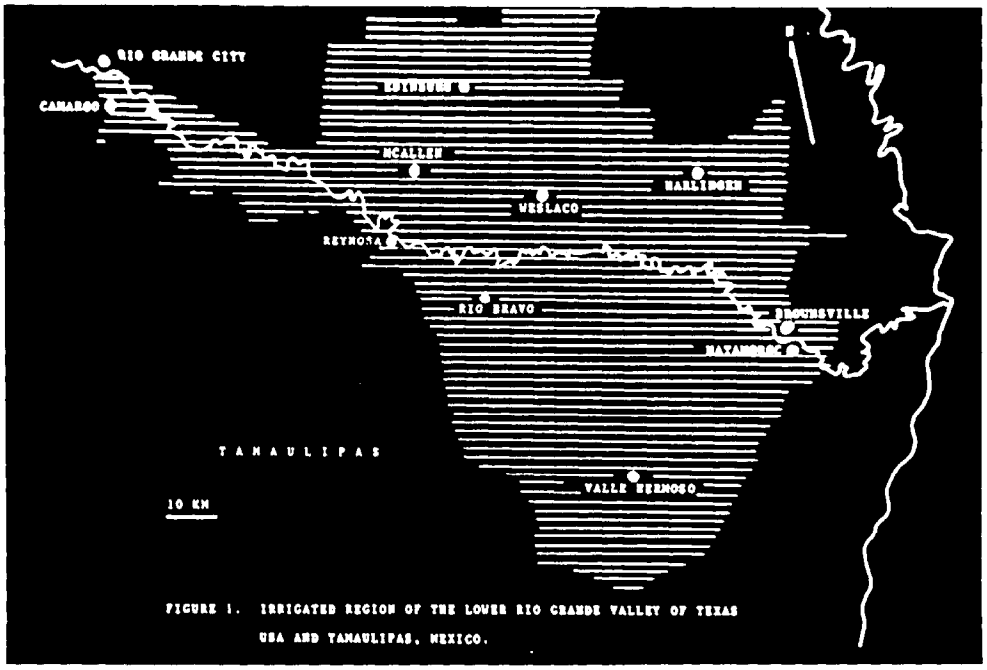

Fig. 2. Irrigated region of Tamaulipas State in northern Mexico and the Lower Rio Grande Valley of Texas.

Meteorological and ground-based radar observations were conducted near Donna, TX during June of 1989. In addition, an airborne radar was operated on the nights of June 20-21 on flights from Weslaco to San Antonio, TX. Readers are referred to Wolf et al. 1986a, Hobbs & Wolf (1989), and Wolf et al. (1990), for specific details of these operations and data collections.

Results and Discussion

Prior to initiation of soil samples in the LRGV, eight corn fields in Mexico were sampled weekly to determine infestation levels of both CEW and FAW. Because very low numbers of FAW were detected in whorl-stage corn, there was no evidence that local populations were responsible for the subsequent heavy infestations observed on mature corn during mid-June. Also, pheromone traps positioned in the LRGV did not indicate the presence of significant FAW activity during May or early June. High FAW populations often occur on irrigated corn grown in southern Tamaulipas. Raulston et al. (1986a) determined that corn grown near Abasolo produced an estimated 0.4 billion FAW adults in 1984. It is unlikely that the 500,000 ha of dryland sorghum normally grown due south of the irrigated region was a source area for the LRGV since little of that crop was planted in 1989 due to a severe drought over most of northern Mexico and south Texas. Hence, we suspect that irrigated crops such as corn at Abasolo or other hosts not affected by the drought in areas farther south the most likely initial inocula for the sudden and widespread FAW infestation of ear-stage corn in the LRGV.

All fields in the LRGV and 95% of those at Uvalde had ears infested with FAW larvae. As might be expected of the FAW, populations were clumped and the most severely affected fields were located on the southeastern portion of the LRGV. In the LRGV, 86% of the fields produced FAW pupae while only 35% of the fields at Uvalde

produced pupae (Table 1). In the LRGV, 59% of the fields produced FAW populations exceeding 1.0/m² or 10,000/ha. In three fields, populations exceeded 20 pupae/m² (200,000/ha). The most heavily infested field averaged 59 pupae/m² (590,000/ha). This field was ca. 400 ha in size and potentially produced 236 million FAW. The maximum number of FAW produced in a single field in the Uvalde area was 3.0/m² (30,000/ha). These data do not take into account the potential adult production from medium and large larvae remaining in the ears at either location.

The resultant adult FAW production from ear stage corn in the LRGV and at Uvalde was estimated at 3.97 and 0.39/m², respectively, during June 1989 (Table 2). Adult FAW emergence had already commenced in the LRGV since 15.9% of the stages recovered were exuviae. However, FAW exuviae were not recovered at Uvalde, indicating that no local emergence had yet occurred. Estimates of adult production from 1984-1985 (Raulston et al. 1986a) and 1986-1988 (J. R. Raulston, unpubl.) are included for comparative purposes. Based upon the total hectarage of corn grown in the LRGV and at Uvalde during 1989, we estimated that 7.94 and 0.06 billion adult FAW, respectively, were produced at the two locations. The production of FAW during 1989 was 2× that observed during the study conducted in 1986, when an estimated 3.27 billion FAW were produced. Mortality of FAW prepupae and pupae due to nematodes and unidentified pathogens amounted to 10.2% in the LRGV. No mortality of FAW was observed in the samples taken at Uvalde.

The 1989 studies in the LRGV probably underestimate the actual FAW production due to several factors. The soil samples were taken coincidental to when maximum CEW pupation occurred. FAW are typically secondary invaders where high CEW larval infestation exists, and as a result, many FAW were still completing development when sampling occurred. Based upon samples of 100 ears in each field, there remained 1.77 billion ($\bar{x}$ = 0.88/row m) medium larvae and 3.69 billion large FAW larvae ($\bar{x}$ = 1.84/row m) yet to complete development in the LRGV. These estimates did not include numerous large FAW larvae observed feeding on the often dense growth of crabgrass and *Amaranthus* sp. prevalent in many fields. Mexican producers may use little or no herbicides contributing to weedy conditions within the corn fields. Assuming that only 50% of the medium and 75% of the large FAW larvae found in the ears completed development, the total FAW production in the LRGV may have exceeded 11.5 billion adults during late June and early July 1989. In addition, mature corn in the LRGV also produced an estimated 6.9 billion CEW adults during June 1989 (J. R. Raulston, unpubl.).

The additional production of FAW adults developing from ears at Uvalde was considerably less than that in the LRGV. At Uvalde, an average of 0.35 medium and 0.69 large FAW larvae/row m still remained in the ears when soil samples were taken. Based

TABLE 1. FREQUENCY OF FALL ARMYWORM PREPUPAE, PUPAE, AND EXUVIAE IN SOIL SAMPLES[1] IN LRGV AND AT UVALDE, TX. JUNE 1989.

	% of fields	
Average FAW/m²	LRGV	Uvalde
0.0	14.0	65.0
0.5-1.0	27.0	25.0
1.5-5.0	37.0	10.0
5.5-10.0	15.0	0.0
10.5-20.0	4.0	0.0
>20.5	3.0	0.0

[1]Soil samples taken to a depth of 8-10 cm.

TABLE 2. ESTIMATED FALL ARMYWORM PRODUCTION DEVELOPING IN CORN THE LRGV AND AT UVALDE, TEXAS, 1984-1989.[1]

Year[2]	Location	No. fields sampled	No. m^2 soil sampled	Avg. no. FAW/m^2±SD	Est. no. adults produced (billions)
1984	LRGV	9	134	0.858±1.16	1.72
1985	LRGV	100	200	0.160±0.53	0.32
1986	LRGV	120	240	1.633	3.27
1987	LRGV	90	180	0.128	0.25
1988	LRGV	90	180	0.117	0.23
1989	LRGV	100	200	3.97 ±8.50	7.94
1989	Uvalde	40	80	0.39 ±0.91	0.06

[1]Based on m^2 soil samples taken in 200,000 ha of corn in the LRGV, and 16,200 ha at Uvalde, TX.
[2]Data for 1984-1985 from J. R. Raulston et al. 1986c; data for 1986-1988 are from J. R. Raulston (unpublished).

on the total hectarage, 55.8 million medium and 110 million large larvae had yet to complete development at that location. Adults developing from larvae at Uvalde and the LRGV would likely have emerged through mid-July.

Cumulative emergence of adult FAW from field-collected pupae in the LRGV (not considering exuviae), surpassed 50% on the night of June 16, and reached 100% by June 23. Pheromone traps positioned throughout the LRGV failed to reflect the expected dramatic change in local FAW adult populations. From May 1-July 31, avg. capture/trap night exceeded 10 FAW males only during mid-June and again in mid-July. Based on total catches over 10 day periods, the highest numbers were captured June 20-June 29 (77/trap) and from July 10-19 (105/trap). Pheromone traps located within the source areas apparently did not provide evidence of the local emergence of FAW from mature corn. Pheromone traps detected peaks of CEW emergence from whorl-stage corn in the LRGV but again failed to detect peaks of CEW emergence from mature corn (Raulston et al. 1990). Apparently certain physiological cues prompt migration from a decaying habitat (Hughes 1979), as little oviposition occurred on locally susceptible crops such as cotton. Similarly, Browne & Swaine (1966) observed that African armyworm, *S. exempta* (Wlk.) outbreaks rarely recur in the same vicinity and concluded that long-distance migration of moths takes place successively from one outbreak to another.

An unusually early appearance of FAW in more northerly areas provided further evidence that a large proportion of the emerging FAW population in the LRGV migrated from the region. Large numbers of FAW males were captured in pheromone traps at Uvalde (400 km NNW) and at Lubbock, TX (1000 km NNW of the LRGV) during June 19-22 (Fig. 3). In the absence of local FAW emergence, captures of FAW males at Uvalde averaged 414/trap on the night of June 21 and approached or exceeded 200/night through June 30. Subsequent smaller peaks occurred on July 9. At Lubbock, large catches of FAW coincided with those observed at Uvalde. The highest average numbers occurred in traps from June 20-28, with the highest number of males captured on the nights of June 20 (153/trap) and June 26 (155/trap). Smaller numbers were captured through the first half of July prior to the first expected generational peak (ca. July 15), suggesting that additional immigration into the Lubbock area had occurred. Unfortunately, traps were installed at the northern locations too late to fully bracket the initial emergence and dispersal of FAW from the LRGV. However, these data are indicative of an en masse migration of FAW from the LRGV to areas where local FAW populations were either not established or had not developed to the adult stage. The earliest FAW infestation in 22 years occurred on whorl-stage corn at Ankeny, Iowa during mid-July, 1989. Day-degree analysis of FAW development rates suggested that migrants arrived

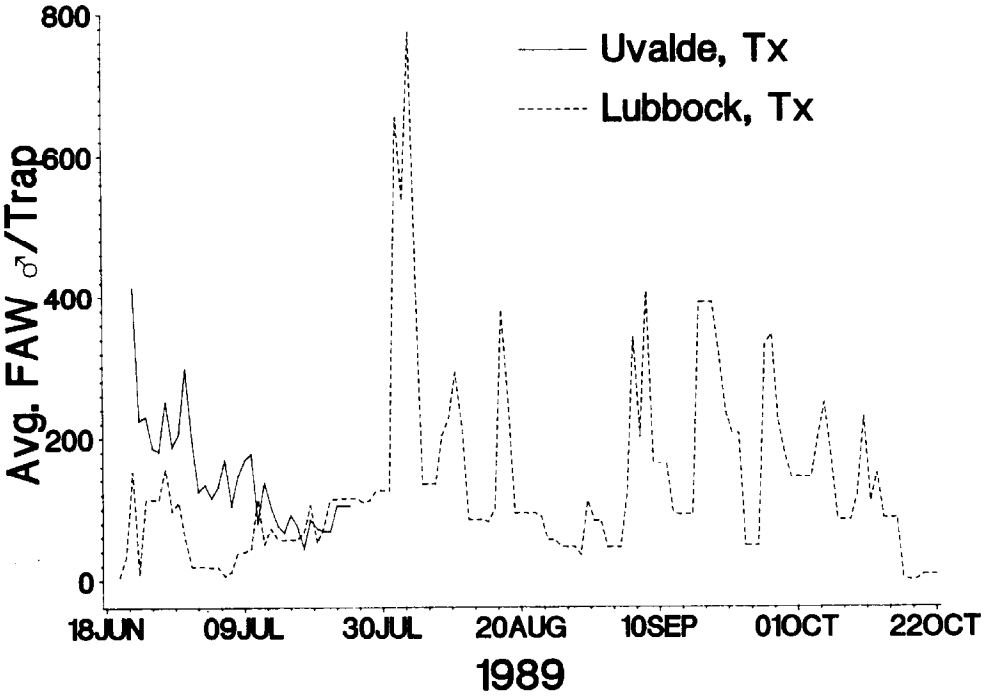

Fig. 3. Average number of FAW males captured nightly in pheromone traps at Uvalde (June 21-July 24) and Lubbock, TX (June 19-Oct 22), 1989.

in the Ankeny area on June 20-25 (W. B. Showers, pers. comm.). Light infestations were also noted at Columbia, MO during mid-June (Armand Keaster, pers. comm.). Very low trap captures of FAW were noted at Lane, Oklahoma and at Crowley, LA, indicating that migrating FAW either did not converge in those areas or overflew them to more distant locations. FAW populations as indexed by traps, surveys, and pest reports were low throughout the Southeast during 1989, indicating that migrant FAW from the LRGV did not contribute significantly to infestations in those states (S. D. Pair, unpubl.).

Throughout the summer of 1989, FAW populations increased in severity on the Texas High Plains as evidenced by extremely heavy FAW captures of 775 males/night during early August. Similar to the pattern of infestations observed in the LRGV, the heaviest damage was first detected in the southern and southeastern portions of the High Plains area. Initial infestations in June and subsequent generations occurred primarily on late-planted grain sorghum, with varying degrees of FAW damage occurring in irrigated corn in Texas and eastern New Mexico (W. P. Morrison, pers. comm.). Of the 525,000 ha of sorghum produced on the High Plains, ca. 80,000 ha in the more southern counties of Crosby, Lubbock, Lamb, and Floyd were the most severely affected and required insecticidal application to control headworms. Corn grown north of these counties did receive FAW damage, but not to the degree observed in sorghum. FAW damage was not reported on crops in the Uvalde area, probably because of the advanced stage of corn maturity and the lack of other preferred hosts in the area. In early July, severe damage to drought-stressed dryland corn occurred near Corpus Christi, and larval populations of FAW averaged ca. 130/m^2 in hay pastures between Corpus Christi and San Antonio (Roy Parker, pers. comm.).

Radar and meteorological data (Wolf et al. 1990) provide further evidence of the LRGV as a source area and for the potential long-distance displacement of FAW from

the LRGV to the High Plains and other northern locations. During the emergence events in the LRGV, several frontal systems crossed the Great Plains which offered optimum opportunities for long-distance transport of FAW. On June 20, a cold front was located in the Central Great Plains. By 0600h on June 23 the front was positioned across Central Texas. Calculated trajectories, based on 500 m altitude (above ground level) wind velocities measured by the ground-based radar and interpolated twice-daily NWS weather data, indicated displacement of passive objects to the vicinity of extreme northern Texas and to western Oklahoma by June 24 (Fig. 4a, b). The displacement of passive insects from the LRGV on June 22 was calculated to have terminated in the Lubbock, TX vicinity on July 24 (Fig. 4c). NWS upper-air data typically underestimate the nocturnal wind speed, especially during episodes of low-level jet formation (Westbrook et al. 1989). Meteorological soundings near Donna, TX indicated the presence of a low-level wind jet from 142 to 161 degrees azimuth during the night of June 20. As in previous studies

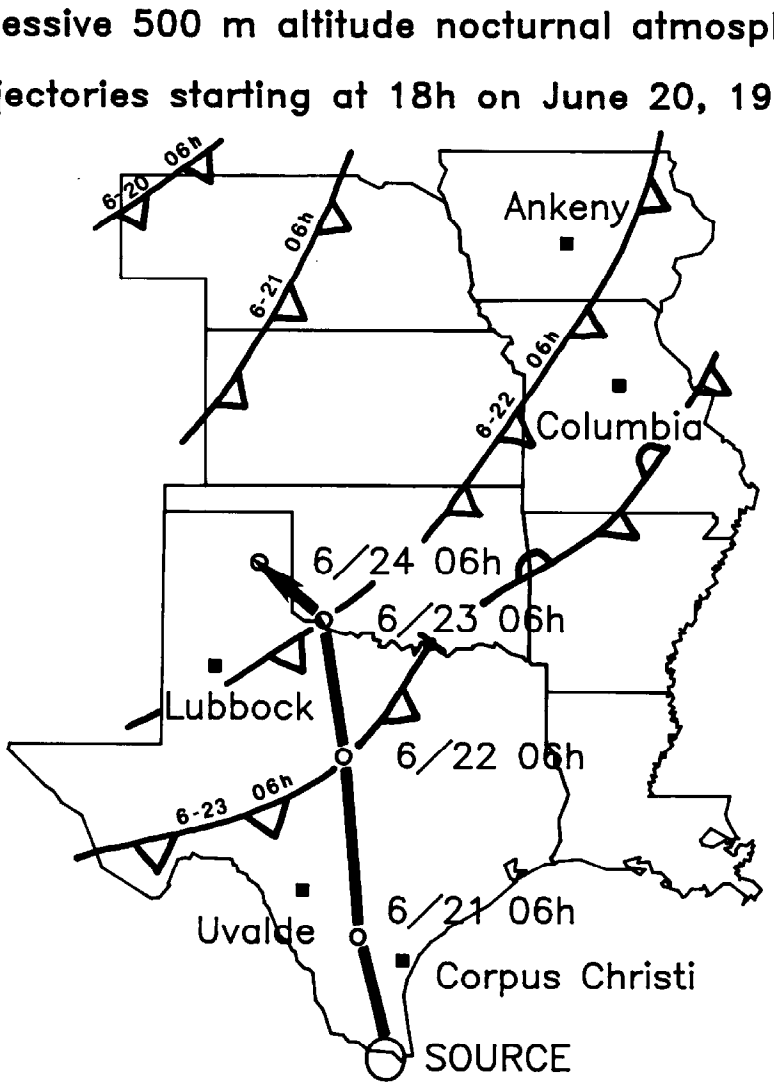

Fig. 4a, b, c. Successive nocturnal atmospheric trajectories at 500 m altitude starting at 1800 h from Donna, TX on June 20, 21, and 22, 1989.

(Sparks et al. 1989), winds from any direction other than southerly resulted in low densities of airborne insects observed by radar. Due to the emergence peaks of both FAW and CEW and the accompanying southerly winds, the highest densities of airborne insects detected by the ground-based radar during this study were recorded on this date. Initially, the ground-based radar, located at the northern (downwind) edge of the corn growing area, detected early evening take-off and departure of large numbers of insects emanating from corn fields. Simultaneously, the airborne radar detected low numbers of flying insects 50 km downwind of the source area. A large cloud of insects was detected flying at 200-700 m altitude as the airborne radar approached the LRGV, and was subsequently tracked from near Weslaco, TX, northward to San Antonio (400 km) on the same night. Interpolated wind vectors during the night of June 20 indicated displacements toward the 350 degrees azimuth, a heading consistent with the flight path of the insect cloud tracked by airborne radar from the LRGV. The remains of twelve insects were collected from the engine cowling following these flights, two were positively

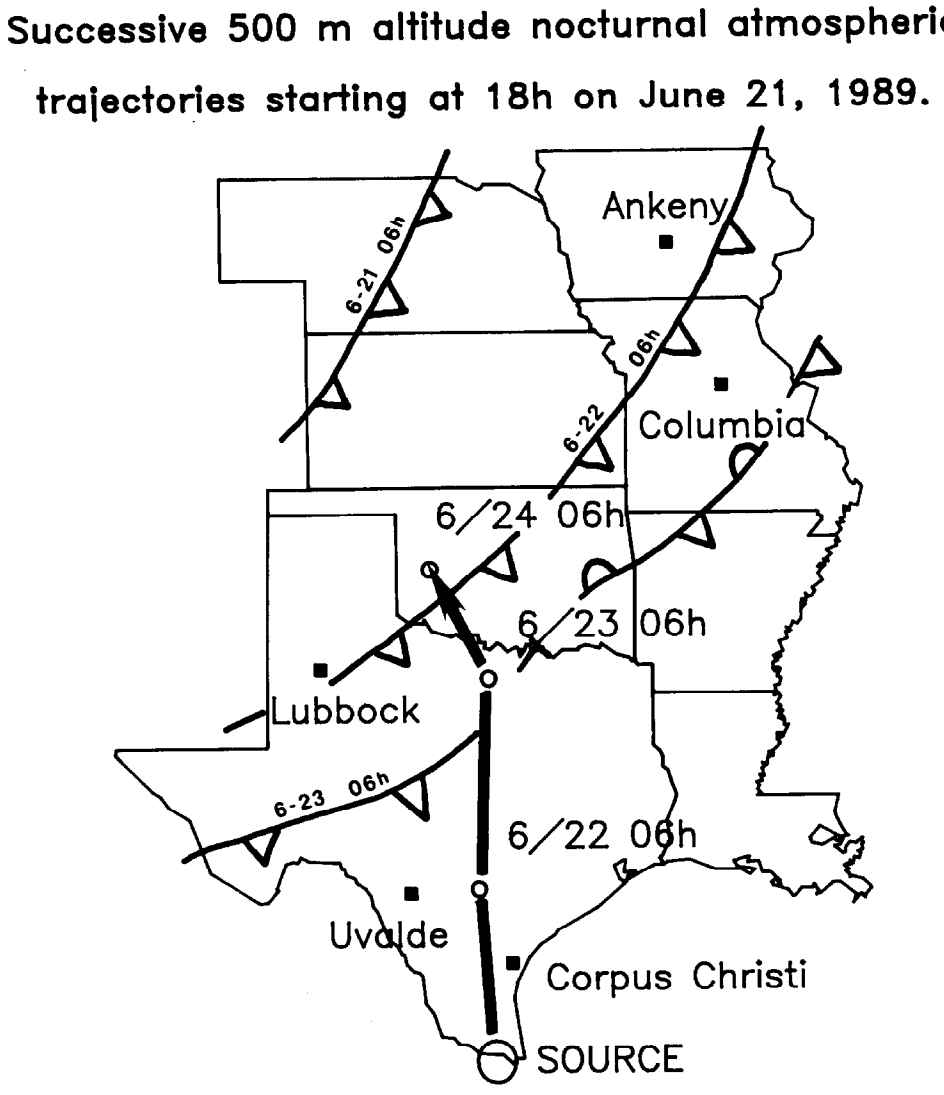

Fig. 4b. Continued

identified as CEW, but it is likely that the insect cloud contained FAW as well. Further evidence of a simultaneous exodus of FAW and CEW from the LRGV may be inferred by the simultaneous and unusually early arrival of CEW on cotton on the High Plains during late June and early July (Leser 1989).

Determining source areas of migrant FAW and their resultant impact on local crops has been identified as a critical need in developing area-wide suppression programs (Knipling 1980, Sparks 1986). Our studies clearly demonstrate the need to accurately delineate source populations on an annual basis when considering potential noctuid movement in agroecosystems. There are few other instances where sources of immigrant FAW and their subsequent invasion of crops were specifically documented. Hinds & Dew (1915) described the successive progression of FAW populations from crops in the Mobile, AL area northward during the outbreak of 1912. Rose et al. (1975) documented an en masse arrival of FAW in Sault Ste. Marie, Canada. Backtrack analyses suggested the flight originated 1600 km to the south in the Lower Mississippi River Valley. An

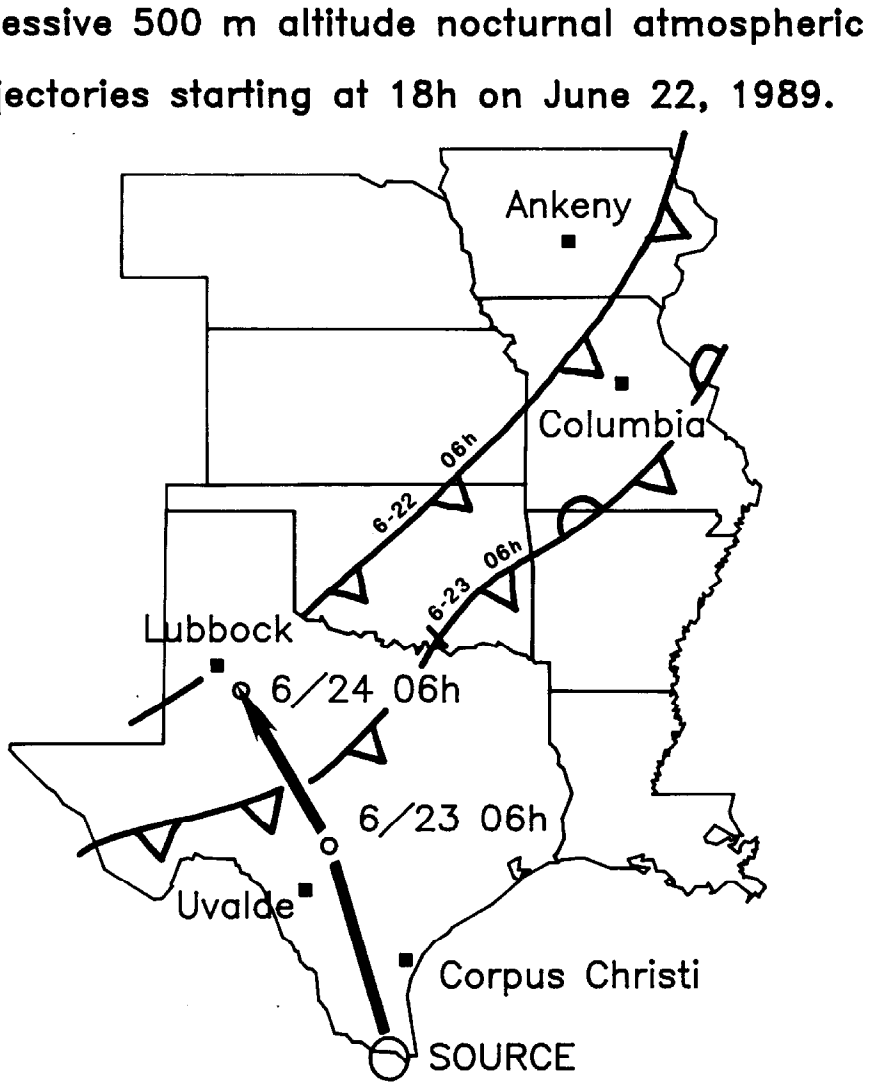

Fig. 4c. Continued

analysis of the seasonal phenology of FAW infestations across Mississippi during 1978-1979 suggested that immigrants arrived via storm systems from unidentified source areas (Hogg et al. 1982). FAW populations demonstrate a successive progression north and northwesterly of their overwintering sites in Florida, and the spring arrival of FAW males in adjacent states appears to be associated with the presence of certain synoptic weather systems (Pair & Sparks 1986, Pair et al. 1986). Circumstantial evidence also exists that a reverse FAW migration from the Texas High Plains to the LRGV occurred during the fall of 1984 (Pair et al. 1987). Research also indicates that FAW may undertake transoceanic flights across the Gulf of Mexico (Wolf et al. 1986b). However, our study provides the first combined ecological, meteorological, and radar evidence for migratory flights of FAW from a defined geographical area to impact crops far removed from the source.

The outbreak discussed in this paper obviously did not approach the severity of those described in 1899, 1912, or 1977, but the potential certainly existed. A widespread outbreak could occur in the presence of favorable conditions if heavy populations existed simultaneously during the early summer in both northern Mexico and in the southeastern states. It is conceivable that a similar situation triggered the massive outbreak east of the Rockies in 1912. The sudden appearance of FAW in the LRGV and at more northerly locations emphasizes that persistent efforts are needed to identify source areas and monitor FAW populations via traps and/or within-field scouting. Such endeavors are requisite for timely prediction of severe infestations (Barfield et al. 1980, Sparks et al. 1985). Indeed, epicenters of extremely severe FAW populations may develop within a general infestation over a relatively widespread area as demonstrated by the events in the LRGV in 1989.

The production of CEW from mature corn grown in the LRGV has been identified as a potentially major threat to cotton and other crops in northern Texas and elsewhere (Sparks et al. 1986, 1989). Data collected from 1984-1989 indicate that FAW production on mature corn in the LRGV averaged 2.3 billion adults annually, and assuming a 1:1 sex ratio exists, 1.1 billion were females. If each female then oviposits an average of 500 viable eggs, and if hypothetically 25,000 eggs/ha of crop are needed to create an economic infestation, then FAW that were produced in the LRGV had the potential for impacting 22 million ha of susceptible crops. Similarly, the magnitude of FAW populations produced in the LRGV during 1989 had the potential for infesting 79 million ha of crops. Thus, mature corn in the LRGV should be considered as a major source of FAW populations having the potential to migrate and inflict widespread economic damage in much of the central U.S.

Acknowledgments

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DEVELOPMENT OF FALL ARMYWORM ON DIETS CONTAINING RESISTANT AND SUSCEPTIBLE CORN SILKS

B. R. WISEMAN
USDA-ARS-IBPMRL
Tifton, GA 31793

D. J. ISENHOUR
Department of Entomology
Coastal Plain Exp. Stn.
University of Georgia
Tifton, GA 31793

ABSTRACT

Growth and development of fall armyworm, *Spodoptera frugiperda* (J. E. Smith), larvae on pinto bean diet containing dry corn, *Zea mays* L., silks of resistant, 'Zapalote Chico', or susceptible, 'Stowell's Evergreen', at 0, 18.75, 37.50, and 67.0 mg silk/ml diet were evaluated at 20, 25 and 30°C. Weight of larvae that fed on resistant and susceptible silk-diets averaged 38 and 205 mg, respectively. At 20°C, the weight of larvae that fed on various concentrations of silk/diet did not differ between the resistant and susceptible genotypes or among the various concentrations within each corn genotype. However, at 20°C, significant differences were found between the resistant and susceptible for development time, weight of pupae and time to adult eclosion for larvae that fed on various concentrations of silk/diet. Significant differences were consistently recorded for all characters measured ($P < 0.05$) between the resistant 'Zapalote Chico' and susceptible 'Stowell's Evergreen' at 25 and 30°C. Larvae failed to develop to pupae at the highest concentration (67.0 mg/ml) of resistant silks at 20, 25, or 30°C.

RESUMEN

Se evaluó a temperaturas de 20, 25 y 30 °C el crecimmiento y desarrollo de larvas de cogollero, *Spodoptera frugiperda* (J. E. Smith), en dieta de fríjol prieto, la cual contenía maíz (*Zea mays* L.) seco, cabellos de maíz resistente "Zapalote chico," o susceptible "Stonewell's Evergreen," en concentraciones de 0, 18.75, 37.50 y 67.0 mg de cabellos/ml de dieta. El peso de la larva alimentada con cabellos de variedades resistentes o susceptibles dió un promedio de 38 y 205 mg, respectivamente. A los 20°C, el peso de la larva alimentada de varias concentraciones de dieta con cabellos, no difirió entre genotipos susceptibles o resistentes o entre las concentraciones de cada genotipo. Sinembargo, aquellas larvas alimentadas con dietas de varias concentraciones de cabellos resistentes y susceptibles, criadas a los 20°C, se encontraron diferencias significativas en el tiempo de desarrollo, peso de pupas y duración de los estados desde larva a emergencia de adultos. La diferencias significativas fueron consistentes para todos los caracteres ($P > 0.05$) entre la variedad susceptible "Stonewell's Evergreen" a 25 y 30°C. Las larvas no alcanzaron estado de pupa en las concentraciones mas altas (67.0 mg/ml) de los cabellos resistentes a 20, 25 y 30°C.

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is a serious economic pest of several grass species in the United States, particularly corn, *Zea mays* L., in the Southeast. The use of resistant corn cultivars to manage the fall armyworm appears to be the most viable alternative to the use of chemicals for its control (Wiseman 1985).

Numerous studies have shown various levels of resistance in whorl stage corn to the fall armyworm since the discovery of resistance in the 'Coastal Tropical Flint' corn. In particular, the whorl stage of the 'Antigua' group of dent corn has a high level of resistance to the fall armyworm (Anonymous 1965, Wiseman et al. 1966, Wiseman and Davis 1979). A high level of resistance against the fall armyworm and the corn earworm, *Helicoverpa zea* (Boddie), also was found in the silks of an exotic dent corn cultivar, 'Zapalote Chico 2451# (PC3)' (Wiseman & Widstrom 1986, 1987). Zapalote Chico is a floury dent corn from the state of Oaxaca, Mexico that has little agronomic value in its present form. However, it has a great genetic potential as a source of resistance for reducing losses in corn by the fall armyworm and corn earworm.

In recent years, research on the resistance of corn to fall armyworm has provided new methods and approaches to differentiate resistant and susceptible corn genotypes (Davis et al. 1989). The development of laboratory bioassays would be beneficial for determining basic biological effects of the resistant cultivar on the insect and useful in determining the chemical basis of resistance. We report effects of different concentrations of resistant and susceptible corn silks mixed in meridic diets on the growth and development of fall armyworm under controlled conditions.

Materials and Methods

Larvae used in this study were obtained from a colony maintained on pinto bean diet (Burton 1967) at the Insect Biology and Population Management Research Laboratory, Tifton, Ga. Two corn genotypes, 'Stowell's Evergreen' (SEG), a sweet corn susceptible to fall armyworm feeding on silks, and 'Zapalote Chico 2451# (PC3)', (ZC), a dent corn resistant to fall armyworm silk and ear feeding in the field, were selected for study. Each cultivar was grown in bulk in single-row plots, 6.1 m long and 0.76 m apart, at Tifton in 1986, using accepted agronomic practices common to the area.

Silks of each corn genotype were harvested 2 d after emergence from the husk leaves. The silks were excised at the tip of the ear, bulked, oven dried at 41°C for about 10 d, and ground to pass through a 1.0 mm screen using a Cyclotec TC1093 (Fisher Scientific, Atlanta) sample mill. Dry silks from each corn genotype were then stored in a freezer at –10°C until needed. Concentrations of 0, 18.75, 37.5, and 67.0 mg silk/ml diet were mixed into a diluted (300 ml diet:100 ml distilled water) pinto bean diet for bioassay. The silk-pinto bean diet mixtures were dispensed into 36 30 ml plastic diet cups at a quantity of ca. 10 ml per cup and allowed to solidify for about 2 h. One neonate larva was then placed in each cup, and the cup was capped with a paper lid.

The experiment was arranged as a split split-plot design with 11 replications. The experimental unit was the mean of two cups per replicate for each treatment. Whole plots were temperature regimes of 20, 25, and 30 ± 2°C. Subplots were corn genotypes and the final split was concentration of silk per ml of diet. Each environmental room was maintained with a 14:10 (L:D) photoperiod and 70 ± 5% RH.

Data recorded were weight of larvae at 10 d, developmental time in days, weight of pupae, and time from egg hatch to adult eclosion. Data were analyzed as replicate means by General Linear Models Procedure, and means were separated with the appropriate use of Tukey's honest significant differences (HSD) at $P < 0.05$ or t-test at $P < 0.05$ (SAS Institute 1985).

Results and Discussion

Weights of 10-d-old fall armyworm larvae fed varying amounts of silk-diet mixtures of Zapalote Chico and Stowell's Evergreen at three temperature regimes are presented in Table 1. The weight of larvae averaged over the three temperatures at 10 d that

TABLE 1. MEAN WEIGHT OF 10-D-OLD FALL ARMYWORM LARVAE THAT WERE FED VARYING CONCENTRATIONS OF RESISTANT OR SUSCEPTIBLE CORN SILKS IN MERIDIC DIETS.

		$\bar{x}$ weight of larvae (mg) at indicated temperature (°C)[1]								
		20			25			30		
Mg silk/ ml diet	n	SEG	ZC		SEG		ZC	SEG		ZC
0	11	10 a	9 a		270 a		265 a	435 b		464 a
18.75	11	6 a	2 a		231 ab	*	56 b	493 a	*	214 b
37.50	11	6 a	1 a		216 b	*	12 bc	511 a	*	55 c
67.00	11	5 a	0.3 a		96 c	*	2 c	280 c	*	1 d

[1]Means within a column not followed by the same letter (Tukey's HSD mean separation) or cultivar means within a temperature separated by * (*t*-tests) are significantly different ($P < 0.05$) SAS Institute (1985). SEG = Stowell's Evergreen, susceptible; ZC = Zapalote Chico, resistant. n = Experimental unit is the response of two larvae per replicate per treatment.

were fed SEG and ZC were 205 and 38 mg, respectively. No larval mortality occurred by 10 days. A significant three-way interaction occurred; thus, the data are illustrated accordingly (Table 2). Growth of the fall armyworm larvae was extremely slow at 20°C, and no significant differences in weights of larvae were detected among different concentrations of silks or between corn genotypes (Table 1). However, at 25 and 30°C, significant differences were detected in the weights of larvae that were fed various silk concentrations/diet for SEG and ZC. At a given temperature, there was no significant difference between the weight of larvae that were fed on the standard laboratory diet without corn silks. The weights of larvae that were fed 18.75, 37.50, and 67.00 mg ZC silk/ml diet concentrations were significantly less than those larvae that were fed SEG silks at similar concentrations. Even though there was about a 50% decrease in weight of larvae that were fed SEG at 67 mg silk/ml diet compared to the weight of the larvae that were fed the 37.50 mg SEG/ml diet, there was still a 48 and 280-fold difference in weight between the larvae that were fed on SEG and ZC silk diets at the highest silk concentration (67 mg silk/ml diet) at 25 and 30°C, respectively. Significant differences in weight of larvae between those that were fed on SEG and ZC were found at 25°C and 30°C for all concentrations of silk/diet.

TABLE 2. RESULTS OF PROC GLM FOR WEIGHTS OF FAW LARVAE FED RESISTANT AND SUSCEPTIBLE CORN SILK DIETS FOR 10-D.

Source	df	ss	F[1]
Replication	10	23421.65	—
Temperature	2	4020570.45	858.58**
Rep * Temp (Error A)	20	46828.25	—
Genotype	1	999067.58	331.82**
Temp * Genotype	2	648587.26	144.48**
Rep * Geno (Temp) (Error B)	30	67334.85	144.48**
Concentration	3	1086236.56	120.26**
Temp * Conc.	6	586042.49	32.44**
Geno * Conc.	3	456719.14	50.56**
Temp * Geno * Conc.	6	347308.82	19.22**
(Error C)	180	541964.66	—

[1]** indicates highly significant 0.01 level of probability.

TABLE 3. RESULTS OF PROC GLM FOR DEVELOPMENT TIME OF FAW LARVAE FED RESISTANT AND SUSCEPTIBLE CORN SILK DIETS.

Source	df	ss	F[1]
Replication	10	26.83	—
Temperature	2	21171.97	4649.03**
Rep * Temp (Error A)	20	45.45	—
Genotype	1	1153.96	345.89**
Temp * Genotype	2	69.37	10.40**
Rep * Geno (Temp) (Error B)	30	100.08	—
Concentration	3	2179.16	376.99**
Temp * Conc.	6	379.99	32.87**
Geno * Conc.	2	891.53	231.35**
Temp * Geno * Conc.	4	54.44	7.06**
(Error C)	150	289.02	—

[1]** indicates highly significant 0.01 level of probability.

A significant three-way interaction also was noted for development time of larvae (Table 3). Overall, it required about 2.6 times as long for the larvae to develop at 20°C as compared with those tested at 30°C for all diet concentrations. Even though no significant differences (Table 4) were detected among weights of 10-d-old larvae at 20°C (Table 1), significant differences in development time were found between SEG and ZC for 18.75 and 37.50 mg silk/ml diet. Larvae failed to develop to pupae when fed the 67.0 mg of resistant silk/ml diet at all three temperatures.

There was a significant genotype and silk-concentration/diet interaction for weight of pupae (Table 5). Pupal weights of larvae fed SEG silk-diets declined less rapidly than those fed ZC silk-diets with increasing silk concentrations (Table 6). There were significant differences among weights of pupae for larvae fed silk diet mixtures of SEG and ZC for the various silk concentrations/diet and between SEG and ZC at the 37.5 mg silk/diet. The mean weight of pupae from larvae that were fed the various concentrations of silk-diet mixtures differed significantly among temperatures: 20°C (243a), 25°C (256b), and 30°C (251b). As mentioned earlier, no larvae developed to pupation when fed on the highest ZC silk concentration.

TABLE 4. MEAN DEVELOPMENT TIME FOR FALL ARMYWORM LARVAE FED DIFFERENT CONCENTRATIONS OF SILKS OF RESISTANT OR SUSCEPTIBLE CORN GENOTYPES IN MERIDIC DIETS.

Mg silk/ ml diet	n	x̄ development time (days) at indicated temperature (°C)[1]					
		20		25		30	
		SEG	ZC	SEG	ZC	SEG	ZC
0	11	30a	30a	15a	15a	12a	12a
18.75	11	34b	* 38b	16a	* 19b	12a	* 15b
37.50	11	35b	* 49c	16a	* 26c	12a	* 20c
67.00	11	38c	—[2]	19b	—[2]	15b	—[2]

[1]Means within a column not followed by the same letter (Tukey's HSD) or cultivar means within a temperature separated by * (*t*-tests) are significantly different ($P < 0.05$). SAS Institute (1985). SEG = Stowell's Evergreen, susceptible; ZC = Zapalote Chico, resistant. n = Experimental unit is the response of two insects per replicate per treatment.

[2]No fall armyworm developed to pupae.

TABLE 5. RESULTS OF PROC GLM FOR WEIGHTS OF FAW PUPAE FROM LARVAE FED RESISTANT AND SUSCEPTIBLE CORN SILK DIETS.

Source	df	ss	F[1]
Replication	10	6712.43	—
Temperature	2	7496.92	7.50**
Rep * Temp (Error A)	20	9992.85	—
Genotype	1	23506.41	41.20**
Temp * Genotype	2	1372.84	1.20 ns
Rep * Geno (Temp) (Error B)	30	16399.73	—
Concentration	3	122375.16	56.93**
Temp * Conc.	6	3507.30	0.82 ns
Geno * Conc.	2	31145.53	21.73**
Temp * Geno * Conc.	4	5977.05	2.09 ns
(Error C)	147	105336.30	—

[1]** indicates highly significant 0.01 level of probability.

A significant interaction between genotype and concentration of silk/diet occurred for the time of egg hatch to adult eclosion (Table 7). Significant differences in the time required for adult eclosion for larvae fed the various silk concentrations were found both among SEG and among ZC treatments and between SEG and ZC for the 18.75 and 37.5 mg of silks (Table 8). Mean time to adult eclosion was greater for larvae fed ZC diets than for those fed SEG diets. Only 22 of 33 insects emerged as adults for those larvae fed the 37.5 mg ZC/ml diet, indicating some carry-over effects of the resistance, resulting in lowering the total number that emerged as adults. Furthermore, larvae that were fed the highest concentrations of ZC silk diets failed to develop beyond the larval stage.

Also, a significant temperature and genotype interaction occurred for the time of egg hatch to adult eclosion (Table 7). Significant differences in days to adult eclosion were found between SEG and ZC at all three temperatures for both SEG and ZC (Table 9). The mean time to adult eclosion for the three temperatures were: 20°C (52d), 25°C (27.5d), and 30°C (21.5d). Again, larvae that were fed the highest concentration of silk/diet failed to develop beyond the larval stage.

Four separate resistance characteristics were measured in this study: weight of larvae at 10 d, larval development time, weight of pupae, and days from egg hatch to adult eclosion. As expected for poikilotherms, fall armyworm growth and development were the slowest at 20°C and the fastest at 30°C. Significant differences between the

TABLE 6. MEAN WEIGHT (MG) OF FALL ARMYWORM PUPAE FROM LARVAE THAT FED ON VARYING CONCENTRATIONS OF CORN SILKS FROM RESISTANT AND SUSCEPTIBLE GENOTYPES IN MERIDIC DIETS AT 20-30°C.

Mg silk/ ml diet	n	$\bar{x}$ pupae wt (mg)[1] SEG		ZC
0	33	274a		275a
18.75	33	265ab		255b
37.50	33	261b	*	205c
67.00	33	214c		—[2]

[1]Means within a column not followed by the same letter (Tukey's HSD) or row means separated by * are significantly different (*t*-test) ($P < 0.05$) SAS Institute (1985). SEG = Stowell's Evergreen, susceptible; ZC = Zapalote Chico, resistant. n = experimental unit is the response of two pupae per replicate per treatment.

[2]No fall armyworm developed to pupae.

TABLE 7. RESULTS OF PROC GLM FOR DAYS TO ADULT ECLOSION FOR FAW FED RESISTANT AND SUSCEPTIBLE CORN SILK DIETS.

Source	df	ss	F[1]
Replication	10	316.27	—
Temperature	2	16645.33	4200.10**
Rep * Temp (Error A)	20	39.63	—
Genotype	1	555.15	198.78**
Temp * Genotype	2	20.99	3.76*
Rep * Geno (Temp) (Error B)	30	194.30	3.17**
Concentration	3	1272.34	207.78**
Temp * Conc.	6	129.94	10.61**
Geno * Conc.	2	360.76	88.37**
Temp * Geno * Conc.	4	15.57	1.91 ns
(Error C)	121	246.98	—

[1]** indicates highly significant 0.01 level of probability.

TABLE 8. MEAN DAYS TO ADULT ECLOSION FOR FALL ARMYWORM LARVAE THAT FED ON VARYING CONCENTRATIONS OF SILKS OF RESISTANT OR SUSCEPTIBLE CORN GENOTYPES IN MERIDIC DIETS AT 20-30°C.

Mg silk/ ml diet	x̄ days to adult eclosion[1]		
	SEG(n)		ZC(n)
0	30b (33)		30a (38)
18.75	32c (32)	*	36c (33)
37.50	32c (30)	*	33b (22)
67.00	28a (30)		—[2]

[1]Means within a column not followed by the same letter (Tukey's HSD) or row means separated by * (*t*-tests) are significantly different ($P < 0.05$) SAS Institute (1985). SEG = Stowell's Evergreen, susceptible; ZC = Zapalote Chico, resistant. n = experimental unit in parenthesis is the response of two insects per replicate per treatment.
[2]No fall armyworm emerged.

TABLE 9. MEAN DAYS TO ADULT ECLOSION FOR FALL ARMYWORM FROM LARVAE THAT FED ON DIETS WITH SILKS FROM RESISTANT OR SUSCEPTIBLE CORN GENOTYPES.

	x̄ days to adult eclosion at indicated temperature (°C)[1]		
	20 (n)	25 (n)	30 (n)
SEG	51a (39) *	26a (42) *	20a (44)
ZC	53b (26) *	29b (29) *	23b (33)

[1]Means within a column not followed by the same letter (Tukey's HSD mean separation) or row means between temperatures separated by * are significantly different (*t*-tests) ($P < 0.05$) SAS Institute (1985). SEG = Stowell's Evergreen, susceptible; ZC = Zapalote Chico, resistant. Days to eclosion are averaged across concentrations within SEG or ZC. n = experimental unit in parenthesis is the response of two insects per replicate per treatment.

measured characters for ZC and SEG were consistent at 25 and 30°C. However, caution should be made for using 30°C for complete development studies because sometimes the diet tends to dry much faster than at 20 and 25°C, and growth of larvae is enhanced on the lower concentrations of ZC silk/diet at 30°C as compared with those fed ZC silks at 25°C.

The resistance of the silks of ZC against the fall armyworm was strongly expressed with as little as 18.75 mg silk/ml diet, but was expressed even greater at 37.5 mg silk/ml diet. At the 67.0 mg ZC silk/ml diet, the antibiotic effects were specific, cumulative, and persistent for the recorded measurements of weight at 10 d, development time, weight of pupae, and for adult eclosion. In fact, the resistance with 67.0 mg ZC silk/ml diet was so strong that no fall armyworm developed beyond the larval stage.

Resistance measurements should be recorded at the time or under conditions that permit the greatest separation of the resistant and susceptible treatments or cultivars (Wiseman et al. 1980). In addition, as many characters as possible should be measured. The information reported here will enable us to use this bioassay, with the effective temperature regime and related concentration of silk/diet, to determine the chemical factor(s) present in the silks of Zapalote Chico.

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FALL ARMYWORM RESISTANCE IN PROGENY OF MAIZE PLANTS REGENERATED VIA TISSUE CULTURE

D. J. ISENHOUR
Department of Entomology
Coastal Plain Experiment Station
University of Georgia
Tifton, GA 31793 USA

B. R. WISEMAN
USDA-ARS
Insect Biology and Population
Management Laboratory
Tifton, GA 31793 USA

ABSTRACT

Plant regeneration of maize genotypes known to be resistant to leaf-feeding by the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), was attempted via somatic embryogenesis. Successful regeneration from callus tissue cultures was achieved for the maize genotypes 'Antigua 2D-118', 'MpSWCB-4', 'Mp496', and some selected single crosses. Progeny from these regenerates were evaluated under laboratory and field conditions for their levels of resistance to fall armyworm leaf-feeding as compared to their respective non-regenerated parental lines. Significant differences in resistance to leaf-feeding by the fall armyworm were observed between the regenerated and non-regenerated lines. Differences were of a positive as well as a negative nature in regards to the levels of resistance in the regenerates as compared to their non-regenerated parental line. This is further evidence of the potential of somaclonal variation for obtaining agronomically useful traits for crop improvement, in this instance plant resistance to insect attack.

RESUMEN

Se intentó, por medio de embriogenenesis somaticas, la regeneración de plantas de genotipos de maíz resistentes a el consumo de hojas del cogollero *Spodoptera frugiperda* (J. E. Smith). La regeneración de callos de cultivos de tejido fue lograda para los genotipos "Antigua2D-118," "MpSWCB-4," Mp496, y para algunos cruces simples. Bajo condiciones de laboratorio e invernadero, se compararon los niveles de resistencia a el cogollero entre la progenie obtenida a partir de plantas regeneradas y comparada con las lineas no regeneradas de los padres. Las diferencias fueron de naturaleza positivas y negativa en referencia a los niveles de resistencia en las lineas regeneradas y comparados con sus lineas paternas no regeneradas. Esto se considera como una evidencia mas del potencial de la variacion somaclonal para obtener caracteres de mejoramiento del cultivo para resistencia de este a el ataque de insectos.

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is a serious pest of maize in the Americas (Horovitz 1960, Sparks 1979, Dicke & Guthrie 1988). Sparks (1979) reviewed the biology of the fall armyworm and Ashley et al. (1989) provided the most current bibliography of this pest.

Maize genotypes resistant to leaf-feeding by the fall armyworm have been developed (Scott & Davis 1981a, b). Several studies have shown the effects of resistant genotypes

on the growth and development of the fall armyworm (Wiseman et al. 1981, Williams et al. 1983, Isenhour et al. 1985). At the present time the utilization of resistant genotypes exhibits the greatest potential as an alternative to insecticides for fall armyworm control in maize. Wiseman (1987) stressed the value of planting resistant cultivars and how compatible this control strategy was with others.

Continued progress in a crop breeding program is dependent in large part on the ability to obtain new sources of genetic variation. Traditionally the source of this variation has been in the form of plant introductions or exotic germplasm. This material was then incorporated into the breeding program. A new source of genetic variation that is now being utitlized is that derived from plant tissue culture. Plant tissue culture-induced variation, or somaclonal variation, has been reported for several agronomic crops (Larkin & Scowcroft 1981, Earle & Gracen 1985, Evans & Sharp 1986, Lee et al. 1988, Croughan & Quisenberry 1989). Croughan & Quisenberry (1989) reported the first instance of somaclonal variation with respect to resistance to insect feeding. They found increased levels of resistance to fall armyworm in regenerates of bermudagrass, *Cynodon dactylon* (L.) Pers.

Herein we report on the regeneration and potential for obtaining increased levels of resistance in selected maize genotypes known to be resistant to the fall armyworm.

Materials and Methods

Plant Regeneration

The maize genotypes 'Antigua 2D-118', 'MpSWCB-4', 'Mp496', and Pio. X 304C were selected as candidate genotypes for their ability to express totipotency in cell culture. The F1 progeny of a single cross of A188 × Antigua 2D-118 were also evaluated. A188 was used as a parent because of its reported high level of regeneration potential from cell culture (Earle & Gracen 1985).

Multiple field plantings of the selected maize genotypes were made during the summers of 1986-1988 at the Coastal Plain Experiment Station, University of Georgia, Tifton, GA using standard agronomic practices. Plants were selfed by means of hand pollinations to ensure a uniform source of immature maize embryos.

Callus tissue was initiated from immature embryos using procedures described by Green et al. (1974) and Duncan et al. (1985). These procedures involve the culturing of immature maize embryos on agar-based media supplemented with necessary plant inorganic salts, nutrients, vitamins, and plant growth regulators. Callus tissue forms and can be cultured for several months by transferring it to fresh media. Plant regeneration is achieved by varying the plant growth regulator concentrations of the medium. Figure 1 provides an overview of the tissue culture procedures used in the initiation of callus tissue and the subsequent regeneration of plants back from the callus cultures. Regenerated, or Ro, plants were transferred from their agar substrate to soil in the greenhouse, allowed to mature, and then selfed. Seed from these plants, designated as R1 seed, was then planted in the field.

Evaluation for Fall Armyworm Resistance

Field screening at the whole plant level and laboratory bioassays using meridic diets were the two methods employed to measure the levels of resistance to the fall armyworm in the progeny of the regenerated plants.

Field testing utilized artificial infestations of laboratory reared fall armyworms. A randomized complete block design was used with individual plots consisting of a single row 3 m in length. There were 10 and 6 replications for 1988 and 1989 respectively. A

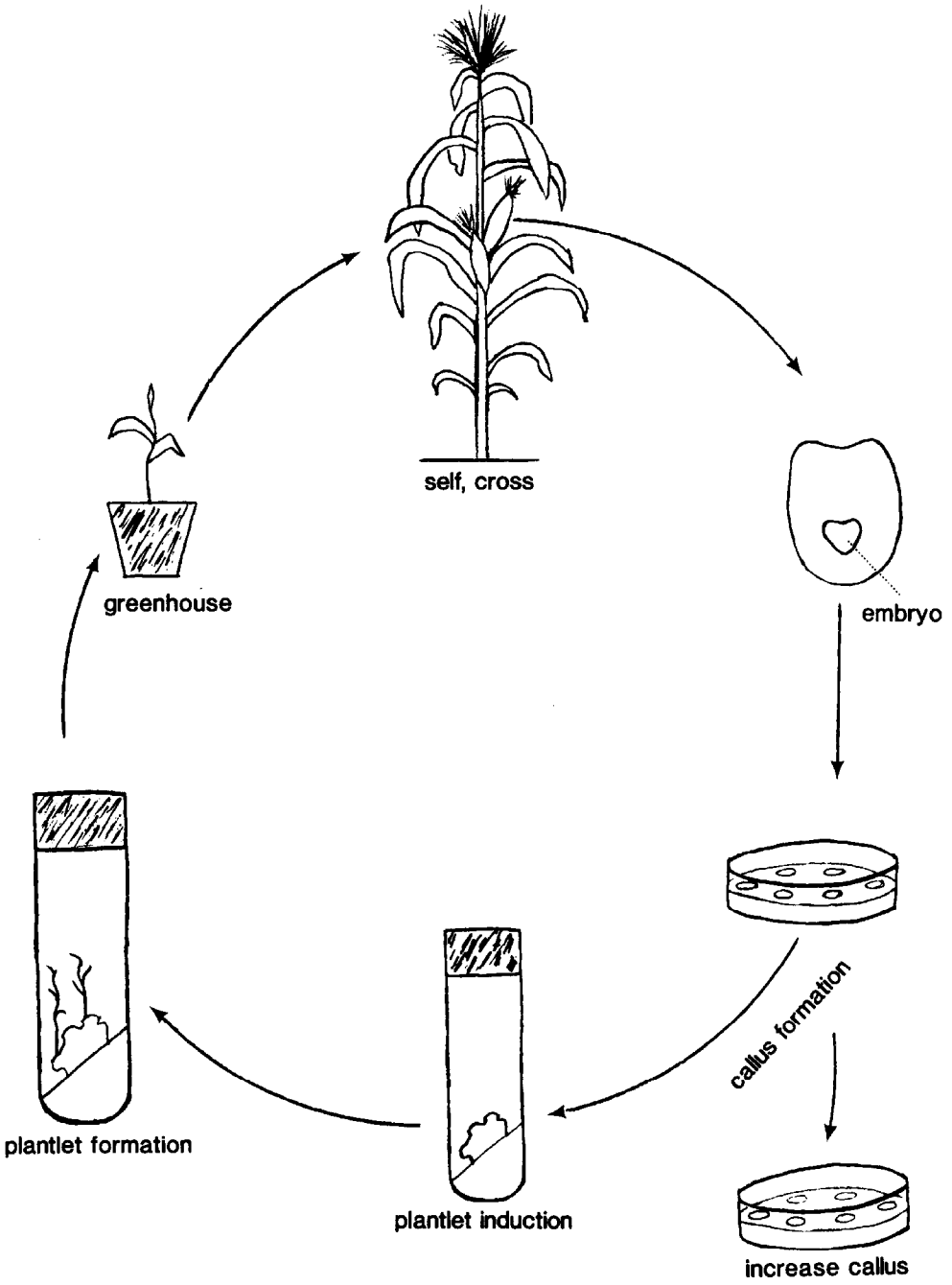

Fig. 1. Procedures for plant regeneration of maize via callus tissue initiated from immature embryo culture (after Green et al. [1974]).

fall armyworm colony was initiated with feral larvae collected from maize. The colony was maintained as describe by Mihm (1983) and feral larvae are added every summer. Infestation procedures were those described by Wiseman et al. (1980) and Mihm (1983) with an infestation rate of 40 neonates per plant. Leaf-feeding by the fall armyworm was visually rated using a system with 1=resistant to 9=susceptible developed by Davis

(USDA-ARS, Mississippi, MS personnel communication) and reported by (Diawara et al. 1990).

Meridic diets were made by incorporating oven-dried maize whorl tissue from field grown plants into a pinto bean diet (Wiseman et al. 1984, Isenhour et al. 1985). Whorl leaves were manually removed from the plants, cut into 4-6 cm sections and oven-dried for 72 h at 42°C. Leaves were then ground in a Cyclotec 1093 mill (1.0 mm mess screen size). Powdered foliage was then held at –20°C until diets were made.

Powdered maize foliage was incorporated into the pinto bean diet to a final concentration of 45 mg/ml of diet. Diets were dispensed in 10 ml amounts into 30-ml diet cups. The diet was allowed to solidify and then a single fall armyworm neonate was placed on the diet surface and the cup was capped with a paper lid. Cups were held at 26°C and a photoperiod of 14L:10D in a growth chamber. A randomized complete block design was used with 25 replications.

Statistical analysis was the same for the field and laboratory portions of this study. Analysis of variance was by the least-squares procedures (SAS Institute 1985) and mean differences were determined by Duncan's multiple range test (Duncan 1955). Significance was determined at the 0.05 level.

RESULTS

PLANT REGENERATION

We define successful plant regeneration as the attainment of a viable plant capable of developing to maturity in soil. Plant regeneration was achieved for Antigua 2D-118, MpSWCB-4, Mp496, and A188 × Antigua 2D-118. No plants were successfully regenerated from callus cultures of Pio. X 304C, however this maybe more of a reflection on our technique rather than on this genotype.

Table 1 lists the number of successful regenerations by genotype for the 1987, 1988, and 1989 seasons. Also listed are values for "percent efficiency" determined based on the number of regenerates obtained divided by the total number of immature maize embryos that had been placed on media to initiate callus formation. The concept of percent efficiency is perhaps a rather crude measurement of the given genotypes capacity to form totipotent callus tissue, but it does provide an indication of how the genotypes used in this study compare with each other in regards to plant regeneration.

Antigua 2D-118 exhibited the highest degree of regeneration efficiency of the genotypes we evaluated, but we cannot say how the genotypes would compare if other regeneration procedures were employed (Table 1). Even though the greatest number of plants were regenerated from MpSWCB-4, it had the poorest efficiencies of regeneration. We used this genotype as one of our "standards", and therefore it received more

TABLE 1. PLANTS REGENERATED FROM CALLUS TISSUE CULTURES OF MAIZE GENOTYPES RESISTANT TO LEAF-FEEDING BY *S. FRUGIPERDA*, 1987-1989, TIFTON, GA.

Genotype	No. of Plants	% Efficiency[1]
Antigua 2D-118	42	53
MpSWCB-4	342	15
Mp496	93	25
(A188 × Ant. 2D-118)	6	13

[1]Total number of plants obtained divided by the number of immature embryos that were placed on media.

emphasis in this study than its ability to regenerate might have warranted. The single cross with A188 as the female parent did not express a higher degree of regeneration when compared to the parent of interest, Antigua 2D-118. Similar results have been observed in crosses with A188 and 'Zapalote Chico' (Isenhour and Wiseman unpublish. data).

Evaluation for Fall Armyworm Resistance

Results of the 1988 field evaluation of the progeny of Ro plants (R1's) and non-regenerated parental lines are presented in Table 2. Significant differences in resistance to leaf-feeding by fall armyworm were observed between the R1 plants and the non-regenerated parental plants. However, these difference were found to be both positive as well as negative in nature in regards to their degree of resistance. Higher levels of resistance were observed for the R1's of MpSWCB-4 as compared to the non-regenerated plants of this genotype. The reverse was observed for A188 × Antigua 2D-118, with the R1 plants showing a greater degree of susceptibility to leaf-feeding by the fall armyworm as compare to the F1 of this cross (Table 2).

Table 3 presents the results of the field evaluations for 1989. The R2 plants failed to exhibit the increased levels of resistance to leaf-feeding by *S. frugiperda* as compared to their non-regenerated parents, as was the case in 1988. The difference in resistance exhibited by the R2 plants of (MpSWCB-4 × Mp496-Ro) as compared to F2's of a comparable single cross was an encouraging sign. Due to a limited amount of seed this line was not screened as an R1 in 1988. This line was derived by crossing a female non-regenerated MpSWCB-4 with pollen from an Ro plant of Mp496. The progeny from this cross were then selfed and given as "R" designation due to the fact they had a regenerated parent.

Table 4 provides the results of the laboratory trial utilizing meridic diets to evaluate for resistance to feeding by the fall armyworm. The differences in resistance between the R2 and F2 lines of (MpSWCB-4 × Mp496) observed in the field evaluation were also detected in the diet trial. Significantly lower larval weights and longer time required for adult eclosion were observed for fall armyworm larvae fed the diet with leaf tissue from (MpSWCB-4 × Mp496 Ro) R2 as compared to any of the other diet treatments.

TABLE 2. Damage ratings for leaf-feeding by *S. frugiperda* at 7 and 14 days after artificial infestation for R1 and non-regenerated parental lines. Tifton, GA, 1988.

Genotype	Damage Rating[1]	
	7 Days	14 Days
Antigua 2D-118 NR-R[2]	4a[3]	6ab
MpSWCB-4 R1	5abc	5a
MpSWCB-4 NR	4ab	6ab
(A188 × Ant. 2D-118) R1	6c	8c
(A188 × Ant. 2D-118) F1	5ab	7b
Pio. 3369A NR-S[2]	6abc	7b

[1]Visual rating scale where 1 is resistant and 9 susceptible (Davis et al. unpublish. data; USDA-ARS, Mississippi State, MS).

[2]NR: non-regenerated controls, R: Resistant, S: Susceptible.

[3]Means within a column followed by the same letter do not differ significantly at the 0.05 level (Duncan [1955] multiple range test).

TABLE 3. DAMAGE RATINGS FOR LEAF-FEEDING BY *S. FRUGIPERDA* AT 7 AND 14 DAYS AFTER ARTIFICIAL INFESTATION FOR R2 AND NON-REGENERATED PARENTAL LINES. TIFTON, GA, 1989.

Genotype	Damage Rating[1]	
	7 Days	14 Days
MpSWCB-4 R2	7a[2]	8a
MpSWCB-4 NR-R[3]	6b	7b
(MpSWCB-4 × Mp496 Ro) R2	6b	7b
(MpSWCB-4 × Mp496) F2	8a	8a
Pio. 304C NR-R[3]	8a	8a
Pio. 3192 NR-S[3]	8a	8a

[1]Visual rating scale where 1 is resistant and 9 susceptible (Davis et al. unpublish. data; USDA-ARS, Mississippi State, MS).

[2]Means within a column followed by the same letter do not differ significantly at the 0.05 level (Duncan [1955] multiple range test).

[3]NR: non-regenerated controls, R: Resistant, S: Susceptible.

DISCUSSION

We are very encouraged by the results of the field and laboratory evaluations of (MpSWCB-4 × Mp496) R2. Levels of insect resistance were enhanced to a limited degree, and no detrimental agronomic characteristics occurred. However, segregation is still occurring in this line, which also might explain in part the lack of difference found in 1989 in the level of resistance in the R2's of MpSWCB-4 and the non-regenerated parents.

The phenomenon of the occurrence of variations in a plant line owing strictly to the stresses incurred during tissue culture has been termed somaclonal variation (Larkin & Scowcroft 1981). There is still uncertainty as to the mechanisms involved, but it has been likened to an "earthquake" within the plant's genome. No foreign DNA has been added, rather an alteration has occurred. There is evidence that transposable elements, or "jumping genes", play a role in the genetic mechanisms involved in the expression of somaclonal variation (Peschke et al. 1987).

While somaclonal variation is now recognized as a viable source of genetic variation, there are problems for its application in plant resistance to insects. In herbicide resist-

TABLE 4. MEAN LARVAL WEIGHTS AT 8 AND 12 DAYS FOR FALL ARMYWORMS THAT WERE FED MAIZE LEAF TISSUE FROM REGENERATED AND NON-REGENERATED MAIZE LINES IN MERIDIC DIETS.

Genotype	Larval Weight (mg)		
	8 d	12 d	Adult Eclosion (d)
MpSWCB-4 R2	28a[1]	172b	31ab
MpSWCB-4 NR-R[2]	28a	169b	31ab
(MpSWCB-4 × Mp496 Ro) R2	19b	132c	33a
(MpSWCB-4 × Mp496) F2	30a	204ab	30b
Pio. 304C NR-R[2]	29a	184ab	30b
Pio. 3192 NR-S[2]	35a	233a	30b

[1]Means within a column followed by the same letter do not differ significantly at the 0.05 level (Duncan [1955] multiple range test).

[2]NR: non-regenerated controls, R: Resistant, S: Susceptible.

ance/tolerance screening using tissue culture the selection is actually made at the cell level by adding the herbicide to the medium. Thus, surviving Ro plants have been challenged by the given herbicide and should process some degree of resistance. This is not the case for screening for resistance to insects. The Ro plant has not "survived" a stressing agent during its development. It will be the Ro plant, or its progeny, that will be stressed with an insect pest at the whole plant level rather than the cell level. Viewed in this regard, using tissue culture for resistance to insects is not as efficient as for herbicide tolerance.

Tissue culture is a very labor intensive procedure, expensive in both time and money. Somaclonal variants are not always of a positive, or desired, nature. In the case of maize, we observed a high degree of male sterility in our Ro plants. However, even with the constraints that we have outlined, somaclonal variation can be a valuable tool for plant breeding.

When this program was first initiated there were concerns regarding the utility of a regeneration system based on callus tissue. A system using protoplasts was deemed more valuable from the standpoint of it being more suitable from gene transfer work. However, the regeneration of maize from protoplasts is still not as efficient as callus tissue and successful gene transformation has been achieved using the particle gun to "shoot" a gene into maize callus (Ludwig et al. 1990).

In summary, we are pleased with being able to isolate somaclonal variants from the lines that have been regenerated which exhibited increased levels of resistance to leaf-feeding by the fall armyworm as compared to their non-regenerated parental lines. However, the regenerated lines should be valuable as "acceptor lines" for gene transfer efforts by means of the particle gun. If a gene for a specific trait is to be placed in a maize plant, would it not be more reasonable to use a genotype that is already resistant to a type of stress? We would encourage individuals engaged in gene transfer of maize to consider using one of the insect resistant maize lines shown in this study to regenerate via callus culture.

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ACTIVITY OF MAIZE LEAF CUTICULAR LIPIDS IN RESISTANCE TO LEAF-FEEDING BY THE FALL ARMYWORM

GUANG YANG,[1] DAVID J. ISENHOUR,[2]
AND KARL E. ESPELIE[1]
[1]Department of Entomology
University of Georgia
Athens, GA 30602

[2]Department of Entomology
Coastal Plain Experiment Station
University of Georgia
Tifton, GA 31793

ABSTRACT

Genotypes of maize, *Zea mays* L., known to vary in their resistance to fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), were utilized in a study designed to examine the role that cuticular lipids play in host plant resistance. The surface lipids were extracted from green and yellow whorl foliage of maize genotypes 'MpSWCB-4', 'Cacahuacintle X's', 'Pioneer 3192' and 'Pioneer X304C'. FAW larvae were reared on meridic diet to which either the extracted foliage or unextracted foliage had been added. FAW growth was monitored and shown to be enhanced when larvae were reared on diet containing foliage from which the cuticular lipids had been removed. Additionally, FAW growth was inhibited when larvae were fed meridic diet containing cuticular lipid extracts from foliage of the four maize genotypes.

RESUMEN

En un estudio designado a examinar el papel de los tejidos cuticulares en la resistencia de plantas, se examinaron varios genotipos del maíz, *Zea mays* L., conocidos por su variablidad en su resistencia al cogollero *Spodoptera frugiperda* (J. E. Smith). Los lipidos superficiales fueron extraidos de follaje verede y amarillo de los genotipos "MpSWCB-4," Cacahuacintle X's', "Pioneer 3192" y "Pioneer X304C." Larvas de FAW fueron criadas en dietas meridicas a las cuales se les habia añadido o suprimido extractos de follaje. Se observo el crecimiento de FAW, y se demostró que acrecentó cuando la larva fue criada en dieta con follaje al cual se le substrayeron los lipidos cuticulares. Adicionalmente, el crecimiento de FAW fue inhibido cuando la larva fue alimentada con una dieta que contenía extractos de lipidos cuticulares provemientes el follaje de 4 genotipos de maíz.

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), is a serious pest of maize, cotton, sorghum, peanut and other crops in North and Central America, causing more than $60 million damage in the southeastern United States per year (Sparks 1986). The development of sources of resistance to the FAW in crop plants is an economical and environmentally desirable method to control this pest. The effects of resistant plant varieties on an individual pest insect are generally specific, cumulative and persistent (Painter 1968). Due to these characteristics, plant resistance to insects is probably the most useful of all means of integrated pest control (Wiseman et al. 1983).

The identification of sources of FAW resistance in maize is an important aspect in the development of a control program for this pest. Several maize genotypes have been

reported to be resistant to FAW (Wiseman & Davis 1979, Wiseman et al. 1981, 1984, Scott & Davis 1981a, b, Williams et al. 1983, Isenhour et al. 1985, Pair et al. 1986). The identification of the chemical basis for this resistance would better allow for the incorporation of these characteristics in breeding programs.

The plant surface, with which an insect pest first comes in contact, plays an important role in plant/insect interactions (Chapman & Bernays 1989). Many herbivorous insects seem to be attracted to their potential host plants by visual, olfactory or tactile stimulative cues based on the physical and chemical characteristics of the plant surface. The cuticular lipids of a plant can affect many aspects of insect behavior, such as orientation, movement, oviposition and feeding (Bernays et al. 1976, Chapman 1977, Stork 1980, Städler 1986, Woodhead & Chapman 1986, Espelie et al. 1990, Eigenbrode et al. 1990).

Variations in the chemical composition of plant cuticular lipids may result in variable plant resistance to insect attack (Woodhead 1983, Maloney et al. 1988, Woodhead & Padgham 1988, Tsumuki et al. 1989). In a few instances, individual classes of cuticular lipid components have been shown to either stimulate or deter insect herbivory (Klingauf et al. 1978, Mori 1982, Woodhead 1983). In other cases organic solvent extracts of leaf material, which contain the cuticular lipids, have been shown to affect the feeding behavior of herbivorous insects (Blaney & Chapman 1970, Bernays & Chapman 1975, Varela & Bernays 1988, de Boer & Hanson 1988, Quisenberry et al. 1988). In the present paper we examine the role that the cuticular lipids of maize foliage may play in resistance to FAW feeding.

Materials and Methods

Plant Material

Four maize genotypes ('MpSWCB-4', 'Cacahuacintle X's', 'Pioneer X304C', and 'Pioneer 3192') were planted during the spring and summer of 1989 in Tifton, Georgia, using agronomic practices common to the area. No soil or foliar insecticides were utilized. Separate planting sites were employed for both field and laboratory evaluations. Plants of each genotype were cut at the 10-12 leaf stage, placed in plastic bags and transported to the laboratory. Foliar tissue was excised, separated into yellow and green whorl fractions and either processed immediately for use in laboratory tests or else stored at –20°C.

Field Evaluation of Resistance to FAW

The four genotypes of maize were planted in a randomized complete block design with 10 replications. Individual plots consisted of 1 row × 3 m in length. Middle-whorl stage maize plants were artificially infested with FAW at a rate of 30 neonates per plant on 5 June 1989 using procedures described by Wiseman et al. (1980). Damage to maize foliage was recorded on the 14th day after infestation according to a 1-9 rating score (1 = most resistant; 9 = most susceptible) (Wiseman et al. 1966, Wiseman & Davis 1979, Diawara et al. 1990).

Growth of FAW on Diet Containing Maize Foliage or Extracted Maize Foliage

Field grown plants of 'MpSWCB-4', 'Cacahuacintle X's', 'Pioneer X304C' and 'Pioneer 3192', in the mid-whorl stage, were excised at the soil level and taken to the laboratory. Approximately 7 to 10 cm of tissue in the middle of each leaf was discarded. The midrib of each leaf was also excised and discarded. Fresh green whorl and yellow whorl foliage was cut into 10-15 cm long pieces and divided into two equal fractions. One fraction was

dipped in redistilled chloroform for 1 min. at room temperature to remove the cuticular lipids and air-dried (Espelie & Bernays 1989). The other fraction of foliage was not treated with solvent. Each of these foliar fractions (45 g) was ground and blended with an artificial bean diet (180 ml) and distributed into 20 diet cups (30 ml) (Mihm 1983, Wiseman et al. 1984). Each diet cup was infested with a single FAW neonate and maintained at 28°C in an environmentally controlled chamber. Tests were arranged as a split-split-plot (4×2×2 factorial) design with 20 replications plus a diet check. The following developmental parameters were recorded: 7 d and 14 d larval weights, days to pupation, pupal weight and days to adult eclosion.

Growth of FAW on Artificial Diet or on Diet Containing Maize Cuticular Lipids

Fresh green whorl and yellow whorl foliage (50 g) of the four maize genotypes, obtained in the same manner as described above, were sequentially extracted with 250 ml of each of the following redistilled solvents: hexane, chloroform and methanol. Each extraction was carried out at room temperature for 1 min. Each extract was concentrated to a volume of 4 ml in a rotary evaporator at 30°C and then stored at –20°C. Extracts were absorbed onto "Celufil-hydrolyzed" (1 g), air-dried for 12 hours at room temperature, blended into artificial diet (100 ml) and distributed into 30 ml diet cups. Each cup was infested with a single FAW neonate and kept at 29°C. Tests were arranged as a split-split-plot (4×2×3 factorial) design with 15 replicates plus blank solvent and diet checks. The solvent checks contained artificial diet to which 1 g of Celufil had been added after 4 ml of the appropriate solvent (hexane, chloroform, or methanol) had been removed by air drying. Insect growth was monitored as described above.

All data were analyzed by an analysis of variance and significant mean differences were separated with the use of Least Significant Difference (LSD) or Waller-Duncan k ratio t test and significance was determined at the 0.05 level (Waller & Duncan 1969, SAS Institute 1985, Ott 1988).

RESULTS

Field Evaluation of Resistance to FAW

Field tests of FAW feeding on the whorl stage of maize indicated that there were major differences between the four genotypes in the 14 d damage ratings for FAW (Table 1). MpSWCB-4 and Pioneer X304C exhibited strong resistance to FAW feeding, but Cacahuacintle X's and Pioneer 3192 showed susceptibility to FAW.

TABLE 1. RESISTANCE TO FOLIAGE-FEEDING BY FALL ARMYWORM IN SELECTED MAIZE GENOTYPES[1].

Genotype	14 Day Damage[2]
'MpSWCB-4'	3.0 ± 0.0d
'Pioneer X304C'	4.8 ± 0.4c
'Cacahuacintle X's'	6.2 ± 0.4b
'Pioneer 3192'	7.6 ± 0.5a

[1]Means (n=10) followed by a different letter are significantly different ($P \leq 0.05$); Waller-Duncan k ratio t test; Waller & Duncan 1969; SAS Institute 1985).

[2]Rating Score: 1 = most resistant; 9 = most susceptible (Wiseman et al. 1966, Wiseman & Davis 1979, Diawara et al. 1990).

TABLE 2. GENOTYPIC VARIATION IN THE RESPONSE OF FALL ARMYWORM FED MERIDIC DIET CONTAINING MAIZE FOLIAGE OR SOLVENT-EXTRACTED MAIZE FOLIAGE.[1]

		Green Whorl		Yellow Whorl	
Parameter	Genotype	Foliage	Extracted Foliage	Foliage	Extracted Foliage
7 Day Wt. (mg)	'MpSWCB-4'	18.6bc	35.2a	12.4c	25.2b
	'Pioneer X304C'	13.2b	20.3ab	22.8a	22.7a
	'Cacahuacintle X's'	17.6ab	22.2a	12.9b	25.1a
	'Pioneer 3192'	10.5b	21.5a	16.1ab	16.8ab
14 Day Wt. (mg)	'MpSWCB-4'	329.5a	401.9a	286.1a	353.7a
	'Pioneer X304C'	265.7b	296.9ab	339.1ab	401.9a
	'Cacahuacintle X's'	200.9b	409.4a	361.8ab	311.8ab
	'Pioneer 3192'	290.2b	448.2a	299.5b	247.8b
Days to Pupation	'MpSWCB-4'	19.7a	17.9b	19.7a	18.9ab
	'Pioneer X304C'	19.3a	18.5a	19.1a	18.5a
	'Cacahuacintle X's'	20.0a	18.8a	19.0a	18.5a
	'Pioneer 3192'	20.4a	19.0a	20.5a	19.0a
Pupal Wt. (mg)	'MpSWCB-4'	206.0ab	223.6ab	188.8b	225.0a
	'Pioneer X304C'	191.5a	204.1a	212.2a	217.3a
	'Cacahuacintle X's'	163.9b	210.9ab	202.0ab	228.5a
	'Pioneer 3192'	222.5ab	231.9a	175.3c	188.6bc
Adult Eclosion (days)	'MpSWCB-4'	28.9a	27.5b	29.2a	29.0a
	'Pioneer X304C'	29.0a	28.1b	28.3ab	28.4ab
	'Cacahuacintle X's'	28.3a	28.8a	29.3a	28.1a
	'Pioneer 3192'	29.8a	28.8a	29.0a	29.6a

[1]Means (n=20) within a row (a genotype) not followed by the same letter are significantly different ($P \leq 0.05$) (Least Significant Difference; Ott 1988).

Growth of FAW on Diet Containing Maize Foliage or Extracted Maize Foliage

FAW larvae reared on artificial diet containing maize foliage from which the cuticular lipids had been extracted were larger and developed more rapidly than those larvae which were grown on diet containing unextracted foliage (Table 2). For ten of the forty pairs of data (developmental parameters of FAW larvae reared on artificial diet containing either foliage or extracted foliage), FAW larvae developed significantly better on the diet containing foliage from which the cuticular lipids had been extracted than they did on the diet containing unextracted foliage. In most of the remaining instances (24 of 30 data pairs) the FAW larvae developed better on diet with extracted foliage than they did on diet containing unextracted foliage, but the differences were not significant. None of the larvae developed significantly better on diet containing unextracted foliage than those reared on diet containing extracted foliage.

The differences between the developmental parameters of FAW reared on diet with unextracted and extracted foliage of maize genotype MpSWCB-4 were relatively larger than those observed for the FAW reared on diet containing foliage from the other genotypes and these differences were significant for 5 of the 10 data pairs (Table 2). Those pairs for which the differences were significant included the 7 d weights for the larvae reared on diet containing both green and yellow whorl MpSWCB-4 foliage. Although there were several differences between FAW growth on green vs. yellow whorl foliage, these differences were not consistent. There were, however, more instances where the differences in growth parameters were significant between larvae reared on diet containing extracted or unextracted green whorl foliage (seven out of ten) than there were for those larvae reared on diet containing yellow whorl foliage (three out of ten) (Table 2).

The average developmental parameters of FAW larvae reared on artificial diet containing either maize foliage or maize foliage from which the cuticular lipids had been removed are shown in Table 3. These values were obtained by combining the values for green and yellow whorl and for each of the four maize genotypes. Each data point, therefore, has 160 replicates. FAW reared on diet containing extracted foliage developed significantly better than those larvae reared on diet containing unextracted foliage as measured by 4 of the 5 growth parameters (Table 3).

Growth of FAW on Artificial Diet or on Diet Containing Maize Cuticular Lipids

Growth of FAW larvae reared on artificial diet containing the cuticular lipid extracts of maize foliage was significantly reduced compared to those larvae reared on the control diets (Table 4). There were no consistent significant differences between the growth of larvae reared on diet containing hexane extracts of maize foliage compared to those

TABLE 3. RESPONSE OF FALL ARMYWORM FED MERIDIC DIET CONTAINING MAIZE FOLIAGE OR SOLVENT-EXTRACTED MAIZE FOLIAGE.[1]

Parameter	Foliage	Extracted Foliage
7 Day Wt (mg)	15.5 ± 9.5a	24.0 ± 13.5b
14 Day Wt (mg)	299.9 ± 107.7a	373.0 ± 140.4b
Days to Pupation	19.7 ± 1.7a	18.6 ± 1.1b
Pupal Wt (mg)	198.4 ± 40.7a	219.0 ± 39.6a
Adult Eclosion (days)	29.0 ± 1.4a	28.4 ± 1.2b

[1]Means (n=160) followed by the same letter within a row are not significantly different ($P \leq 0.05$). (Least Significant Difference; Ott 1988).

TABLE 4. MEAN WEIGHTS (MG) OF FALL ARMYWORM LARVAE AFTER 6 AND 9 DAYS ON MERIDIC DIET CONTAINING SOLVENT EXTRACTS OF MAIZE FOLIAGE.[1]

Genotype	6 Day Wt	9 Day Wt
'MpSWCB-4'	27.3 ± 13.7bc	193.8 ± 65.0ab
'Pioneer X304C'	20.3 ± 10.1d	159.5 ± 62.4c
'Cacahuacintle X's'	21.8 ± 13.1d	154.5 ± 80.1c
'Pioneer 3192'	23.5 ± 11.3cd	170.7 ± 50.7bc
Solvent Check	32.7 ± 15.7a	211.6 ± 69.3a
Celufil Check	32.0 ± 11.3ab	203.3 ± 29.7ab

[1]Means (n=90) within a column followed by the same letter are not significantly different ($P \leq 0.05$). (Least Significant Difference; Ott 1988).

reared on diet containing the subsequent chloroform or methanol extracts of the foliage. For each genotype the 6 d larval weights were significantly less than those of the larvae reared on the solvent check which was artificial diet containing Celufil from which an equal volume of solvent (hexane, chloroform, or methanol) had been air-dried prior to addition to the diet. The larval 9 d weights were also less for FAW reared on diet containing the solvent extracts (Table 4). The solvent extracts of MpSWCB-4 foliage caused the least reduction in growth of the four maize genotypes examined. There were fewer significant differences observed in the FAW developmental parameters of pupal weight, days to pupation or days to adult eclosion between larvae fed diet containing the cuticular lipids compared to those reared on the solvent check diets.

DISCUSSION

Our results indicate that the cuticular lipids of maize play a role in FAW feeding behavior. Larvae reared on diet containing maize foliage from which the cuticular lipids had been removed had enhanced growth (Tables 2 and 3). Moreover, the addition of the extracted cuticular lipids to diet resulted in inhibition of larval growth (Table 4). These results agree with previous studies which have shown that plant surface lipids affect herbivory by lepidopteran larvae (Mori 1982, de Boer & Hanson 1988, Maloney et al. 1988, Varela & Bernays 1988, Stoner 1990, Eigenbrode et al. 1990). Recently, FAW larvae were shown to have reduced growth when they were reared on diet containing solvent extracts of bermudagrass foliage (Quisenberry et al. 1988).

Previous feeding studies have shown that FAW larvae reared on diet containing green whorl foliage are larger than those reared on diet with yellow whorl foliage (Wiseman & Isenhour 1988). In the present study, the extraction of the cuticular lipids from the maize foliage had a more significant effect upon larvae reared on diet containing green whorl foliage than it did on those larvae fed diet with the yellow whorl foliage (Table 2).

Of the four genotypes utilized in this study, MpSWCB-4 exhibited the greatest resistance to FAW feeding in the field evaluation (Table 1). Larvae reared on diet containing MpSWCB-4 foliage exhibited the largest increase in growth when the cuticular lipids were removed from the foliage (Table 2). Although these results might indicate that the cuticular lipids play a role in the resistance of MpSWCB-4 to FAW attack, the addition of the extracted lipids from this genotype to larval diet resulted in less growth inhibition than that which resulted from the addition of the extracts of the other three genotypes examined (Table 4). The cuticular lipids of maize foliage consist of a variety of classes of plant wax components (Bianchi et al. 1982, Blaker & Greyson 1988). Future work will examine the effect that variations (between genotypes and between locations in the same plant) in specific cuticular lipid components have upon FAW feeding behavior.

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SEASONAL DISTRIBUTION, RESPONSE TO HOST DEVELOPMENTAL STAGE, AND SCREENED-CAGE PERFORMANCE OF *ARCHYTAS MARMORATUS* (DIPTERA: TACHINIDAE) AND *OPHION FLAVIDUS* (HYMENOPTERA: ICHNEUMONIDAE) ON *SPODOPTERA FRUGIPERDA* (LEPIDOPTERA: NOCTUIDAE)

H. R. GROSS AND S. D. PAIR
Insect Biology & Population Management Research Lab,
U.S. Department of Agric., Agric. Res. Serv.
Tifton, GA 31793

ABSTRACT

Laboratory and field studies with *Archytas marmoratus* (Townsend) and *Ophion flavidus* Brullé were designed to provide a better understanding of their individual and combined impact on the fall armyworm, *Spodoptera frugiperda* (J. E. Smith). The highest percentage of natural parasitism by *A. marmoratus* and *O. flavidus* on *S. frugiperda* occurred from late April through mid-June during 1985-1986 near Tifton, Georgia. *Ophion flavidus* parasitized 4th, 5th, and 6th instars with equal success, but were minimally successful in completing development on late 6th instars. *Archytas marmoratus* were equally successful in completing development on 3rd, 4th, 5th, and 6th instars. When *S. frugiperda* were multiply parasitized, *A. marmoratus* did not successfully compete with *O. flavidus*. When two *A. marmoratus* and two *O. flavidus* females, or four *A. marmoratus* and four *O. flavidus* females were released against 5-6th instar *S. frugiperda* in whorl-stage corn within 1.8 × 1.8 × 1.8 m screened cages, the number of emerged *S. frugiperda* adults of the subsequent generation was reduced by 50.6 and 92.1%, respectively. With the development of economical methods for mass propagation of *A. marmoratus* and/or *O. flavidus*, will come primary opportunities for advancing biologically based strategies for managing *S. frugiperda*.

RESUMEN

Se establecieron experimentos en el laboratorio y en el campo con *Archytas marmoratus* (Townsend) y con *Ophion flavidus* Brullé con el fin de entender su impacto individual y combinado con el cogollero *Spodoptera frugiperda* (J. E. Smith). Cerca a Tifton, Georgia, el alto porcentaje de parasitismo natural de *A. marmoratus* y *O. flavidus* en *S. frugiperda* ocurrió desde finales de Abril hasta mediados de Junio, 1985-1986. *Ophion flavidus* parasitó en forma exitosa el estado temprano de los intares, 4to, 5to y el 6to. Pero tuvo un exito mínimo en completar su desarrollo en el estado tardío del 6to instar. Cuando *S. frugiperda* fue parasitado en forma multiple, *A. marmoratus* no compitió con *O. flavidus* cuando 2 hembras de *A. marmoratus* y 2 hembras de *O. flavidus*, o 4 hembras de *A. marmoratus* y 4 de *O. flavidus* fueron liberadas contra el 5to- 6to instar de *S. frugiperda*, el numero de adultos de *S. frugiperda* emergentes fué reducido en la generación subsiguiente en un 50.6 a el 92.1%, respectivamente. Con el desarrollo de los metodos economicos para la propagación masiva de *A. marmoratus* o de *O. flavidus* vendrán nuevas oportunidades para un avance en las estrategias de control biologico para manejo de *S. frugiperda*.

Archytas marmoratus (AM) (Townsend) and *Ophion flavidus* (OF) Brullé are primary parasitoids of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) throughout much of its range (Raulin & Stehr 1984, Ashley 1979, Pair et al. 1986, Gross & Pair 1986). Opportunities to advance AM and OF into the forefront of biologically based systems for the management of *S. frugiperda* will be hastened as we better understand their inherent roles within targeted agroecosystems, assist in their conservation, and where possible release mass-cultured parasitoids to augment feral populations. The current study examines the seasonal distribution of both parasitoids in south Georgia, their individual and competitive response to a common host, and their individual and combined performance when released against larvae of *S. frugiperda* on whorl-stage corn within field screen cages.

Materials and Methods

The AM colony used in all studies has been maintained in culture since 1981, with intermittent introductions of adults emerged from larvae of *Heliothis zea* (Boddie) and *S. frugiperda* collected from whorl-stage corn in south Georgia and north Florida. Since 1984, AM has been cultured according to methods of Gross & Young (1984) and Gross & Johnson (1985) except that sugar cubes and free water were independently provided to adult flies instead of a sucrose solution. The OF colony was established during 1984 from field collected larvae of *S. frugiperda*, and has been maintained under conditions described for AM, except that a 50% honey solution was provided as a food source. *S. frugiperda* larvae used in all studies were obtained from a colony housed at the Insect Biology and Population Management Research Laboratory which was established from collections near Tifton, Georgia.

Following both naturally occurring field and laboratory induced parasitism of *S. frugiperda* larvae by AM and OF, larvae were placed on pinto bean diet (Burton 1969) within 30 ml plastic diet cups, and allowed to complete development at 27 ± 1°C and 13:11; L:D photoperiod. After sufficient time had passed to permit the emergence of moths and parasitoids, the percentage of parasitism by AM and OF in all studies was determined from the number of adult parasitoids emerged (and in the case of OF, larvae that emerged from the host) versus the number of available hosts. No attempt was made to determine the cause of death of hosts that did not yield adult parasitoids or moths.

Seasonal Distribution

The frequency with which AM and OF attacked naturally occurring, and/or artificially introduced populations of *S. frugiperda* in whorl-stage corn was determined weekly at an experimental farm near Tifton, Georgia from late April through September, 1985 and 1986. 'Pioneer-3192' dent corn was planted on ca. 3-week intervals to assure an adequate supply of host plants on which *S. frugiperda* larvae could establish and develop. During times when heavy natural populations of *S. frugiperda* were present, seedling plants were protected from destruction by intermittent application of methomyl insecticide applied at recommended rates. Four 20-m single row plots were infested weekly starting in mid-April each year with 10-15 newly eclosed *S. frugiperda* larvae per plant. Larvae were applied from a "Bazooka" insect applicator in accordance with methods of Wiseman et al. (1980). Artificial introductions of larvae were ceased whenever natural populations reached adequate levels for testing. When larvae reached late 5th-6th instars, they were recollected, placed on diet, and allowed to complete development. Whenever possible, 36 larvae per plot or a total of 144 larvae per sampling date were recollected.

Host/Parasite Responses

The responses of AM and OF were measured following single and/or multiple parasitism of *S. frugiperda* larvae. Except where otherwise indicated, *S. frugiperda* larvae were exposed to 1 OF sting and/or 2 AM maggots, and then were returned to cups containing diet to complete development. (Two AM maggots per host larva were used to increase the probability of successful parasitism). Newly deposited AM maggots were transferred with a camel's hair brush from a larviposition substrate, onto the body of the host larvae. All studies involved 6 replications of 12 *S. frugiperda* larvae each. In tests 1 and 2, the responses of AM and OF, respectively, to 3rd, 4th, 5th, and 6th instar *S. frugiperda* were measured. Tests 3 through 5 were designed to measure the specific and interspecific responses of AM and OF when exposed to selected developmental stages of *S. frugiperda* larvae. In test 3 the responses of AM and OF were measured following individual and multiple parasitism of 5th instar *S. frugiperda*. In test 4, the responses of the subject parasitoids were measured following AM parasitism of 5th instar *S. frugiperda* and subsequent OF parasitism of the same larvae when they reached 1-day 6th instar. In test 5, the responses of AM and OF were measured following individual and/or multiple parasitism of late 6th instar *S. frugiperda*. Unlike previous tests wherein 2 AM maggots were provided per host, *S. frugiperda* larvae in test 5 were exposed to 10-15 AM maggots applied in suspension onto the inside paper cap covering the 30 ml larvae bearing diet cup, in accordance with methods of Gross & Johnson (1985). Paired t-tests were used to determine mean differences ($P=0.05$) among treatments (Snedecor & Cochran 1967).

Parasite Performance

The screened-cage performance of AM and OF was measured against 5th-6th instar *S. frugiperda* in whorl-stage corn during 2 independent trials during 1985. The following treatments (no. of parasitoids/cage) were replicated 8 times within 1.8 × 1.8 × 1.8-m screened cages (Chicopee Manufacturing Company, Gainesville, Georgia 30503-2587) during May and June 1985: 1) 4 AM females, 2) 4 pairs of OF, 3) 4 AM females plus 4 pairs of OF, and 4) control—no parasitoids released. The same treatment arrangements were evaluated during August and September 1985, but with 2 instead of 4 parasitoids used in each case. Three to 4 days before plants were artificially infested, the interior of all cages was sprayed with methomyl insecticide from a 11.4 liter compressed air sprayer at recommended rates, to remove naturally occurring parasitoids, predators, and host larvae. Approximately 10 newly eclosed *S. frugiperda* larvae were introduced per plant with a 'Bazooka' applicator when the 'Silver Queen' sweet corn was 6-8 leaf stage (May trial) and the 'Pioneer-3369A' dent corn was 8-9 leaf stage (August trial). Plants averaged 23.3 and 19.1 per cage, respectively, in the May and August trials.

Female parasitoids were reproductively mature when released within cages between 8-900 h. Male OF were released concurrently with females because the laboratory mating of OF is not as assured as that of AM. (Unmated female OF produce only male progeny.) During the period when parasitoids and host larvae were present, a 12 × 12 cm square of cotton batting placed at the top northwest corner of each cage was maintained moist with a 10% sucrose solution to serve as a food source for parasitoids.

S. frugiperda larvae were allowed to complete development and pupate within the cages without further intervention. Beginning ca. 10 days after larvae had begun to leave the plants to pupate, cages were examined 2-3 times weekly for the presence of *S. frugiperda*, AM and OF adults. Cages were examined until no moths or parasitoids were found on 2 successive sampling dates. ANOVA and Waller-Duncan k-ratio t-test were used to separate mean differences ($P=0.05$) among treatments (SAS Institute 1985).

Results and Discussion

Seasonal Distribution

The mean percentage AM and OF parasitism of *S. frugiperda* larvae recovered from whorl stage corn near Tifton, GA during 1985 and 1986 is presented in Figure 1. Mean percentage of parasitism for both parasitoids peaked during late April through mid-June, generally when naturally occurring populations of *S. frugiperda* in south Georgia are typically at their seasonal lows. It seems probable, therefore, that the early season survival of both parasitoid species is dependent on their access to alternate hosts. AM has been reported from 10 other hosts (Arnaud 1978) and is a well known early season parasitoid of *H. zea* (Gross et al. 1976). Krombein et al. (1979) cite 3 other hosts of OF, also including *H. zea*. Two primary, apparently generational peaks of AM parasitism occurred during April/early May, and during the 3rd week of June when the mean percentage of parasitism reached the seasonal high of 29.2%. Three primary peaks of OF parasitism occurred from late April through mid-June, with two occurring in synchrony with those of AM. The highest mean percentage parasitism (19.5%) by OF also occurred during the 3rd week of June.

Laboratory and field efforts to induce diapause in the larval and pupal stages of AM have been unsuccessful (H. R. Gross, unpublished). Therefore, early season parasitism by AM likely results from migrants originating further south, or from adults which have successfully overwintered in south Georgia. Mean longevity of AM females was reported to be 72.8 days at 21°C (Hughes 1975). It is therefore not improbable that AM adults are capable of overwintering. No data are available to suggest the strategy used by OF to overwinter.

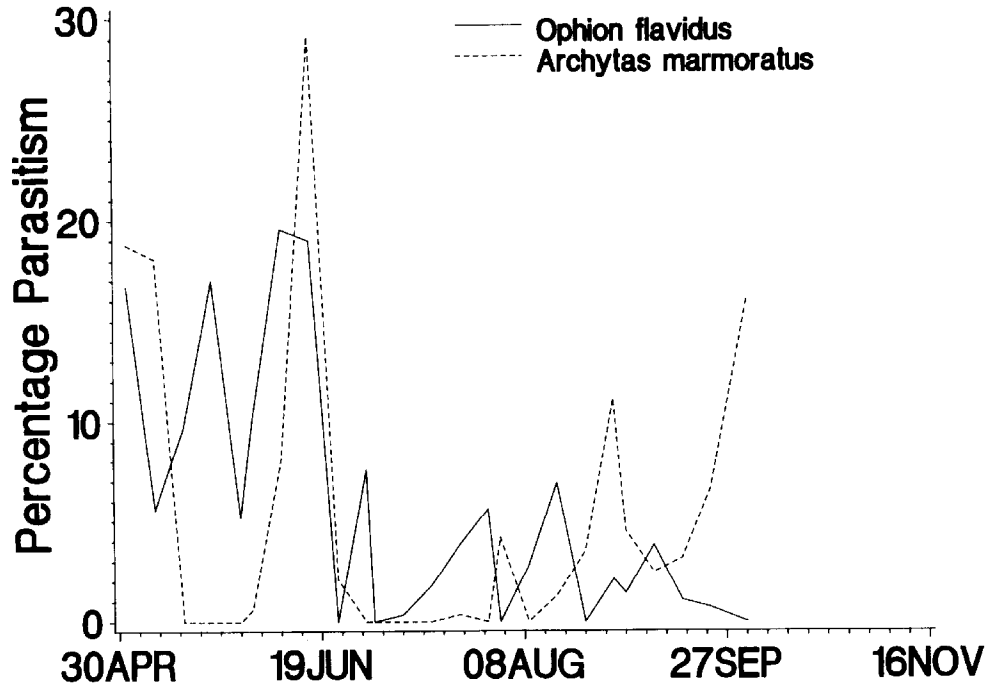

Fig. 1. Seasonal distribution of *Archytas marmoratus* and *Ophion flavidus* on *Spodoptera frugiperda* in whorl stage corn near Tifton, Georgia, 1985-1986.

Percentage parasitism of *S. frugiperda* by AM and OF from July through September was generally below 10%, and was comparable to that reported by Rohlfs and Mack (1985) for southern Alabama. A late season (September and October) resurgence in parasitism by AM has been frequently observed (H.R.G. and S.D.P.) in south Georgia and may contribute to an overwintering adult generation.

Host/Parasite Responses

The mean percentage AM parasitism did not differ significantly among 3rd, 4th, or 5th instars of *S. frugiperda* in test 1 (Table 1). Rohlfs & Mack (1985) similarly reported that AM was recovered from field collections of small, medium and large larvae of *S. frugiperda* in ca. equal percentages. Hughes (1975), however, found that although survival of AM maggots penetrating 2nd, 3rd, and 4th instar *H. virescens* (F.) was comparable, the survival of maggots penetrating 5th instars was significantly higher.

The mean number of OF adults emerged following parasitism of *S. frugiperda* larvae was significantly higher from 4th and 5th instars than from 3rd or late 6th instars (test 2, Table 2). However, when based on the number of emerged OF larvae (from 6th instar *S. frugiperda*) that failed to pupate, the rates of parasitism of 4th, 5th, and 6th instars did not differ significantly. The late 6th instars used in the study may have provided inadequate time and nutrition for OF larvae to complete development before host pupation. Subsequent independent studies conducted as described for Test 2 revealed that the mean percentage emergence of OF adults following parasitism of 1 and 2 day 6th instars was 77.8 and 66.3 (n=144), respectively, thus affirming that early to mid 6th instars were also highly susceptible for parasitism and allowed complete development by OF.

Because the primary development in AM larvae was delayed until after host pupation (Hughes 1975), they were not able to compete with OF either when both parasitized

TABLE 1. RESPONSE OF *A. MARMORATUS* TO SELECTED INSTARS OF *S. FRUGIPERDA*.[1]

Mean Percentage Adult *A. marmoratus* Emergence[2]			
Instar Parasitized			
3rd	4th	5th	6th
58.3	75.0	65.3	76.4

[1]Two newly deposited *A. marmoratus* maggots were transferred onto the body of each larva.
[2]Means are not significantly different (P > 0.05) by ANOVA (SAS Institute, 1985).

TABLE 2. RESPONSE OF *O. FLAVIDUS* TO SELECTED INSTARS OF *S. FRUGIPERDA*.[1,2]

	Instar Parasitized			
	3rd	4th	5th	Late 6th
$\bar{x}$ % Parasitized[3]	20.8a	87.5b	88.9b	75.0b
$\bar{x}$ % Adult Emergence	20.8a	86.1b	84.7b	25.0a

[1]Larvae were exposed to 1 *O. flavidus* sting.
[2]Means followed by letters in common across columns are not significantly different (P ≤ 0.05) according to Waller-Duncan k-ratio t-test (SAS Institute, 1985).
[3]Data based on emergence of *O. flavidus* larvae from host larvae.

5th instar *S. frugiperda* (test 3, Table 3A), or when OF parasitism was delayed until larvae reached 1 day 6th instar (test 4, Table 3B). The only apparent opportunity that AM had to survive in appreciable numbers following multiple parasitism of *S. frugiperda* larvae occurred when OF parasitized larvae were nearing pupation (test 5, Table 3C).

These data suggest that AM and OF are, in general, independent, complementary mortality agents of *S. frugiperda* and that AM provides the final opportunity for a larval

TABLE 3. MEAN PERCENTAGE EMERGENCE OF *A. MARMORATUS* AND *O. FLAVIDUS* ADULTS FOLLOWING SINGLE AND/OR MULTIPLE PARASITISM OF SELECTED INSTARS OF *S. FRUGIPERDA*.

A

Percentage of Emerged Adults[1]			
A. marmoratus		*O. flavidus*	
Single parasitism	Multiple parasitism	Single parasitism	Multiple parasitism
70.8	8.3	84.7	84.7
$\bar{x}$ diff. = –62.5 ± SEM 4.69 t = –13.31[2]		$\bar{x}$ diff. = 0.03 ± SEM 4.31 t = 0.01 NS	

[1]5th instar *S. frugiperda* exposed to 1 *O. flavidus* sting and/or 2 *A. marmoratus* maggots.
[2]Mean difference between treatments is significant ($P \leq 0.05$) according to paired t-test (Snedecor and Cochran 1967).

B

Percentage of Emerged Adults[1]			
A. marmoratus		*O. flavidus*	
Single parasitism	Multiple parasitism	Single parasitism	Multiple parasitism
62.5	12.5	70.8	72.7
$\bar{x}$ diff. = –58.3 ± SEM 6.81 t = –8.56[2]		$\bar{x}$ diff. = 9.70 ± SEM 10.64 t = 0.91 NS	

[1]5th instar *S. frugiperda* exposed to 2 *A. marmoratus* maggots and/or 1 day 6th instar exposed to 1 *O. flavidus* sting.
[2]Mean difference between treatments is significant ($P \leq 0.05$) according to paired t-test (Snedecor and Cochran 1967).

C

Percentage of Emerged Adults[1]			
A. marmoratus		*O. flavidus*	
Single parasitism	Multiple parasitism	Single parasitism	Multiple parasitism
94.4	41.7	55.5	38.9
$\bar{x}$ diff. = –52.7 ± SEM 6.35 t = –8.31[2]		$\bar{x}$ diff. = –16.7 ± SEM 9.62 t = 1.73 NS	

[1]Late 6th instar *S. frugiperda* exposed to 1 *O. flavidus* and/or 10-15 *A. marmoratus* maggots.
[2]Mean difference between treatments is significant ($P \leq 0.05$) according to paired t-test (Snedecor and Cochran 1967).

parasitoid to stay the development of the subsequent generation. An additional opportunity to reduce pupal populations of *S. frugiperda* is provided by the parasitoid *Diapetimorpha introita* (Cresson), and an array of vertebrate and invertebrate predators (Pair & Gross 1984, 1989).

Parasite Efficiency

The mean percentage reduction in the cumulative emergence of *S. frugiperda* adults following larval exposure in whorl stage sweet corn to 4 pairs of OF, 4 AM females, and 4 AM females plus 4 pairs of OF per screened cage was 78.9, 81.6, and 92.1%, respectively (Figure 2). Although all treatment means were significantly lower than that of the control, they did not differ significantly from one another. The mean percentage reduction in the cumulative emergence of *S. frugiperda* adults following larval exposure in whorl stage dent corn to 2 pairs of OF, 2 AM females, and 2 AM females plus 2 pairs of OF per screen cage was 15.2, 38.0, and 50.6%, respectively (Figure 3). The same pattern of response was common to both tests, with the combined effect of both parasitoids yielding the greatest impact on *S. frugiperda* populations, thus supporting laboratory observations that AM and OF are complementary mortality agents. Although differences in percentage reduction in *S. frugiperda* adults caused by OF and AM were not significant, in each trial the effect of AM tended to be greater. Although attempts were made to find and record parasitoids emerging within cages, in neither test did adequate numbers emerge to provide meaningful data. The reason(s) for the limited parasitoid emergence is unknown, but the lower percentage of natural parasitism

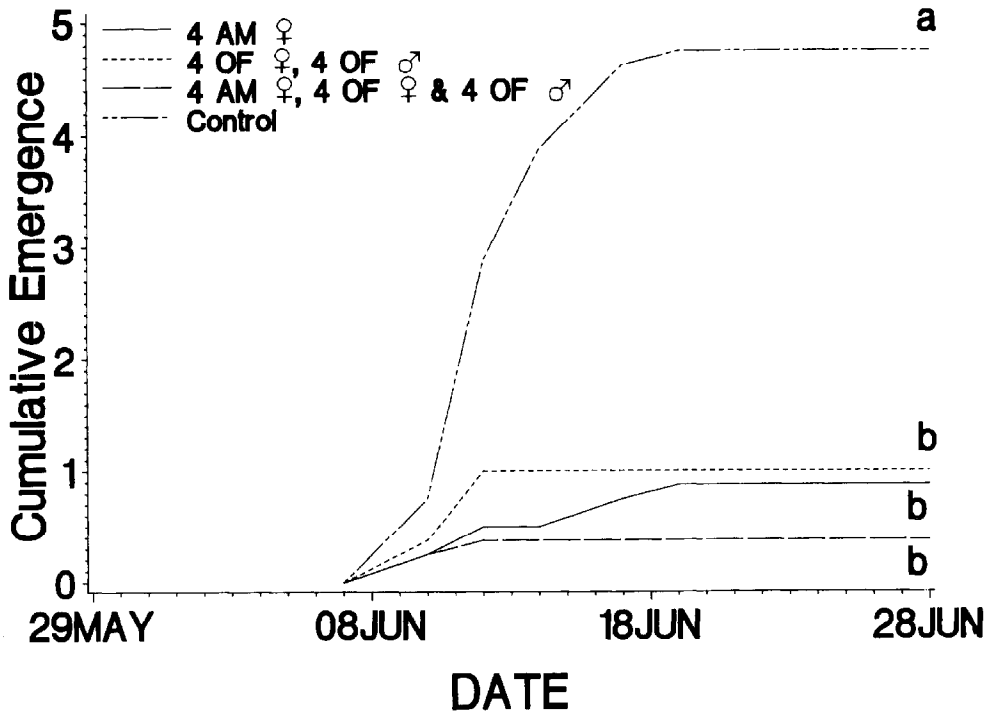

Fig. 2. Mean cumulative emergence of *S. frugiperda* adults following a single release of *A. marmoratus* and/or *O. flavidus* at indicated rates against 5th and 6th instar *S. frugiperda* in 'Silver Queen' sweet corn, Tifton, Georgia, May-June, 1985. Mean total numbers of moths emerged followed by letters in common are not significantly different, by Waller-Duncan k-ratio t-test ($P \leq 0.05$), (SAS Institute 1985).

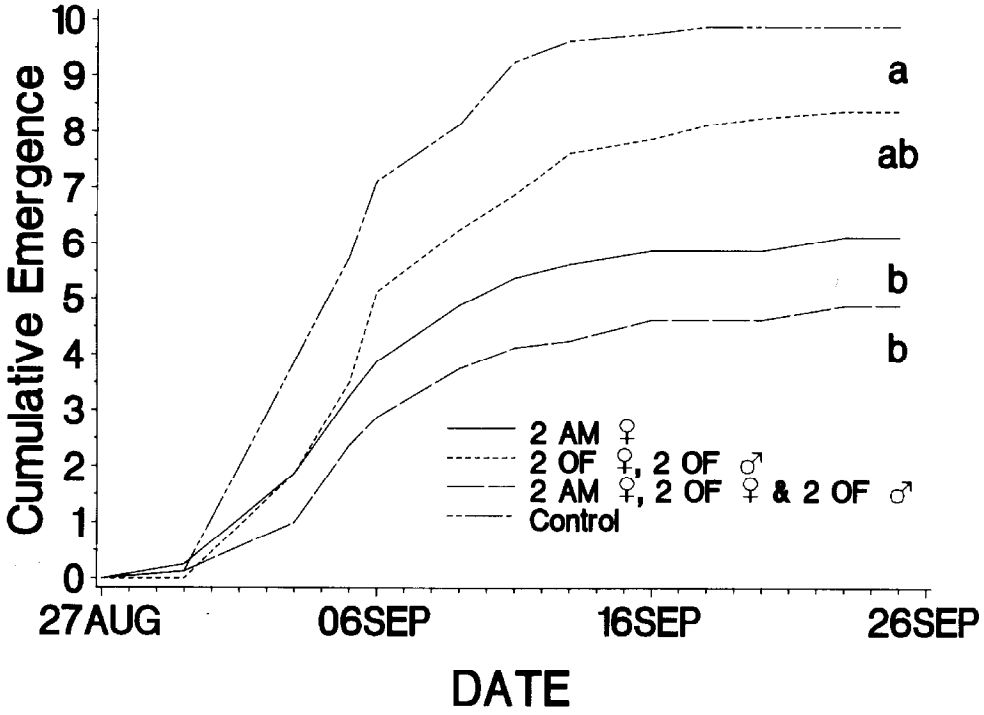

Fig. 3. Mean cumulative emergence of *S. frugiperda* adults following a single release of *A. marmoratus* and/or *O. flavidus* at indicated rates against 5th and 6th instar *S. frugiperda* in 'Pioneer 3369A' dent corn, Tifton, Georgia, August-September, 1985. Mean total numbers of moths emerged followed by letters in common are not significantly different by Waller-Duncan k-ratio t-test ($P \leq 0.05$) (SAS Institute 1985).

by AM and OF that occurred from mid-June through mid-September (Figure 1) may reflect lowered adult parasitoid emergence due to the influence of these same mortality factors.

The mass propagation and release of parasitoids against incipient seasonal populations of lepidopterous pests may provide the greatest opportunity to delay, if not stop, the geometric expansion of subsequent generations that insure economic crop damage and massive intervention with chemical pesticides. With the development of economical methods for mass-propagating quality *A. marmoratus* and/or *O. flavidus* will come primary opportunities for advancing biological strategies for managing *S. frugiperda*.

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This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or the recommendation for its use by the USDA.

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NOCTUIDONEMA GUYANENSE: AN ECTOPARASITIC NEMATODE OF FALL ARMYWORM ADULTS IN THE TROPICAL AMERICAS

C. E. ROGERS, A. M. SIMMONS, AND O. G. MARTI
Insect Biology & Population Management Research Lab,
U.S. Department of Agric., Agric. Res. Serv.
Tifton, GA 31793

ABSTRACT

Noctuidonema guyanense Remillet and Silvain is an ectoparasitic nematode that attacks the adult stage of *Spodoptera frugiperda* (J. E. Smith) and a few other species of *Noctuidae*. The nematode is widely distributed in the neotropics from French Guiana to Florida through the Caribbean Basin, and from Colombia, South America to Texas, North America through mainland countries. Both incidence and intensity of host infestation by *N. guyanense* are greater in Caribbean Basin countries than in the mainland countries. Low relative humidity and low and high temperature adversely impact *N. guyanense* population dynamics in the laboratory. Infestation by *N. guyanense* exhibits an insidious, chronic pathogenicity in hosts. The biology of *N. guyanense* and its acute pathogenicity and mechanics of transmission among hosts remain virtually unknown.

RESUMEN

Noctuidonema guyanense Remillet y Silvain es un nematodo ectoparasitico que ataca el estado adulto de *Spodoptera frugiperda* (J. E. Smith) y otras pocas especies de la familia Noctuidae. Este nematodo esta ampliamente distribuído en los neotropicos desde la Guyana Francesa hasta Florida, a traves de la Cuenca del Caribe y desde los paises continentales desde Colombia, America del Sur, hasta Texas, America del Norte. Tanto la incidencia como la intensidad de la infestación del hospedero por *N. guyanense* son mayores en los paises de la Cuenca del Caribe que en paises continentales. La baja humedad relativa y las temperaturas bajas y altas afectan adversamente la dinamica de poblaciones de *N. guyanenense* en el laboratorio. *N. guyanense* exhibe una patogenicidad cronica e insidiosa en sus hospederos. Se desconoce la biología de *N. guyanense* y su patogenicidad aguda así como los mecanismos de transmisión entre hospederos.

Noctuidonema guyanense Remillet and Silvain (Nematoda: Aphelenchoididae), discovered attacking *Spodoptera androgea* (Cramer) in French Guiana in 1982 (Silvain 1984), was recently described as a new genus and species of insect-parasitic nematode (Remillet & Silvain 1988). In French Guiana, *N. guyanense* is most commonly found on adults of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), a few other *Spodoptera* species, *Anicla infecta* (Ochsenheimer), and *Leucania* spp. (Remillet and Silvain 1988). Although several species of parasitic and predaceous arthropods and a species of nematode are known to attack the larval stages of the fall armyworm (Ashley 1979, Andrews 1988), *N. guyanense* is the first known metazoan parasite of the moth stage. A closely related species of nematode, *Acugutturus parasiticus* Hunt, has been reported from the adult stage of the American cockroach, *Periplaneta americana* (L.), in St. Lucia, West Indies (Hunt 1980).

The economic importance of the fall armyworm to agriculture in the tropical Americas necessitates that *N. guyanense* be investigated as a potential biological control agent for inclusion in management strategies. This paper reports the results of preliminary

research designed to delineate the host-range, distribution, bionomics, and pathogenicity of *N. guyanense*.

Materials and Methods

Host-Range

Insects to be examined for infestation by *N. guyanense* were collected by sweeping vegetation in a variety of habitats, from pheromone traps, and from a 1.5 × 2.0 m white sheet illuminated by UV light at night. Non-lepidopterous arthropods were placed after collection into individual vials containing 10% formalin for preservation, storage, and subsequent microscopic examination. Specimens were identified to family by consulting keys and descriptions in Borror & DeLong (1964) and Jacques (1947).

Collected Lepidoptera were killed immediately by placing them in a kill jar charged with ethyl acetate. Abdomens of dead moths were excised at their juncture with the metathorax and placed into individual vials containing 10% formalin for fixing, preservation, storage, and subsequent microscopic examination. Abdomens of macro-Lepidoptera (notably, large sphingids) were excised approximately 1/3 from the posterior end and handled as stated above. Adult Lepidoptera minus their abdomens were pinned and identified with numbered labels corresponding with their respective abdomens.

Most noctuids collected in French Guiana were identified by comparing adults with reference specimens that have been identified at the British Museum of Natural History, London, and maintained at ORSTOM Center, Cayenne, French Guiana. Other Lepidoptera were identified by comparing collected specimens with voucher specimens housed in the U.S. National Museum, Washington, DC, and from descriptions provided in Borror & DeLong (1964), Covell (1984), Hodges (1983), Howe (1975), Kimball (1965), and Watson & Whalley (1975). Infrequently collected non-hosts of *N. guyanense* were identified only to family.

Collections were made daily in northeastern French Guiana from July 16 through August 11, 1987. Collections also were made periodically from March-September, 1988, near Belle Glade, Brooksville, Homestead, and northern Everglades Park in Florida, and near Tifton, Georgia.

The identity of *Noctuidonema* was determined initially by comparing collected specimens with voucher specimens on file at ORSTOM, French Guiana, and subsequently from descriptions in Remillet & Silvain 1988.

Distribution

Male fall armyworm moths were collected in pheromone traps (International Pheromone Systems, Merseyside, England) from late Fall 1987 through Summer 1988 in several locations from Suriname to Belle Glade, Florida in the Caribbean Basin, and from Bogota, Colombia to Weslaco, Texas through the mainland tropics (Hartstack cone traps were used in Texas). Pheromone traps were baited with a commercial pheromone (Terochem Laboratories, Ltd., Alberta, Canada) to attract males, and contained dichlorvos to quickly kill entrapped moths. The abdomen from about 100 moths captured at each location was separated from the thorax and each placed into a separate vial containing 10% formalin. The vials with abdomens from each location were shipped to Tifton, Georgia for subsequent examination for nematodes. The number of juvenile and adult *N. guyanense* infesting moths and percent of moths infested were recorded for each of the 22 locations.

The incidence and intensity of fall armyworm parasitization by *N. guyanense* at each location were recorded. Data were analyzed by an analysis of variance test, and signif-

icantly different means ($P < 0.05$) were separated by the Waller-Duncan k-ratio t-test (SAS Institute 1985).

Laboratory Biology

Laboratory studies were conducted to measure the effects of temperature and relative humidity on *N. guyanense* populations infesting the fall armyworm. To determine the effects of relative humidity on population changes of *N. guyanense*, 70 infested fall armyworm males were caged and held at 27 ± 1.5°C in darkness at either 20% RH or 80% RH. After being held for 24 and 48 h, nematode populations were subsampled by removing and examining 10 and 5 moths from the cages, respectively. Abdomens from the moths were removed and placed in 10% formalin to kill and preserve the nematodes until they could be counted with the aid of a dissecting microscope. As each moth abdomen was examined, the number and stage of the nematode were recorded.

The effect of temperature on population processes of *N. guyanense* was studied by caging 70 infested males of the fall armyworm in darkness at 80% RH and a constant temperature of 7, 12, 17, 22, 27, 32, or 37 ± 1.5°C for 24 h. After 24 h, the abdomens from 15 randomly selected moths from each temperature were preserved in 10% formalin and examined via a microscope to count the number of juvenile and adult nematodes infecting each moth.

The success of nematode transfer during host mating was studied by pairing field-collected male fall armyworms with laboratory-reared, virgin females in 3.8-liter cartons. Fall armyworm pairs were held at 22°C and 80% RH in darkness for 24 h. After 24 h, the abdomens from 10 male and 10 female moths were excised and preserved in 10% formalin for microscopic examination. The number of juvenile and adult nematodes recovered from the 10 male and female moths was compared with the number recovered from 5 pairs of moths sacrificed at the beginning of the test. Data for the population dynamics study were analyzed by an analysis of variance, with significantly different means being separated by the Waller-Duncan k-ratio t-test (SAS Institute 1985).

Pathogenicity

Abdomens from freshly collected moths were removed, fixed in 10% formalin, and stored for subsequent examination. Male *S. frugiperda* obtained from the Insect Biology and Population Management Research Laboratory (IBPMRL) colony were used as noninfested controls. Abdomens selected for sectioning were dehydrated through ethanol (30-100%) and infiltrated, oriented, and embedded in Sorvall® embedding medium. Transverse and longitudinal sections were cut at 2-6 um with hand-broken glass Ralph® knives. Sections were stained in borate-buffered 0.5% Toluidine blue for 1-3 min, rinsed in water, cleared in xylene, and mounted in Permount®. In some specimens, portions of the posterior cuticle were dissected, dehydrated, cleared, and mounted without staining directly into Permount as whole mounts. Slides of sections or whole mounts were examined with a Nikon Optiphot® photomicroscope using brightfield illumination or Nomarski® differential interference contast optics and photographed with Kodak® Technical Pan film.

Results and Discussion

Host-Range

Lepidoptera abdomens examined for *N. guyanense* included 1,859 specimens representing 150 species in 21 families from Florida, and 1,279 specimens representing 189

TABLE 1. COMMON NOCTUID HOSTS OF *NOCTUIDONEMA GUYANENSE*.[1]

Host	No. hosts examined		% Hosts infested		x̄ No. nematodes/host	
	French Guiana	Southeast U.S.	French Guiana	Southeast U.S.	French Guiana	Southeast U.S.
Agrapha oxygramma (Geyer)	–	12	–	13	–	65
Anicla infecta (Ochsenheimer)	4	20	75	13	54	7
Argyrogramma verruca (F.)	1	5	100	20	123	4
Agrotis subterranea (F.)	–	22	–	5	–	–
Lesmone formularis (Hübner)	28	–	25	–	25	–
Mocis disseverans (Walker)	–	18	–	83	–	70
Mocis latipes (Guenée)	11	296	9	38	–[2]	69
Mocis marcida (Guenée)	–	5	–	40	–	67
Mocis texana (Morrison)	–	22	–	41	–	66
Oxythres splendens Druce	5	–	20	–	–[2]	–
Ptichodis vinculum (Guenée)	–	19	–	53	–	41
Spodoptera androgea (Cramer)	13	–	23	–	65	–
Spodoptera dolichos (F.)	94	–	12	–	30	–
Spodoptera frugiperda (J. E. Smith)	51	541	39	43	21	89
Spodoptera latifascia (Walker)	5	44	40	9	109	–[2]
Spodoptera ornithogalli (Guenée)	–	41	–	29	–	76
Spodoptera n.sp.	5	–	20	–	24	–
Xanthopastis timais (Cramer)	25	–	4	–	34	–
Zale fictilis (Guenée)	14	–	21	–	25	–

[1]Data for host species in which at least 5 specimens were examined at one location.
[2]Nematodes were not counted.

species and 19 families from French Guiana. In French Guiana, moths from 5 families of Lepidoptera harbored *N. guyanense*, although parasitization in Lasiocampidae, Notodontidae, Pyralidae, and Sphingidae occurred in only a single species of each family (Rogers et al. 1990a). Twenty-five species among 20 genera of Noctuidae harbored *N. guyanense* in French Guiana, with the incidence of infestation ranging from 10 to 51%. The intensity of infestation in French Guiana ranged from 7 to 43 nematodes per host. In Florida, infestation of Lepidoptera by *N. guyanense* was confined to 6 species of Noctuidae, in which 19% of the species had an average infestation rate of 32%, harboring an average of 8 adult and 46 juvenile nematodes per host (Rogers et al. 1990b).

Spodoptera frugiperda, *Spodoptera latifascia* (Walker), *Mocis latipes* (Guenée), *A. infecta*, and *Argyrogramma verucca* (F.) were infested by *N. guyanense* in both French Guiana and in the southeastern United States (Table 1). Also, in both continents, *N. guyanense* infested multiple species of *Spodoptera* and *Mocis*. Within Noctuidae, infestation was limited to species of subfamilies Amphipyrinae, Catocalinae, Noctuinae, and Plusiinae in the United States, and to subfamilies Amphipyrinae, Catocalinae, Hadeninae, Noctuinae, Plusiinae, and Sarrothripinae in French Guiana. A more detailed discussion of the *N. guyanense*-host relationships may be found in Rogers et al. (1990a, 1990b).

Of extreme importance when contemplating possible augmentative activities with an entomophagous agent of unknown host range is its impact on non-target and/or beneficial arthropods. Consequently, we identified as many of the non-infested Lepidoptera as possible to species, and non-lepidopteran arthropods to family. Lepidoptera not harboring *N. guyanense* included 121 species among 22 families in southeastern United States, and 150 species among 19 families in French Guiana (Table 2). Moths of Noctuidae were the most common representatives among the Lepidoptera collected in both countries. However, only 15% and 19% of the noctuid species harbored *N. guyanense* in French Guiana and southeastern United States, respectively. Recently, *N. guyanense* has been collected from the black cutworm, *Agrotis ipsilon* (Hufnagel) in Vera Cruz, Mexico, and *Agrotis subterranea* (F.) in the southeastern United States (Simmons & Rogers 1990a).

Noctuidonema guyanense was not found on any of the 466 non-lepidopterous specimens among 171 species of 72 families of Insecta or Arachnida examined from southeastern United States (Rogers et al. 1990b), nor from the 514 non-lepidopterous specimens among 171 species of 78 families of Insecta, Arachnida, and Diplopoda from French Guiana (Rogers et al. 1990a) (Table 3). Hence, it appears that hosts of *N. guyanense* are limited to Lepidoptera, among which a few species of Noctuidae serve as the predominant hosts. No known beneficial species of either Lepidopera or non-lepidopterous arthropods harbored *N. guyanense* in either French Guiana or southeastern United States.

Distribution

Noctuidonema guyanense infested fall armyworm males wherever they were collected in the American tropics from November 1987-August 1988. Moths collected in Caribbean Basin countries usually had a greater incidence of infestation by a higher number of nematodes than moths collected in mainland countries (Table 4). More than 80% of the fall armyworm males collected in Martinique and Suriname were infected. Within the Caribbean Basin, low populations of *N. guyanense* were found in the Virgin Islands and Bahama. The incidence of moth infestation in the mainland countries was low in Colombia, South America and south Texas, North America. From 20 to 47% of *S. frugiperda* males collected from Mexico through Central America harbored *N. guyanense*. Infested moths from mainland countries harbored an average of 26 *N. guyanense* per host, while infected moths from the Caribbean Basin harbored an average

TABLE 2. NON-INFESTED LEPIDOPTERA EXAMINED FOR *NOCTUIDONEMA GUYANENSE*.[1]

Family	No. species examined		No. specimens examined	
	French Guiana	Southeast U.S.	French Guiana	Southeast U.S.
Apatelodidae	1	–	14	–
Arctiidae	4	8	83	99
Ctenuchidae	7	3	31	28
Danaidae	–	1	–	5
Drepanidae	1	–	10	–
Geometridae	8	9	35	34
Hesperiidae	2	6	4	9
Lasiocampidae	?	1	13	3
Limacodidae	–	2	–	7
Lycaenidae	1	1	1	1
Lymantriidae	?	?	32	2
Megalopygidae	?	1	4	2
Noctuidae	121	64	446	684
Notodontidae	5	5	104	8
Nymphalidae	2	2	13	7
Papilionidae	–	1	–	1
Pieridae	–	5	–	11
Pseudosphingidae	1	–	2	–
Pterophoridae	1	–	1	–
Pyralidae	12	10	150	69
Saturniidae	1	3	16	4
Satyridae	–	1	–	1
Sphingidae	4	11	11	27
Tineidae	–	2	–	8
Tortricidae	2	1	2	2
Yponomeutidae	–	1	–	2

[1]A listing of species examined is available on request.

of 56 *N. guyanense* per host. Across all collection sites, nematode populations were greatest in April 1988, when 80% of *S. frugiperda* males were infested with an average of 191.4 *N. guyanense* per host.

Laboratory Biology

As a Pan-neotropical ectoparasite of Lepidoptera adults, *N. guyanense* populations should be impacted by extremes in temperature and relative humidity; laboratory experiments illustrated this to be the case. At 27°C, populations of *N. guyanense* infecting *S. frugiperda* males increased significantly at 80% RH but changed little at 20% RH (Table 5). Also, the juvenile to adult ratio was significantly higher ($P < 0.05$) at 80% than at 20% RH. Even a short period of low RH may have a detrimental affect on *N. guyanense* populations.

A temperature of less than 17°C or greater than 37°C severely impacted populations of *N. guyanense* held at 80% RH (Table 6). A temperature of 32°C seemed to be optimum for *N. guyanense* development, with a juvenile to adult female ratio of 14 to 1.

Pairing of infested, field-collected *S. frugiperda* males with non-infested, laboratory-reared females indicated a significant population shift of *N. guyanense* during host

TABLE 3. NON-LEPIDOPTERAN ARTHROPODS EXAMINED FOR *NOCTUIDONEMA GUYANENSE*.

Taxa	No. families examined		No. species examined		No. specimens examined	
	French Guiana	Southeast U.S.	French Guiana	Southeast U.S.	French Guiana	Southeast U.S.
Insecta						
Coleoptera	18	14	39	41	146	102
Collembola	1	–	1	–	2	–
Dermaptera	–	2	–	3	–	6
Diptera	13	14	23	23	53	68
Ephemeroptera	–	1	–	1	–	1
Hemiptera	7	12	21	31	51	107
Homoptera	5	4	11	10	14	23
Hymenoptera	15	10	37	13	168	50
Isoptera	1	–	1	–	1	–
Neuroptera	1	3	1	3	1	12
Odonata	1	3	2	7	2	18
Orthoptera	6	6	19	11	52	23
Plecoptera	1	–	1	–	2	–
Tricoptera	–	1	–	1	–	1
Thysanoptera	1	–	2	–	4	–
Arachnida						
Acarina	1	–	1	–	3	–
Araneae	5	5	8	8	14	11
Diplopoda						
Millipede	1	–	1	–	1	–

TABLE 4. DISTRIBUTION AND PARASITIZATION OF THE FALL ARMYWORM BY *NOCTUIDONEMA GUYANENSE* IN THE TROPICAL AMERICAS

Country	% FAW infested	$\bar{X}$ No. nematodes per host
Caribbean Basin		
Suriname	88.0	215
Trinidad	41.6	36
Grenada	68.4	44
Martinique	82.8	52
Commonwealth of Dominica	71.3	40
Virgin Islands	1.0	34
Puerto Rico	35.0*	38*
Cayman Island	71.4	110
Bahama	10.1	13
Bermuda	26.0	12
Mainland		
Colombia	3.0	12
Panama	46.8	39
Costa Rica	47.4	38
El Salvador	39.8	17
Honduras	31.4*	28*
Belize	36.0	35
Mexico	20.1*	20*
Southeast U.S.	41.8	21
South Texas	8.7	17

*Data from two locations within country.

mating. Pre-copulatory populations of *N. guyanense* on infested male moths was comprised of 63% juveniles and 37% adults. Following a single copulation of its host, *N. guyanense* populations on a newly infested female averaged 63% adults and 37% juveniles. Juvenile transfer during host mating averaged 11%, compared with 31% transferral of adult nematodes (Simmons & Rogers 1990b).

Pathogenicity

Noctuidonema guyanense may be found around host genitalia, intersegmental areas between abdominal segments, and in tympanic cavities. Most commonly, the nematode

TABLE 5. INFLUENCE OF RELATIVE HUMIDITY ON *NOCTUIDONEMA GUYANENSE* POPULATIONS IN THE LABORATORY AT 27°C.

Relative Humidity	$\bar{X}$ No. nematodes per moth		
	Total	% Juvenile	Juveniles/ ♀ nematode
24 hrs.			
20%	19 a	67	5 a
80%	238 b	74	9 b
48 hrs.			
20%	25 a	84	4 a
80%	392 b	84	11 b

TABLE 6. INFLUENCE OF TEMPERATURE ON *NOCTUIDONEMA GUYANENSE* POPULATIONS IN THE LABORATORY AT 80% RELATIVE HUMIDITY.

	X No. nematodes per moth			
Temperature °C	Total	Adult	%Juvenile	Juveniles/ ♀ nematode
7	18	9	51	1
12	29	10	67	5
17	25	11	56	3
22	52	15	72	7
27	104	21	80	7
32	239	81	66	14
37	8	5	34	<1

is observed on the anterior margin of the eighth abdominal segment and its associated intersegmental membrane. Microscopic examination of stained sections and whole mounts of infested *S. frugiperda* suggests several insiduous, chronic pathologies associated with infestation by *N. guyanense* (Marti et al. 1990). Infested moths frequently exhibit external, irregular dark spots on the cuticle, indicating oxidation of an exudate from probable stylet penetration sites (Fig. 1). Within the intersegmental spaces of infested hosts, the cuticle is frequently furrowed adjacent to nematodes, and branched

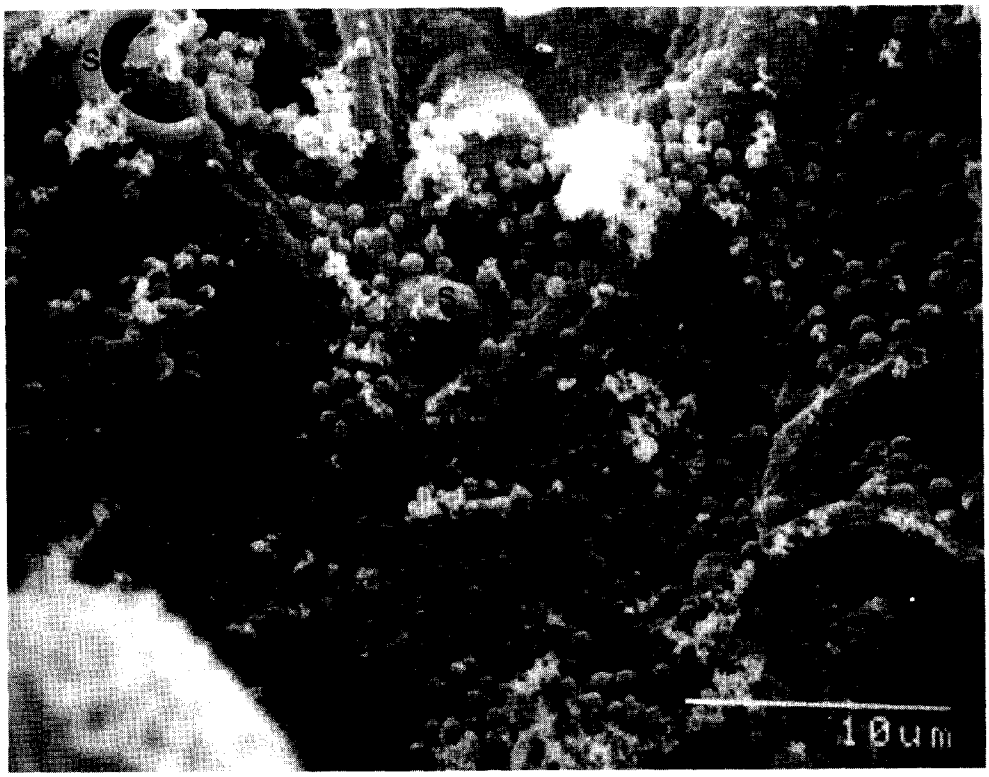

Fig. 1. External view of cuticle on abdomen of fall armyworm with holes (arrows) produced by stylets of *N. guyanense* (X 3,150). (S = scale sockets). (Electron micrograph, courtesy of William Wergin, ARS, Beltsville, MD).

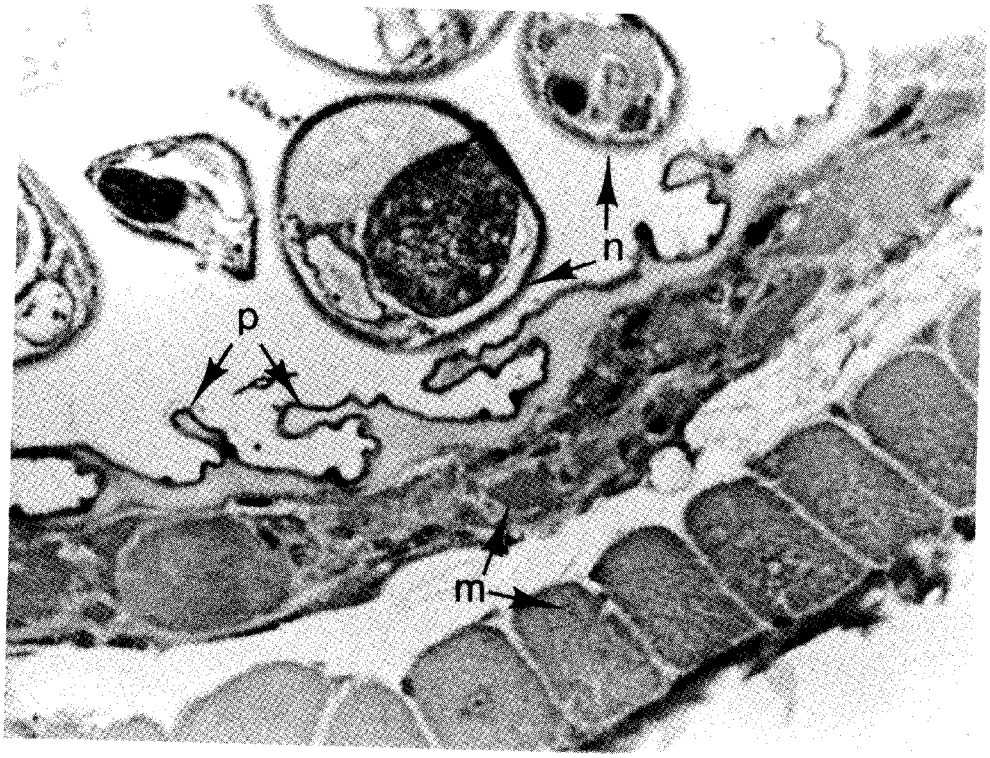

Fig. 2. Cross section of intersegmental area of *Anomis oedema* abdomen showing *N. guyanense* (N) and deterioration of muscles (M) beneath proliferating cuticle (P)(X 590).

cuticular proliferations tend to surround the nematodes. Cuticular erosion in the intersegmental membrane also is found in infested moths. In heavily infested moths, the intersegmental spaces may be hypertrophied at the expense of the homocoel. Also, muscular deterioration beneath intersegmental membranes has been found in heavily infested moths of *Anomis oedema* Guenée (Fig. 2). Infrequent capture of heavily infested male moths in pheromone traps indicates that at some population threshold, *N. guyanense* may interfere with flight by its host.

Virtually nothing is known about the field biology of *N. guyanense*, nor about its acute pathogenicity to moths. Visual evidence suggests that the stylet of the nematode penetrates the cuticle of its host to feed on internal fluids and/or tissue. Nematodes from wild male hosts are characteristically yellow, whereas nematodes from totally laboratory-reared females hosts are frequently blue-green, particularly if infested female moths lay bluish-green eggs. The coloration shift in the nematodes from hosts using different food sources suggest that *N. guyanense* may feed on the hemolymph or reproductive system of its host.

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OVICIDAL PROPERTIES OF FENOXYCARB AGAINST THE FALL ARMYWORM (LEPIDOPTERA: NOCTUIDAE)

WAYNE A. GARDNER
Department of Entomology, College of Agriculture Experiment Stations, Georgia Station, Griffin, Georgia 30223 U.S.A.

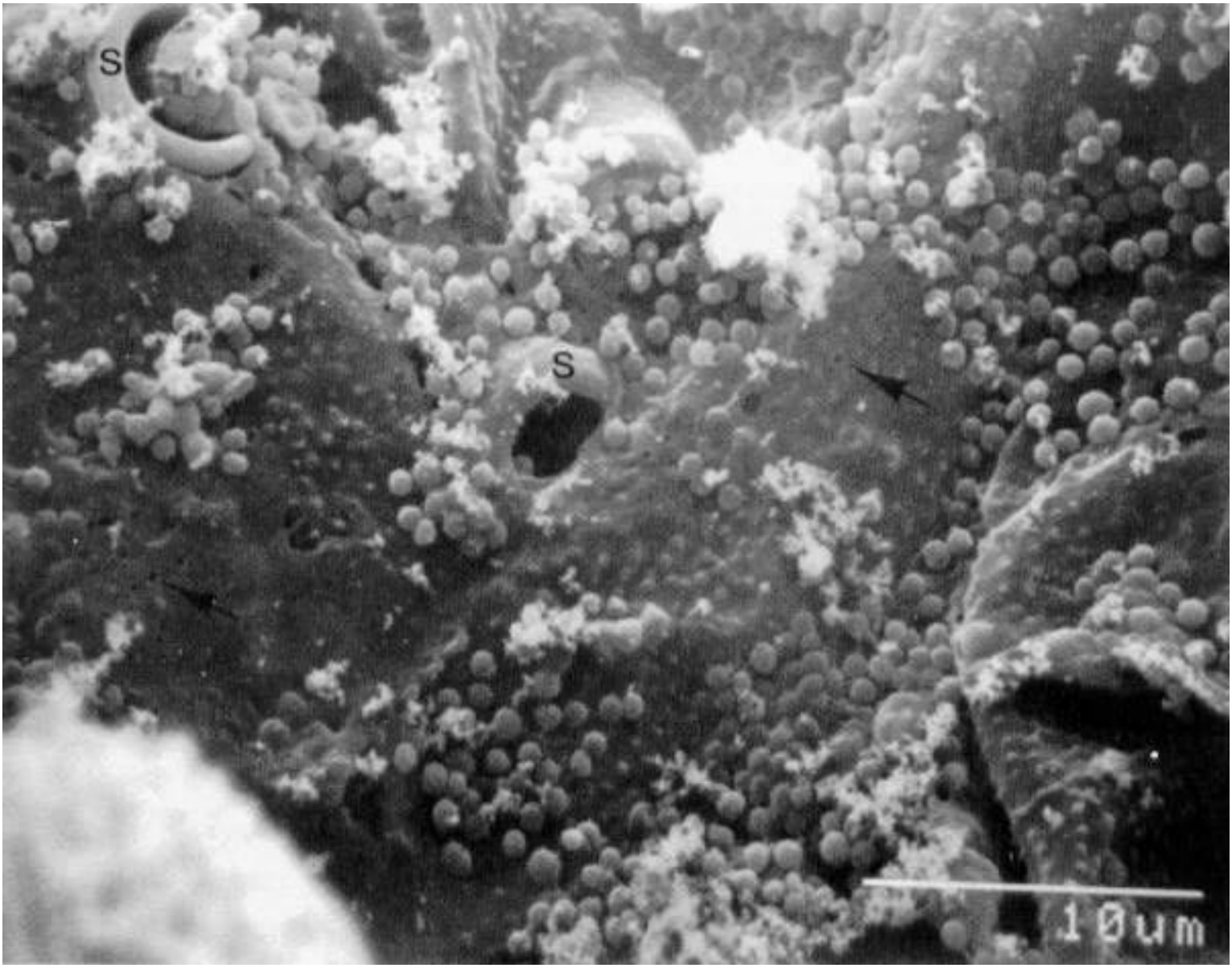
ABSTRACT

Ovicidal effects of fenoxycarb, ethyl[2-phenoxyphenoxyethyl] carbamate, against the fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), egg masses of different ages were investigated in laboratory studies. Egg mass age was a critical factor in the activity of the juvenoid against FAW eggs. Percent eclosion was significantly ($P \leq 0.05$) lower in egg masses treated on Day 1 of oviposition than in masses treated on either Day 2 or Day 3 postoviposition. Mean (± SE) percent eclosion of eggs treated on Day 1 was 86.9 (± 12.1), 30.5 (± 1.2), 10.8 (± 0.7), and 17.4 (± 2.7) following application of fenoxycarb at 0, 50, 100, and 200 gm AI/ha, respectively. Mean percent eclosion of eggs treated with fenoxycarb on Day 2 or Day 3 ranged from 76.1 to 89.0 and did not differ significantly ($P \leq 0.05$) from the untreated checks (83.4% and 93.5%). No delayed developmental effects in either developmental rate, prepupal weight, or adult fecundity were noted in the fenoxycarb treatments.

RESUMEN

Se estudió en el laboratorio los efectos ovicidas de fenoxycarb ethyl [2-phonoxyphenoxyethyl] carbamato, en contra de posturas de huevos de diversas edades de cogollero (FAW) *Spodoptera frugiperda* (J. E. Smith). La edad de las posturas de huevos fué un factor crítico en la actividad de este juvenoide contra los huevos de FAW. El porcentaje de eclosión fue significativamente ($P < 0.05$) mas bajo en aquellos huevos tratados el día de oviposición comparado con aquellos huevos tratados el día 2 o el día 3 después de la oviposición. El procentaje promedio (± SE) de eclosión de huevos tratados en el día fué de 86.9 (± 12.1), 30.5 (± 1.2), 10.8 (± 0.7) y 17.4 (± 2.7) después de una aplicación de fonxycarb al 0, 50, 100 y 200 gramos IA/ha, respectivamente. El porcentaje promedio de eclosión de huevos tratados con fenoxycarb en el día 2 o el día 3 fluctuó entre el 76.1 a el 89.0% pero no difirió significativamente ($P < 0.05$) de los controles tratados (83.4% y 93.5%). No se observaron efectos tardíos de fenoxycarb en la tasa de desarrollo, el peso de prepupas o la fecundidad de los adultos.

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), is a persistent pest of agricultural crops in the southeastern United States and other areas of the Western Hemisphere. FAW immatures are polyphagous but reportedly prefer grasses (Luginbill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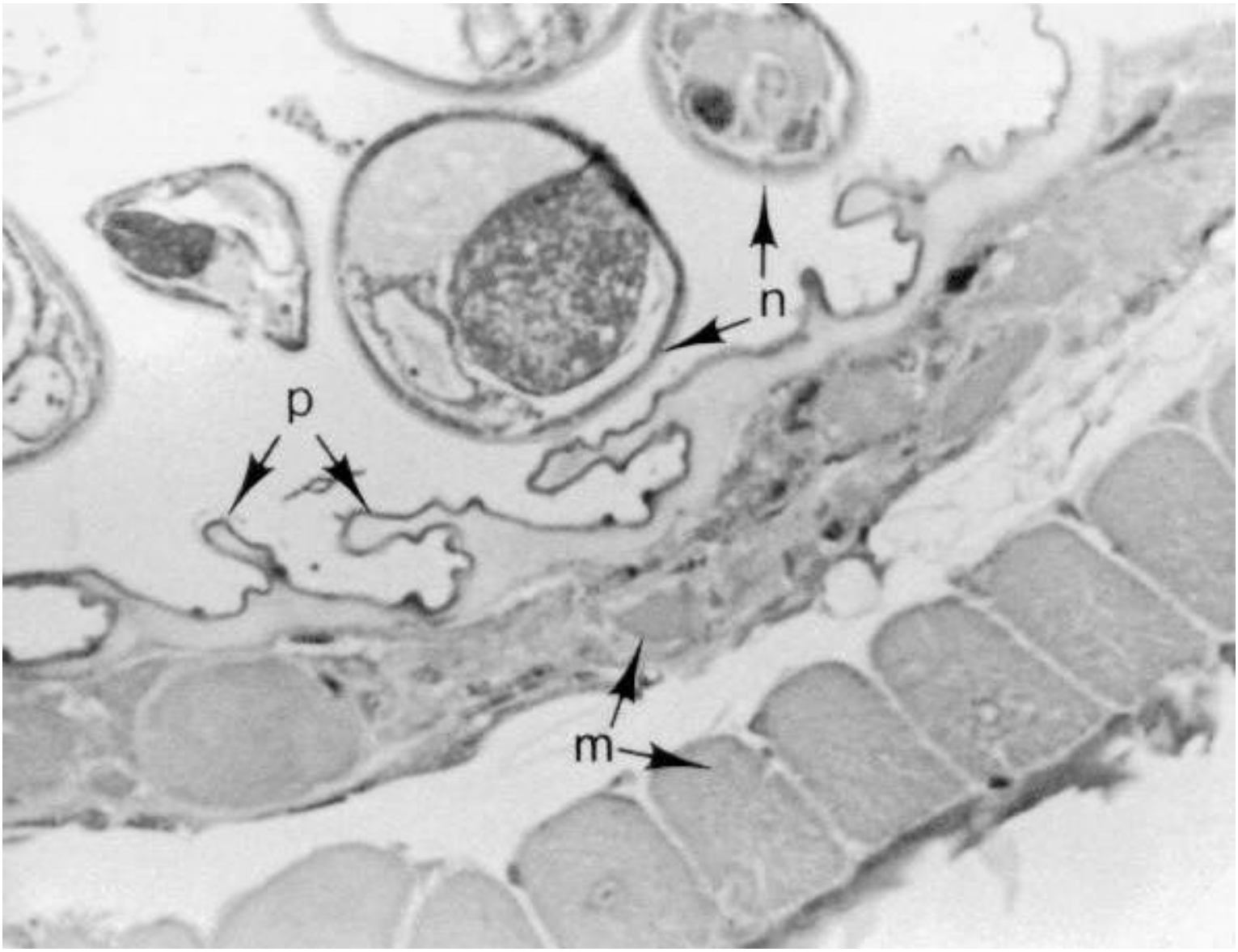
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1928). Insecticidal control is often necessary to protect forage and grain crops (Young 1979, Andrews 1980). Conventional chemical insecticides have proven effective against immatures when formulations and application techniques were appropriate for the host crop and its stage of development (Young 1979, Pitre 1986).

Development of resistance to selected insecticides has been reported. Carbaryl, trichlorfon, methyl parathion, and ethyl parathion have been reported to be ineffective against FAW (Bass 1978, Young 1979, Andrews 1980, Pitre 1986). Other insecticides including diazinon and certain synthetic pyrethroids provide erratic or poor control in selected crops and locations (Harrell et al. 1977, Bass 1978, All et al. 1983). Commercial formulations of *Bacillus thuringiensis* Berliner also have proven ineffective against FAW (Gardner & Fuxa 1980, Gardner et al. 1986, Gardner 1988).

Insect growth regulators (IGRs) based on juvenile hormone analogs have not been thoroughly evaluated against FAW. Recent studies with fenoxycarb, ethyl [2-(*p*-phenoxyphenoxy)ethyl]carbamate (Dorn et al. 1981), have demonstrated morphogenetic (Gancey et al. 1989, Mulye & Gordon 1989) and chemosterilant (King & Bennett 1989, Chen & Borden 1989) effects. Some IGRs also are ovicidal (Staal 1975). The objective of this study was to determine the ovicidal effects of fenoxycarb against FAW.

Methods

Fall armyworm eggs were obtained from a laboratory colony. Larvae were maintained on a semisynthetic diet (Burton & Perkins 1972). The fenoxycarb used in the study was ABG-6231 (Lot No. 06-063-BR) provided by Abbott Laboratories (North Chicago, IL). This chemical is a proprietary product of Maag Agrochemicals Inc. (Vero Beach, FL).

Egg masses were collected at 0800 h for 3 consecutive days. Individual masses were separated by cutting the underlying cheesecloth which served as an ovipositional substrate. Masses were individually weighed to determine the approximate number of eggs and transferred to 30-ml clear plastic creamer cups. The cups were labelled with the egg mass weight and oviposition date and stored at 25°C.

On Day 3 egg masses were grouped according to the ovipositional date. Only masses with weights correlating with 150 to 250 eggs per mass (Lynch et al. 1983) were used for the study. Within each age category, egg masses were randomly assigned to 1 of 5 treatment groups. The treatments were: fenoxycarb at 50, 100, and 200 gm AI/ha; chlordimeform at 140 gm AI/ha; and an untreated control. The chlordimeform was formulated as Galecron 4E. Treatments were applied as an aqueous spray with Potter Precision Laboratory Spray Tower (Burkard Manufacturing Co. Ltd., Rickmansworth, Hertfordshire, England). Each treatment for days 1-3 was replicated 5X in 2 consecutive generations. Each replicate contained 3 to 5 egg masses.

After treatment the egg masses were air dried and returned to their plastic cups and rearing chamber. Larval eclosion was monitored twice daily. When hatching had ceased for a minimum of 3 consecutive days, egg masses were examined microscopically to determine numbers of eggs per mass and the corresponding percentage eclosion. Neonates were individually transferred to 30-ml clear plastic creamer cups each containing 10 ml of semisynthetic diet and were checked daily until death or pupation. In those treatments with at least 10 male and 10 female survivors, 20 pupae (10 female: 10 male) were placed in a 3-liter container. Emerging moths were fed on stale beer. All egg masses oviposited from these adults were collected, weighed, and percent eclosion determined.

The analysis of variance procedure of the Statistical Analysis System (SAS Institute 1985) was used to compare percent eclosion of treated and control egg masses. Larval mortality and fecundity of survivors in response to ovicidal treatment also were analyzed. Means were separated by Duncan's (1951) multiple range test when significant ($P \leq 0.05$) F-ratios occurred within a comparison.

TABLE 1. PERCENT ECLOSION OF FALL ARMYWORM EGGS RECEIVING OVICIDAL SPRAYS AT DIFFERENT EGG MASS AGES.[1]

Ovicide[2] (gm AI/ha)	% eclosion of eggs treated on egg mass age		
	Day 1	Day 2	Day 3
Fenoxycarb (50)	30.5 ± 12.3 a	84.7 ± 7.4 b	88.2 ± 7.1 b
Fenoxycarb (100)	10.8 ± 6.6 a	85.8 ± 5.6 b	87.3 ± 6.3 b
Fenoxycarb (200)	17.4 ± 6.9 a	76.1 ± 8.1 b	89.0 ± 3.8 b
Chlordimeform (140)	17.6 ± 11.9 a	51.6 ± 13.5 a	66.3 ± 10.3 a
Untreated check	86.9 ± 12.1 a	83.4 ± 6.0 a	93.5 ± 5.2 a

[1]Means (± SE) within a row followed by the same letter are not significantly different ($P \leq 0.05$; Duncan's [1951] multiple range test).

[2]Ovicides applied as aqueous sprays through Potter Precision Laboratory Spray Tower with 5 replicates/treatment and 3 to 5 egg masses/replicate.

RESULTS AND DISCUSSION

Egg mass age was a critical factor in the activity of fenoxycarb as an ovicide against FAW. Percent eclosion was significantly ($P \leq 0.05$) lower in egg masses treated on Day 1 of oviposition (10.8% to 30.5%) than in masses treated on either Day 2 (76.1% to 85.8%) or Day 3 (87.3% to 89%) postoviposition (Table 1). Reduced eclosion also occurred following application of chlordimeform, a conventional insecticide/ovicide; however, percent eclosion for this treatment did not differ significantly ($P \leq 0.05$) with respect to egg mass age.

Sensitivity of lepidopteran eggs to IGRs was initially reported by Riddiford & Williams (1967). Staal (1975) noted that IGRs disrupt embryonic development resulting in nonemergence only when applied to insect eggs prior to the blastokinesis phase of development. The activity of fenoxycarb against FAW eggs also appears restricted to these early phases of embryogenesis.

While delayed larval development and mortality following eclosion from IGR-treated eggs has been reported (Staal 1975), no discernable effects were observed among larvae eclosed from egg masses treated in this study. Numbers of larvae totalled 1520, 1037, 1229, 916, and 1150 for the untreated checks, chlordimeform, fenoxycarb (50 gm AI/ha), fenoxycarb (100 gm AI/ha), and fenoxycarb (200 gm AI/ha), respectively. Mean (± SE) larval mortality for the untreated checks was 17.6% (± 4.3). Larval mortality in the ovicide treatments did not deviate significantly ($P \leq 0.05$) from that level. Larval developmental rates were consistent across all treatments with mean prepupal weights of 252.8 (± 1.9) mg for the untreated checks, 260.4 (± 1.9) mg for the chlordimeform treatment, and 253.9 (± 2.2), 251.9 (± 2.2), and 252.0 (± 2.5) mg for the respective 50,

TABLE 2. PERCENT ECLOSION OF FALL ARMYWORM EGGS IN RESPONSE TO OVICIDAL SPRAYS WHEN SUMMED OVER EFFECTS OF EGG MASS AGE.

Ovicide (gm AI/ha)	% eclosion[1]
Fenoxycarb (50)	67.8 ± 8.6
Fenoxycarb (100)	61.3 ± 10.1
Fenoxycarb (200)	60.9 ± 9.0
Chlordimeform (140)	45.2 ± 8.4
Untreated check	81.3 ± 5.3

[1]No significant differences among treatment means (± SE) as determined by analysis of variance (F = 1.59, df = 8).

100, and 200 gm AI/ha rates of fenoxycarb. Fecundity and percent eclosion of eggs produced by adults developing from the treated egg masses also did not differ significantly. Delayed developmental effects in larvae hatching from fenoxycarb-treated eggs did not occur in this study. These data are supported by Riddiford (1972) who noted that the IGR dose required to illicit delayed developmental effects may be 3X to 10X higher than the dose required to prevent eclosion.

Fenoxycarb disrupts the embryonic development of FAW eggs as evidenced by reduced eclosion. Unfortunately, practical utility is restricted because only young eggs are sensitive to the fenoxycarb. Table 2 presents mean (± SE) percent eclosion in response to the ovicide treatments when summed over the effects of egg mass age. Assuming an equal distribution of 1 to 3-day-old egg masses within a crop field, a single fenoxycarb application at either of the three test rates will not significantly reduce eclosion of FAW eggs in that field. Daily applications of fenoxycarb at 50 to 200 gm AI/ha beginning when oviposition is first detected in the field could potentially reduce eclosion by approximately 55 to 75% (Table 1).

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USE OF PYRETHROIDS, METHOMYL, AND CHLORPYRIFOS TO CONTROL FALL ARMYWORM (LEPIDOPTERA: NOCTUIDAE) IN WHORL STAGE FIELD CORN, SWEET CORN, AND SORGHUM

L. P. GUILLEBEAU AND J. N. ALL
Department of Entomology
University of Georgia
Athens, Ga. 30602

ABSTRACT

It is important to identify new insecticides with efficacy for the fall armyworm, *Spodoptera frugiperda* Smith, to allow greater flexibility in management programs and to retard the development of resistance. Field trials showed all rates tested of the pyrethroid insecticides tralomethrin, flucythrinate, and cyhalothrin to be as effective as manufacturers' recommended rates of chlorpyrifos and methomyl against fall armyworm in whorl stage sweet corn, field corn, and sorghum. Permethrin, cypermethrin, fenvalerate, esfenvalerate, fluvalinate, and cyfluthrin gave erratic control of fall armyworm injury in field corn and sweet corn compared with chlorpyrifos and methomyl; these insecticides were comparable with other treatments against fall armyworm in whorl stage sorghum.

RESUMEN

Para una mejor flexibilidad en los programas de manejo del cogollero, *Spodoptera frugiperda* (J. E. Smith), es importante identificar nuevos insecticidas eficaces. Ensayos de campo demostraron que las dosis de los insecticidas piretroides, tralomethrin, flucythrinate, y cyhalothrin fue tan efectiva en el control del cogollero en el maíz dulce, maíz de campo y sorgo, como las dosis recomendadas por los fabricantes de chlorpyrifos y methomyl. Permethrin, cypermethrin, fenvalerate, esfenvalerate, fluvalinate y cyfluthrin dieron un control erratico del cogollero en maíz de campo y en maíz dulce comparado

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con chlorpyrifos y methomyl; estos insecticidas son comparables con otros tratamientos contra el cogollero en sorgo en estado de panoja.

Chemical controls are often necessary to suppress damaging populations of the fall armyworm (FAW), *Spodoptera frugiperda* Smith. However, FAW populations have shown tolerance or resistance to a number of insecticides, including methomyl, carbaryl, and methyl parathion (Bass 1978, Young 1979). To manage resistance, it is important to identify suitable alternatives (Metcalf 1980).

Effective chemical options need to be identified to allow greater flexibility in FAW management. A number of synthetic pyrethroid insecticides such as fenvalerate and permethrin are registered for control of miscellaneous noctuid pests but generally provide erratic control of FAW (Harrell et al. 1977). All et al. (1983) found that only high rates of pyrethroids available at that time controlled FAW in sweet corn; by 1985, pyrethroids with greater efficacy against FAW had been registered (All et al. 1986).

Heavy FAW infestations occurring in whorl stages of corn and sorghum may be difficult to control with insecticides. This paper reviews five years of field studies with synthetic pyrethroids, chlorpyrifos, and methomyl for control of FAW in whorl stage corn and sorghum.

Materials and Methods

Field corn (Dekalb XL 394), sorghum (Dekalb BR83 or BR84), and/or sweet corn (Funk's G80) were planted each July/August 1983-1987. Standard agronomic practices of fertilization, irrigation, and weed control were followed. All experiments utilized a randomized complete block design with plots of 2 rows × 6 m long × 1 m row width × 1.5 m alleys separating 4-5 replicates. Each test had 6-23 treatments. All tests were conducted at the University of Georgia Experiment Station farm near Athens in the north Georgia Piedmont region.

Insecticide treatments began 11-19 days after planting when the plants reached the fourth leaf stage, and 50% of the plants showed leaf feeding symptoms of FAW larvae. Full cone sprays directed over the whorl were applied 2-4 times at weekly intervals. Applications were made with hand-held sprayers at 2460.8 g/cm^2 (35 psi) in 1983-85 or 2109.3 g/cm^2 (30 psi) in 1986-87. A final volume of 467.7 l/ha was applied in 1985 and 233.8 l/ha in other years. One to three weeks after completion of the spray program, plots were rated for fall armyworm damage on a 0-7 scale. A rating of 0, 1, 2, or 3 indicates < 5%, 5-10%, 10-20%, and > 20% leaf damage, respectively, with no feeding in the whorl. The values 4, 5, and 6 denote < 20%, 20-40%, and > 40% leaf injury, respectively, with progressively greater feeding in the whorl. A rating of 7 designates plants that are completely destroyed. In most tests individual plants were visually assessed, and a rating for the plot was determined by averaging the data from individual plants. In other tests an overall plot rating was recorded. Evaluations were conducted once or twice with a 7-10 day interval. In 1983 and 1985 all plants in the center 5 m of each plot of the sorghum tests were cut at ground level and weighed to determine silage yield. Data were subjected to analysis of variance and Duncan's new multiple range test; $P < 0.05$ (SAS 1989).

Results and Discussion

In five years' testing, the pyrethroid insecticides cyhalothrin, tralomethrin, and flucythrinate provided control of FAW injury comparable with manufacturers' suggested rates of chlorpyrifos and methomyl in whorl stage field corn, sorghum, and sweet corn.

Fenvalerate, esfenvalerate, cypermethrin, fluvalinate, cyfluthrin, and permethrin provided erratic control in whorl stage field corn and sweet corn at the rates tested, but compared with other chemical treatments in whorl stage sorghum.

Field Corn

In the first damage ratings of 1983 (Table 1), plots treated with cypermethrin (0.044, 0.075, 0.084, and 0.11 kg [AI]/ha), fluvalinate (0.084 and 0.11 kg [AI]/ha), the higher rate of permethrin (0.11 kg [AI]/ha), or methomyl (0.56 and 0.84 kg [AI]/ha) had significantly less FAW damage than untreated plots. Efficacy of both rates of methomyl was significantly greater than the efficacy of any other compound except cypermethrin at 0.11 kg (AI)/ha. The highest rate of cypermethrin (0.11 kg [AI]/ha) performed significantly better than fenvalerate (0.084 and 0.11 kg [AI]/ha) and the lower rate of permethrin (0.084 kg [AI]/ha). Neither rate of fenvalerate nor the lower rate of permethrin provided a significant level of control of FAW damage relative to untreated plots.

In the second 1983 damage rating, only plots treated with cypermethrin (0.11 kg [AI]/ha) or methomyl (0.84 kg [AI]/ha) had significantly less FAW injury than control plots (Table 1). No other statistical separation occurred among the treatments.

In 1984, all treated plots had significantly less FAW damage than control plots (Table 1). Cyhalothrin (0.017 kg [AI]/ha) had significantly greater efficacy than fenvalerate (0.11 kg [AI]/ha); all other chemical treatments performed significantly better than esfenvalerate at 0.017 kg (AI)/ha. No other statistical separation occurred among the treatments.

In 1985, all insecticide treated plots had significantly lower levels of FAW damage relative to untreated plots in two injury evaluations (Table 1). In the first rating, there were no significant differences among the insecticide treatments. In the second assessment, fluvalinate (0.062 kg [AI]/ha), tralomethrin (0.017 kg [AI]/ha), cyhalothrin (0.017 kg [AI]/ha), flucythrinate (0.056 kg [AI]/ha), and cyfluthrin (0.067 kg [AI]/ha) controlled FAW injury significantly better than methomyl (0.56 kg [AI]/ha).

In both FAW injury ratings taken in 1986, all insecticide treated plots had significantly less FAW damage than control plots (Table 1). There was no statistical separation among the insecticide treatments in the initial assessment; in the second evaluation, every other chemical treatment performed significantly better than esfenvalerate at 0.042 kg (AI)/ha in control of FAW damage.

Sorghum

In 1983, every insecticide treatment provided significant levels of control of FAW injury (Table 2). Fluvalinate (0.084 kg [AI]/ha) had significantly greater efficacy than either rate of methomyl (0.084 and 0.11 kg [AI]/ha); no other statistical separation occurred among the chemical treatments.

All insecticide treatments significantly increased silage yields relative to untreated plots (Table 2) in 1983 except fenvalerate (0.11 kg [AI]/ha); silage yields from all treated plots were statistically comparable. There was a trend for more effective treatments to yield the greatest amounts of silage with two exceptions; silage yields from fenvalerate (0.084 kg [AI]/ha) and permethrin (0.084 kg [AI]/ha) were higher than yields from any other treatment except fluvalinate (0.084 kg [AI]/ha) although these rates of fenvalerate and permethrin did not provide the highest level of protection from FAW injury.

In the initial rating of 1985, cypermethrin (0.067 kg [AI]/ha), cyhalothrin (0.017 kg [AI]/ha), flucythrinate (0.056 kg [AI]/ha), and cyfluthrin (0.067 kg [AI]/ha) provided significant levels of control of FAW damage compared with untreated plots (Table 2). The remaining treatments (fluvalinate [0.062 kg [AI]/ha], esfenvalerate [0.028 kg [AI]/

TABLE 1. PERCENT CONTROL OF FALL ARMYWORM DAMAGE BY INSECTICIDES IN WHORL STAGE FIELD CORN 1983-86. VALUES IN CONTROL ROW INDICATE MEAN DAMAGE RATINGS ASSIGNED TO UNTREATED PLOTS.

Treatment (kg [AI]/ha)	Year						
	1983		1984	1985		1986	
	1st[a]	2nd		1st	2nd	1st	2nd
Control	5.4a[b]	6.7a	5.1a	2.4a	3.9a	3.6a	4.6a
Fenvalerate							
(0.084)	22.3ab	3.0ab	–.–	–.–	–.–	–.–	–.–
(0.11)	17.6ab	10.4ab	84.0c	–.–	–.–	–.–	–.–
Permethrin							
(0.084)	21.3ab	10.4ab	–.–	–.–	–.–	–.–	–.–
(0.11)	38.0bc	14.9ab	86.1cd	–.–	–.–	–.–	–.–
Cypermethrin							
(0.045)	30.6bc	14.9ab	–.–	–.–	–.–	–.–	–.–
(0.056)	–.–	–.–	91.6cd	–.–	–.–	–.–	–.–
(0.067)	27.8bc	14.9ab	–.–	72.9b	75.6bc	–.–	–.–
(0.090)	43.5bc	16.4ab	–.–	–.–	–.–	–.–	–.–
(0.11)	54.6cd	22.4b	–.–	–.–	–.–	–.–	–.–
Fluvalinate							
(0.062)	–.–	–.–	–.–	72.9b	92.3c	–.–	–.–
(0.084)	30.6bc	11.9ab	–.–	–.–	–.–	–.–	–.–
(0.11)	35.2bc	13.4ab	95.3cd	–.–	–.–	–.–	–.–
Tralomethrin							
(0.017)	–.–	–.–	–.–	91.7b	85.9c	–.–	–.–
(0.021)	–.–	–.–	–.–	–.–	–.–	62.2b	90.3c
Esfenvalerate							
(0.017)	–.–	–.–	62.1b	–.–	–.–	–.–	–.–
(0.028)	–.–	–.–	–.–	83.3b	83.3bc	–.–	–.–
(0.042)	–.–	–.–	–.–	–.–	–.–	70.6b	59.5b
Cyhalothrin							
(0.017)	–.–	–.–	97.7d	95.8b	82.3c	–.–	–.–
(0.021)	–.–	–.–	–.–	–.–	–.–	97.2b	88.6c

Flucythrinate (0.056)	–.–	–.–	–.–	87.5b	88.5c	–.–	–.–
Cyfluthrin (0.067)	–.–	–.–	–.–	91.7b	85.9c	–.–	–.–
Methomyl (0.56)	73.1de	16.4ab	90.9	87.5	64.1b	86.1b	82.7c
(0.84)	74.1de	22.4b	–.–	–.–	–.–	–.–	–.–
Chlorpyrifos (0.56)	–.–	–.–	89.0cd	95.8b	80.8bc	77.1b	91.1c

[a]1st and 2nd indicate order of multiple damage readings.
[b]Duncan's multiple range test; means within columns followed by the same letter are not significantly different (SAS User's Guide 1990).

TABLE 2. PERCENT CONTROL OF FALL ARMYWORM DAMAGE BY INSECTICIDES AND SILAGE YIELD IN WHORL STAGE SORGHUM 1983-87. VALUES IN CONTROL ROW INDICATE MEAN DAMAGE RATINGS ASSIGNED TO UNTREATED PLOTS.

Treatment (kg[AI]/ha)	Year						
	1983	1985			1987		
		Yield	1st[a]	2nd	Yield	1st	2nd
Control	4.2a[b]	6141a	2.9a	2.8a	15884a	0.7a	0.8a
Fenvalerate							
(0.084)	57.6bcd	8393b	–.–	–.–	—	–.–	–.–
(0.11)	61.2bcd	6252ab	–.–	–.–	—	–.–	–.–
Permethrin							
(0.084)	64.3cd	8188b	–.–	–.–	—	–.–	–.–
(0.11)	76.4cd	7983b	–.–	–.–	—	–.–	–.–
Cypermethrin							
(0.067)	–.–	—	69.6e	63.6cd	18504a	81.5cd	71.8e
Fluvalinate							
(0.062)	–.–	—	30.4abcde	27.3abc	17434a	–.–	–.–
(0.084)	90.0d	8495b	–.–	–.–	—	–.–	–.–
(0.11)	84.0cd	7472b	–.–	–.–	—	–.–	–.–
Esfenvalerate							
(0.028)	–.–	—	17.4abc	22.7ab	18879a	81.5cd	87.5
Cyhalothrin							
(0.017)	–.–	—	65.2e	72.7d	17648a	–.–	–.–
(0.028)	–.–	—	–.–	–.–	—	47.1cd	90.6e
Tralomethrin							
(0.017)	–.–	—	13.0ab	36.4abcd	18665a	29.6cd	84.4e
Flucythrinate							
(0.056)	–.–	—	60.9de	61.4bcd	—	–.–	–.–
Cyfluthrin							
(0.028)	–.–	—	–.–	–.–	—	85.2cd	90.6e
(0.067)	–.–	—	56.5cde	54.5bcd	18557a	–.–	–.–

Methomyl								
(0.084)	46.4bc	7472b	—.—	—.—	——	—.—	—.—	
(0.11)	48.1bc	7369b	—.—	—.—	——	—.—	—.—	
(0.28)	—.—	—	—.—	—.—	——	55.6cd	71.8e	
(0.56)	—.—	—	30.4abcde	22.7ab	19734a	85.2cd	93.8e	
(0.84)	—.—	—	—.—	—.—	—	92.6d	96.9e	
Chlorpyrifos								
(0.28)	—.—	—	—.—	—.—	——	96.3d	68.8e	
(0.56)	—.—	—	21.7abcd	27.3abc	17060a	81.5cd	75.0e	

[a]1st and 2nd indicate order of multiple damage readings.
[b]Duncan's multiple range test; means within columns followed by the same letter are not significantly different (SAS User's Guide 1990).

ha], tralomethrin [0.017 kg [AI]/ha], methomyl [0.56 kg [AI]/ha], and chlorpyrifos [0.56 kg [AI]/ha]) did not significantly reduce FAW injury relative to the control. Additionally, cypermethrin (0.067 kg [AI]/ha), cyhalothrin (0.017 kg [AI]/ha), and flucythrinate (0.056 kg [AI]/ha) performed significantly better than esfenvalerate (0.28 kg [AI]/ha) and tralomethrin (0.017 kg [AI]/ha). FAW damage in plots treated with cypermethrin (0.067 kg [AI]/ha) and cyhalothrin (0.017 kg [AI]ha) had significantly less FAW injury than chlorpyrifos (0.56 kg [AI]/ha); cyfluthrin (0.067 kg [AI]/ha) had significantly greater efficacy than tralomethrin (0.017 kg [AI]/ha).

Analysis of second 1985 data set was similar; only plots treated with cypermethrin (0.067 kg [AI]/ha), cyhalothrin (0.017 kg [AI]/ha), flucythrinate (0.056 kg [AI]/ha), and cyfluthrin (0.067 kg [AI]/ha) had significantly less FAW injury than control plots. Cyhalothrin (0.017 kg [AI]/ha) performed significantly better than fluvalinate (0.062 kg [AI]/ha), esfenvalerate (0.017 kg [AI]/ha), methomyl (0.56 kg [AI]/ha), and chlorpyrifos (0.56 kg [AI]/ha); efficacy of cypermethrin (0.067 kg [AI]/ha) was statistically greater than the efficacy of esfenvalerate (0.017 kg [AI]/ha) and methomyl (0.56 kg [AI]/ha).

Differences among silage yields in 1985 were not significant (Table 2). Yields generally did not correlate with efficacy. Silage yields from methomyl (0.56 kg [AI]/ha) and esfenvalerate (0.028 kg [AI]/ha) plots ranked 1st and 2nd, respectively, among ten treatments, while yields from plots treated with cyfluthrin (0.067 kg [AI]/ha), cypermethrin (0.067 kg [AI]/ha), and cyhalothrin (0.017 kg [AI]/ha) ranked 5th, 6th, and 7th, respectively.

In the two injury ratings of 1987, all chemical treatments provided significant levels of control of FAW damage relative to untreated plots (Table 2). No other statistical differences occurred among the treatments in either of the two ratings.

Sweet Corn

Two sweet corn tests were conducted in 1986. In the first test, mean (ñ S.D.) FAW injury in untreated plots rated 5.2 ñ 0.54 in the initial assessment. All chemical treatments provided significant levels of protection against FAW damage, relative to untreated plots ($F = 11.3$; $P = 0.05$; DMRT, SAS User's Guide 1990). Mean (ñ S.D.) percent control by tralomethrin at 0.028 kg (AI)/ha (100.0 ñ 0.0%) and by chlorpyrifos at 0.84 kg (AI)/ha (97.4 ñ 4.7%) was significantly higher than control by esfenvalerate at 0.028 kg (AI)/ha (63.9 ñ 36.5%), cyhalothrin at 0.028 kg (AI)/ha (86.5 ñ 13.9%), and cyfluthrin at 0.028 kg (AI)/ha (67.0 ñ 27.4%). Efficacy of chlorpyrifos at 0.56 kg (AI)/ha (93.8 ñ 10.6%) was significantly greater than efficacy of cyhalothrin at 0.028 kg (AI)/ha and esfenvalerate at 0.028 kg (AI)/ha. Percent FAW control in the remaining treatments did not differ significantly from any other chemical treatment: methomyl at 0.56 kg (AI)/ha and at 0.84 kg (AI)/ha (75.3 ñ 19.5% and 87.4 ñ 16.8%, respectively), flucythrinate at 0.067 kg (AI)/ha (87.9 ñ 13.4%) and cypermethrin at 0.067 kg (AI)/ha (74.3 ñ 25.1%).

Greater separation occurred among the chemical treatments in the second rating of the first 1986 test ($F = 12.7$, $P = 0.05$). All chemical treatments significantly controlled FAW injury, compared with untreated plots (mean injury rating [ñ S.D.], 5.5 ñ 0.50). Percent control of FAW damage by tralomethrin at 0.028 kg (AI)/ha (97.0 ñ 4.1%), by flucythrinate at 0.067 kg (AI)/ha (97.4 ñ 2.3%), and by methomyl at 0.084 kg (AI)/ha (96.8 ñ 3.1%) was significantly greater than control by all other treatments, except chlorpyrifos at 0.56 kg (AI)/ha and 0.085 kg (AI)/ha (94.0 ñ 6.4% and 88.8 ñ 21.7%, respectively) and methomyl at 0.56 kg (AI)/ha (77.9 ñ 20.9%). Chlorpyrifos at either rate was significantly more effective than cyfluthrin at 0.028 kg (AI)/ha (53.6 ñ 35.0%); efficacy of chlorpyrifos at 0.56 kg (AI)/ha was significantly greater than the efficacy of esfenvalerate at 0.028 kg (AI)/ha (67.2 ñ 24.0%) and the efficacy of cyhalothrin at 0.028 kg (AI)/ha (89.2 ñ 18.9%). No additional statistical separation occurred; cypermethrin (0.067 kg [AI]/ha) provided 69.2 ñ 22.7% control of FAW injury.

In a single rating, FAW injury in the untreated plots averaged (ñ S.D.) 3.7 ñ 0.31 in the second test of 1986. Every chemical treatment provided significant levels of protection (F = 24.4, P = 0.05). Mean percent control by tralomethrin at 0.028 kg (AI)/ha (98.3 ñ 1.6%), by cyfluthrin at 0.028 kg (AI)/ha (97.9 ñ 2.2%), by methomyl at 0.56 kg (AI)/ha (96.8 ñ 2.1%), and by cyhalothrin at 0.011 kg (AI)/ha and at 0.028 kg (AI)/ha (each with 98.9 ñ 1.5% control) was significantly greater than control by esfenvalerate at 0.011 kg (AI)/ha and at 0.028 kg (AI)/ha (70.1 ñ 18.5% and 83.0 ñ 20.0%, respectively). Additionally, the efficacy of tralomethrin at 0.011 kg (AI)/ha (94.6 ñ 2.6%), of cyfluthrin at 0.011 kg (AI)/ha (88.0 ñ 6.3%), and of methomyl at 0.17 kg (AI)/ha (87.2 ñ 10.3%) was significantly greater than the efficacy the lower rate of esfenvalerate (0.011 kg [AI]/ha).

In the first evaluation of the 1987 test, FAW injury in untreated plots averaged (ñ S.D.) 5.4 ñ 0.43. Cyfluthrin at 0.028 kg (AI)/ha (27.8 ñ 25.1% control), chlorpyrifos at 0.28 kg (AI)/ha (36.7 ñ 33.9%), chlorpyrifos at 0.56 kg (AI)/ha (44.2 ñ 26.3%), cypermethrin at 0.067 kg (AI)/ha (49.2 ñ 18.9%), tralomethrin at 0.017 kg (AI)/ha (58.4 ñ 30.2%), methomyl at 0.56 kg (AI)/ha (66.9 ñ 11.3%), methomyl at 0.28 kg (AI)/ha (70.5 ñ 16.5%), methomyl at 0.84 kg (AI)/ha (87.1 ñ 9.0%), and cyhalothrin at 0.028 kg (AI)/ha (76.9 ñ 24.6%) provided significant levels of control of FAW injury (F = 14.5, P = 0.05); esfenvalerate at 0.028 kg (AI)/ha (12.2 ñ 13.8%) did not. Additionally, methomyl (0.84 kg [AI]/ha) was significantly more effective than any non-methomyl treatment, except cyhalothrin. Cyhalothrin was significantly more effective than cypermethrin, both rates of chlorpyrifos, cyfluthrin, and esfenvalerate. The efficacy of methomyl at 0.28 kg (AI)/ha was significantly greater than the efficacy of chlorpyrifos, of cyfluthrin, and of esfenvalerate. With the exception of cyfluthrin, every other chemical treatment was significantly more effective than esfenvalerate.

In the second assessment of the 1987 experiment, FAW damage in untreated plots rated a mean (ñ S.D.) 5.5 ñ 0.94; all chemical treatments significantly reduced FAW injury (F = 4.6, P = 0.05. Mean percent control of FAW injury by cyhalothrin at 0.028 kg (AI)/ha (88.8 ñ 6.6%) was significantly greater than control by any other treatment, except tralomethrin at 0.017 kg (AI)/ha (71.1 ñ 18.5%). Tralomethrin and methomyl at 0.84 kg (AI)/ha (64.7 ñ 23.0%) had significantly greater efficacy than any other treatment, except cyhalothrin and methomyl at 0.56 kg (AI)/ha (60.6 ñ 9.2%).Methomyl at 0.56 kg (AI)/ha was significantly more effective than cyfluthrin at 0.028 kg (AI)/ha (30.6 ñ 10.8%), methomyl at 0.28 kg (AI)/ha (40.6 ñ 24.6%), and esfenvalerate at 0.028 kg (AI)/ha (19.2 ñ 34.3%). Additionally, the efficacy of chlorpyrifos at 0.28 kg (AI)/ha and 0.56 kg (AI)/ha (46.0 ñ 22.0% and 43.5 ñ 30.3% control, respectively) and the efficacy of cypermethrin at 0.028 kg (AI)/ha (40.3 ñ 24.6%) were significantly greater than the efficacy of esfenvalerate. Methomyl at 0.28 kg (AI)/ha (40.6 ñ 31.4%) and cyfluthrin at 0.028 kg (AI)/ha (30.6 ñ 10.8%) were statistically comparable with esfenvalerate, cypermethrin, and chlorpyrifos (0.56 and at 0.28 kg [AI]/ha).

In summary, these tests indicate that control of FAW damage in whorl stage field corn, sweet corn, and sorghum provided by the pyrethroid insecticides tralomethrin, flucythrinate, and cyhalothrin is comparable with recommended rates of methomyl and chlorpyrifos. The other pyrethroids tested; fluvalinate, fenvalerate, esfenvalerate, permethrin, cypermethrin, and cyfluthrin; were relatively less effective in the corn experiments. However, they were comparable with other treatments in control of FAW injury in whorl stage sorghum.

Many pyrethroid insecticides have shown activity against noctuid larvae, but often failed to provide adequate control of FAW (Harrell et al. 1977). More recently developed pyrethroids, including tralomethrin, flucythrinate, and cyhalothrin have been shown to control FAW attacking sweet corn ears (All et al. 1986). Our results indicate that these pyrethroids and others now available are also effective against FAW populations in whorl stage corn and sorghum.

Since the late 1970's, FAW populations have shown resistance to a number of insecticides including methomyl (Bass 1978, Young 1979). Identification of suitable alternatives is basic for the management of resistance (Metcalf 1980). Our results indicate that a number of pyrethroids can be substituted for methomyl or chlorpyrifos in FAW management programs.

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EFFECT OF VARIOUS CHEMIGATION METHODOLOGIES ON SUPPRESSION OF THE FALL ARMYWORM (LEPIDOPTERA: NOCTUIDAE) IN CORN

L. D. CHANDLER AND H. R. SUMNER
Insect Biology and Population Management Research Laboratory
USDA-ARS, Tifton, GA 31793

Abstract

Studies were conducted in Tifton, Georgia during 1989 to compare the effectiveness of center-pivot irrigation sprinkler packages and various formulations of insecticides for the control of fall armyworm, *Spodoptera frugiperda* (J. E. Smith), infesting corn. Chemigation with Whirl-jet (E53) sprinklers provided better control of the pest than impact sprinklers or a Pass system. Chemigation with whirl-jet sprinklers controlled fall armyworm as well as a conventional hi-clearance sprayer. Asana XL 0.66 EC + oil chemigated with an irrigation simulator provided the most consistent control of fall armyworm larvae in whorl stage corn when compared with Asana XL + water, Lorsban 4E + oil, Lorsban 4E + water, Lorsban 6 (tech.) + oil, Larvin 3.2 + oil, and Larvin 3.2 + water. All tested materials resulted in significant reductions in fall armyworm damage to the whorls of corn.

Since the late 1970's, FAW populations have shown resistance to a number of insecticides including methomyl (Bass 1978, Young 1979). Identification of suitable alternatives is basic for the management of resistance (Metcalf 1980). Our results indicate that a number of pyrethroids can be substituted for methomyl or chlorpyrifos in FAW management programs.

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RESUMEN

En estudios realizados en Tifton, Georgia en 1989, se comparó la efectividad de varias formulaciones de insecticidas al ser usadas en el sistema de riego por aspersión contra el cogollero, *Spodoptera frugiperda* (J. E. Smith) en máz. La quimigación con aspersorios tipo Whirl-jet (E53) brindó un mejor control de la plaga que los aspersorios de impacto o el sistema Pass. La chemigación con los aspersorios tipo Whirl-jet controló el cogollero tan bien como un equipo convencional de aspersión. Asana XL 0.66 EC + aceite usado en el riego por aspersión brindó el control mas consistente del cogollero cuando el maíz estaba en estado de mazorca, comparado con Asana XL + agua, Lorsban 4E + aceite, Lorsban 4E + agua, Lorsban 6 (tech.) + aceite, Larvin 3.2 + aceite y Larvin 3.2 + agua. Todos los materiales dieron resultados significativos en la reducción de daño del cogollero a la mazorca del maíz.

Fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), is a major pest of corn throughout the southeastern United States. Typically, sweet corn is double-cropped throughout the region with the second crop planted late in the growing season when populations of FAW are largest (Harrell et al. 1977). Insecticides are the primary mechanism for control of the FAW. Recent studies conducted in Florida indicate that maintaining the sweet corn crop relatively free of FAW prior to the silk stage can reduce the total number of conventionally applied insecticide treatments needed to protect the ears (Foster 1989). However, more than 10 applications during silking are still needed to provide control in late summer and fall crops. Young (1980) suggested that insectigation (application of insecticides in irrigation water) was the best method available for the application of insecticides to control FAW larvae, especially when late planted corn became infested. Insectigation allows maximum insecticide coverage without limitation of water volume as in conventional sprayer operations. Greater volumes of water aid insecticide penetration into corn whorls. Later studies suggested that FAW larvae could better be controlled with technical chlorpyrifos (Lorsban®) formulated in oil (as opposed to EC formulation) and applied on an established schedule through a center-pivot irrigation system (Young 1986). This method requires 12-14 insecticide applications during the spring growing season and 21-26 applications during the summer-fall season (Young 1986) in order to produce 97+% worm free ears of sweet corn. Technical chlorpyrifos presently is not commercially available or labeled for use in center-pivot systems, thus alternative formulations and insecticides are needed.

Chemigation has economic advantages over conventional application methods. Chemigation costs are estimated to be $1.70/ha when applied with 10 mm of irrigation compared to $5.60/ha for conventional treatments (Threadgill 1981). The dollar savings should make chemigation attractive. However, widespread adoption of chemigation has been slow. In 1983, growers of an estimated 200,000+ ha, or about 2% of the total sprinkler-irrigated area in the United States, were using insectigation (Threadgill 1985). This hectarage has since increased, but the safety of insectigation and improvement of insectigation application technology are concerns of growers and researchers. Additional studies related to insectigation application technology are necessary to optimize the efficiency of the chemigation system and to compare insectigation with conventional control methods. This paper reports studies designed to evaluate and improve FAW control in sweet corn using insectigation technology. The objectives of the studies were 1) to study FAW control variability following insecticide application with various irrigation sprinkler packages, 2) to compare insectigation techniques with conventional application methods for FAW control, and 3) to evaluate various insecticide formulations and carriers for use in insectigation to manage FAW.

MATERIALS AND METHODS

Evaluation of Irrigation Sprinkler Packages

'Merit' variety sweet corn was direct-seeded on 5 July, 1989 in three quadrants (0.15 ha/quadrant) of two center-pivot irrigation systems located on the Coastal Plains Experiment Station in Tifton, Georgia. The corn was grown using established agronomic practices except for the insecticide applications. Insecticides were applied in a single quadrant with one of the following irrigation sprinkler packages: a) the Spraying System Whirl-jet nozzle (E53) calibrated to deliver 17,770 liters/ha of water applied at 69 kPa (kilopascals); b) the Pass system (Whirl-jet E2-E20 nozzles) designed to put insecticides into the system at the outer edge of the pivot and calibrated to deliver 1683 liters/ha of water applied at 69 kPa; and c) the low angle impact sprinkler system calibrated to apply 17,770 liters/ha of water at 310 kPa. Insecticides formulated with non-EC oil for a total formulation volume of 4.9 liters/ha were direct-injected with the injection nozzle pointed downstream into the irrigation mainline. The water velocities at the injection site were 2.1, 2.8, and 1.1 m/sec for Whirl-jet, Pass and impact systems, respectively. Applications of chlorpyrifos (Lorsban®) and cypermethrin (Cymbush®) combinations were initiated just prior to tasseling (Table 1) and continued through corn ear maturity following a treatment schedule devised by Young (1986). Treatments were made prior to tasseling and then every day for five days (beginning at 5% silk), followed by every other day for four applications and then every third day until harvest. Six 3.8 m long double row (91-cm spacing) plots/quadrant were established during the whorl plant growth stage to evaluate effectiveness of sprinkler packages for FAW control. The plot mid-points were 18, 24, 27, 31, 33, and 39 m from the pivot point in each quadrant. Each pivot system was 48 m in length from pivot point to wheel track. During whorl stage, 20 plants per plot were randomly selected and examined for presence of FAW larvae and new feeding damage following the fourth insecticide application. Mature ears were harvested on 7 Sept. All ears in each plot were collected and the total number of marketable size ears was determined. The number of worm-free ears/plot was noted and an insect damage index (Widstrom 1967) calculated from 15 randomly selected ears from each plot sample. The damage index was based on a 0 (no damage) to n scale, where n = the total depth of larval feeding in 1 cm units. The total number of larvae found in ears in each plot was noted and species of each determined.

Evaluation of Conventional vs Insectigation Treatments

'Merit' variety sweet corn was direct-seeded on 11 July, 1989 in two quadrants (0.15 ha each) of a single center-pivot irrigation system at Tifton, Georgia. Established agronomic practices for corn production were followed except for the application of insecticides in irrigation water. Insecticides were applied in one quadrant using the Spraying System Whirl-jet (E53) sprinkler package described in the above test. The main line water velocity was 1.1 m/sec at the point of insecticide injection. The additional quadrant was treated during the whorl stage of plant growth with a Ford 400 hi-clearance tractor equipped with a Johnson PTO mounted sprayer and during the period from silk to harvest with a John Deere 600 Hi-cycle sprayer. Both sprayers were calibrated to deliver 281 liters/ha of total spray volume. Chlorpyrifos and cypermethrin applications were initiated just prior to tasseling and continued through harvest as noted in the above test. An untreated control area was provided at the outer edge of the conventionally treated quadrant wherein six 3.8 m-long double-row plots were established at the same time that plots were established within the treated quadrants. Mature ears were harvested on 14 Sept., and insect damage evaluations were conducted as above.

Evaluation of Insecticide Formulations and Carriers

A 0.8-ha field was direct-seeded to 'Pioneer 3320' variety field corn on 23 Aug. 1989 at Tifton, Georgia. The field was divided into 32 plots, each 5 rows wide (91-cm spacing) by 12.2 m long. Each plot was separated by 0.9 m alleys on the same rows. Plots were arranged in a randomized complete block design with four replications. Seven different insecticide treatments were applied on whorl stage (4-10 leaf stage) plants with an irrigation simulator (Sumner et al. 1989) calibrated to deliver 25,400 liters of water per ha through four E53 Whirl-jet nozzles at 69 kPa. Desired insecticide concentrations were mixed in either vegetable oil or water and applied, at a rate of 4.9 liters of total material per ha, following injection into the main line which carried a water velocity of 2.4 m/sec. Thirty plants per plot were randomly selected from the center three rows of each plot, and the number of freshly damaged plants and lepidopterous larvae noted. Larvae were identified by species. Insect damage evaluations were performed prior to each application date and again 48 hours after treatment. Three applications were made.

Statistical Analyses

Means and standard deviations were calculated for all data. Analysis of variance procedures were performed and treatment means separated by Duncan's multiple range test (Duncan 1955). Regression analyses of the effects of distance from the pivot point on ear damage ratings were conducted on both center-pivot irrigation tests.

Results and Discussion

Evaluation of Irrigation Sprinkler Packages

Whirl-jet (E53) sprinklers provided FAW control in whorl-stage sweet corn that was statistically superior ($P \leq 0.05$) to that noted with impact sprinklers and the Pass system (Table 1). The number of infested whorl stage corn plants in the quadrant treated with Whirl-jet sprinklers was ca. 1/2 the infestation noted in the quadrant treated with impact sprinklers and ca. 1/10 the infestation in the Pass system quadrants. As the corn progressed into the tassel/silk stage the number of FAW within the plots increased dramatically. The percentage of larvae identified as FAW on ears at harvest ranged from 63 to 95%. Scheduled applications of insecticides did not decrease the FAW population or resulting damage to a level acceptable for fresh market production. This phenomenon was likely caused by the low rates of insecticides used, which were less than the recommended label rates. The lower rates were intentionally used to provide less than 100% insect control to better distinguish insect control levels among the three application systems. The number of damaged ears harvested was similar ($P > 0.05$) in the Whirl-jet and impact sprinkler treated quadrants (Table 1). However, insect damage indices per quadrant were significantly less ($P \leq 0.05$) in the Whirl-jet treated quadrant compared with the impact and Pass system treated plots.

Table 2 presents results of regression analyses conducted to determine the effectiveness of insect control as influenced by the distance from the center point of the center-pivot system. The analyses show that in plots treated with either Whirl-jet or impact sprinklers insect control decreased with distance from the pivot point, indicating that the insecticide is not effectively reaching the target at distances over 30 m from the center. It is probable that this phenomenon is related to the velocity of water flowing through the mainline at the insecticide injection point. Insecticides were injected into the system with a main-line velocity of ca. 1.1 and 2.1 m/sec for impact and Whirl-jet sprinklers, respectively. These velocities may not allow for sufficient break-up of oil

TABLE 1. COMPARISON OF CHEMIGATION SPRINKLER PACKAGES FOR FALL ARMYWORM CONTROL IN SWEET CORN. TIFTON, GEORGIA 1989.[a]

	Whorl stage	Ear stage			
Sprinkler type	No. infested plants/plot ($\bar{x} \pm SD$)[b]	No. marketable ears/plot at harvest ($\bar{x} \pm SD$)[b]	No. damaged ears of 15 ears/plot ($\bar{x} \pm SD$)[b]	Damage rating on 15 ears/plot ($\bar{x} \pm SD$)[b,c]	% FAW larvae/plot (total no. counted)[d]
Whirl-jet E53	2.5 ± 0.8a	34.3 ± 7.7a	11.0 ± 2.5 a	6.8 ± 3.0a	79.6 (49)
Impact	6.5 ± 4.3b	36.7 ± 9.1a	12.5 ±2.8ab	11.1 ± 4.5b	95.2 (165)
PASS E2-E20	11.5 ± 2.4c	30.0 ± 4.9a	14.3 ± 1.0b	11.0 ± 2.0b	63.1 (65)

[a]Presilk treatments: Lorsban 4E (561 g AI/ha) + oil - 7/10.
Lorsban 4E (280 g AI/ha) + Cymbush (56 g AI/ha) + oil - 7/21 & 7/28.
Lorsban 4E (561 g AI/ha) + oil - 8/5 & 8/10.
Lorsban 6 (561 g AI/ha) + oil - 8/11, 8/15 & 8/18.
Silk-harvest treatments: Lorsban 6 (280 g AI/ha) + Cymbush (14 g AI/ha) + oil - 8/21, 8/22, 8/23, 8/24, 8/25, 8/27, 8/29, 8/31, 9/2 & 9/5.
Materials were formulated with Orchex 796 non-EC oil for a total of 5.0 L/ha.
[b]Means within a column followed by the same letter are not significantly different (DMRT, $P > 0.05$).
[c]Damage ratings based on index developed by Widstrom (1967).
[d]Percent FAW of total species.

TABLE 2. RESULTS OF REGRESSION ANALYSES COMPARING DAMAGE RATINGS AGAINST DISTANCE FROM PIVOT POINT IN EACH SPRINKLER SYSTEM. TIFTON, GEORGIA, 1989.[a]

Plot distance (m) from pivot point	Damage rating[b]/plot/sprinkler type		
	Whirl-jet	Impact	PASS
18	4.5	6.8	9.7
24	4.9	6.4	9.5
27	4.4	7.7	12.3
31	6.8	14.9	8.6
33	8.3	15.3	13.0
39	12.1	15.4	13.1
Statistics			
R^2	0.787	0.765	0.339
F value	14.749	12.995	2.051
Prob. > F 5	0.018[b]	0.023[b]	0.225

[a]Damage ratings based on index developed by Widstrom (1967).
[b]F test significant at $P \leq 0.05$.

droplets carrying the insecticide and thus would allow large droplets of the oil formulation to float to the top of the pivot line and exit through sprinkler nozzles that are closest to the pivot point. Therefore, less insecticide in the form of small droplets would be applied at the farthest end of the system, resulting in poor insect control. The Pass system is designed in such a way that insecticides come into the system at the outer edge of the pivot and flow toward the pivot point. In addition, water velocity at the point of injection was greater (2.8 m/sec) with the Pass system than with the other two systems. Therefore, FAW damage ratings were similar throughout the quadrant treated with the pass system and did not show any correlation between distance from the pivot center and damage ratings (Table 2). Insect control was poor, however, in the Pass system treated quadrant.

Evaluation of Conventional vs Insectigation Treatments

Quadrants of sweet corn treated with Whirl-jet (E53) sprinklers for chemigation and a hi-clearance sprayer for the conventional application were similar ($P > 0.05$) in damage during both the whorl stage and when ears were harvested (Table 3). Damage in tne untreated plots was significantly greater ($P \leq 0.05$) than in both of the treated quadrants. Although FAW pressure was quite high (95-100% of total larvae in each quadrant were FAW), it was clear that both the conventional and chemigation methods provided some control of the pest, even at the reduced rates used.

Table 4 presents data compiled from the analyses of insect damage ratings vs distance from the pivot point for the conventional and chemigation treated quadrants. As in the data presented in Table 2, Whirl-jet treated quadrants showed definite loss of control as evaluations progressed outward from the pivot point. The data presented here were much more pronounced than in the above study. Control in the first three plots was outstanding, but decreased rapidly after reaching 30 m from the center. Regression analysis showed that this loss of control was linear. The poor control was associated with the insecticide being injected into low velocity water in the main line of the system. Insecticides were injected at 1.1 m/sec, which is probably not adequate for good formulation droplet breakup and uniform distribution of pesticide mixed in oil along the pivot line. The same phenomenon was not observed in the conventional treated quadrant.

TABLE 3. COMPARISON OF CHEMIGATION VS. CONVENTIONAL APPLICATION METHODOLOGIES FOR FALL ARMYWORM CONTROL IN SWEET CORN. TIFTON, GA, 1989.[a]

	Whorl stage	Ear stage			
Application Type	No. infested plants/plot ($\bar{x} \pm SD$)[b]	No. marketable ears/plot at harvest ($\bar{x} \pm SD$)[b]	No. damaged ears of 15 ears/plot ($\bar{x} \pm SD$)[b]	Damage rating on 15 ears/plot ($\bar{x} \pm SD$)[b, c]	% FAW larvae/plot (total no. counted)[d]
Chemigation (Whirl-jet)	1.8 ± 1.7a	67.7 ± 4.3b	9.8 ± 5.4a	8.7 ± 6.7a	95.4 (87)
Hi-clearance sprayer	1.8 ± 1.9a	64.0 ± 5.1b	12.7 ± 2.6ab	12.1 ± 2.9a	100.0 (37)
Untreated	12.0 ± 3.3b	46.5 ± 9.0a	15.0 ± 0.0b	15.9 ± 0.1b	97.2 (283)

[a]Presilk treatments: Lorsban 4E (561 g AI/ha) + oil - 7/14.
Lorsban 4E (280 g AI/ha) + Cymbush (56 g AI/ha) + oil - 7/31.
Lorsban 4E (561 g AI/ha) + oil - 8/5 & 8/10.
Lorsban 6 (561 g AI/ha) + oil -(chemigation), and
Lorsban 4E (561 g AI/ha) - (conventional) - 8/11, 8/16, 8/18, and 8/24.
Silk-harvest treatments: Lorsban 6 (280 g AI/ha) + Cymbush (142 g AI/ha) + oil - (chemigation), and
Lorsban 4E (280 g AI/ha) + Cymbush (142 g AI/ha) - (conventional) - 8/29, 8/30, 8/31, 9/1, 9/2, 9/4, 9/6, 9/8, 9/10 & 9/13.
[b]Means within a column followed by the same letter are not significantly different (DMRT, $P > 0.05$).
[c]Damage ratings based on index developed by Widstrom (1967).
[d]Percent FAW of total species.

TABLE 4. RESULTS OF REGRESSION ANALYSES COMPARING DAMAGE RATINGS AGAINST DISTANCE FROM PIVOT POINT IN CHEMIGATION AND CONVENTIONAL APPLICATION SYSTEMS. TIFTON, GEORGIA, 1989.

Plot distance from center pivot (m)	Damage rating[a]/plot/nozzle type	
	Whirl-jet	Hi-clearance sprayer
18	2.0	9.4
24	1.7	13.6
27	4.1	12.3
31	14.6	8.0
33	15.7	13.3
39	13.9	15.9
Statistics		
R^2	0.729	0.258
F value	10.767	1.393
Prob. > F	0.030[b]	0.303

[a]Damage ratings based on index developed by Widstrom (1967).
[b]F test significant at $P \leq 0.05$.

Additional data are needed to better understand the influence main-line water velocity has on droplet size and distribution of insecticides along the pivot line.

Evaluation of Pesticide Formulations and Carriers

Control of FAW in whorl stage corn was achieved with several EC formulated insecticides mixed with either oil or water, as well as a technical insecticide mixed with oil and applied through an irrigation simulator (Table 5). Applications of Asana XL 0.66 EC mixed with oil provided the most consistent control of any of the tested materials following three insecticide applications. On the final sampling date, only 2.5 ± 2.5 SD out of 30 plants/plot in the Asana XL 0.66 EC + oil treatments were newly damaged. All insecticides tested, however, provided significant ($P \leq 0.05$) FAW control compared with the control plot. On most sampling dates FAW larvae comprised 100% of the insect population sampled (including control plots). Applications of Lorsban 6 Tech. + oil resulted in control that was similar ($P > 0.05$) to that achieved with Asana XL 0.66 EC + oil, but insect control was not consistent for the last sampling date. Larvin 3.2 mixed with either water or oil did not provide control numerically as good as that achieved with the above two compounds. Though statistically better ($P \leq 0.05$) than the control plots, Larvin 3.2 did not provide the levels of control needed. The thickness of the Larvin + oil mix prohibited uniform mixing and pumping of the chemical into the injection site, which reduced the effectiveness of chemigation. In general, EC materials mixed with water did not provide control that was numerically as good as that achieved with EC + oil materials.

The above tests showed that corn can be protected from FAW larval populations with chemigation. In most cases significant reductions of FAW larval populations were achieved with all tested sprinkler packages and insecticide formulations. However, much refinement is still needed. Our studies demonstrated that the Whirl-jet (E53) sprinkler performed as well, or better than the impact sprinklers, the Pass system, or conventional hi-clearance sprayers. Minimum insecticide rates and application frequencies required to achieve acceptable insect control need to be determined. Further studies are needed to determine which insecticide rates work best for chemigation and what carrier and

TABLE 5. NUMBER OF INFESTED CORN PLANTS/PLOT ON DATE INDICATED FOR TESTED INSECTICIDES APPLIED THROUGH AN IRRIGATION SIMULATOR. TIFTON, GEORGIA, 1989.

Treatment	Rate (g AI/ha)	Carrier[c]	Pretreatment 9/13/89	Number of damaged plants/plot ($\bar{x}$ + SD)[a, b] 9/15/89	9/19/89	9/21/89	10/2/89	10/4/89
Asana XL 0.66EC	56	Oil	3.8±4.2a	2.0±1.2a	6.8±1.9a	3.8±3.6a	18.8±5.9ab	2.5±2.5a
Asana XL 0.66EC	56	Water	4.0±2.8a	5.0±2.9ab	12.5±6.8ab	7.8±6.1a	14.5±7.7a	14.8±10.3b
Larvin 3.2	673	Oil	2.8±1.0a	9.3±3.4b	20.3±5.7bc	17.8±9.2b	29.8±0.5c	6.5±0.6ab
Larvin 3.2	673	Water	4.8±1.7a	6.0±2.8ab	14.8±6.3ab	10.5±6.1ab	22.3±5.3b	11.5±10.5ab
Lorsban 4E	561	Oil	2.3±1.5a	3.0±2.8ab	12.0±8.4ab	1.5±1.7a	29.0±1.4c	5.3±3.9ab
Lorsban 4E	561	Water	4.8±0.5a	5.8±9.5ab	12.8±11.7ab	7.0±8.3a	26.0±3.6bc	14.8±5.2b
Lorsban 6 (Tech)	280	Oil	2.3±0.5a	1.8±2.4a	6.3±5.0a	4.0±3.6a	29.3±1.5ab	8.8±4.9ab
Untreated	–	–	4.5±2.1a	18.5±4.7c	27.0±4.7c	25.8±5.7b	30.0±0.0c	30.0±0.0c

[a]Means within a column followed by the same letter are not significantly different (DMRT $P > 0.05$).
[b]Insecticides applied after insect damage evaluations on 13 Sept., 19 Sept., and 2 Oct. 1989.
[c]Materials were formulated in the carrier for a total volume of 4.9 L/ha and direct injected into a 2.66-cm diameter main line for a water velocity of 2.4 m/sec.

formulations provide optimal coverage. The whorl stage corn study indicated that pyrethroids are valuable in managing FAW populations in chemigated fields.

As noted by this study and the work of Young (1980 and 1986), numerous applications of insecticides by chemigation or conventional systems are required to provide a high percentage of pest-free corn ears. However, studies designed to evaluate the residual effect of chemigated insecticides on corn insect population dynamics could result in more effective control with reduced rates and frequency of application.

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INFLUENCE OF CHEMIGATION PARAMETERS ON FALL ARMYWORM CONTROL IN FIELD CORN

HAROLD R. SUMNER
U.S. Dept. of Agric.
Agricultural Research Service
Tifton, GA 31793

RICHARD B. CHALFANT
Dept. of Entomology
Coastal Plain Exp. Sta.
University of Georgia
Tifton, GA 31793

DAVID COCHRAN
Agricultural Engineering Dept.
University of Florida
Gainesville, FL 32611

ABSTRACT

The application of pesticides in irrigation water (chemigation) is developing into a highly efficient and economical pest management strategy as the influence of application parameters are understood. In the current study, the effects of main-line water velocity, injection port direction, and sprinkler nozzle type were evaluated with two rates of chlorpyrifos to control fall armyworm larvae, Spodoptera frugiperda (J. E. Smith), in whorl-stage field corn grown under 0.6 ha center pivot irrigation systems. Chlorpyrifos injected into a main-line water velocity of 2.7 m/s generally gave as good or better fall armyworm control than when injected into a water velocity of 0.9 m/s regardless of sprinkler type. Upstream injection of chlorpyrifos formulated in non-emulsifiable oil resulted in better control of fall armyworm than did downstream injection. Chlorpyrifos applied with a 360° spray sprinkler with coarse plates and nozzle orifice diam. between 3.6 and 9.5 mm at a main-line water velocity of 0.9 m/s gave the poorest fall armyworm control while an impact sprinkler gave the best control. The formulation droplet breakup in the main line and at the sprinkler were important factors in the distribution of insecticides to the target.

RESUMEN

La aplicación de insecticidas en el agua de irrigación (quimigación) se esta convirtiendo en una estrateia de manejo integrado de plagas bastante eficiente. En este estudio, los efectos de la velocidad del agua a traves de el tubo principal de irrigacion, la dirección de la inyección, y el tipo de boquilla de irrigación, fueron evaluadas con dos dosis de chlorpyrifos, con el proposito de controlar las larvas del cogollero del maíz, *Spodoptera frugiperda* (J. E. Smith), en un campo de maíz en estado de mazorca, cultivado bajo un sistema de irrigación centro-pivote de 0.6 has. El chlorpyrifos fué inyectado en el tubo principal con una velocidad del agua de 2.7 m/s el cual dió un control mejor o igual que cuando el producto fue inyectado en el agua a una velocidad de 0.9 m/s, sin que importara el tipo de boquilla de asperción. Chlorpyrifos formulado con aceite no emulsionable e injectado contra la corriente, resultó en un mejor control que la inyección en el mismo sentido de la corriente. El chlorpyrifos aplicado con un equipo de aspersión de 360° con platillos gruesos y con una boquilla de aspersión con un orificio de diametro entre 3.6 y 9.5 mm con una velocidad del agua de la tubería principal de

0.9 m/s , dió el control mas bajo del cogollero mientras que el rociador de impacto dió el mejor control. La separación de la gota de la formulación en la tubería principal y en el rociador fue uno de los factores mas importantes en el contacto de el pesticida con la plaga.

Advances in irrigation systems and insecticide injection equipment design have stimulated research to improve the efficiency and reliability of insecticides conveyed in irrigation water (chemigation) against economic pests of production agriculture. For foliar chemigation, oil-soluble insecticides formulated with non-emulsifiable oils have the best potential for consistent and effective control of insect pests on plant foliage. These formulations form discrete droplets of oil-carrying insecticides that are transported in the irrigation water and adhere to the plant foliage at application (Young 1984 and Chalfant & Young 1981). Three times as much chlorpyrifos insecticide was found on the foliage of corn plants when formulated in oil than when formulated as an emulsifiable concentrate and chemigated with 0.6 mm of water (Wauchoupe et al. 1990).

The droplet size distribution of pesticides applied with conventional equipment influences their effectiveness (Smith et al. 1973 and Gebhardt et al. 1985). Therefore, the efficiency of chemigated pesticides probably is influenced by droplet size distribution. Sumner and Cochran (1988) developed a system to measure oil droplet size distribution emanating from irrigation sprinklers during chemigation. However, studies to correlate droplet size of oil-formulated insecticide with insect control in chemigation field tests have not been performed, since the determination of droplet size distribution of oil-formulated insecticide from irrigation sprinklers requires the collection and disposal of large volumes of insecticide during testing. Laboratory studies on the effect of irrigation and injection parameters on oil droplet size distribution (Grosselle et al. 1986, Cochran et al. 1984, 1985, 1988, Sumner & Cochran 1988) indicated that main-line water velocity, pesticide injection direction (with respect to main-line flow), sprinkler nozzle diameter, system pressure, and sprinkler type all influenced the size of generated droplets. Therefore, if oil droplet diam. does in fact influence insect control, then the selection of the appropriate irrigation and pesticide injection systems are critical for achieving the maximum performance from a pesticide.

The purpose of the current research was to evaluate the influence of main-line water velocity, injection direction, and sprinkler type on the control of fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) in whorl-stage field corn.

Materials and Methods

Lorsban 6 technical insecticide (chlorpyrifos) was evaluated against larvae of the FAW in whorl-stage field corn grown under two single tower center-pivot irrigation systems (0.6 ha each) in 1988 and 1989. Two low insecticide dosages (70 and 140 g/ha active ingredient; 12 and 25% of rates recommended by the Georgia Cooperative Extension Service) were selected to better separate parameter effects. Chemigation parameters evaluated were sprinkler type (impact, Wobbler, 360° Super Spray, and Rotator), main-line water velocity (2.7 and 0.9 m/s), and pesticide injection port orientation (upstream center and downstream center). Pivot "A" was equipped with two sprinkler types, 1) Nelson (Route 4, Box 169, Walla Walla, WA) 33AA impact sprinklers with nozzle orifice diam. between 3.57 and 5.55 mm, operating at 310 kPa, and 2) Senninger (6416 Old Winter Garden Rd, Orlando FL) Wobbler sprinklers with nozzle orifice diam. between 3.57 and 9.53 mm, operating at 138 kPa. Pivot "B" was also equipped with two sprinkler types, 1) Senninger 360° Super Spray sprinklers with course plates and nozzle orifice diam. between 3.57 and 9.53 mm for application at 138 kPa, and 2) a Nelson

33AA impact sprinkler package. In 1989, the impact sprinklers were replaced with Nelson Rotator R30 sprinklers with U4 plates and nozzle orifice diam. between 6.75 and 8.73 mm operating at 172 kPa. Two different interchangeable main-line injection port regions were utilized to achieve the desired main-line velocities at the injection port. For high main-line velocity, insecticides were injected into the center of a 6.4 cm diam. pipe with a water velocity of 2.7 m/s. For low main-line velocity, insecticides were injected into the center of a 10.8 cm diam. pipe with a water velocity of 0.9 m/s. A diaphragm injection pump, operating at 72 pulses/min, metered the oil-insecticide formulation into the water at 120 ml/min through a 6.4-mm diam. stainless steel tube. The insecticides were formulated in soybean oil and were delivered at a total volume of 4.9 liters/ha.

The area under each pivot was divided into quadrants. Treatment parameters in each quadrant consisted of a combination of one nozzle type and one insecticide rate. This arrangement provided four randomized, nonreplicated main plot treatment combinations in a 2 × 2 factorial split plot design. In each quadrant there were 20 plots, [2 rows (1.83 m) wide by 3.1 m long] with 1.5 m between plots. In these subplots there were 5 treatments with 4 replications in a randomized block design with a 2 × 2 factorial for main-line velocity and injection direction, plus an untreated check.

In the spring of 1988 and 1989, 'Pioneer 3365' dent field corn was planted four weeks apart on alternate row beds under each of the two center pivot systems to provide for two treatment dates (four tests were conducted during each year). Corn plants in each plot were infested with laboratory reared (Burton 1969) FAW neonate larvae at the rate of 12 to 17 per plant in 1988 and 5 to 12 per plant in 1989, which were allowed to reach 2nd-3rd instar before treatments were applied. Artificial infestation of the whorl was accomplished using a rotating larval dispenser mounted on a tractor in 1988 (Sumner and Gross 1990) and a modified manual unit (H.R.S., unpublished) in 1989.

Chemigation treatments were applied between 7:00 and 10:00 AM when the wind velocity was less then 8 km/h. To maintain treatment integrity, portable, metal-framed, fiberglass-covered crop shelters, 1.8 m wide × 3.6 m long, were used to cover 16 plots in each quadrant that were not to be treated during each application. Four passes of the pivot across each quadrant were required to produce all combinations of main-line velocity and injection port orientation. Since new plant growth originates in the whorl and the plant grows fast enough to provide new untreated whorls with 5 to 6 days, plots for the second treatment date (second planting) were not covered when treatments on the first date were applied. Insect control was evaluated 2-3 days after treatments were applied. Ten plants in 1988 and 15 in 1989 were randomly selected from each plot, excised, placed in plastic bags and taken to the laboratory for examination. The number of live and dead FAW larvae found on each plant was recorded. Artificial infestation, chemigation treatment, and treatment efficiency evaluation dates for the tests are given in Table 1.

Mean differences in the percentage of live FAW larvae found on the plants were analyzed by ANOVA and means and interactions separated by least significant differences (LSD) at $P = 0.05$ (SAS Institute, Inc., 1985). Arcsine transformations of the percentage of live larvae were used for statistical analysis.

RESULTS

Variations between and within seasons, the application of the treatments, and the number of larvae surviving in the untreated checks did not allow a comparison between years and application dates. Therefore, each application date and pivot evaluation test was analyzed separately. Arcsine transformations of percent live larvae were analyzed,

TABLE 1. ARTIFICIAL INFESTATION, INSECTICIDE TREATMENT, AND EVALUATION DATES FOR EACH PIVOT TEST.

Pivot	Test	Infested		Date	
		Date	Larvae/plant	Treated	Evaluated
A	1	4/26/88	12	4/29/88	5/4/88
B	1	4/29/88	12	5/9/88	5/11/88
A	2	5/6/88	17	5/16/88	5/18/88
B	2	5/16/88	16	5/23/88	5/25/88
A	1	4/27/89	12	5/3/89	5/5/89
B	1	5/3/89	6	5/9/89	5/10/89
A	2	5/12/89	7	5/18/89	5/19/89
B	2	5/22/89	5	5/30/89	5/31/89

and results were no different from percent live larvae. Data are presented as percent live FAW larvae in Table 2.

1988 test: Pivot A—There was a significant interaction between sprinkler type and main-line velocity for FAW larval control on May 4. The impact sprinkler provided significantly better FAW control than the Wobbler sprinkler (7.4 and 19.7% live larvae, respectively, LSD 11.5) at the high main-line velocity but no significant differences in the effect of nozzles were observed at the low main-line velocity. On May 18, FAW control was influenced by a significant interaction among sprinkler type, main-line velocity, and insecticide injection port orientation. With downstream insecticide injection, there were no significant differences in percent live FAW larvae between sprinklers or main-line velocities. With upstream insecticide injection, the Wobbler sprinkler provided better control than the impact sprinkler (13.1 and 40.2% live larvae, respectively, LSD = 13.2) at high main-line water velocities, while there were no significant differences in percent live larvae at low main-line water velocities. Chlorpyrifos injected upstream and applied from the Wobbler sprinkler was significantly more effective in reducing the percent of live FAW larvae when introduced into the high main-line water velocity than at low main-line water velocity (13.1 and 29.4% live larvae, respectively, LSD = 13.2).

Pivot B—On May 11 there was a significant interaction between chemical rate, sprinkler type, and main-line water velocity for FAW control. For the high chlorpyrifos rate (140 g/ha) there were no significant differences in percent live FAW larvae between main-line water velocity and sprinkler type. However, there was a significant difference in percent FAW survival between the untreated and the treated plots (58.8 and 7.6% live larvae, respectively, LSD = 14.0, data not shown in Table 2). At the low chlorpyrifos rate (70 g/ha) there was a significant interaction between sprinkler type and main-line water velocity for FAW control. Chlorpyrifos delivered from the impact sprinkler provided better FAW control than when applied from the Super Spray sprinkler (4.0 and 27.7% live larvae, respectively, LSD = 14.0) at the high main-line water velocity. The Super Spray sprinkler was numerically but not significantly superior to the impact sprinkler (11.3 and 21.1% live larvae, respectively, LSD = 14.0) at the low main-line water velocity. On May 25, chlorpyrifos injected upstream was significantly better than downstream injection (18.5% and 30.2% live larvae, respectively, LSD = 10.5, data not shown in Table 2). Additionally, there was a significant interaction for percent FAW larval survival between chemical rate and main-line water velocity. The high chlorpyrifos rate controlled FAW larvae better than the low rate (12.1 and 48.2% live larvae, respectively, LSD = 10.5) when applied at the low main-line water velocity, while there were no significant differences in larval survival at the high main-line water velocity. Chlorpyrifos applied at 70/g ha in the high main-line water velocity provided better FAW

TABLE 2. EFFECTS OF CHEMIGATION PARAMETERS ON THE CONTROL OF THE FALL ARMYWORM WITH CHLORPYRIFOS APPLIED BY CHEMIGATION. PERCENT LIVE LARVAE FOUND AFTER TREATMENT IN EIGHT TESTS.

Year, Pivot, Test Date	Parameter		% Live larvae			
			Water velocity			
	Sprinkler	Other[3]	High	Low	Check	LSD
1988, A May 4	Impact	—	7.4a[1]	7.9a *[2]	58.0a	11.5
	Wobbler	—	19.7b	12.2a *	78.5b	11.5
1988, A May 18	Impact	Upstream	40.2b	31.7a	40.0a	13.2
	Wobbler	Upstream	13.1a *	29.4a	28.4a	13.2
	Impact	Downstream	24.4a	30.0a	40.0a	13.2
	Wobbler	Downstream	17.1a	19.2a	28.4a	13.2
1988, B May 11	Impact	70 g/ha	4.0a *	21.1a *	70.0b	14.0
	Super Spray	70 g/ha	27.7b *	11.3a *	51.7a	14.0
	Impact	140 g/ha	7.3a	4.8a *	57.5a	14.0
	Super Spray	140 g/ha	8.1a	10.4a *	60.0a	14.0
1988, B May 25	Both[4]	70 g/ha	21.1a *	48.2b *	85.7b	17.1
	Both	140 g/ha	16.0a *	12.1a *	59.6a	17.2
1989, A May 5	Impact	70 g/ha	30.8a *	55.2a *	85.3a	21.4
	Wobbler	70 g/ha	59.8b	69.7a *	95.8a	21.4
	Impact	140 g/ha	40.2a	37.7a *	93.8a	21.4
	Wobbler	140 g/ha	23.3a *	52.8a *	83.4a	21.4
1989, A May 19	Both	—	20.7 *	35.7 *	83.6	8.8
1989, B May 10	Super Spray	70 g/ha	71.8b	61.5b	87.1a	20.8
	Rotator	70 g/ha	10.4a	23.8a *	69.7a	20.8
	Super Spray	140 g/ha	56.3b *	82.4b	88.7a	20.8
	Rotator	140 g/ha	14.6a	21.1a *	82.5a	20.8
1989, B May 31	Super Spray	—	33.1a *	67.7a *	89.2a	15.0
	Rotator	—	58.0b	68.8a *	88.0a	25.0

[1]Within any test, vertical means with letters in common are not significantly different (P = 0.05).
[2]* = significant difference between horizontal means (LSD test, P = 0.05).
[3]Pesticide injection port orientation - upstream or downstream - or rate of chlorpyrifos applied - 70 or 140 g/ha.
[4]Both - applies to the two sprinkler types used on the pivot.

control than when applied in the low main-line water velocity (21.1 and 48.2% live larvae, respectively, LSD = 10.5).

1989 tests: Pivot A—There was a significant interaction among sprinkler type, insecticide rate, and main-line water velocity for FAW control on May 5. Chlorpyrifos applied at 70 g/ha in a high main-line water velocity performed significantly better with the impact sprinkler than with the Wobbler sprinkler (30.8 and 59.8% live larvae, respectively, LSD = 21.4). At 70 g chlorpyrifos per ha and low main-line water velocity there was no significant difference in FAW control between the sprinklers. However, chlorpyrifos (70 g/ha) applied from the impact sprinkler gave significantly better FAW control when used with the high main-line water velocity. At 140 g chlorpyrifos per ha, FAW control was not influenced by sprinkler type at either main-line water velocity. However, chlorpyrifos (140 g/ha) applied from the Wobbler sprinkler provided significantly better FAW control when used with high main-line water velocity than with the low main-line water velocity (23.3 and 52.8% live larvae, respectively, LSD = 21.4). On May 9, chlorpyrifos applied in the high main-line water velocity significantly decreased FAW larval survival compared with the low main-line water velocity (20.7 and 35.7% live larvae, respectively, LSD = 8.8); otherwise there were no significant differences in FAW control among the chemigation parameters.

Pivot B—A significant interaction among sprinkler types, main-line water velocity, and insecticide rate influenced the levels of control of FAW larvae on May 10. Chlorpyrifos, when applied at 70 and 140 g/ha in both low and high main-line water velocities yielded significantly better control of FAW larvae when delivered from the rotator sprinkler than from the Super Spray sprinkler. Significantly better FAW control was achieved when chlorpyrifos (140 g/ha) was applied in a high main-line water velocity from the Super Spray sprinkler than from the Rotator sprinkler (56.3 and 82.4% live larvae, respectively, LSD = 14.7). On May 31, a significant interaction between sprinkler type and main-line water velocity influenced percent FAW larval control. Chlorpyrifos (140 g/ha) applied at the high main-line water velocity from the Super Spray sprinkler provided significantly better FAW control than when applied from the Rotator sprinkler (33.1 and 58.0% live larvae, respectively, LSD = 15.0). Chlorpyrifos control of FAW was not significantly influenced by sprinkler type when applied at the low main-line water velocity.

Discussion and Conclusions

Significant interactions among and between the chemigation parameters indicated that the effect of any particular parameter on insecticidal performance was conditioned by one or more of the other parameters. High main-line water velocity positively influenced sprinkler performance in most tests. FAW larval control with chlorpyrifos injected at high main-line water velocity was generally as good or better than when injected at low main-line water velocity, regardless of sprinkler type. This finding suggests that a main-line water velocity at or below 0.9 m/s probably does not generate oil-pesticide droplets small enough to obtain satisfactory, uniform distribution of the insecticide to sprinklers in some of the systems tested. At low main-line water velocities, larger droplets are generated by the lower shear between the flowing water and the injected oil-pesticide than at high main-line water velocities. Upstream injection of oil-pesticide into the main line resulted in better insect control than with downstream insecticide injection (18.5 and 30.2% live larvae, respectively, LSD = 10.5) in 1988 - Pivot B, date 2. Here again, improved insect control was obtained because smaller formulation droplets were generated by upstream insecticide injection than by downstream insecticide injection. An increase in main-line water velocity could probably be used to overcome the difference in droplet size and the resulting poor insect control found in downstream compared to upstream insecticide injection.

The combination of application parameters in these tests represents a wide range of conditions; however, with the variable results observed between tests, clear-cut evidence was not found to indicate that specific equipment combinations should be avoided when chemigating. The Super Spray sprinkler at low main-line water velocity resulted in the poorest FAW larval control while the impact sprinkler gave the best control. Formulation droplet size should be smaller with the impact sprinkler since it operates at high pressure through a high-shear small nozzle diameter. The impact sprinkler generally provided as good or better FAW larval control than the Wobbler or Super Spray sprinkler in these tests. The Rotator sprinkler performed as well as or better than the Super Spray sprinkler. Consistent and effective application uniformity of chemigated insecticides is influenced by proper selection of sprinkler type and main-line water velocity.

Chemigation at recommended insecticide rates has been successful with a large range of insecticide injection parameters and sprinkler types (Young 1986). Research designed to better understand chemigation parameters will ultimately result in the development of application methods, devices, and systems that will provide efficient control of FAW larvae and other pests at safe and effective application rates of pesticide. Formulation droplet size distribution is probably the key to understanding the advantages of specific chemigation equipment combinations that optimize pest control.

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LANGOSTA: A LEPIDOPTEROUS PEST COMPLEX ON SORGHUM AND MAIZE IN HONDURAS

HECTOR E. PORTILLO AND HENRY N. PITRE
Department of Entomology,
Mississippi Agricultural and Forestry Experiment Station,
Mississippi State University, Mississippi State, MS 39762, USA

DAN H. MECKENSTOCK
Department of Soil and Crop Science, Texas A&M University
College Station, TX 77843, USA

KEITH L. ANDREWS
Department of Plant Protection, Escuela Agrícola Panamericana,
Tegucigalpa, Honduras

ABSTRACT

A lepidopterous pest complex, collectively referred to as "langosta" by subsistence farmers, is an important constraint to sorghum and maize production in southern Honduras. The objectives of this study were to identify the insect species in the *langosta* complex, determine their population density and their relationships to crop and non-crop vegetation. Relative and destructive whole plant samples were taken on intercropped sorghum and maize from May to August in plots managed using farmer's technology and farmer's technology plus weed control in 1988 and 1989. Weed identity and density were recorded. *Spodoptera frugiperda* (J. E. Smith), *S. latifascia* (Walker), *Metaponpneumata rogenhoferi* (Moschler), and *Mocis latipes* (Guenee) larvae were identified as the principal insect species in the *langosta* complex.

The fall armyworm, *S. frugiperda*, was the predominant species collected throughout the study period. *Spodoptera latifascia* and *M. rogenhoferi* were present only early in the season. Populations of *S. frugiperda* on the crops were higher in plots without weeds; *Spodoptera latisfacia* and *M. rogenhoferi* populations did not appear to be influenced by non-crop vegetation in the treatment plots, but were influenced by vegetation adjacent to plots where they fed prior to planting. The grass looper, *M. latipes*, was present in mid-season and populations on sorghum and maize were higher in plots without weed control.

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Department of Entomology,
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RESUMEN

Un complejo de lepidopteros plaga, colectivamente conocido por agricultores de subsistencia como "langosta", es una limitante importante para la producción de sorgo y maíz en el sur de Honduras. Los objetivos de este estudio fueron identificar las especies de insectos en el complejo langosta, determinar su densidad poblacional y su relación con dichos cultivos, asi mismo como con la vegetación de malezas. Muestreos relativos y destructivos fueron tomados en plantas de sorgo y maíz intercalados de mayo a agosto durante 1988 y 1989. La identidad y densidad de las malezas fue registrada. Larvas de *Spodoptera frugiperda* (J. E. Smith), *S. latifascia* (Walker), *Metaponpneumata rogenhoferi* (Moschler) y *Mocis latipes* (Guenee) fueron identificadas como las principales especies. El gusano cogollero, *S. frugiperda*, fue la especie mas común a traves del estudio; por otro lado, *S. latifascia* y *M. rogenhoferi* estuvieron presentes solamente al inicio de la temporada de cultivo. Las poblaciones de *S. frugiperda* en los cultivos fueron mas altas en parcelas sin malezas; *S. latifascia* y *M. rogenhoferi* aparentemente no fueron influenciados por la vegetación de malezas en las parcelas en estudio, pero fueron influenciados por la vegetación de malezas en areas adjacentes, donde se alimentaron antes de la siembra de los cultivos. El gusano medidor, *M. latipes*, estuvo presente a mediados de la temporada de cultivo y las poblaciones de este en sorgo y maiz fueron mas altas en parcelas sin control de malezas.

Maize, *Zea mays* L., and sorghum, *Sorghum bicolor* (L.) Moench, are the first and third most important basic grains produced in Honduras (Secretaría de Planificación 1987). Ninety percent of the sorghum acreage in southern Honduras is intercropped with maize because of adverse environmental and agronomic conditions which are best characterized by erratic precipitation, high temperature, and low soil fertility (Meckenstock 1988, Secretaría de Recursos Naturales 1980). Therefore, if the maize crop is lost to drought, farmers substitute sorghum for maize to feed their animals and family (DeWalt & DeWalt 1987).

Insect pests are an important constraint to sorghum and maize production in southern Honduras (DeWalt & DeWalt 1982). Research has shown that different types of larvae damage sorghum and maize, but peasant farmers in southern Honduras do not distinguish between species of larvae and tend to group them as one. They refer to this group of larvae as the "langosta", a term used to describe the extensive feeding damage associated with locust populations. Langosta in spanish means locust.

The langosta was reported by DeWalt & DeWalt (1982) to be a major insect pest around Pespire, southern Honduras. Pitre (1988) reported the extensive damage caused by several insect larvae to sorghum and maize during the early growing season, and identified the langosta as a complex of noctuids including *S. frugiperda*, (J. E. Smith) (fall armyworm), *Metaponpneumata rogenhoferi* (Moschler), *Spodoptera latifascia* (Walker), and *Mocis latipes* (Guenee). Based on observations, he suggested a close relationship existed between the species in the complex and non-crop vegetation present in infested fields.

It is widely stated (*e.g.*, Altieri 1980) that in most agricultural systems, lower herbivore populations are observed when intercropping practices are used or when crops are intermingled with weeds. However, in southern Honduras, seedling sorghum and maize can be destroyed by the *langosta* which also infests non-crop vegetation and then migrates to field crops (Pitre 1988). The agro-ecosystems in this area vary with particular differences in soil, slope, rainfall pattern, and presence of non-crop vegetation, all of which may contribute to development of insect populations in an area (Pitre 1988). The objective of this study was to collect information on the population dynamics of the components

of this lepidopterous pest complex on intercropped sorghum and maize and non-crop vegetation in southern Honduras.

MATERIALS AND METHODS

1988 STUDY

This study was conducted at two locations in the Department of Valle which is situated in southern Honduras. The locations were El Conchal, which is on the Pacific coastal plain (ca. sea level) near the border with El Salvador, and La Coyota which is located nearby in the foothills at 52 meters above sea level (Fig. 1). The two areas were separated by about 16 km with coordinates ca. 13° 31′ N, 87° 43′ W. The fields on the plains have a higher crop production technology level (land prepared with tractors or ox-pulled plows, some use of fertilizers, and insecticides applied at planting and/or on foliage) because land is more suitable for agriculture and therefore generates more income for insecticide and herbicide use and other agricultural practices. In the hills, fields predominantly have steep slopes and rocky soils and in most instances the farmers' economic means do not permit the use of tractors or chemicals for crop protection (Pitre 1988). Use of fertilizer is limited. Native landrace sorghum and maize varieties are grown at both locations.

Results reported herein were collected on-farm and were part of a larger study which examined the influence of intercropping practices on insect pest populations. Three farms were selected at each location. Fields, 1200 m², were planted during late May and early June. Landrace sorghum and maize populations commonly grown by subsistence farmers were used on all farms. The intercropping system was sorghum and maize planted simultaneously in alternate hills on 70-90 cm rows. Two treatments were established at each farm, one representing the farmer's technology and the other with the farmer's technology plus weed control. Plot size of each treatment was 600 m². Atrazine, 1.5 kg/ha (80 g ai/kg), was applied preemergence in the weed free treatment and then

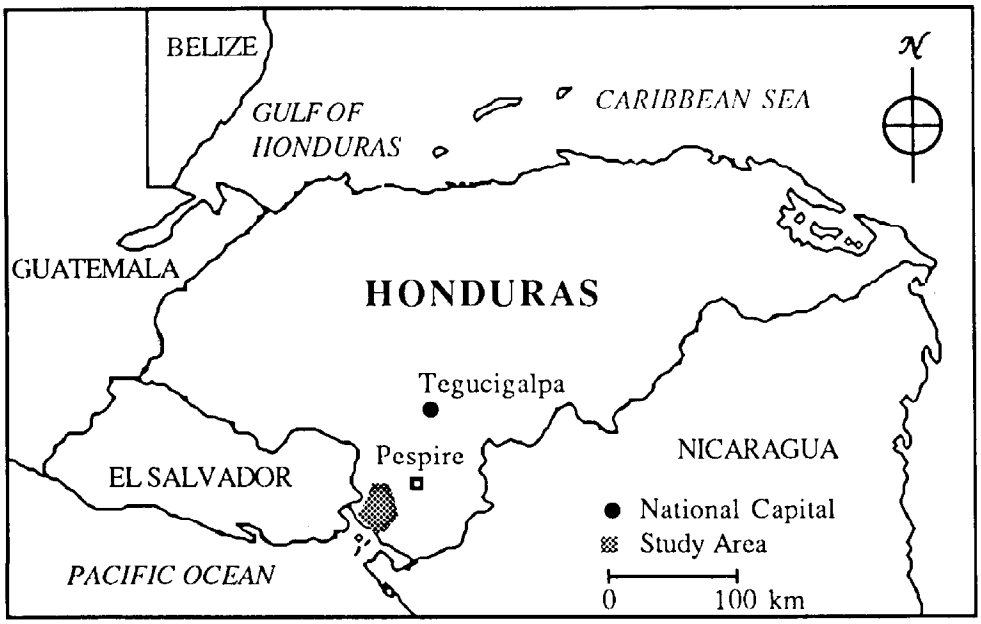

Fig. 1. Research sites in southern Honduras.

followed up as needed with manual weeding to keep this plot free of weeds. Insecticide applications were made on both treatments when considered necessary (plants receiving extensive defoliation) by the farmer. The insecticide used most often in this area is Lannate (methomyl) at rates from 0.25 to 0.5 kg a.i./hectare depending upon pest infestation and plant damage.

Non-destructive plant samples (plants searched with minimum damage) were taken from the center area (5 × 5 m) of each treatment. Ten sorghum hills (ca. 8 plants/hill) and 15 maize hills (ca. 3 plants/hill) were sampled every three days during seedling and early whorl stages, and weekly or bi-weekly during mid-whorl stages to maize maturity. Whole plants in each hill were examined and the number and identity of the lepidopterous pests present were recorded; the same hills were examined on each sampling date. Although whole plant samples require more time, the information obtained is more accurate than sampling using many other procedures.

Non-crop vegetation (weeds) in the fields was sampled every two weeks. Four stations of 0.25 m^2 each were set up at predetermined locations in each treatment at planting. Data collected included visual estimation of percentage of ground area covered by weeds, weed diversity, and presence or absence of larvae feeding on the weeds. Weeds were collected and sent to the Panamerican Agricultural School at El Zamorano, Honduras for identification.

1989 Study

The same locations, planting system, and crop varieties used in 1988 were used in 1989. Because of extreme differences in planting dates, the 1989 study used only two of the three farms established in both the hills and the plains. Treatments were established as in 1988; however, plot size was 400 m^2 for a net total area of 800 m^2 on each farm. Herbicide use, manual weed control, and insecticide application was as discussed for the previous year. Sample size consisted of observations on 15 sorghum plants and 25 maize plants selected at random in each plot (ca. 10% of the plant population was sampled throughout the season). Destructive plant sampling methods as described by Castro et al. (1989) were used. Sampling frequency was as described for the 1988 study. Fewer plants were sampled in 1989 than in 1988 because the whole plant sampling technique provided more accurate information on the total insect infestation (larvae of all sizes) on the crops. The identity and absolute number of the lepidopterous pests present were recorded. The same data types were recorded on the non-crop vegetation except sampling areas were selected at random; predetermined locations were not used.

The chi-square test of homogeneity was performed on data for both years over the proportions (pooled data for the two treatments and crops for each location, Fig. 4) of *S. frugiperda*, *S. latifascia*, *M. rogenhoferi* and *M. latipes* encountered during early, mid-and late season (Daniel 1990).

Results and Discussion

Spring rains triggered the onset of the lepidopterous complex on both maize and sorghum. The fall armyworm was the predominant insect species in fields in the foothills and plains (Figs. 2-4). Although abundance of *S. frugiperda* varied between locations and years, its predominance was not altered, except when considering seasonal occurrence, where at some locations the other species were more abundant (Fig. 5). The chi-square test for homogeneity indicated that the proportions of these four lepidopterous species occurring during early, mid- and late season were not significantly heterogeneous at any one location or year. Because of the size of the contingency table for this test (3 × 4), interpretations of these results do not necessarily mean that all proportions were

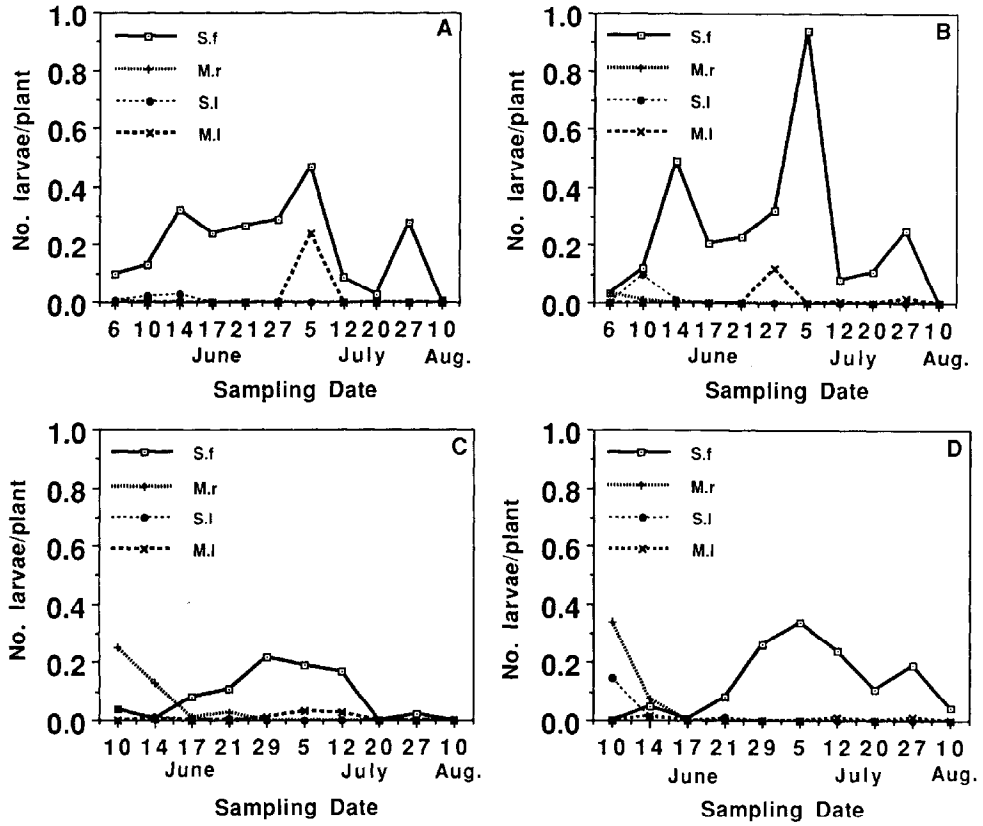

Fig. 2. Population densities of a lepidopterous complex on maize in southern Honduras, 1988. A) plains, plots with farmer's technology, B) plains, plots with farmer's technology and weed control, C) hills, plots with farmer's technology, and D) hills, plots with farmer's technology and weed control. S.f = *Spodoptera frugiperda*, M.r = *Metaponpneumata rogenhoferi*, S.1 = *Spodoptera latifascia*, M.1 *Mocis latipes*.

homogeneous throughout the table. And at specific times in the season, especially when the proportions of *S. frugiperda* were much higher than that of the other species, the proportions may not be homogeneous (Fig. 5) (Daniel 1990).

In 1988, the abundance of *S. frugiperda* was greatest in fields on the plains (Figs. 2, 3), whereas in 1989 this species was more abundant in the hills (Fig. 4). In both years, *S. frugiperda* showed a preference for maize over sorghum regardless of location; ca. 70% of the larvae was recorded on maize. This is consistent with other reports (Castro et al. 1989, Van Huis 1981). The *S. frugiperda* population density peaked at mid-season (late June to early July) before initiating a gradual decline. Population density for this species was as high as 0.9 larvae/maize plant in 1988 (Fig. 2B) and 0.7 larvae/maize plant in 1989 (Fig. 4D). *Spodoptera frugiperda* was also observed acting as a cutworm, causing considerable damage to plant stands in both years. However, the principal feeding damage caused by this pest is to whorl foliage.

Weeds influenced densities of *S. frugiperda* and *M. latipes*. In general, when weed infestation was high (pooled average of 60% of ground covered in 1988 and 35% in 1989) the *S. frugiperda* population was lower on sorghum and maize than when weed infestation was low (pooled average of 20% of ground covered in 1988 and 10% in 1989), but the *M. latipes* population was higher when weed infestation was high (Figs. 2-4). Both *S. frugiperda* and *M. latipes* were observed feeding on the predominant weed grass

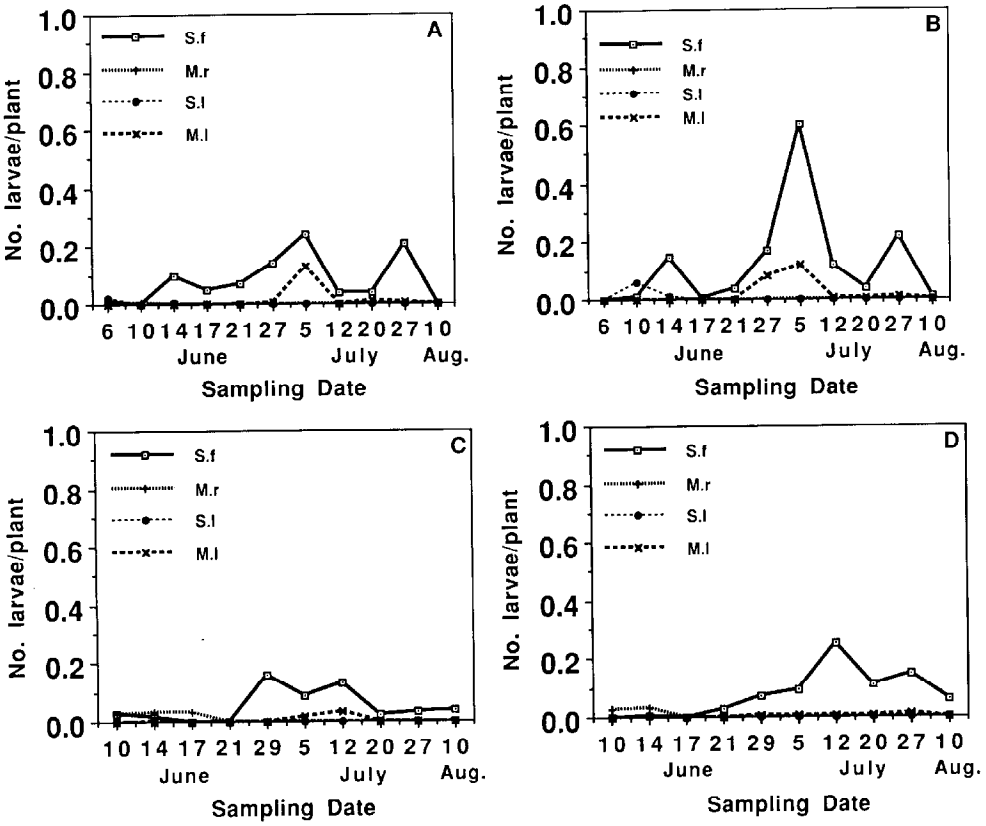

Fig. 3. Population densities of a lepidopterous complex on sorghum in southern Honduras, 1988. A) plains, plots with farmer's technology, B) plains, plots with farmer's technology and weed control, C) hills, plots with farmer's technology, and D) hills, plots with farmer's technology and weed control. S.f = *Spodoptera frugiperda*, M.r = *Metaponpnemata rogenhoferi*, S.1 = *Spodoptera latifascia*, M.1 = *Mocis latipes*.

Ixophorus unisetus (Pres L.) Schlecht on the plains. This grass was not present in the hills where legumes were more commonly observed both in and outside production fields. *Ixophorus unisetus* appeared to be as suitable as maize for *S. frugiperda* larval feeding. Thus the larvae were distributed over the non-crop and crop vegetation resulting in lower infestation on the crops. Studies on the suitability of this grass species and other non-crop vegetation to *S. frugiperda* and other lepidopterous pests in the langosta complex are needed to elucidate the role of these plants in the dynamics of the pest species.

First instar larvae of *M. latipes* were observed feeding on the weed grasses *I. unisetus* and *Echinocloa colonum* (L.) Link, (both were present on the plains but only *E. colonum* was observed in the hills). As these larvae developed and their extensive and aggressive feeding habits exhausted this preferred habitat, later instars migrated to surrounding sorghum and maize. Thus, somewhat higher populations of *M. latipes* were observed on the crops in treatments with highest densities of these weed grasses (Figs. 2A, C; Fig. 3C; Fig. 4A). Dean et al. (1985) reported that *M. latipes* moths preferred certain weed grasses over maize for oviposition and that early instar larvae develop to later instars on these grasses during the time that they were building to higher populations. This would explain the somewhat lower infestations observed in the treatments with low weed infestation (Figs. 2B, D; Fig 3D; Fig 4B). *Mocis latipes* larvae

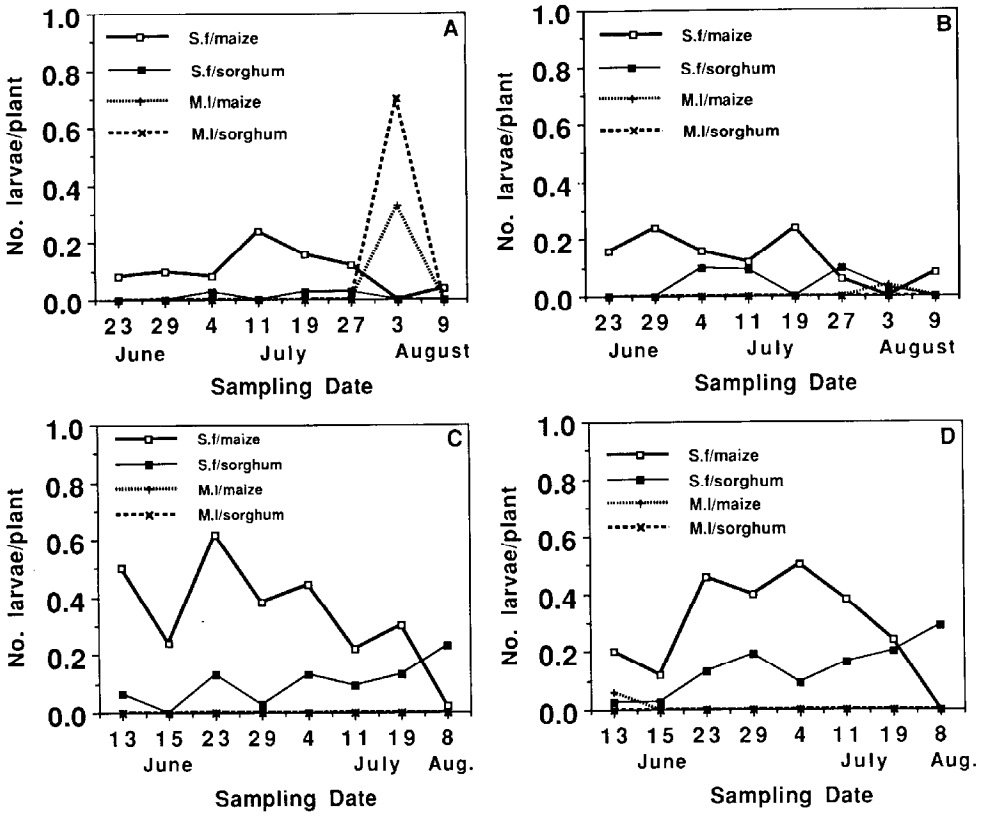

Fig. 4. Population densities of a lepidopterous complex on sorghum and maize in southern Honduras, 1989. A) plains, plots with farmer's technology, B) plains, plots with farmer's technology and weed control, C) hills, plots with farmer's technology, and D) hills, plots with farmer's technology and weed control. S.f = *Spodoptera frugiperda*, M.l = *Mocis latipes*.

were recorded in low numbers in the hills during early season (first three weeks of June; Figs. 2C, D; 4C), but populations in both locations peaked during early July to early August, at which time maize plants had silks emerging or were in the blister stage (Figs. 2A, B, C; Figs. 3A, B, C; Fig. 4A). Their density increased to a high of 0.2 larvae/plant in 1988 (Fig. 2A) and to 0.7 larvae/plant in 1989 (Fig. 4A). Although this species represented 70% of the insect complex on sorghum and maize late in the season on the plains during 1989 (Fig. 5C), it contributed to no more than 15% in any other location or year (Figs. 5A, B, D). Sorghum and maize were equally infested by this species. The feeding behavior of *M. latipes* is characterized by consumption of the leaf blade leaving only the midrib and this damage is similar to that of locust. Farmers usually apply insecticides to reduce infestations of this pest and prevent yield loss.

The other two species in the complex, *M. rogenhoferi* and *S. latifascia*, were observed on sorghum and maize only during the early season in 1988 (late May to mid-June) (Figs. 2, 3). Populations of these two species were higher in the hills than on the plains and peaked in early June. Their densities increased to 0.3 and 0.2 larvae/plant, respectively before disappearing by late June (Fig. 2D). These two species represented the highest initial percentage (58% and 14%, respectively) of the complex on sorghum and maize at the onset of the season in the hills. Of the larvae collected, on average 80% of *M. rogenhoferi* and 70% of *S. latifascia* were recorded on indigenous maize which was strongly preferred to exotic sorghum. An attempt was made to rear these larvae in the

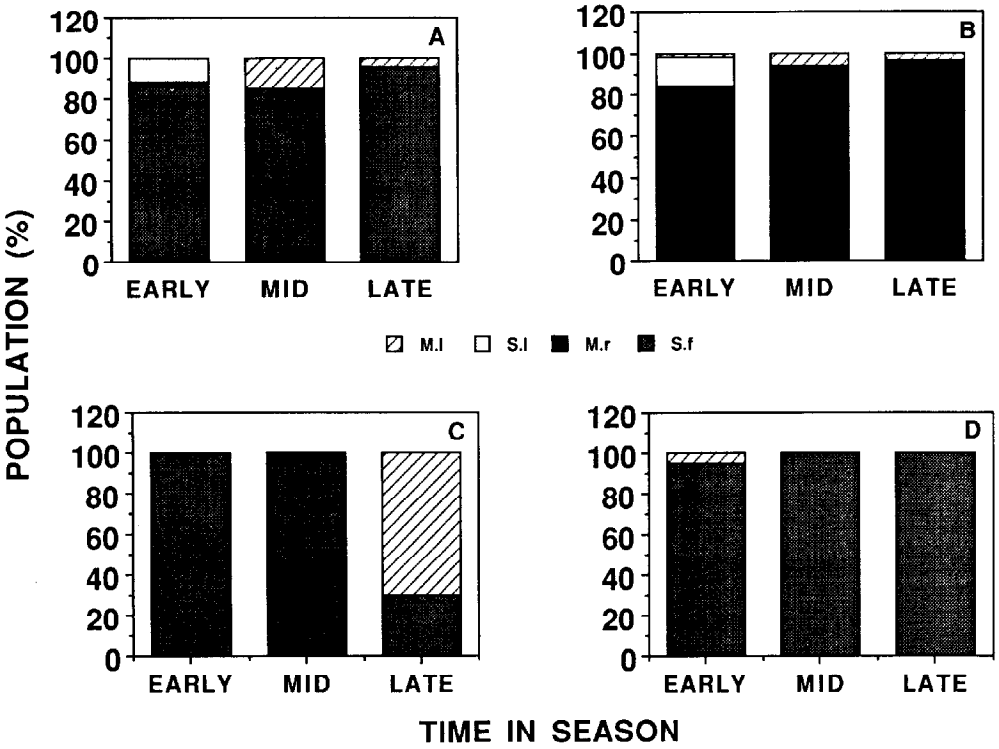

Fig. 5. Percentage of species composition of a lepidopterous complex in southern Honduras. A) plains, pooled data, 1988, B) hills, pooled data, 1988, C) plains, pooled data, 1989, D) hills, pooled data, 1989. S.f = *Spodoptera frugiperda*, M.r = *Metaponpneumata rogenhoferi*, S.1 = *Spodoptera latifascia*, M.1 = *Mocis latipes*.

laboratory but adults failed to emerge from pupae, suggesting that maize and sorghum may be sink habitats. A sink habitat is "an area where (environmental) factors are not sufficient for a species to carry out its life history" (Pulliam 1988). The degree of acceptability of these plants as hosts for these pests should be determined.

Although *M. rogenhoferi* and *S. latifascia* were not recorded in treatments in 1989, they were observed feeding in large numbers on non-crop vegetation adjacent to fields prior to planting on the plains and in lower densities on some sorghum and maize seedlings planted in fields during late April and early May in the hills. The non-crop vegetation was the earliest available host plants. The main environmental difference during the two year study was that the rains initiated first in the hills in 1988, whereas the opposite was true for 1989. It is plausible that the source habitat of *M. rogenhoferi* and *S. latifascia* exists in the foothills or further inland. A source habitat is "the range of values of environmental factors that are necessary and sufficient to allow a species to carry out its life history" (Pulliam 1988). Pitre (1988) observed fall armyworm larvae in all stages in grasses growing in and along irrigation ditches on the plains in southern Honduras during the dry season. Related species may also survive in this habitat during periods when suitable host plants are not present in dry areas before the rainy season in this region. Accordingly, when these colonists left their dry season niche in the hills at the onset of the rains in 1989, there was already sufficient non-crop vegetation to sustain the population in the coastal plains; whereas in 1988, the colonists arrived on the plains when green vegetation was scare and were forced to migrate to surrounding marginal habitats like maize and sorghum once preferred non-crop vegetation had been ravaged.

Preliminary laboratory feeding preference studies conducted with *M. rogenhoferi* and *S. latifascia*, which were collected on non-crop vegetation adjacent to fields in 1989, indicate that these species can develop on *Thrianthema portulacastrum* L. (Aizoacea), *Cassia leiophila* Vogel (Leguminosae), *Ipomoea* sp. (Convolvulacea), *Melampodium divaricatum* (Rich. ex pers) DC (Compositae) and *Amaranthus spinosus* L. (Amaranthaceae), (H. Portillo, unpublished data). These are five of the most common broad leaf weed species found in fields in southern Honduras. *Spodoptera latifascia* did not develop as well on mature sorghum and maize leaves as on some of the weeds. The feeding behavior of *M. rogenhoferi* and *S. latifascia* is very similar. They both feed on young outer plant leaves, but do not move into the whorl. Seedlings are cut at the growing point and die (deadheart). Plant stands will be dramatically reduced if no insecticide is used. Their most damage is usually inflicted in the hills where poor farmers can not purchase insecticides.

Fall Armyworm and the Langosta Challenge

The occurrence of the lepidopterous pest complex (langosta) on sorghum and maize creates the biological illusion that the component species coexist conjointly. Actually, the complex is the product of a fine-grained mosaic of different micro-habitats, each supporting a well-adapted successful species. Except for *S. frugiperda*, sorghum and maize apparently serve as a sink habitat where the net lepidopterous population decreases, and survival and population increase depend on nearby non-crop source habitats. Source and sink habitats serving to complicate ecology have been discussed by Lewin (1989).

Because of the geographical and biological diversity involved by the complex, controlling the langosta is a formidable challenge. Although many farmers spray their crops after the langosta has arrived, this has no effect on the core population of at least two of the species, nor does it reduce their subsequent generations since these species are unable to complete or appear to have difficulty in completing their life cycle on maize and sorghum.

More effective control measures would include management of non-crop vegetation or source habitats. Monitoring source habitats and synchronizing planting dates to follow migration would be a low cost control measure that could be employed by subsistence farmers. Likewise, destruction of relatively small source habitats before planting could lead to local population extinction of some pest species. These tactics are within the means of resource poor farmers since they primarily involve investment of their own labor. Insecticide applications could contain the insect pest in the source habitat but it is unlikely that subsistence farmers will be willing to invest in spraying weeds.

The diversity of the lepidopterous pest complex ensures that sustaining adequate control of the langosta will depend on an array of integrated pest management practices. Because manipulation of a niche may affect one species adversely only to benefit another, as in the case with weed control which reduced the population of *M. latipes* but increased population size of *S. frugiperda*, a greater understanding of the ecology behind each species is required before a technological control package can be developed. Other areas of additional needed research include host oviposition preference of moths, additional studies on feeding preference including young and old plant tissues, and parasitization of larvae.

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GAMMA IRRADIATION AS A QUARANTINE TREATMENT FOR CARAMBOLAS INFESTED WITH CARIBBEAN FRUIT FLIES

WALTER P. GOULD AND DONALD L. VON WINDEGUTH
Subtropical Horticulture Research Station
Agricultural Research Service
U.S. Department of Agriculture
13601 Old Cutler Road
Miami, Florida 33158

ABSTRACT

Carambolas infested with the Caribbean fruit fly *Anastrepha suspensa* (Loew), eggs and larvae were exposed to ionizing gamma radiation. Probit 9 was estimated to be 22.95 Gy (95% fiducial limits 16.68 Gy - 49.73 Gy). Over 100,000 immature *A. suspensa* infesting carambolas were treated at 50 Gy with no adult survivors. This dose did not cause any observable damage to the fruit. The 50 Gy dose satisfies quarantine requirements for treatment of fruits exposed from fruit fly infested areas.

RESUMEN

Carambolas infestadas con huevos y larvas de la mosca del Caribe, *Anastrepha suspensa* (Loew), fueron expuestas a radiaciones ionizantes. El probit 9 fue estimado a 22.95 Gy (Limite de confianza del 95 %, 16.68 Gy - 49.73 Gy). Mas de 100,000 estados inmaduros de *Anastrepha suspensa* infestando carambolas fueron tratadas a 50 Gy sin obtener adultos sobrevivientes. Esta dosis no causó daños detectables a la fruta. La dosis de 50 Gy satisface los requerimientos de cuarentena para el tratamiento de frutas exportadas de areas infestadas con moscas de fruta.

The carambola, *Averrhoa carambola* L., has been grown in Florida since the late 1880's (Reasoner Brothers 1887). It has only recently achieved commercial status in this state (Campbell 1987). Swanson & Baranowski (1972) reported that carambolas were a host of the Caribbean fruit fly *Anastrepha suspensa* (Loew). Howard & Kenney (1987) reported that carambolas were infested when exposed to laboratory-reared, gravid females in an outdoor infestation cage. Because reports have shown that carambola fruit can be infested with Caribbean fruit fly, quarantine treatments must be developed if it is to be exported to countries or states which impose quarantine restrictions on Caribbean fruit fly infestable commodities. Ionizing radiation is one alternative method of quarantine treatment under investigation at our facility and has been found to provide an acceptable quarantine treatment for grapefruit and mangos infested with eggs and larvae (von Windeguth 1986, 1987). Barring a phytotoxic response of the carambola, irradiation may also be of use as a quarantine treatment for this fruit.

MATERIALS AND METHODS

Commercially harvested carambolas were obtained from J. R. Brooks & Son, a Homestead, Florida, packing house. In the early tests, cultivars used were 'Arkin', 'Star King', and 'Golden Star'. In the later "confirmatory" test, only 'Arkin', which is the main commercial variety, was used.

Fruit were infested for 3 to 5 days (depending on the time of year; the longer period in the cooler months) in an outdoor infestation cage containing approximately 100,000

adult Caribbean fruit flies, half of which were gravid ovipositing females. After removal from the infestation cage, fruit were either irradiated immediately (to assure that some of the immature stages were unhatched eggs), or held for 4 days for larval maturation (to assure the treatment of mature 3rd instar larvae) and then irradiated.

Irradiations were performed in either a Gammacell 220^{R} irradiator (Atomic Energy of Canada Limited [AECL]) containing 26,060 curies of Cobalt^{60} (Jan 1983), or a Gammarad GR12^{R} (U.S. Nuclear) containing 4,500 curies of Cobalt^{60} (Dec 1968). The measured dose rate at the center of the Gammacell chamber during the time of this study was from 170 to 145 Gray (Gy) per minute; the dose rate of the Gammarad 4.1 to 3.5 Gy per minute, depending on the date on which the irradiation was performed. Irradiation at doses less than 5 Gy were done in the Gammarad; those of 5 Gy and above in the Gammacell. Because of the small capacity of the chambers (20.3 high x 15.5 cm diameter), only 6 to 16 fruit (depending on size) could be irradiated at a time. After irradiation, the treated fruit were placed in plastic, open-mesh bottomed nursery plant trays (5 x 25 x 50 cm). The trays were placed on racks in screened, fruit holding towers. Each tower was capable of holding about 500 carambolas. Larvae that survived the treatment crawled out of the fruit and fell through a funnel located in the base of the tower into a sand filled box where they pupated. Because of the large amount of liquid in the carambolas and the speed of fruit degradation at 24°C, the sand had to be sifted and larvae and pupae removed at least every other day to prevent the larvae from drowning in the juice. Recovered pupae were held under optimum conditions (in moist vermiculite at 24°C) for adult emergence. With the exception of irradiation, the control fruit were treated in the same manner. Of any given lot of fruit, approximately 1/5 were used as a control and 4/5 were treated. The number of insects treated was estimated from the mean number of pupae per fruit in the control times the number of fruit irradiated.

Dose mortality curves for adult emergence were calculated by probit analysis using SAS (SAS Institute 1988) using the log transformation on radiation dose (Grays). Natural adult mortality was calculated by combining insect emergence rates from the controls of each test and calculating the mean emergence which was 61%, thus 39 out of each 100 pupae failed to complete eclosion. Equations from Finney (1971) were used to estimate Probit 9 (99.9968% mortality) and determine 95% fiducial limits.

The confirmatory test consisted of 18 separate tests performed over a period of several months. Treatment and post treatment holding procedures were as outlined above.

To determine if there were any potential phytotoxic effects of the radiation treatment, groups of 100 fresh, unrefrigerated fruit were irradiated at doses of 50, 100, 200, 500, 1000, and 1500 Gy and held at room temperature (24°C) for up to 12 days following treatment. Fruit were evaluated for an increase in normal rot or decay as well as visible defects attributable to treatment.

Results and Discussion

Evaluation of the efficacy of a commodity treatment involving ionizing radiation is based on prevention of adult emergence. This differs from those using heat, cold, or fumigation in that these treatments generally kill the stage of the insect treated in situ and efficacy of the treatment is based on prevention of larval pupation (Baker 1939). With irradiation, some mortality will occur at the stage treated but many larvae will crawl out and pupate; therefore, the actual efficacy of the treatment must be based on adult emergence.

Table 1 presents data on insect mortality following treatment. Mortality of immatures was calculated from the actual recovery of pupae formed compared to the number projected to have been present, based on the control population.

TABLE 1. EFFECTS OF IONIZING RADIATION ON MORTALITY OF IMMATURE AND ADULT CARIBBEAN FRUIT FLIES WHEN TREATED AS IMMATURES INFESTING CARAMBOLAS.

Irradiation Dose (Grays)	No. insects treated	Insects killed		% Mortality	
		Immatures	Adults	Immatures	Adults
1.0	1119	68	607	6.1	54.2
2.5	1119	0	491	—	43.9
5.0	1119	204	678	18.2	60.6
7.5	1119	419	999	37.4	89.3
10.0	6233	618	6076	9.9	99.5
12.5	1119	416	1112	37.2	99.4
15.0	1119	197	1115	17.6	99.6
20.0	1119	182	1119	16.3	100.0
25.0	10373	3120	10370	30.1	99.9
50.0	6423	84	6423	1.3	100.0
75.0	5114	873	5114	17.1	100.0
100.0	5304	2320	5304	43.7	100.0
150.0	5304	3680	5304	69.4	100.0
175.0	337	321	337	95.3	100.0
200.0	337	251	337	74.5	100.0
225.0	337	320	337	95.0	100.0
250.0	337	296	337	87.8	100.0

Probit analysis of the data using SAS gave the following regression parameters: intercept = 0.277 (S.E. 1.1106), slope = 6.410 (S.E. 1.1921), LD-50 = 5.46 Gy, 95% fiducial limits 4.22 Gy and 6.28 Gy, LD-95 = 9.85 Gy, 95% fiducial limits 8.91 Gy and 11.38 Gy. Probit 9 (99.9968% mortality) was estimated to be 22.95 Gy with lower and upper 95% fiducial limits of 16.68 Gy and 49.73 Gy, respectively.

The upper fiducial limit for Probit 9, rounded up to the next highest whole number (50 Gy) was used as the dose level for a large scale (confirmatory) test. We treated in excess of 100,000 immature Caribbean fruit flies infesting carambolas and recovered no adults; therefore, 50 Gy provides an acceptable quarantine treatment. It should be understood that the 50 Gy radiation dose must be delivered to the innermost, least accessible location in the load when the carambolas are irradiated in bulk, as they would be in a commercial operation. This could require a dose as high as 200 Gy or more be applied to the outermost fruit in order to assure a dose of 50 Gy to the innerpart of the load. Grapefruit required 150 Gy and mango 75 Gy to achieve Probit 9 (von Windeguth 1986, 1987). Carambolas are smaller and the core distance is smaller requiring less outside dose to reach the core of the fruit.

Phytotoxicity tests at doses ranging from 50 to 1500 Gy indicated that no observable damage occurred at levels between 50 and 500 Gy when 'Arkin' carambolas were irradiated at 25°C and then held for 9 days at the same temperature. At doses above 500 Gy there was some darkening of the outermost area of the longitudinal ribs. It has been reported that some other cultivars of carambola are more susceptable to radiation damage than the 'Arkin' (Abd. S. Rahman, MARDI, Malaysia, personal communication).

More tests are needed under actual commercial conditions involving normal transport and storage practices before approval can be made; however, the results of our laboratory testing show that irradiation seems to be promising as a quarantine treatment for carambolas.

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SUGARCANE RESISTANCE TO STALKBORERS (LEPIDOPTERA:PYRALIDAE) IN SOUTH TEXAS

R. S. PFANNENSTIEL[1] AND R. L. MEAGHER, JR.
Texas Agricultural Experiment Station
2415 East Highway 83
Weslaco, Texas 78596

ABSTRACT

Evaluation of 5 commercial sugarcane clones (cultivars) and 54 noncommercial clones which are part of the Texas A&M University sugarcane breeding program indicated that there were significant differences among clones to injury by the Mexican rice borer, *Eoreuma loftini* (Dyar). The commercial clone CP 70-321 was among the most resistant clones in all tests. However, the clones TCP 83-3196 and TCP 83-3180 were significantly less injured than CP 70-321, and 7 other clones exhibited levels of resistance similar to CP 70-321. *Eoreuma loftini* injury levels averaged 29.4% bored internodes; the sugarcane borer, *Diatraea saccharalis* (F.) population levels were low in both years causing less than 1.0% bored internode injury to sugarcane.

RESUMEN

Se evaluaron 5 cultivares comerciales y 54 no comerciales de caña de azucar, los cuales hacen parte del programa de mejoramiento de la Universidad de Texas A&M. Se reportan diferencias significativas entre los cultivares a el daño del barrenador mexicano del arroz *Eoruma loftini* (Dyar). El cultivar comercial CP 70-321 fue el mas resistente en todas las pruebas. Sinembargo, los cultivares TCP 83-3196 y TCP 83-3180 tuvieron un daño significativamente menor que CP 70-321 y otros 7 cultivares los cuales

[1]Current address: Department of Entomology, University of Kentucky, Lexington, KY 40546-0091.

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mostraron resistencia similar a CP 70-321. Los niveles de daño de *Eoreuma loftini* dieron un promedio de 29.4 % de entrenudos barrenados; los niveles de poblacion del barrenador de la caña *Diatraea saccharalis* (F.) fueron bajos en ambos años causando menos del 10% de dano a los entrenudos.

Stalkboring pyralids have been the most serious insect pests of the sugarcane (interspecific hybrids of *Saccharum*) industry in the Lower Rio Grande Valley (LRGV), Texas, since its inception in 1972. During the 1970's, the sugarcane borer, *Diatraea saccharalis* (F.), was the primary pest (Fuchs et al. 1973), until establishment of the braconid parasitoid *Cotesia flavipes* (Cameron) (Fuchs et al. 1979) brought about biological control.

The Mexican rice borer, *Eoreuma loftini* (Dyar), an immigrant from Mexico, was first detected in the LRGV in 1980 (Johnson 1981) and has replaced *D. saccharalis* as the primary pest. Insecticidal control has been inconsistent and generally unsatisfactory with less than 75% injury reduction using either ground or aerial applications of labelled insecticides at recommended rates (Johnson 1985, Pfannenstiel et al. 1990a, b). The lack of success with insecticidal control, classical biological control (Browning & Melton 1987, Hawkins et al. 1987, Smith et al. 1987), or entomophagous nematodes (Pfannenstiel & Browning 1989) have led to increased emphasis on plant resistance.

Plant resistance has been an important component of an IPM program against *D. saccharalis* on sugarcane in Louisiana for many years (Bessin et al. 1990, Hensley et al. 1977, Mathes & Ingram 1942). Plant resistance to *D. saccharalis* has been associated with increased yields even when insecticidal control was effective and economical (Hensley & Long 1969). As part of an IPM program where insecticides are less effective, as with *E. loftini*, plant resistance can be even more important. However, plant resistance has not been pursued in depth in sugarcane relative to *E. loftini*, and differential susceptibility to *E. loftini* among clones has been detected only recently (Ring & Browning 1990). Identification of resistant clones and the subsequent incorporation of resistance into commercial clones (cultivars) may reduce the effects of insects on sugarcane yields.

Sugarcane clone resistance to stalkborers may be classified into 4 categories: 1) unattractiveness of the host-plant to the adults for oviposition, 2) host-plant characters unfavorable for entry of the larvae into the plant, 3) adverse effects of the host plant to larval development and survival, and 4) the ability of the host-plant to yield in spite of a high infestation (Mathes & Charpentier 1969). Seasonal injury differences among clones (bored internodes) under field conditions may be due to resistance to stalk entry by early larval instars (Bessin et al. 1990), differential selection of clones for oviposition by adults, or some aspects of antibiosis (larval survival).

We examined the injury by *E. loftini* and *D. saccharalis* to 5 commercial sugarcane clones (cultivars) and 54 noncommercial clones which were in advanced stages of screening for yield and disease resistance as part of the Texas A&M University sugarcane breeding program. Our objectives were to identify levels of resistance to *E. loftini* among clones and to document sugarcane injury by *D. saccharalis*.

Materials and Methods

In 1988-89, 9 field plantings of 40 noncommercial clones (4 fields in second ratoon, 13 clones; 2 fields in first ratoon, 15 clones; and 3 fields in plant cane, 12 clones) and the Texas commercial clones (cultivars) CP 70-321, NCo 310, and CP 65-357 were evaluated for injury by *E. loftini* and *D. saccharalis*. In 1989-90, 3 plantings of 18 noncommercial clones (all plant cane) and the Texas commerical clones (cultivars) NCo 310, CP 68-350, and CP 70-324 were evaluated. A severe freeze in December, 1989 prevented further

evaluation of the plantings evaluated in 1988-89. Plots were 4 10-m long rows of sugarcane on a 1.5-m row spacing. There were no buffers between plots although each group of plots was buffered within a commercial sugarcane clone (cultivar). Field layout was a randomized complete block design with all clones in each planting replicated 4 times within each field. Sugarcane management practices were the same as for the commercial field where each planting was located. Management included from 0-3 aerial applications at labelled rates of either monocrotophos (Azodrin 5) or azinphosmethyl (Guthion 2L) during May-September.

To evaluate stalkborer injury to each clone at harvest, 25 stalks were removed from the outer 2 rows of each plot, split longitudinally and examined. The total number of internodes and the number of internodes injured by *E. loftini* and *D. saccharalis* were counted per stalk. Injury by the 2 stalkborer species was separated by differences in larval tunnel construction. *E. loftini* tunnels are generally packed with frass, restricted to 1 internode, and found throughout the internode. *D. saccharalis* tunnels are usually open, often more than 1 internode is injured, and usually the tunnels are in the center of the stalks.

For analysis, the number of injured internodes attributable to each species was divided by the total number of internodes in each stalk to yield a percentage of injured internodes. Percentages in each planting were subjected to analysis of variance (Proc GLM, SAS Institute 1985). The null hypothesis that clone was not an important source of variation was tested using the planting by clone interaction term as the error term (McIntosh 1983), and means were separated using Duncan's multiple range test (SAS Institute 1985).

Results and Discussion

Evaluations in the 1988-89 and 1989-90 seasons showed significant differences ($P < 0.05$) in bored internode injury by *E. loftini* among clones for each planting (Tables 1 and 2). *Eoreuma loftini* bored internodes ranged from 10.7% (second ratoon TCP 83-3180) to 53.4% (plant cane NCo 310) in 1988-89 (Table 1). The commercial cultivar CP 70-321 was injured significantly less than the cultivar NCo 310. CP 70-321 was among the most resistant clones, usually exhibiting either the least damage of all clones (first ratoon), or no significant difference from the least injured clone (plant cane). Only 2 clones evaluated were injured less than CP 70-321 in any planting, and 11 clones reacted as equally resistant. The clones exhibiting least injury were TCP 83-3196 and TCP 83-3180 from the second ratoon plantings.

Injury in 1989-90 ranged from 19.0% bored internodes (TCP 82-3101) to 37.4% (CP 81-1320) (Table 2). Although CP 70-321 was not evaluated in the 1989-90 tests, its sibling CP 70-324 exhibited low levels of *E. Loftini* injury. This was the only example in these studies of progeny of the same cross showing similar levels of injury.

Injury by *D. saccharalis* was not significantly different among clones in 1988-89 ($P > 0.05$), with less than 3% bored internodes. Significant differences in *D. saccharalis* injury were observed in 1989-90 ($P < 0.05$), however, injury averaged less than 1.0% for all plantings and the population was too low to evaluate sugarcane resistance. Injury by *D. saccharalis* in Texas sugarcane prior to establishment of *C. flavipes* averaged 18.7% bored internodes in untreated plots in 1972 (Fuchs et al. 1973) and about 31% (12 to 51%) in 1977 (Reeves 1978). Our results suggest a dramatic reduction in *D. saccharalis* injury since the mid 1970's. Overall injury to sugarcane by stalkborers, however, appears to have remained approximately the same, with the range of bored internodes (10.7-53.4%) similar to that observed in the mid 1970's. Direct yield reduction per internode bored by *E. loftini* has not been determined for any clone, therefore effects of equivalent percentages of bored internodes by the 2 species cannot be directly compared.

TABLE 1. MEXICAN RICE BORER INJURY (PERCENT BORED INTERNODES) IN SECOND RATOON, FIRST RATOON, AND PLANT CANE SUGARCANE PLANTINGS, LRGV, TEXAS, 1988-89.

Second Ratoon		First Ratoon		Plant Cane	
Clone	% Bored Internodes	Clone	% Bored Internodes	Clone	% Bored Internodes
TCP 83-3190	32.0 a	CP 84-723	44.2 a	NCo 310	53.4 a
TCP 83-3215	30.2 ab	TCCP 84-3232	35.5 b	TCP 85-802	52.7 a
NCo 310	28.2 bc	TCP 84-3257	35.4 b	TCP 85-3290	52.6 a
CP 83-631	27.5 bcd	TCP 84-3259	35.2 b	TCP 85-3340	43.4 b
CP 65-357	27.1 bcd	TCP 84-3231	33.5 bc	TCP 85-3287	42.6 b
TCP 83-3217	26.0 cd	TCP 84-3230	31.3 cd	TCP 85-3319	41.8 b
PM 72	24.5 de	LCP 81-30	30.2 de	TCP 85-3310	41.4 b
CP 72-1370	24.4 de	NCo 310	29.7 de	TCP 85-3289	41.4 b
TCP 83-3210	21.9 ef	L 80-38	29.1 def	LCP 81-10	40.1 b
TCP 83-3206	21.7 ef	L 81-26	28.6 def	CP 85-810	36.1 c
Mex 74-1901	20.5 f	CP 84-720	27.6 ef	CP 72-370	34.3 c
TCP 83-3211	17.0 g	TCP 84-3271	26.8 ef	CP 70-321	28.0 d
TCP 82-3101	16.4 g	TCP 84-3263	26.1 f	TCP 85-3342	27.1 d
CP 70-321	15.9 g	L 80-2	20.1 g	CP 85-818	26.2 d
TCP 83-3196	11.4 h	CP 84-750	18.0 g	MEAN	40.08
TCP 83-3180	10.7 h	TCP 84-3266	17.7 g		
MEAN	22.22	CP 70-321	16.8 g		
		MEAN	28.58		

[1]Means within % bored internode columns followed by the same letter are not significantly different ($P > 0.05$, Duncan's Multiple Range Test, SAS 1985).

This study suggests that 7 noncommercial clones exhibited low levels of stalkborer injury and could show promise for commercial use particularly if they are agronomically acceptable and provide good yield characteristics. Data on sugarcane clone resistance to *E. loftini* injury could be utilized in conjunction with data generated through the breeding program on clone yield and disease resistance to select new clones for release to Texas sugarcane producers. Integration of plant resistance studies into the Texas A&M University breeding program offers potential for reduced yield losses due to *E. loftini* injury.

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TABLE 2. MEXICAN RICE BORER INJURY (PERCENT BORED INTERNODES) IN PLANT CANE SUGARCANE PLANTINGS, LRGV, TEXAS, 1989-90.

Clone	*E. loftini*	*D. saccharalis*
CP 81-1320	37.4 a	0.4 bcd
TCP 86-3346	37.3 a	0.1 cd
CP 80-1743	31.8 b	0.9 a
TCP 86-3361	30.6 bc	0.2 bcd
TCP 84-3271	30.1 bc	0.1 cd
TCP 86-3369	29.2 bcd	0.1 cd
CP 81-1405	28.3 cde	0.2 bcd
TCP 86-3374	28.0 cde	0.1 cd
TCP 83-3215	27.8 cde	0.4 bcd
CP 80-1953	27.6 cde	0.4 bcd
NCo 310	27.6 cde	0.3 bcd
TCP 83-3211	27.2 de	0.3 bcd
CP 86-936	25.8 def	0.6 ab
CP 80-1151	25.4 ef	0.0 d
CP 86-946	22.8 fg	0.2 bcd
TCP 83-3196	22.7 fg	0.6 ab
CP 70-324	21.3 gh	0.3 bcd
CP 68-350	20.3 gh	0.2 bcd
CP 80-1827	20.1 gh	0.3 bcd
TCP 86-3368	20.1 gh	0.3 bcd
TCP 82-3101	19.0 h	0.9 a
MEAN	26.69	0.33

[1]Means within stalkborer species followed by the same letter are not significantly different ($P > 0.05$, Duncan's Multiple Range Test, SAS 1985).

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ADDITIONS TO THE PHORID FAUNA (DIPTERA: PHORIDAE) OF NORTH AMERICA NORTH OF MEXICO

JEFFREY K. BARNES
Biological Survey
New York State Museum
The State Education Department
Albany, New York 12230

ABSTRACT

The phorid genus *Melaloncha* Brues and the species *Beckerina setifrons* Borgmeier, *Coniceromyia latimana* (Malloch), *Megaselia lanceata* Borgmeier, *Megaselia luteicauda* (Borgmeier), and *Melaloncha nigricorpus* Borgmeier are reported for the first time from North America north of Mexico. *Megaselia seclusa* Beyer is synonymized with *M. lanceata* [NEW SYNONYMY]. New locality records are given for *Dohrniphora divaricata* (Aldrich). Alterations to existing keys are suggested that will allow identification of these taxa.

RESUMEN

Se reporta por primera vez en Norte America al norte de Mexico, el genero phorid *Melaloncha* Brues y las especies *Beckerina setifrons* Borgmeier, *Coniceromyia latimana* (Malloch), *Megaselia lanceata* Borgmeier, *Megaselia luteicauda* (Borgmeier), and *Melaloncha nigricorpus* Borgmeier. *Megaselia seclusa* es sinonimo de *M. lanceata*

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[Nuevo Sinonimo]. Se publican nuevos registros de localidades para *Dohrniphora divaricata* (Aldrich). Se sugieren alteraciones para las claves actuales, lo cual permitirá la identificación de este taxon.

I recently identified over 7000 specimens of phorid flies from the Florida State Collection of Arthropods, Gainesville (FSCA), the Mississippi Entomological Museum, Mississippi State (MEMM), the Snow Entomological Museum, University of Kansas, Lawrence (SEMK), and the collection of Texas A & M University, College Station (TAMC). The following distribution records are significant because they represent species not previously reported, or only recently reported, from North America north of Mexico. Most of the species reported here from the southeastern United States were known previously only from the West Indies and were identified with the aid of Borgmeier's (1969a) study of the Phoridae of Dominica. Some of the specimens are deposited in the New York State Museum, Albany (NYSM).

Beckerina setifrons Borgmeier

Beckerina setifrons Borgmeier, 1969b: 62.

Borgmeier (1969b) described this species from a female collected on a beach in Cuba. It can be distinguished from other species of *Beckerina* by the two to four pairs of setulae lateral to the supra-antennal bristles on the anterior edge of the frons, the presence of wing vein R_{2+3}, the yellow halteres, and the single hair seam on the hind tibia. It keys easily in Borgmeier's (1971) improved key to the world species of *Beckerina*.

Beckerina setifrons and *B. aliena* Malloch are the only known North American species in the genus that have a dorsal hair seam on the hind tibia. The type (and only known specimen) of the latter species apparently has been lost (Borgmeier 1963). Nevertheless, Malloch (1924b) made no mention of supernumerary bristles lateral to the supra-antennals in *B. aliena*. Therefore, it seems that these bristles are the best character for distinguishing the two species.

Males of *B. setifrons* possess a small, circular, raised area, about 0.05 mm in diameter, on the notopleuron just posterior to the lateral edge of the postpronotal lobe. A similar structure in males of *B. luteola* Malloch is generally darker and bears a stout central peg. No such structure exists in males of *B. orphnephiloides* Malloch. These areas are morphologically distinct from the notopleural cleft found in males of *Woodiphora*, some *Megaselia*, and both sexes of *Gymnophora* (Disney 1989).

MATERIAL EXAMINED. FLORIDA: Gadsden County, Quincy, D. E. Hardy, 10.VII.1939 (1 ♂, SEMK); Liberty County, Torreya State Park, H. V. Weems, Jr., 5.VII.1965 (1 ♀, FSCA); H. V. Weems, Jr. and C. R. Artaud, 30.IV-5.V.1973 (1 ♂, FSCA); Highlands County, Archbold Biological Station, H. V. Weems, Jr. and F. E. Lohrer (1 ♂, FSCA); Alachua County, Gainesville, Doyle Conner Building, H. V. Weems and C. R. Artaud, 6.X.71 (1 ♀, NYSM), 15.XI.1971 (1 ♂, FSCA), 13.XII.1971 (1 ♂, FSCA); west of Gainesville, Pierce's homestead, W. H. Pierce, 20.XI.1973 (1 ♂, FSCA), 1.XI.1975 (2 ♂♂, NYSM), 2.XI.1975 (2 ♂♂, FSCA; 1 ♂, NYSM), 3.XI.1975 (3 ♂♂, FSCA; 3 ♂♂, NYSM), 10.XI.1975 (1 ♂, FSCA; 1 ♂, NYSM), 11.XI.1975 (2 ♂♂, FSCA; 1 ♂, 1 ♀, NYSM), 15.XI.1975 (1 ♂, FSCA; 1 ♂, NYSM), 26.XI-1.XII.1975 (1 ♂, FSCA; 1 ♂, NYSM), 24-28.XII.1975 (1 ♂, 1 ♀, FSCA; 2 ♂♂, NYSM), 31.XII.1975 (6 ♂♂, FSCA; 6 ♂♂, NYSM), 4.I.76 (2 ♂♂, FSCA; 1 ♂, 1 ♀, NYSM).

Coniceromyia latimana (Malloch)

Conicera latimana Malloch, 1924a: 73.
Coniceromyia latimana (Malloch) [Schmitz, 1927: 66].

This species was known previously only from the West Indies. It is the only known North American species of *Coniceromyia* with a bare anepisternum. Males are recognized easily by the especially broad first tarsomere and dark apical tarsomere of the foreleg (see Borgmeier 1969a, Fig. 11).
MATERIAL EXAMINED. FLORIDA: Monroe County, No Name Key, W. H. Pierce, 3.II.1972 (1 ♀, FSCA), 10.II.1972 (1 ♂, FSCA). JAMAICA: Parish St. Catherine, Worth Park, 2.2 mi. N. on Camper-down Rd., R. E. Woodruff, 11.V.1969 (1 ♂, FSCA). DOMINICA: Clarke Hall, W. W. Wirth, 21-31.I.1965 (1 ♂, NYSM), 11-20.III.1965 (1 ♀, NYSM).

Dohrniphora divaricata (Aldrich)

Phora divaricata Aldrich, 1896: 437.
Dohrniphora divaricata (Aldrich) [Borgmeier, 1961: 111].
Dohrniphora diffusa Borgmeier, 1960: 281 [Borgmeier, 1961: 111].

This species was originally described from specimens collected on St. Vincent in the Lesser Antilles, and Borgmeier (1968) reported it from Argentina and Brazil. Khalaf (1971) first reported it in North America from several coastal sites in Mississippi. Males are readily distinguished from other North American *Dohrniphora* by the configuration of the "stimulatory patches" (Barnes 1990) on the posterobasal surface of the hind femur (see Borgmeier 1969a, Fig. 3). Females are confused easily with those of *D. perplexa* (Malloch).
MATERIAL EXAMINED. KANSAS: Douglas County, Lawrence, University of Kansas, L. R. Ertle, 1.VII.1965 (1 ♂, SEMK). MISSISSIPPI: Pontotoc County, 1 mile southeast of Ecru, W. H. Cross, 19.VI.1980 (1 ♂, MEMM), 15.VIII.1980 (1 ♂, MEMM); G. L. Snodgrass, 7.VII.1980 (1 ♂, NYSM); Panola County, 3 miles west-south-west of Sardis, W. H. Cross, 13.IX.1979 (1 ♂, MEMM). OKLAHOMA: Latimer County, K. Stephan, VI.1986 (1 ♂, FSCA).

Megaselia lanceata Borgmeier

Parametopina lanceolota Schmitz, 1928: 40 (preocc. Brues, 1924: 220 [*Aphiochaeta*]).
Megaselia lanceata Borgmeier 1962: 338 (replacement name).
Megaselia seclusa Beyer, 1966: 190. NEW SYNONYMY.

I recently identified a single male specimen from a locality in Kansas as *Megaselia lanceata*, a species previously known only from Mexico. This distinctive species has an extremely short, thick costa and lacks wing vein R_{2+3}. Subsequently, a series of 9 females collected at exactly the same locality at about the same time came to my attention. Although the costa is more slender, and the specimens match Beyer's (1966) description of *M. seclusa*, which was based on a single female from Arizona, these female specimens are otherwise nearly identical with the male. In the only similar species for which the female is known, *M. tumidula* Borgmeier (1962), the costa of the male is considerably thicker than that of the female. I therefore conclude that *M. lanceata* is sexually dimorphic, and *M. seclusa* is in fact the female of this species, and therefore this name is a synonym of the former. Attempts to locate and borrow holotypes of these nominal species to check my conclusions yielded no results.

Megaselia lanceata can be distinguished from all other species listed in Borgmeier's (1964) key to *Megaselia* Group III by the lack of wing vein R_{2+3}.

MATERIAL EXAMINED. KANSAS: Douglas County, Lawrence, University of Kansas, Coll. #8, Malaise Trap, L. R. Ertle, 30.VI.1965 (1 ♀, SEMK), 1.VII.1965 (1 ♀, SEMK), 2.VII.1965 (1 ♀, NYSM; 1 ♀, SEMK), 6.VII.1965 (1 ♀, NYSM; 1 ♀, SEMK), 7.VII.1965 (1 ♀, NYSM: 1 ♀, SEMK), 22.VII.1965 (1 ♂, SEMK); University of Kansas Natural History Reserve, Malaise Trap #1, L. R. Ertle, 27.V.1965 (1 ♀, SEMK). TEXAS: Zavala County, Nueces River, 4 miles east of La Pryor, Byers and Thornhill, 9.IX.1972 (1 ♂, NYSM); Brazos County, College Station, pan trap, R. Wharton and M. Hrncir, 19-26.III.1982 (1 ♂, TAMC).

Megaselia luteicauda (Borgmeier)

Aphiochaeta luteicauda Borgmeier, 1925: 145.
Megaselia luteicauda (Borgmeier) [Borgmeier, 1962: 293].

This species was previously known only from Argentina, Brazil, Costa Rica, and Dominica. Females are readily recognized by the brown abdominal tergites 1-3, which contrast sharply with yellow and membranous segments 4-6. Males key to couplet 6, *Megaselia relicta* Borgmeier, in Borgmeier's (1964) key to North American Group I *Megaselia*. However, they differ from males of that species by their yellow halteres and the contrast between dark abdominal tergites 1-3 and lighter tergites 4-6, which is less striking than in the female.

MATERIAL EXAMINED. FLORIDA: Alachua County, Pierce's homestead, S9-T10S-R18E, W. H. Pierce, 4..X.1973 (3 ♂♂, 6 ♀♀, FSCA; 3 ♂♂, 6 ♀♀, NYSM), 21.XII.1973 (2 ♀♀, FSCA), 1.I.1974 (2 ♀♀, FSCA), 3.I.1974 (1 ♀, FSCA), 28.X.1974 (1 ♀, FSCA); Gainesville, Pierce's homestead, W. H. Pierce, 10.XI.1975 (1 ♀, FSCA), 15.XI.1975 (1 ♀, FSCA), 31.XII.1975 (2 ♂♂, FSCA); Gainesville, Doyle Conner Building, H. V. Weems and C. R. Artaud, 16.IX.1971 (1 ♀, FSCA), 23.IX.1971 (1 ♂, FSCA), 30.IX.1971 (1 ♀, FSCA), 4.X.1971 (1 ♂, FSCA), 12-15.X.1971 (1 ♂, 3 ♀♀, FSCA; 1 ♂, 1 ♀, NYSM), 18-20.X.1971 (1 ♂, 1 ♀, FSCA), 29.X.1971 (1 ♀, FSCA), 1-3.XI.1971 (1 ♂, 1 ♀, FSCA); 1 ♂, 2 ♀♀, NYSM), 12.XI.1971 (2 ♂♂, FSCA; 1 ♂, NYSM), 18.XI.1971 (1 ♂, 1 ♀, FSCA), 30.XI.1971 (1 ♀, FSCA); H. V. Weems, Jr., 4-6.IX.1973 (2 ♀♀, FSCA), 14-17.IX.1973 (3 ♀♀, FSCA); Gainesville, DPI, L. A. Stange, 25.II.1982 (1 ♂, 1 ♀, FSCA); Gainesville, Beville Heights, L. A. Stange, 16-31.V.1986 (1 ♀, FSCA), 9 miles northwest of Gainesville, University of Florida horticulture unit, SR 232, H. N. Greenbaum and H. V. Weems, Jr., 13-16.IV.1977 (1 ♀, FSCA). MISSISSIPPI: Oktibbeha County, 6 miles southwest of Starkville, R. L. and B. B. Brown, 14.VIII.1984 (1 ♀, MEMM), 30.VIII.1984 (1 ♂, MEMM; 1 ♂, NYSM), 2.IX.1984 (1 ♂, MEMM), 17.X.1984 (1 ♂, MEMM).

Melaloncha nigricorpus Borgmeier

Melaloncha nigricorpus Borgmeier, 1934: 183.

A single specimen from Texas keys to *Melaloncha piliapex* Borgmeier in Borgmeier's (1971) key to females of this genus, and it matches well with Borgmeier's (1938) original description of that species. However, the ovipositor of the specimen from Texas is not parallel sided in dorsal view, but rather attenuated toward the apex due to lateral compression. The ovipositor of *M. piliapex* is dorsoventrally flattened at the apex. To settle the question of the specimen's true identity, I borrowed the types of *M. piliapex*, its synonym, *M. simillima* Borgmeier, and some related species for comparison. I

discovered that the sixth couplet of Borgmeier's (1971) key is incorrect, and the second branch should read, "Ovipositor bare or with very fine, short, erect pubescence." The specimen from Texas will then key to couplet 7, and the species is identified as *M. nigricorpus* Borgmeier, which is also known from Bolivia and Brazil. It fits the original description and matches the holotype of *M. nigricorpus*, except that it is smaller (only 1.48 mm long to the apex of the sixth tergite, as opposed to 2.40 mm for *M. nigricorpus*), and its antennae and palpi are yellow instead of orange.

In Peterson's (1987) key to the genera of Nearctic Phoridae, *Melaloncha piliapex* will key to couplet 52, which in turn leads to the second branch of couplet 76 of Brown's (1988) additions to that key. That branch indicates that the keyed specimen belongs to the genus *Styletta*, but more recent findings show that the Holarctic species should be transferred to a new genus, which at the present time does not bear a published name (Brown, in press). The single known Nearctic species, *camponoti* Brown, possesses two pairs of supra-antennal bristles, a brown flagellomere 1, a frontal ratio of about 1.0, a short costa (only 0.29 to 0.36 of wing length), and a mean costal sector ratio (humeral crossvein to R_1:R_1 to R_{4+5}) of 2.7. *M. piliapex* differs by the lack of supra-antennals and the presence of a yellow flagellomere 1, a narrow frons (about twice as long as wide), a long costa (0.52 of wing length), and a small costal sector ratio of 1.2.

MATERIAL EXAMINED. TEXAS: Cameron County, L. D. Beamer, "8-3-28" (1 ♀, SEMK). BOLIVIA: Mapiri, Sarampioni, 700 meters (1 ♀, holotype, Museu de Zoologia, Universidade de São Paulo [MZSP]).

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SEASONAL CHRONOLOGY OF *NOCTUIDONEMA*, AN ECTOPARASITIC NEMATODE OF ADULT MOTHS, IN TROPICAL AND SUBTROPICAL AMERICA

A. M. SIMMONS, C. E. ROGERS, K. U. BUCKMIRE[1], B. GRAY[2], K. D. MONKMAN[3], A. PANTOJA[4], J. R. RAULSTON[5], AND V. H. WADDILL[6]
Insect Biology and Population Management Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Tifton, Georgia 31793-0748

ABSTRACT

Male moths of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), were examined for *Noctuidonema guyanense* Remillet and Silvain, an ectoparasitic nematode of adult Lepidoptera, during a 1-year (mid-September 1988 to mid-September 1989) study at locations in tropical and subtropical America (Hamilton, Bermuda; Belle Glade, Florida; St. Georges, Grenada; Panama, Republic of Panama; Isabela, Puerto Rico; and Weslaco, Texas) and in Tifton, Georgia. Host parasitism and nematode population density varied among locations and over time. Overall parasitism of *S. frugiperda* males averaged about 30%, with about 30 nematodes per parasitized moth. However, parasitism averaged 77% in Grenada, but only about 1% in Texas. Nematodes were more numerous at lower latitudes than higher latitudes. Nematode densities were correlated with temperature and humidity. However, because seasonal fluctuations of nematode populations occurred at locations with fairly stable climatic conditions, other factors (e.g., host migration and age of the host) may also affect the nematode populations.

RESUMEN

Machos adultos del gusano cogollero, *Spodoptera frugiperda* (J. E. Smith), fueron examinados para determinar la presencia de *Noctuidonema guyanense* Remillet y Silvain, un nematodo parasítico de adultos lepidopteros. El estudio se realizó durante un año (Septiembre 1988 a Septiembre 1989) en siete localidades de América tropical y subtropical (Hamilton, Bermuda; Belle Glade, Florida; Tifton, Georgia; St Georges, Grenada; Panama, Republic of Panama; Isabela, Puerto Rico; y Weslaco, Texas). El parasitismo y la densidad poblacional del nematodo fueron diferentes entre localidades y cambiaron a traves del tiempo. El promedio de parasitismo en machos de *S. frugiperda* fue del 30 % con approximadamente 30 nematodos por adulto. En contraste, el parasitismo alcanzó hasta el 77 % en Grenada, pero sólo 1 % en Texas. Se encontró un número mayor de nematodos en latitudes bajas que en latitudes altas. La población de nematodos está corelacionó con humedad y temperatura. Fluctuaciones estacionales observadas en la población de los nematodos en localidades con condiciones climáticas estables, sugieren que otros factores (migración y edad del hospedero) pueden también afectar las poblaciones del nematodo.

[1]Caribbean Agricultural Research & Development, Ministry of Agriculture Botanical Gardens, P. O. Box 431, St. Georges, Grenada, W. I.
[2]Universidad de Panama, Facultad de Ciencias Agropecuarias, CEIAT, Ciudad Universitaria Octavio Mendez Pereira, Panama City, Republic of Panama.
[3]Department of Agriculture & Fisheries, Botanical Gardens, P. O. Box HM834, Hamilton HJMCX, Bermuda.
[4]Formerly, University of Puerto Rico, Mayaguez Campus and Agricultural Experiment Station; Currently, CIAT Rice Program, Apartado Aereo 6713, Cali, Colombia, S. A.
[5]USDA-ARS-SARL, 2413 East Highway 83, P. O. Box 267, Weslaco, Tex. 78596.
[6]Everglades Research and Education Center, P. O. Box Drawer A, Belle Glade, Fla. 33430.

Ectoparasitic nematodes have rarely been found on adult insects. Hunt (1980) found the first known ectoparasitic nematode of an adult arthropod occurring on a cockroach (*Periplaneta americana* (L.)) in Saint Lucia, West Indies, but there was no additional published report regarding that nematode. Subsequently, an ectoparasitic nematode, *Noctuidonema guyanense* Remillet and Silvain (Nematoda: Aphelenchoididae), was found on adults of several species of Lepidoptera, including the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), in French Guiana (Remillet & Silvain 1988, Rogers et al. 1990). *N. guyanense* was later recovered from *S. frugiperda* throughout tropical and subtropical America (Simmons & Rogers 1990a). This nematode lives only on adult moths and is transmitted during host mating (Remillet & Silvain 1988, Rogers et al. 1990, Simmons & Rogers 1990b). In the United States, the fall armyworm has overlapping generations year-round in south Florida and in south Texas; it does not diapause, and usually does not survive the winter north of these border areas (Luginbill 1928, Snow & Copeland 1969). When the fall armyworm migrates northward in the United States during the spring and early summer, *N. guyanense* is carried with it (Simmons & Rogers 1991). As the season advances, prevalence and density of the transported nematodes increases and then decreases during the fall; however, overlapping host generations are necessary for continuous maintenance of this nematode (Simmons & Rogers 1991). Data on incidence and density of *N. guyanense* have been collected, but samples were generally only made within one month per location and collection dates were not synchronized among locations in a survey at 22 tropical and subtropical locations where the fall armyworm has overlapping generations year-round (Simmons & Rogers 1990a).

To obtain a thorough understanding of the seasonal chronology of *N. guyanense*, data were needed using coinciding collecting dates from locations where the hosts occur year-round. The objective of this study was to obtain information on the seasonal chronology of *N. guyanense* at locations where the fall armyworm (an economically important pest in the Americas) has year-round overlapping generations.

Materials and Methods

Moths of *S. frugiperda* were collected and handled as described by Simmons & Rogers (1991), except as noted below. From mid-September 1988 to mid-September 1989, specimens of adult male fall armyworms were collected at six locations in tropical and subtropical America: Hamilton, Bermuda; Belle Glade, Fla.; St. Georges, Grenada; Panama, Republic of Panama; Isabela, Puerto Rico; and Weslaco, Tex., as well as in Tifton, Ga. (Fig. 1). Additional collections were made at Fortuna and Vega Baja, Puerto Rico; these data were combined with data collected at Isabela, Puerto Rico. Fall armyworm moths can normally be found year-round at all of these locations, excluding Tifton. Tifton was selected for a comparison with the warmer locations.

There were 18 specific collection weeks: 19-23 September, 10-14 October, 31 October - 4 November, 21-25 November, 12-16 December, 2-6 January, 23-27 January, 13-17 February, 6-10 March, 27-31 March, 17-21 April, 8-12 May, 29 May - 2 June, 19-23 June, 10-14 July, 31 July - 4 August, 21-25 August, and 11-15 September, starting in 1988 and ending in 1989. The number of moths recovered for examination per sampling period from each location is shown in Table 1. Nematode counts were for adults and juveniles combined. Mean daily temperature, relative humidity, and rainfall data were averaged over 21 d preceding each sampling period. Vapor pressure deficiency was used as an index of humidity. Voucher specimens from each location were deposited with the USDA Nematode Collection, Beltsville, Md.

Data were analyzed using SAS (SAS Institute 1985) computations. Percentage infestation data were analyzed after arcsine transformation; log transformation, base 10, was used before analysis of the nematode population data. Means presented herein are for back-transformed data. Unless stated otherwise, $P < 0.05$ level of significance was used.

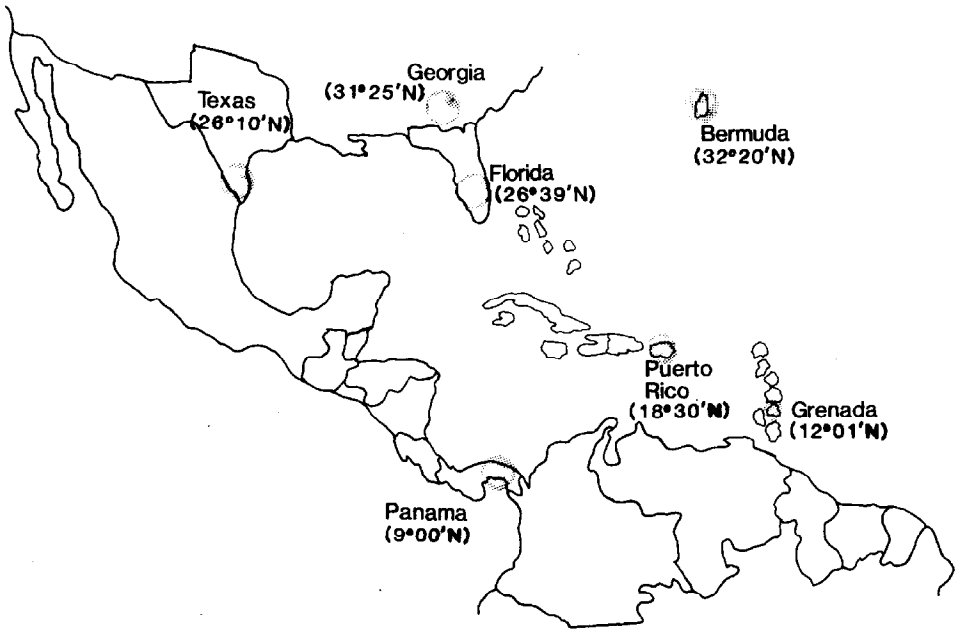

Fig. 1. Locations, with corresponding latitudes, where male *S. frugiperda* moths were sampled for *Noctuidonema* from mid-September 1988 to mid-September 1989.

Results and Discussion

Although our objective was to examine 50 male fall armyworm moths per sampling week per location, frequently, fewer than 50 moths or occasionally no moths were recovered. Also, the preservative fluid leaked from a few vials (maximum of 3 samples per location per week) during shipment, rendering collected specimens unsuitable for examination. Traps were checked as scheduled, but moths were recovered only during one period (mid-December) at Vega Baja and at 5 periods (mid-September to mid-December 1988) at Fortuna, Puerto Rico. Data of coinciding periods for the 3 locations in Puerto Rico were similar and were therefore combined. Each sample size in Table 1 between 1 and 47 may be interpreted as the relative number of moths collected during or near a designated sampling week. However, because of the limit of 50 moths for examination and because no attempt was made to collect moths during some weeks, the association between moth captures and moth populations is partially obscured. Snow et al. (1968) reported sharp peaks about every 4-5 weeks in number of fall armyworm moths captured in pheromone traps in St. Croix, U.S. Virgin Islands, and noted that although populations overlapped year-round, temperature did not influence the fluctuation in trapping data.

The overall percent parasitism of *S. frugiperda* by *N. guyanense* varied among locations, but averaged around 30% (Table 2). Two notable exceptions were 77% parasitism in Grenada and 1% in Texas. Nematode population density averaged about 30 nematodes per parasitized moth at each location (Table 2). However, the mean number of nematodes per parasitized moth was 13 in Georgia, 38 in Puerto Rico and 44 in Grenada.

Percent *S. frugiperda* parasitism and the number of nematodes per host in this study were similar to levels seen at 22 other tropical and subtropical locations during a brief collecting period during 1987/88 (Simmons & Rogers 1990a). There was a positive correlation between the number of nematodes per host and percentage of *S. frugiperda* parasitized ($P < 0.05$). Simmons & Rogers (1990a) also found such a relationship with

TABLE 1. NUMBER OF MALE *S. FRUGIPERDA* MOTHS EXAMINED FOR *NOCTUIDONEMA* DURING SPECIFIC WEEKS (FROM MID-SEPTEMBER 1988 TO MID-SEPTEMBER 1989) AT SELECTED TROPICAL AND SUBTROPICAL LOCATIONS.

	Number of moths examined per designated period																	
Location	Sept. 19-23	Oct. 10-14	O-N 31-4	Nov. 21-25	Dec. 12-16	Jan. 2-6	Jan. 23-27	Feb. 13-17	Mar. 6-10	Mar. 27-31	Apr. 17-21	May 8-12	M-J 29-2	June 19-23	July 10-14	J-A 31-4	Aug. 21-25	Sept. 11-15
Bermuda	50	50	50	48	50	49	49	50	48	49	50	25	50	—	49	49	49	48
Florida	27	50	49	50	100	0	0	0	50	50	49	—	50	50	50	47	50	10
Georgia	10	10	12	10	0	28	10	13	12	11	1	2	68	45	57	64	30	31
Grenada	—	—	37	6	75	4	9	76	5	42	50	28	10	3	6	7	0	49
Panama	22	6	0	0	0	0	0	0	0	0	0	16	14	50	50	0	0	50
Puerto Rico	61	73	55	52	28	6	0	50	4	1	15	0	50	0	0	0	50	46
Texas	0	20	49	42	0	42	43	2	0	0	0	46	40	50	1	43	20	15

Dash (—) indicates no attempt was made to collect moths.

TABLE 2. PREVALENCE AND NUMBER OF *NOCTUIDONEMA* ON MALE *S. FRUGIPERDA* MOTHS AT SELECTED TROPICAL AND SUBTROPICAL AMERICAN LOCATIONS FROM MID-SEPTEMBER 1988 TO MID-SEPTEMBER 1989 (±SEM).

Location	No. moths examined	Mean % parasitism	Mean no. nematodes per infested moth
Bermuda	813	24.0 ± 1.5	26.8 ± 3.5
Florida	682	38.0 ± 1.8	25.6 ± 3.1
Georgia	414	20.0 ± 2.0	13.1 ± 2.2
Grenada	407	77.4 ± 2.1	43.5 ± 3.8
Panama	208	34.6 ± 3.3	26.3 ± 5.7
Puerto Rico	471	46.6 ± 2.3	37.9 ± 4.6
Texas	413	1.2 ± 0.5	27.8 ± 2.5

field-collected moths in the tropical and subtropical Americas. The prevalence of *N. guyanense* infestation and number of nematodes per host were not consistent over time, although data were more variable at some locations than at others.

In Georgia, the number of nematodes per moth in the fall of 1988 declined to zero as the season progressed (Fig. 2). From 1 November 1988 to late May 1989, none of the collected moths in Georgia was parasitized (Fig. 2). Thereafter, there was an increase in both the prevalence and number of *N. guyanense* per host. The winter of 1988-89 was warmer than most winters in Georgia. Consequently, a few fall armyworm moths were collected throughout much of the winter, although some of those moths may have resulted from emigration from southern locations rather than from local emergence. Local moth populations, not overlapping during the winter months, could result in a long period of zero parasitism because an adult host is required for the nematode. Asynchrony of populations of parasitized and non-parasitized moths may also help explain the reduction in parasitism during the late fall. Nematode population and rate of parasitism peaked during late summer of 1989 in Georgia. Similarly, Simmons & Rogers (1991) reported a peak in nematode activity during mid-to-late-August in Georgia in 1988.

Populations of *N. guyanense* in locations extending from Bermuda to Puerto Rico in the Caribbean Basin, as well as Georgia, had low numbers in winter which became higher in spring and summer (Fig. 2). There was a reduction in Bermuda's populations during the winter; the effect was lessened southward from Florida to Puerto Rico, but not in Grenada. Also, as in Georgia, moths were collected throughout most of the year in south Texas. However, parasitized moths were only collected during two weeks in 1989, in late May/early June and in late August. The number of nematodes on *S. frugiperda* averaged 28 per infested moth during the restricted collecting period in Texas. There was much more nematode activity on *S. frugiperda* in Panama than in Texas. During the first sampling date in Panama, none of the collected moths was parasitized, and only one of 6 specimens during the next sampling period was parasitized. (Thereafter, data are missing for several sampling weeks.) However, parasitism of *S. frugiperda* in Panama declined from a high of about 85% in early-May 1989 to a low of about 20% in mid-September 1989. Simmons & Rogers (1990a) also reported higher parasitism and more nematodes on *S. frugiperda* at locations in the Caribbean Basin than at locations on the mainland of tropical and subtropical America (from Colombia, South America to southern Texas).

Across all locations, percent parasitism and the number of nematodes per moth were positively correlated ($P < 0.001$, $r^2 = 0.57$ and $P < 0.05$, $r^2 = 0.42$, respectively) with temperature, but less association occurred with mean vapor pressure deficiency. An analysis of data from each location suggests that temperature was correlated with pop-

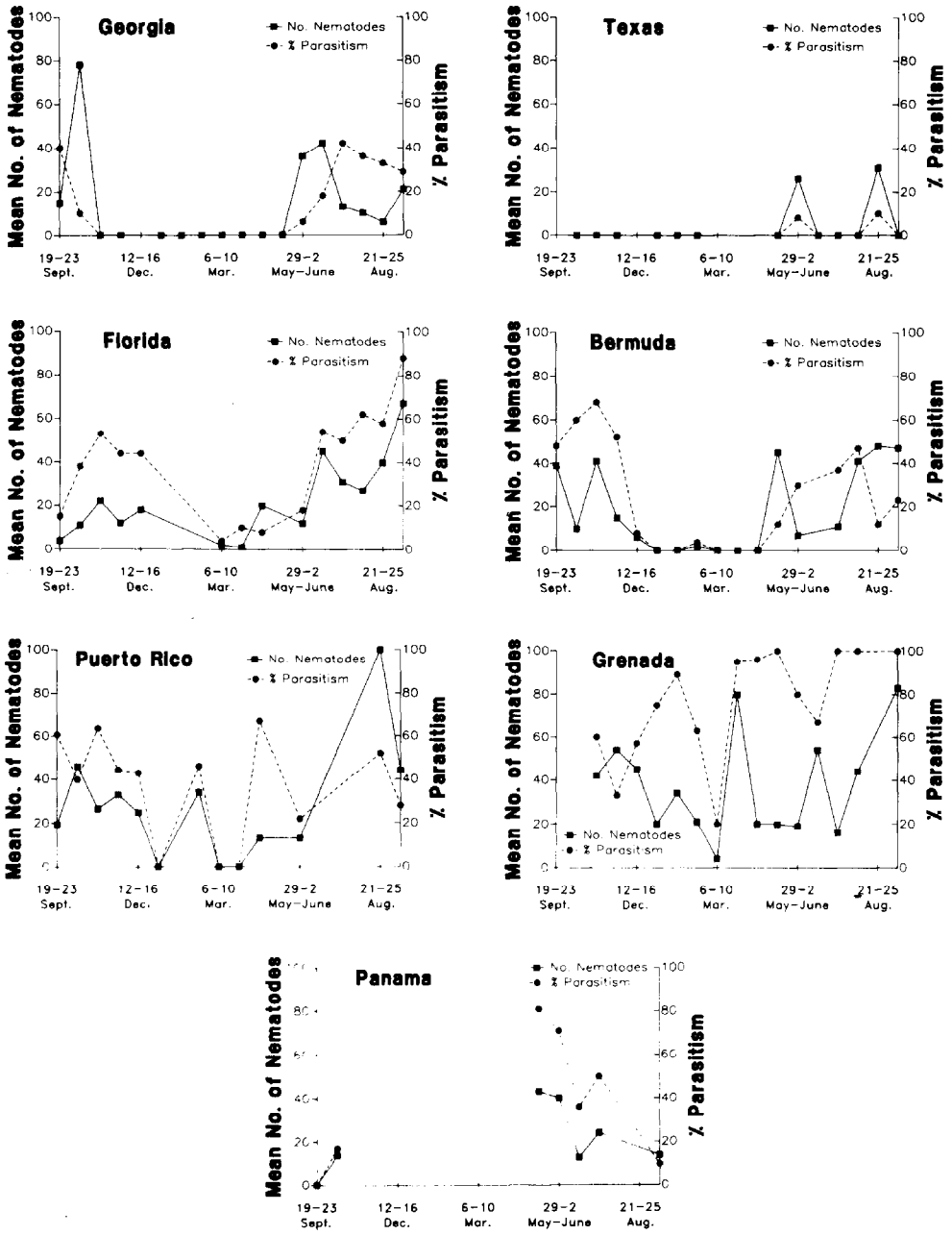

Fig. 2. Prevalence and mean number of *Noctuidonema* per infested *S. frugiperda* moth at sample locations from mid-September 1988 to mid-September 1989.

ulations more at some locations, e.g., Georgia, than at others, e.g., Puerto Rico (Table 3). In general, temperature appeared to be more closely related to nematode abundance than was humidity, although humidity data were only available for 4 locations. The importance of temperature was apparently more pronounced at higher latitudes (Georgia, Bermuda, and Florida) than lower latitudes (Puerto Rico, Grenada and Panama). Locations in lower latitudes were characterized by less extreme daily and seasonal temperature fluctuations as well as by warmer overall temperature. There was high fidelity

TABLE 3. CORRELATION OF PREVALENCE AND NUMBER OF *NOCTUIDONEMA* PER INFESTED *S. FRUGIPERDA* MOTH WITH MEAN TEMPERATURE, MEAN RELATIVE HUMIDITY, OR RAINFALL AT SELECTED TROPICAL AND SUBTROPICAL LOCATIONS IN 1988-1989.

	Temperature			Vapor Pressure Deficiency			Rainfall		
		Correlation coeff.[a]			Correlation coeff.[a]			Correlation coeff.[a]	
Location	Mean	% parasitism	No. of nematodes	Mean	% parasitism	No. of nematodes	Total (mm)	% parasitism	No. of nematodes
Bermuda	22.8	0.73***	0.75*	4.52	0.48†	0.19	1,291	0.50*	0.01
Florida	23.3	0.58*	0.65*	3.13	0.35	0.05	747	0.57*	0.60*
Georgia	19.7	0.83*	0.69†	4.48	0.47†	0.03	1,098	0.58*	0.35
Grenada	26.7	0.58*	0.16	7.52	0.53*	0.08	1,870	0.22	0.33
Panama	26.4	0.65	0.45	—	—	—	1,945	-0.78*	0.10
Puerto Rico	24.4	0.53†	0.44	—	—	—	1,508	0.22	0.34
Texas	25.6	0.28	ne	—	—	—	279	0.19	ne

[a]Correlation coefficients; †, significant at $P < 0.1$; *, significant at $P < 0.05$; *** significant at $P < 0.001$; ne = not estimable; — indicates missing data; number of nematodes are per parasitized moth.

between the nematode populations and temperature at the more northerly sites (Georgia, Bermuda, and Florida). For example, in Bermuda (Fig. 2), the decline in nematode population occurred with a decrease in temperature during the winter months, but as the temperature increased during the following spring, the number of nematodes and percent parasitism likewise increased. In the laboratory, Simmons & Rogers (1990b) substantiated that *N. guyanense* is adapted for a tropical environment; it does best at high temperature and high relative humidity. They found that a temperature of less than 20°C or low relative humidity (about 20%) were not favorable for either growth or survival of *N. guyanense*. Climatological effects on the nematode could not be adequately evaluated for the Texas location because parasitized moths were collected only on two dates.

Although we feel that temperature and humidity have large effects on *N. guyanense* populations, other factors undoubtedly affect its bionomics as well. For example, the age of the moths or moth migration may be involved. Over time, the population of *N. guyanense* on a host increases because of nematode development and reproduction (Simmons & Rogers 1990b). As the fall armyworm ages, its incidence of mating events increases, hence, increasing its probability of acquiring or disseminating nematodes. During periods of significant moth emergence, the majority of moths within a population would be virgin or would have mated only a few times. Consequently, moths collected from a newly-emerged population may have zero or a low rate of parasitism and harbor zero or a few nematodes. With overlapping generations, captured moths were of different ages on a given day. Thus, we also attribute some of the large variation in nematode populations among moths and among dates to age differentials among collected moths. Older moths were more likely to have been parasitized, and were more likely to harbor more nematodes, resulting from nematode reproduction, than were younger moths. We made no attempt to determine the relative age or mating status of the moths collected during this study. Nevertheless, observations indicated that moths which looked newly-emerged, i.e., with most of their scales still intact, were the least likely to have a high density of nematodes. Yet, at locations where parasitism was high throughout the year (e.g., Grenada), numerous fresh-looking moths also harbored nematodes. During the winter months in Georgia, when no nematodes were recovered, many captured moths appeared to be newly-emerged. Conversely, in Texas, where nematodes were recovered only from a few moths during the spring/summer months, both fresh-looking and worn moths were collected. Apparently, moth immigration was an important factor in reintroducing nematodes to Texas. Similarly, the parasitized moths which appeared in Georgia in late May were most likely immigrants (Pair & Sparks 1986, Pair et al. 1986).

Across all locations, percent parasitism but not number of nematodes was positively correlated ($P < 0.05$, $r^2 = 0.28$) with rainfall. However, the importance of rainfall was not consistently evident at each location (Table 3). Parasitism was negatively correlated with rainfall in Panama, which received more rainfall than any other location. On the other hand, nematode abundance was positively correlated with rainfall in Florida, and percent parasitism with rainfall in Bermuda, Georgia, and Florida. Numerous *N. guyanense* were found in the preservative fluid of the storage vials, but we do not know if significant numbers may be washed from the host by rainfall. Eggs and some nematodes are not as easily removed from the host because of their association with sticky material and concealment within the intersegmental folds of the abdomen (Marti et al. 1990).

In summary, *N. guyanense* population fluctuations during the year were correlated with variations in temperature and humidity, with other factors also likely being important. Hence, the seasonal chronology of *N. guyanense* may vary among locations. We found little association of humidity with nematode populations. Most locations were humid, and relative humidity fluctuations during the year were usually not dramatic; similarly, temperature varied little at the more tropical locations. We had hoped to compare humidity effects on *N. guyanense* from the more arid Texas location with the

effects from more humid locations, but parasitism of *S. frugiperda* at the former location was too low. These field data, coupled with laboratory studies (e.g., Simmons & Rogers 1990b) provide vital basic information to help us understand the field biology of *N. guyanense* on *S. frugiperda* and other pest lepidopterans. However, much additional research, including the impact of *N. guyanense* on host survival, host migratory ability, etc., in the laboratory and field are needed to ascertain its utility as a natural enemy in pest management schemes.

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ANNOTATED BIBLIOGRAPHY OF THE GRAPE ROOT BORER (LEPIDOPTERA: SESIIDAE)

ROGER N. WILLIAMS
Department of Entomology
Ohio Agricultural Research and Development Center
The Ohio State University
Wooster, Ohio 44691

J. WENDELL SNOW
Tropical Fruit & Vegetable Research Laboratory
USDA-ARS
P. O. Box 2280
Honolulu, Hawaii 96822

ABSTRACT

An annotated bibliography of the grape root borer, *Vitacea polistiformis* (Harris) is presented. The entries include information on the biology, control, damage impact, distribution, and importance of the species in the eastern United States. This pest is of growing importance to the commercial grape industry.

RESUMEN

Se presenta una bibliografía del barrenador de la uva *Vitacea polistiformis*. La bibliografía incluye información sobre la biología, control, daño, distribución, e importancia de las especies en el Este de los Estados Unidos. Esta plaga está aumentando en importancia para la industria comercial viticola.

The grape root borer, *Vitacea polistiformis* (Harris) (Lepidoptera: Sesiidae) is an important pest on grapes in the eastern United States. The species has an obligate diapause and attacks the roots of grape vines. The life cycle requires two years, approximately twenty three months of which are spent as larvae feeding within and under the cambium of the root tissue. Pupation begins in early summer of the second year, and depending on geographic location, adults fly from mid-June through October.

The most recent information on distribution shows that the species occurs as far south in the United States as central Florida and as far north as southwestern Michigan (Snow et al. 1989). This area includes all of the Atlantic Coast states south of Connecticut and east of Kansas. Populations are greatest in the southern states, with incidence gradually decreasing the further north one goes. The species has been recorded in significant numbers in southern Pennsylvania (Jubb 1982) and Ohio (Alm et al. 1989), but it does not occur in the northern areas of these states around Lake Erie, where there is a concentration of commercial grape production. However, it is reported from southwestern Michigan along Lake Michigan.

Damage caused by the grape root borer has resulted in enormous losses to the commercial grape industry. It has been blamed for the destruction of entire vineyards in Florida (Adlerz 1982), and in South Carolina, it is cited as the cause of the total cessation of bunch grape production (Pollet 1975). Dutcher & All (1979) determined that a single larva is capable of causing a 6% girdling of the vine trunk which is associated

with a 47% reduction in yield. Those authors also indicate that two or three larvae are capable of killing an entire vine if they are feeding in an essential part of the root system.

All varieties of grapes, both cultivated and wild are subject to attack by the grape root borer. For many years, 'Scuppernong', a variety of muscadine, was thought to be resistant to attack (Brooks 1907), but this later proved incorrect (Wylie 1972).

Several natural enemies have been documented over the years. Among these are the barn swallow *Hirundo rustica erythrogaster* Boddaert, the mockingbird *Mimus polyglottos polyglottos* (L.), the crested flycatcher *Myiarchus crinitus* (L.), the braconid wasp parasite *Bracon caulicola* (Gahan), the lightning bug larva *Photuris pennsylvanica* De Gerr, the nematode *Neoaplectana carpocapsae* Weiser, and two insect pathogenic fungi, *Beauvaria bassiana* (Balsamo) and *Metarrhizium anisopliae* (Metchnikoff) (lark & Enns 1964, Sarai 1972, Dutcher & All 1977, Brooks 1907, and Sorensen 1975).

Many methods of cultural control have been attempted. Some of the earliest methods involved techniques such as pouring hot water on the exposed roots to scald the larvae (Saunders 1889), or simply replanting vineyards away from old, infested ones (Ritcher 1939). Today, the best cultural method appears to be mounding of soil under the vines to prevent emergence of adults. Dutcher & All (1985) reported this technique results in an 83% reduction in adult emergence. This method is also successful in preventing new larvae from penetrating the soil (All & Dutcher 1978). Attwood (1963) and Wylie (1972) reported polyethylene strips placed under grape trellises were effective as a control.

The best method of control at the present time is with insecticides. All et al. (1982) reported chlorpyrifos (Lorsban) effective in killing newly-hatched larvae. Ethylene dibromide and ethylene dichloride are also effective against larvae if applied correctly. All & Dutcher (1977) demonstrated that a pressure-flow injection device is the most practical method of injecting toxicants into the soil. Other methods of application, such as soil surface applications, foliar sprays, and systemics, gave less than satisfactory results.

The discovery by Schwarz et al. (1983) of the grape root borer pheromone, (*E*,*Z*)-2,13 octadecadien-1-ol acetate and its later improvement by Snow et al. (1987) provided researchers with a reliable tool for monitoring the adult seasonal activity of the species. As a result, the timing of control measures can now be scheduled more efficiently than in the past, when exuviae counts were the only means of detecting the pest. Future expansion of this technology may lead to improved methods of control.

It has been our attempt in this publication to provide researchers and other interested persons with all the published information available on the grape root borer, including biology, distribution, economic importance, and control. The bibliography provides the literature citations necessary for obtaining the articles, and the annotations summarize the contents of the articles. The subject index is designed to lead the reader to articles that deal with particular subjects. A few publications that we were unable to obtain are not annotated, but most of them are old and outdated.

This paper was written because of increased grape production in the eastern United States and an increased interest in *V. polistiformis* due to its growing economic importance.

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24. Brooks, F. E. 1918. Papers on deciduous fruit insects: II. The grape root borer. U. S. Dept. of Agric. Bull. 730:1-28. Reports research observations in West Virginia in 1916 and 1917. Nature of injury and life stages described and pictured. Natural enemies and cultural control discussed. Thorough cultivation of the soil around the vines in June and July beneficial in destroying larvae and pupae.
25. Clark G. N., and W. R. Enns. 1964. Life history studies of the grape root borer (Lepidoptera: Sesiidae) in Missouri. J. Kansas Entomol. Soc. 37:57-63. Excellent paper on the biology and economic importance in Missouri. Reported as serious pest. Some vineyards completely destroyed. Adults reported to emerge from July to September in single or bimodal peaks. Observations on mating and number of eggs laid also reported. Most ovipositions on weeds beneath the vines or on low hanging leaves of grapevine. No larval preference reported for age or size of roots attacked. As many as 25 larvae reported within 1 ft radius of crowns. *Beauvaria bassiana* and *Metarrhizium anisopliae* reported as fungal pathogens. Birds reported as predators of adults.
26. Davidson, R. H., and W. F. Lyon. 1979 (7th Ed.). Grape root borer. Insect Pests of Farm, Garden, and Orchard. John Wiley & Sons, New York. p. 439. Describes the pest and damage. Pictures of larvae and adults.
27. Duckworth, W. D., and T. D. Eichlin. 1973. The type material of North American clearwing moths (Lepidoptera: Sesiidae). Smithsonian Contrib. to Zoology. 148:34. Lists the type and holotype of *Vitacea polistiformis* from 'Huron' as located in the United States north of Mexico.
28. Duckworth, W. D., and T. D. Eichlin. 1977. A classification of the Sesiidae of America north of Mexico (Lepidoptera: Sesiidae). Occasional Papers in Entomol. California Dep. of Food and Agric., Div. Plant Ind., Sacramento, California. pp. 26-54. Taxonomic paper includes description of genus *Vitacea*. Four species listed as belonging to genus, all of which attack various plants in family Vitaceae.
29. Dutcher, J. D., and J. N. All. 1976. Beware the grape root borer! J. Am. Fruit Grower. 76:18-19. Popular article written for growers. Discusses life cycle and chemical control.
30. Dutcher, J. D., and J. N. All. 1977. The summer activity, damage impact, and

control of the grape root borer in northeast Georgia. Proc. S. E. Branch Entomol. Soc. Am. 51:9-10. Discusses the biology and behavior in northeast Georgia. Recommends methods of chemical and cultural control.

31. Dutcher, J. D., and J. N. All. 1978. Predictive models for the summer activity of *Vitacea polistiformis* in Concord grape vineyards. Environ. Entomol. 7(3):456-460. Summer activity in three northern Georgia 'Concord' vineyards presented as set of regression models of pupal development and grape berry sugar accumulation as state variables forced by degree-day input. Significant correlation between these two phenological regressions. Useful pest management tool which can predict pupal development state from accumulated berry sugar content.
32. Dutcher, J. D., and J. N. All. 1978. Survivorship of the grape root borer in commercial grape vineyards with contrasting cultural practices. J. Econ. Entomol. 72:751-754. Life tables constructed for single two year generations of grape root borer in two 'Concord' grape vineyards with contrasting cultural systems. With scheduled insecticide treatments, annual intertrellis tillage, and 4-arm Kniffin training system, egg mortality from predation 11.6% and egg hatchability of eggs not killed by predators 25.3%. With no insecticide treatment, no annual tillage, and Modified Munson training system, egg mortality by predation 61.7% and egg hatchability 76.8%. No significant differences for survival of subterranean life stages. Lowest survival in larval period from eclosion from egg to establishment of first feeding site; highest survival in larval period spent in feeding site and during pupal stage.
33. Dutcher, J. D., and J. N. All. 1978. Reproductive behavior of *Vitacea polistiformis* (Harris). J. Georgia Entomol. Soc. 13(1):59-63. Mating, calling behavior, and oviposition cycle presented in excellent detail. Mating occurs between 1300 and 1800 hours and is completed in one to four hours. Male moths attracted to a calling female exhibit characteristic mating sequence. Male briefly contacts female antennae, then hovers over the female abdomen, thrusting with genitalia, then couples. Oviposition begins between 8:00 and 9:00 on morning following mating and continues during day for up to eight days. Moths oviposit 51% of eggs within 24 hours of mating. Mean fecundity 354 eggs/female. Mean incubation period 14 days at 30 degrees C. Squash vine borer males attracted to calling grape root borer females, but repelled when flying within 1-2 cm of the female.
34. Dutcher, J. D., and J. N. All. 1979. Biology and control of the grape root borer in Concord grape vineyards. Fruit South. 3(5):6-8, 11-15. Very good overview. Includes literature overview and own research over five year period. Data presented deal with reproductive behavior, bionomics, and control, and pest management strategy proposed. Control achieved by combining subsurface applications of fumigants against subterranean larvae and pupae, accurate timing of foliar insecticides against moths, and soil mounding to prevent adult emergence from soil and neonate larva from reaching grapevine roots. Natural enemies of subterranean stages, particularly *M. anisopliae*, *B. bassiana*, and *N.* (=*Steinernema*) *carpocapsae*, enhanced by increasing soil moisture through irrigation.
35. Dutcher, J. D., and J. N. All. 1978. Models of distribution of *Vitacea polistiformis* in Concord grape vineyards. Environ. Entomol. 7(3):461-465. Distribution of larvae and pupae around grape vines reported. Pupae distributed evenly around trunk base with no significant angular orientation. Pupal density decreases exponentially from trunk base to periphery area. Small larvae distributed evenly throughout sampled area. Medium to large larvae skewed toward larger roots and trunk base.
36. Dutcher, J. D., and J. N. All. 1979. Biology and control of the grape root borer in Concord grape vineyards. Georgia Agric. Exp. Sta. Res. Bull. 232:18 pp. Extensive coverage of biology and control by authors in recent years.

37. Dutcher, J. D., and J. N. All. 1979. Damage impact of larval feeding of the grape root borer in a commercial Concord grape vineyard. J. Econ. Entomol. 72:159-161. Relationship between root injury by grape root borer and vine vigor parameters in a commercial vineyard. Single larva can cause a 6% girdling of the trunk base, associated with 47% reduction in yield. Feeding on trunk base much more detrimental than feeding in peripheral roots. Low economic injury level of grape root borer suggests an even lower economic threshold level. Conclude that insecticidal control measures should be used as soon as presence of grape root borer is detected in vineyard.
38. Edwards, J. 1889. Bibliographical catalogue of the described transformations of the North American Lepidoptera. United States Nat. Mus. Bull. 35:147. Reports on the grape root borer in the United States in the early 1850s-1880s. Includes larval, pupal, adult, and damage reports. Reported as *Sciapteron polistiformis* (in U.S.).
39. Eichlin, T. D., and W. D. Duckworth. 1988. The moths of America north of Mexico. Sesioidea: Sesiidae. Fascicle 5.1. The Wedge Entomological Research Foundation. p. 1-176. Recent, complete source of information on family Sesiidae. Includes taxonomic descriptions and classifications of all known species, as well as life history, biology, life cycle, host preference, damage, distribution, and seasonality. When known, sex pheromone preference given, and color plates provided for 64 species.
40. Engelhardt, G. P. 1946. The North American clear-wing moths of the family Aegeriidae. United States Nat. Mus. Bull. 190:1-222. Contains thorough discussion of taxonomic classifications, host range, seasonal cycles, importance, and distribution. Very useful when overview of insect needed.
41. Fitch, A. 1856. Third report of the noxious, beneficial, and other insects of the state of New York. Trans. New York State Agric. Soc. 16:387, 423, 429. Grape root borer reported from North Carolina.
42. Forbes, W. T. M. 1923. The Lepidoptera of New York and neighboring states. Cornell Agric. Exp. Sta. Mem. 68:360-374. Gives brief taxonomic description.
43. French, G. H. 1878. Economic entomology in Illinois. Seventh report of the state entomologist on the noxious and beneficial insects of Illinois for 1877.
44. Glover, T. 1855. Rep. U.S. Com. Pat., 1854, p. 80, pl.6, figs.
45. Glover, T. 1868. Rep. U.S. Comm. Agric., 1867, p. 72, figs; 1873, p. 59, 1874.
46. Glover, T. 1873. Entomological record. In U.S. Dept. Agric. monthly report for Oct., p. 496-499. According to Brooks 1918, Glover reported 5000 vines, representing 107 varieties imported from Paris and planted at Albermarle, North Carolina, lost as result of attack by grape root borer.
47. Glover, T. 1867. Monthly Report (USDA), Oct:329. Grape root borer reported as attacking grapes near Albermarle, North Carolina and probable report given for Cincinnati, Ohio. 'Scuppernong' reported as resistant to attack.
48. Gray, P. A., and D. T. Johnson. 1983. Survival of the nematode *Neoaplectana carpocapsae* in relation to soil temperature, moisture and time. J. Georgia Entomol. Soc. 18(4):454-460. Technique described for extracting nema from soil. Laboratory study showed highest survival in soil at 30° C. Survival declined significantly as temperature exceeded 35° C. Nematodes collected from infected grape root borer larvae. Reared on greater wax moth larvae.
49. Harris, T. W. 1854. Report on some of the diseases and insects affecting trees and vines. Proc. Am. Pomol. Soc. Cong. of 1854:197-217. Gives an early account of grape root borer on grapes. Includes general description of all stages, along with damage and biology as known at the time.
50. Harris, T. W. 1854. Note upon the insects injurious to the roots of the cultivated grape vine in North Carolina. In E. Mitchell, The Grape Vine. Raleigh Register

Semi-Weekly, 5 April:2. According to Bambara 1977, in this article the grape root borer originally named *Aegeria polistiformis* by Harris. In addition to original description, notes given on habits.

51. Holland, W. J. 1968. The Moth Book - a popular guide to a knowledge of the moths of North America. Dover Publ. Inc., New York: 379-390. Grape root borer listed as *Memythrus polistiformis* (Harris). Brief taxonomic description included. Excellent color plates.
52. Horton, D. 1988. Identifying and controlling your grape root borer problem. Proc. Viticul. Sci. Sym., Florida A & M Univ. p. 178-182. General, extension-type paper discusses biology and control of grape root borer in Georgia. Mounding of soil and Lorsban recommended for control. Suggests pheromone trapping to monitor seasonality to determine best time for control measures.
53. Hunt, T. N. 1973. The grape root borer, *Vitacea polistiformis* (Lepidoptera: Aegeriidae). North Carolina State Univ. Entomol. Insect Survey Notes. (July 31, 1973). 3 pp. Very nice line drawings of adult, empty pupal skin at soil interface, and mature larva. Reviews biology, economic importance, and distribution in North Carolina.
54. Hunt, T. N. 1973. Grape root borer distribution survey. North Carolina State Univ. Entomol. Insect Survey Notes. (Aug. 12-Oct. 1, 1973). 6 pp. Reports 16 North Carolina counties infested with grape root borer. Flight occurs mainly during mid-August.
55. Johnson, D. T. 1979. Progress report on grape insect research. Proc. Arkansas State Hort. Soc. 100:87-90. Data presented on number of grape root borer that emerged weekly in 1979, based on exuviae counts on soil beneath vines. First emergence July 20, and last emergence Sep. 25. Peak emergence during last week of August and first week of September. The value of "hoed soil to the row" discussed.
56. Johnson, D. T., R. L. Mayes, and P. A. Gray. 1981. Status of grape root borer (Lepidoptera: Sesiidae) management and feasibility of control by disruption of mating communication. Misc. Publ. 12(2):1-7. Provides general review of literature and reports attempts to disrupt mating with (*Z*,*Z*)-3,13 octadecadien-1-ol acetate, peachtree borer pheromone. Results indicated pheromone disrupted mating communication. However, pheromone captured only one male in traps, indicating not suitable for monitoring grape root borer activity.
57. Johnson, D. T., J. R. Meyer, and R. L. Mayes. 1986. Evaluation of Hercon laminated dispensers baited with Z,Z-3,13-octadecadien-1 ol acetate for suppression of the grape root borer, *Vitacea polistiformis* (Harris), (Lepidoptera: Sesiidae), populations in grapes. J. Entomol. Sci. 21(3):231-236. Z,Z-3,13-octadecadien-1 ol acetate, major component of peachtree borer pheromone, evaluated in vineyards in Arkansas and North Carolina as mating disruptant and population suppressant. Density decreased twice as fast in pheromone treated plots than in check plots.
58. Jubb, G. L., Jr. 1982. Occurrence of the grape root borer, *Vitacea polistiformis* in Pennsylvania. Melsheimer Entomol. Series. 32:20-24. Gives a good account of occurrence in Pennsylvania as of 1982. Based on pupal cases and larval collections, 11 of 44 commercial vineyards and backyard plantings in southern Pennsylvania infested. Infestation ranged from 0.8% to 37.5% of sampled vines. Counties infested: Adams, Cumberland, Lancaster, Lebanon, Northumberland, York.
59. Kellicott, D. S. 1890. Our injurious Aegeriians. J. Columbus Hort. Soc. 5:11-19. Mimicry among Sesiidae discussed in detail. Grape root borer not important in Ohio.
60. Keularts, J. L. W., and R. N. Williams. 1989. Survey and control attempts of grape root borer and erineum mite. Proc. Ohio Grape-Wine Short Course. Ohio

Agric. Res. & Dev. Ctr., Hort. Series 598:28-30. At present, grape root borer found only in southern half of Ohio. Monitoring northern half of state will continue to see if range extends. Current research activities aimed at control include cultural control (plastic mulch), chemical control (chlorpyrifos), and use of confusion/disruption technique.

61. Klun, J. A., M. Schwarz, B. A. Leonhardt, and W. W. Cantelo. 1990. Sex pheromone of the female squash vine borer (Lepidoptera: Sesiidae). J. Entomol. Sci. 25(1):64-72. Synergic effect of combination of 2,13 and 3,13 isomers for improved attraction of grape root borer males compared with attraction of squash vine borer males.
62. Kron, F. J. 1854. To all cultivators of the grape vine in the south. In E. Mitchell, The Grape Vine. Raleigh Register Semi-Weekly, 5 April:2. According to Bambara 1977, this was first report of grape root borer attacking cultivated grapes in North Carolina. Adult activity reported from 8:00 AM to 6:00 PM with peak activity about 1:00 PM.
63. Lugger. 1895. Fourth Annual Report of the Entomologist. Agric. Exp. Sta., Minnesota. 1868.
64. Lugger. 1898. Butterflies and moths injurious to our fruit-producing plants. Minnesota. Agric. Exp. Sta. Bull. 61:55-334. Single moth seen flying about wild grapevine in Minnesota in 1898. Information on grape root borer found on p. 109-111.
65. MacKay, M. R. 1968. The North American Aegeriidae (Lepidoptera). A revision based on late instar larvae. Mem. Entomol. Soc. Canada. 58:112. Contains revision of family based on larval characteristics of about 60 species. Discusses and illustrates larval characteristics for most species. Larvae of grape root borer collected from French Creek, West Virginia; Atlanta, Georgia; and Tifton, Georgia.
66. Marten, J. 1881. Tenth report of the state entomologist on the noxious and beneficial insects of the state of Illinois. Trans Illinois Dep. Agric. for 1880:106-110. Provides brief discussion and description of larval stages and damage caused by larvae of economically important sesiid species.
67. Mason, E. P. 1969. Efficacy of the green muscadine fungus, *Metarrhizium anisopliae* (Metch) Sor., against the grape root borer, *Vitacea polistiformis* (Harris) (Lepidoptera: Sesiidae) in northwestern Arkansas. Masters Thesis, Univ. Arkansas. 52 pp.
68. McDunnough, J. 1939. Check list of the Lepidoptera of Canada and the United States of America. pt. 2, no. 8796. Grape root borer listed as *Paranthrene polistiformis*.
69. McGiffen, K. C., and H. H. Neunzig. 1985. A guide to the identification and biology of insects feeding on muscadine and bunch grapes in North Carolina. North Carolina Agric. Res. Ser. Bull. 470:50-51. Very good general publication on grape root borer in North Carolina. Grape root borer considered most destructive insect pest on grapes. Discusses biology, host plant, and economic importance. Descriptions of egg, last stage larva, pupa, and adult given. Adult emergence in North Carolina begins in early July and continues into September with peak flight in mid- to late July. Populations scattered and variable in intensity. Discusses mimicry (likeness to Polistes wasps), sexual behavior, and oviposition. One hymenopterous parasite, *Bracon caulicola* (Gahan) listed. Cerambycid larvae also found in grape vine roots; differ from grape root borer in lacking well-developed thoracic legs, prolegs, and crochets.
70. McGuire, J. M., and W. D. Wylie. 1969. Nematode parasites of insects: the possibility of utilizing certain nematodes for biological control of some insect pests is being explored. Arkansas Farm Res. 18(3):12. Discusses nematodes as biological control for several species of insects. *Neoaplectana* (=*Steinernema*) species found

to parasitize grape root borer. They carry bacterium, *Pseudomonas aeruginosa* or *P. septica*, which is fatal to insect (septicemia). Field tests with nematode against peach tree borer were conducted in Arkansas. Nematodes sprayed onto vine trunks with low pressure sprayer. Adequate moisture critical to infestation.

71. Metcalf, C. L., W. P. Flint, and R. L. Metcalf. 1962 (4th Ed.). Destructive and useful insects, their habits and control. McGraw Hill Book Co., New York. 1087 pp. On p. 772 in field key of insects attacking grape is description of mature grape root borer larva and damage to roots.
72. Mitchell, E. 1854. The grape vine. Raleigh Register Semi-Weekly. 5 Apr:2.
73. Nielsen, D. G., F. F. Purrington, and G. F. Shambaugh. 1977. EAG and field responses of sesiid males to sex pheromones and related compounds. In Pheromones of the Sesiidae. USDA, SEA, Agric. Res. Results ARR-NE6-6:11-25. Deals with pheromones identified for clearwing moths and responses to those pheromones. Research done before identification of the grape root borer pheromone, but some captures recorded in traps baited with a combination of (*Z*,*Z*) ODDA and two alcohols.
74. O'Kane, W. C. 1924. Injurious insects - how to recognize and control them. MacMillan and Co., New York: p. 231-232, 237-241, 243-244. Gives brief account of grape root borer. Cultivation in June and July cited as destroying many pupae.
75. Packard, A. S. 1889. Guide to the study of insects and a treatise on those injurious and beneficial to crops, for the use of colleges, farm-schools, and agriculturalists. Henry Holt and Co., New York: 276-279. 'Scuppernong' reported as resistant; later disproved. General description of life stages also reported.
76. Pollet, D. K. 1975. The grape root borer in South Carolina. Clemson Univ. Ext. Ser. Circ. 550:7. Extension-type paper that first reports grape root borer in South Carolina in 1967. Since that time, 300-350 acres of bunch grapes have been destroyed, and yields greatly reduced. As a result, some counties have ceased bunch grape production. Reported in 22 counties. No chemical control cited, but mounding with grape hoe reported as providing good control. Time of activity in South Carolina cited as early as June 27 and as late as Sep. 20. Peak activity reported about August 15. Two year life cycle reported.
77. Quaintance A. L., and C. L. Shear. 1921. Insect and fungus enemies of the grape. Farmers Bull. USDA, 1220:43-45. Contains brief description of insect and its damage. Photographs of damage, adult moths, and cocoons included.
78. Riley, C. V. 1871. Third annual report on the noxious, beneficial, and other insects of the state of Missouri. Jefferson City, Missouri. 57 pp. Mentions destructiveness of grape root borer in Kentucky and recorded capturing adults in Missouri.
79. Riley, C. V. 1873. Editorial summary - grape vine borers. Canadian Entomol. 5:218. Grape root borer reported as attacking all varieties of grape in North Carolina except 'Scuppernong'.
80. Ritcher, P. O., W. D. Valleau, and W. W. Magill. 1939. Fruit pests and their control. Kentucky Agric. Exp. Sta. Bull. 393:119-179. Grape root borer reported as important pest of grapes, particularly in eastern Kentucky. Suggests replanting vineyards as far away as possible from infested vines as control.
81. Sarai, D. S. 1969. Effect of burial of grape root borer pupae on adult emergence. J. Econ. Entomol. 62:1507-1508. Soil hoed out from vineyard, then thrown back on grapevine roots with grape hoe when most of mature larvae had pupated. Data showed ridge about 7.5 inches high and two feet wide gave effective control of pupae. Considered practical by author and also helped to control weeds. Seasonal adult cycle also given for both control and treated plots.
82. Sarai, D. S. 1972. Seasonal history and effect of soil moisture on mortality of newly hatched larvae of the grape root borer in southern Missouri. J. Econ. Entomol. 65:182-184. General paper on seasonality of grape root borer. Details of

head capsule measurements, oviposition, seasonal pattern of emergence, survival in roots with different moisture levels, etc., covered. Concludes three year life cycle probable, based on presence of three different sizes of larvae in roots. Peak adult emergence on Aug. 10, 1987, and July 25, 1968. Larvae and some pupae attacked by *Beauvaria bassiana* and *Metarrhizium anisopliae*.

83. Saunders, M. C., and J. N. All. 1985. Association of entomophilic rhabditoid nematode populations with natural control of first-instar larvae of the grape root borer, *Vitacea polistiformis*, in Concord grape vineyards. J. Invert. Path. 45(2):147-151. Laboratory and field bioassays determined susceptibility of 1st instar larvae to entomophilic rhabditoid nematode, *Neoaplectana* (=*Steinernema*) *carpocapsae*. Augmentation of nema population during critical period of oviposition and eclosion suggested as control technique.
84. Saunders, W. 1889 (2nd Ed.). Insects injurious to fruits. J. B. Lippincott & Co., p. 229. General, extension-type paper on grape root borer as known in 1889. General description of life stages. Suggested control: remove earth from the vine and apply hot water. Also, mounding as recommended for peachtree borer cited as probably beneficial.
85. Schmidt, J., and J. N. All. 1978. Chemical attraction of *Neoaplectana carpocapsae* (Nematoda: Steinernematidae) to insect larvae. Environ. Entomol. 7:605-607. *Neoaplectana* (=*Steinernema*) *carpocapsae* isolated from grape root borer larva and cultured in laboratory on several insect species (not grape root borer). Nematode tested against several other insect species.
86. Schwarz, M. T., J. A. Klun, B. A. Leonhardt, and D. T. Johnson. 1983. (*E*,*Z*)-2,13 octadecadien-1-ol acetate. A new pheromone structure for sesiid moths. Tetrahedron Letters. 24(10):1007-1010. Grape root borer pheromone identified as (*E*,*Z*)-2,13 octadecadien-1-ol acetate. Biological activity established by capture of grape root borer males in traps and by visual observation of male flight activity in vicinity of traps. Attractiveness of synthetic pheromone not compared with virgin females because of their unavailability.
87. Sharp, J. L., and T. D. Eichlin. 1979. Distribution and seasonal occurrence of Sesiidae (Lepidoptera) attracted to E,Z and Z,Z acetate and alcohol. Florida Entomol. 61(4):245-250. Male captured in Broward County, Florida on July 2, 1978 in a trap baited with (*Z*,*Z*)-3,13 ODDA (not its attractant). Three additional males captured on Sept. 4, 1978.
88. Slingerland, M. V., and C. R. Crosby. 1922. Manual of fruit insects. (The grapevine root borer, *Memythrus polistiformis* (Harris), pp. 452-454.) MacMillan Co., New York. 503 pp. Life cycle and distribution given. Frequent shallow cultivation of vineyard from mid-June to mid-July said to reduce number of moths present.
89. Snow, J. W., M. Schwarz, and J. A. Klun. 1987. The attraction of the grape root borer, *Vitacea polistiformis* (Lepidoptera: Sesiidae) to (*E*,*Z*)-2,13 octadecadien-1-ol acetate and the effects of related isomers on attraction. J. Entomol. Sci. 22(4):371-374. The addition of one (1) percent (*Z*,*Z*)-3,13 octadecadien-1-ol acetate to the grape root borer pheromone. (*E*,*Z*)-2,13 octadecadien-1-ol acetate, greatly increased capture of males in sticky traps. Numbers collected increased from three to seven times, depending on test, location, and time of season. New blend sufficiently attractive to provide effective monitoring system.
90. Snow, J. W., M. Schwarz, and T. D. Eichlin. 1989. Captures of clearwing moths (Lepidoptera: Sesiidae) with various octadecadienyl acetates and alcohols in central Georgia in 1983-1985. Environ. Entomol. 18(2):216-222. Reports on the results of trapping with (*E*,*Z*)-2,13 octadecadien-1-ol acetate and various blends containing that compound. Twelve species of sesiid moths collected in traps; grape root borer collected in all blends containing (*E*,*Z*)-2,13 ODDA.

91. Snow, J. W., D. T. Johnson, J. R. Meyer, D. G. Pfeiffer, R. F. Mizell, M. C. Saunders, J. N. All, C. S. Gorsuch, J. D. Dutcher, R. N. Williams, S. R. Alm, J. H. Jarratt, J. C. Killian, W. C. Adlerz, W. Taft, D. Smitley, S. R. Race, H. G. Townsend, G. L. Jubb, M. Schwarz, and T. D. Eichlin. 1991. The seasonal occurrence of the grape root borer, *Vitacea polistiformis* (Harris) in the Eastern United States. In Press: J. Entomol. Sci. Seasonality of grape root borer in 13 eastern states determined by trapping with the sex attractants (*E*,*Z*)-2,13 ODDA and (*E*,*Z*)-2,13 ODDA/(*Z*,*Z*)-3,13 ODDA 99:1. Activity began about same time in all states, but peak flight occurred later in southern states than in northern states. Bimodal curves most common in the South, and single peaks most common in the North.
92. Sorensen, K. A. 1973. The grape root borer. North Carolina State Univ. Entomol. Fruit Insect Note. G-3. Extension-type publication covers damage, detection, life history, habits, and chemical control. Natural enemies, root stocks, sex attractants, and cultural methods listed as potential controls. Very good general publication.
93. Sorensen, K. A. 1975. The grape root borer: present status of research and control. J. Vinifera Wine Growers, 2:24-27. Grower-type review article covering life history, host plants, detection, natural enemies, and control. Excellent figures included on adult, larvae, life cycle, seasonal occurrence, and effect of soil depth on survival.
94. Still, G. W., and R. W. Rings. 1973. Insect and mite pests of grapes in Ohio. Ohio Agric. Res. & Dev. Ctr. Res. Bull. 1060: 30 pp. Short write-up on grape root borer. Describes damage and brief biology. Contains figures depicting life stages and damage to vine.
95. Stout, O. E. 1879/1880. Rep. Kansas Hort. Soc. p. 88. Makes a brief mention of grape root borer and its seasonal cycle.
96. Swartout, H. G., and W. R. Enns. 1967. Suggestions for spraying commercial grape vineyards. Univ. of Missouri Ext. Div., p. 4. Extension-type circular for control of diseases and insects of grapes in Missouri. No chemical control listed for the grape root borer, but cultural control, including keeping the vineyard free of weeds, frequent disking, and hoeing recommended.
97. Syme, P. D. 1961. The morphology of lepidopterous eggs with descriptions of two hundred and forty-eight species. Ph.D. Thesis, Univ. of Toronto Canada. 171 pp. Fairly detailed description given for grape root borer egg.
98. Taft, W., D. Smitley, and J. W. Snow. 1991. A guide to the clearwing borers (Sesiidae) of the north central United States. In Press: North Central Regional Coop. Ext. Service. Michigan State Univ., E. Lansing, Michigan. Briefly discusses biology and importance of grape root borer in Michigan. Many fine color pictures of clearwing moths.
99. Taylor, R. 1965. A progress and status report on the grape root borer. Proc. Arkansas State Hort. Soc. 86:26-27. Mentions several possible natural enemies: skunks, rats, mice, and birds along with a green muscadine fungus. Insecticides tested against young larvae as they entered the soil, before becoming established on the roots. Guthion and Diazinon controlled young larvae up to eight weeks after application.
100. Tietz, H. M. 1959. The Lepidoptera of Pennsylvania. A Manual. Pennsylvania State College of Agric. Exp. Sta. 194. Grape root borer listed as problem on wild and cultivated grapes in Pennsylvania.
101. Townsend, H. C. 1980. Grape insect research. Proc. Arkansas State Hort. Soc. 101:107-110. Major insect problem in grapes in Missouri, thus, most entomological research conducted on it. Studying life history, chemical control, and laboratory

rearing. Air and soil temperature at surface and 3 inches below surface monitored during adult emergence period. Vines with no grape root borer emergence average yield were 4.97 kg per vine; vines from which 6 grape root borer emerged averaged only 2.41 kg per vine. Yield increased as distance from old vineyard increased.

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ENDNOTES

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PASSIVE CHOICE AND POSSIBLE MATE GUARDING IN THE STONEFLY *PTERONARCELLA BADIA* (PLECOPTERA: PTERONARCYIDAE)

DAVID D. ZEIGLER
Department of Biology
Box 5087
Pembroke State University
Pembroke, NC 28372

ABSTRACT

Evidence for passive choice for near males in *Pteronarcella badia* was demonstrated by comparing female answering rates to near males (30 cm distance) versus distant males (60 cm distance). Though statistically different, female answering rates were high to both near and distant males suggesting that males may engage in a form of scramble competition to locate the female before another competing male(s). Evidence for mate guarding in *P. badia* is presented and discussed. The possibility of purposeful interference signaling between near and distant males was considered, but the data gave no indication of this behavior.

RESUMEN

La evidencia para la selección pasiva de machos cercanos de *Pteronarcella badia* se demostró comparando las respuestas de las hembras a los machos cercanos (30 cm. de distancia) y contra los machos distantes (60 cm de distancia). Aunque estadisticamente diferente, las respuestas de las hembras hacia los machos fueron altas a ambos, cercanos y distantes, sugiriendo que los machos podrian entregarse a una forma de competencia confusa para localizar las hembra antes que otro contendiente. La evidencia para un guardián del macho o hembra en *P. badia* es tambien presentada y discutida. Se consideró la posibilidad de un sistema de señales de interferencia intencional entre los machos cercanos y distantes pero la evidencia no proveyó indicaciones claras de esta conducta.

Parker (1982) defined passive choice as the random attraction of females to the male signal of highest intensity. The term random here implies that signal intensity is the overriding criteria which a female will use to select a male when signals from two or more males are being received. Parker contrasted passive choice, which he viewed as less costly, to active choice which implies that certain males are rejected as mates for reasons other than their signal intensity. Searcy & Andersson (1986) elaborated on this concept by pointing out that if intensity is taken to mean loudness, then the relative proximity of two or more males should be an important factor in instances of passive choice. Assuming a small variance in individual calling intensity, the nearest male should on average produce the most intense call, and females using passive choice should move toward (or in some way select) the near male because his is perceived as the most intense signal.

Searcy & Andersson (1986) suggested that male proximity might actually be the key factor in passive choice decisions since moving toward or selecting near males might involve less costs to the female. These costs would include the time, energy, and risks required to move toward the male. The present work attempts to detect evidence for female passive choice in the stonefly *Pteronarcella badia* (Hagen). Many stonefly species, including *P. badia* (Zeigler & Stewart 1977), are known to engage in an intersexual vibrational communication termed drumming. Males produce call signals, and receptive

virgin females answer with their own distinct signal. In stoneflies, the female typically remains stationary between drumming exchanges while the male searches (Stewart & Zeigler 1984a). Nevertheless, females should be capable of detecting the relative distances of signaling males through intensity cues. Females might still benefit by utilizing passive choice since near males should be able to locate the female more successfully and in less time than a distant male with more terrain to traverse. Also, near males may have positioned themselves more effectively in prime sites for female detection.

Materials and Methods

Mature *Pteronarcella badia* nymphs were collected from the Conejos River, Conejos Co., CO in mid-June 1988 and reared in styrofoam ice chests near streamside. Adults were separated at emergence to insure virgin condition. Passive choice experiments were done near streamside in natural shaded lighting. The passive choice test utilized an arrangement of three acoustically coupled containment chambers (Fig. 1). Each triangular chamber measured 7.5 cm on a side and 1.5 cm deep. The sides and floor were made of balsa wood 1.5 mm in thickness. A lid of clear plastic (not shown in figure) permitted observations from above. The long central rod and two lateral connector rods were wooden dowels 4.0 mm in diameter. All joints were made with a non-toxic wood glue (Elmers®) and the whole construction was suspended at either end by short columns of modeling clay. The linear distance from the center of the female chamber to the center of the near-male chamber was 30 cm. The distance from the center of the female chamber to the center of the distant-male chamber was 60 cm.

The distant-male chamber was monitored using a directional electret condenser microphone placed 3.0 mm below the chamber center. The female chamber was monitored by way of a substrate transducer (an ADC® XLM MKII phono cartridge) which was coupled to one corner of her enclosure. The two channels were recorded in stereo (Yamaha® TC-320 cassette deck) on cassette tape and later played into a Tektronix® 5111 dual-beam storage oscilloscope for final analysis. Figure 2 shows a portion of one "trio run" with the distant male channel on the lower trace. The upper trace using the more sensitive substrate transducer effectively picks up all three individuals whereas the lower trace (channel) picks up only the two males (male signal amplitude is greater than that of female signals).

Before leaving the river, freshly collected nymphs were placed in ice chests for transport to, and rearing in, the lab (at Southwest Texas State University, San Marcos, TX) where observations of direct interactions were made with the insects in square containment chambers of balsa wood 6.5 cm on a side and 1.5 cm deep with clear plastic lids. Event durations are reported as means ± sample standard deviations.

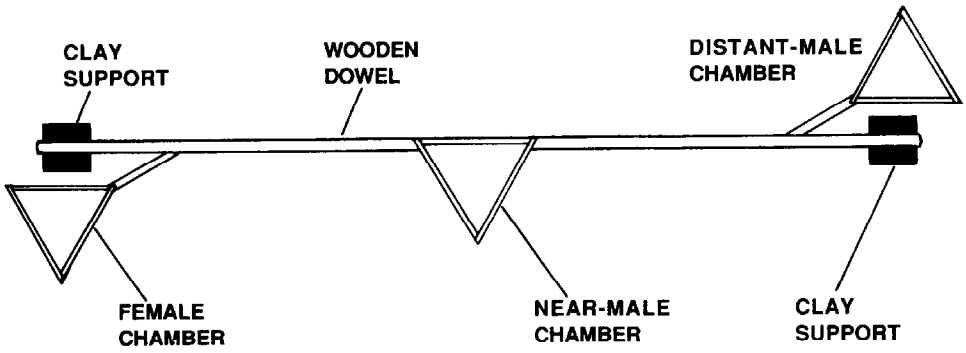

Fig. 1. Top view of the three-chambered apparatus used in all passive choice trio runs.

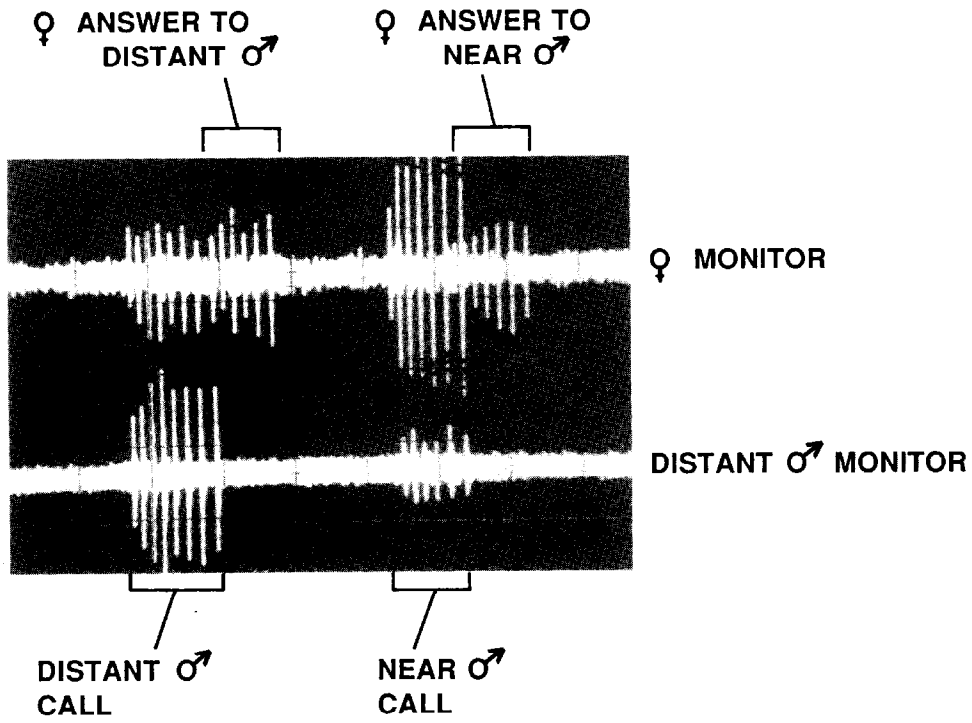

Fig. 2. Dual-trace oscillograph showing two male-to-female exchanges in a trio run. The first exchange is initiated by a call from the distant male, the second by a call from the near male. The female answers overlap the calls by 1-2 beats.

Results and Discussion

Passive Choice

Fourteen trio runs were completed. These runs began with the first male call and continued until 30 male calls had been observed (these being a mixture of near male and distant male calls). Some runs were therefore initiated by the near male while others were initiated by the distant male. The females typically answered most of the calls from either male. However, a one-tailed paired-sample t-test detected a significant decrease in answering rates (% of respective male calls answered) to the calls of the distant male ($P < .025$) thus indicating the presence of passive choice in *P. badia*.

These results are not an artifact of the three-chamber apparatus used (i.e. might some distant male calls not have been received effectively by the female) since in seven of the 14 runs the female's answering rate toward the distant male was $\geq$ her answering rate to the near male. Also, Stewart & Zeigler (1984b) reported that 10 of 10 female *P. badia* were able to respond to male calls over a linear wooden substrate 8.0 m in length which is more than 10 times the length of the apparatus used herein. Ten of the 14 females were mated randomly with either the near or distant male just after their respective runs. These isolated matings (only one male present) lasted 16.6 ± 9.5 minutes. As these matings took place under field conditions, temperatures varied from 19 to 24° C. These mated females subsequently laid 357 ± 82 eggs which compares well with previously reported egg counts from *P. badia* (Zeigler 1990).

MATE GUARDING

In other observations under lab conditions (22-23° C) of direct male/female encounters, six separate observations were made on "pairings" of two males and one female of *P. badia* (all virgin). In each observation, the three individuals were gently placed into a square balsa-wood enclosure with a clear-plastic lid. In all six observations, mating involved only one of the two males (one had been marked with a dot of white ink for identification purposes). The first male to contact the female mated her while the second male later climbed on and attempted unsuccessfully to engage the female's genitalia (as they were blocked by those of the other male). No clearly aggressive actions were noted between the two males as they clung to the female. All movements of the second male appeared to be directed at holding on and engaging the female's genitalia. In four of the six observations, the non-mating male eventually dismounted the mating pair and either remained separate or attempted mounting a second time. Second attempts to mount the pair were quickly aborted.

All matings (or couplings) lasted over 100 minutes. One coupling lasted over 170 minutes. Unfortunately, time availability prevented direct observation of any of the six couplings from start to finish (i.e. first males were still mounted at the end of all six observation periods). Though these observations are thus incomplete, they strongly suggest mate guarding by the first male when these coupling times are compared to the typical couplings above (16.6 ± 9.5 min).

For comparison purposes, mating was also observed in five separate pairings of two females and one male of *P. badia* (all virgin). Here only one observation resulted in a lengthy coupling of over 130 minutes (observations ended here). In the other four observations, first matings lasted 38 ± 10 minutes. After first matings, these four males mounted the second female in the chamber, but these couplings lasted only 6 ± 1 minutes and in one case was clearly ended by the female who struggled and moved her abdomen about which dislodged the mounted male. This female had previously answered a drumming call from this same male after he had dismounted the first female. It appears that although the call was acceptable, the male was not. These observations could suggest sperm depletion in the just-mated males which was sensed by the females after coupling. In the one lengthy coupling above, the second female "mounted" the mating pair and clung to them for several minutes. The male may have perceived this female as a rival male and thus engaged in mate guarding. Males of *P. badia* do not readily distinguish males from females and will even occasionally attempt mating with other males (Zeigler 1990). A similar incident of a female climbing onto a mating pair occured earlier in preliminary observations, but mating time was not recorded.

INTERFERENCE SIGNALING

The design of the 3-chambered apparatus (Fig. 1) allows for effective signal transfer from the near-male chamber to both the female chamber and to the distant-male chamber. This design should facilitate the detection of interference signaling which occurs when one male intentionally signals during the call or signal of another male in an attempt to scramble his call and make it seem aberant or unrecognizable to receiving females (Otte 1977, Lloyd 1979). Overlapping calls occurred in nine instances in six of the 14 trio runs. The 18 calls (9 instances x 2 overlaping calls) are 4.3% of the 420 recorded calls (14 trio runs x 30 male calls per run). The overlapping calls were not simultaneous, so only 9 calls, or 2.2% of the total, could be interpreted as interference attempts. For interference signaling to be effective, the interferring male should consistently interfere with the second males calls while attempting to produce a few isolated calls of his own (Otte 1977), but this was not the pattern observed in *P. badia*.

Of the nine instances of overlap, only two went unanswered by the respective female. Once receptive female stoneflies have received and answered typical male calls, their threshold of call recognition or acceptance is often relaxed such that they will answer incomplete or aberant calls (Zeigler & Stewart 1986) which is probably what was observed here. In short, the evidence here does not strongly support intentional interference signaling by *P. badia* males. The few instances of call overlap were probably chance occurences.

Conclusions

Though evidence for passive choice has been shown, the mean answering rates were high for both near males (95.9%) and for distant males (85.4%). It has been pointed out before that in some cases there is a distinction between statistical significance and practical significance (Moore 1979). Four of the 14 females answered all calls received and none of the females showed an obvious decrease in distant-male answering rate during a trio run. By answering both males, the female increases the chances that one of the males will locate her and fertilize her eggs. Since fit males must effectively receive, interpret, and orient to females signals, as well as engage in effective searching behavior, a female who answers two or more calling males may be staging a form of scramble competition between the males in which distant males could conceivably win by outsearching the near male. This would classify as a form of intrasexual selection which Lloyd (1979) terms passive selection. Certainly not all matings in nature involve passive choice or even drumming. Adults of *P. badia* are often collected from underneath rocks and streamside debris where searching behavior and chance encounters may result in mate location.

Mate guarding appears to be a possible strategy in *P. badia*. This suggests that females may be remated, though probably not with their "approval" (see Zeigler 1990), and sperm displacement/competition may occur. Finally, interference signaling does not appear to be a strategy for *P. badia* males who are searching for, and in communication with, the same female.

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DERAECORIS NEBULOSUS (HETEROPTERA: MIRIDAE): LITTLE KNOWN PREDATOR IN COTTON IN THE MISSISSIPPI DELTA

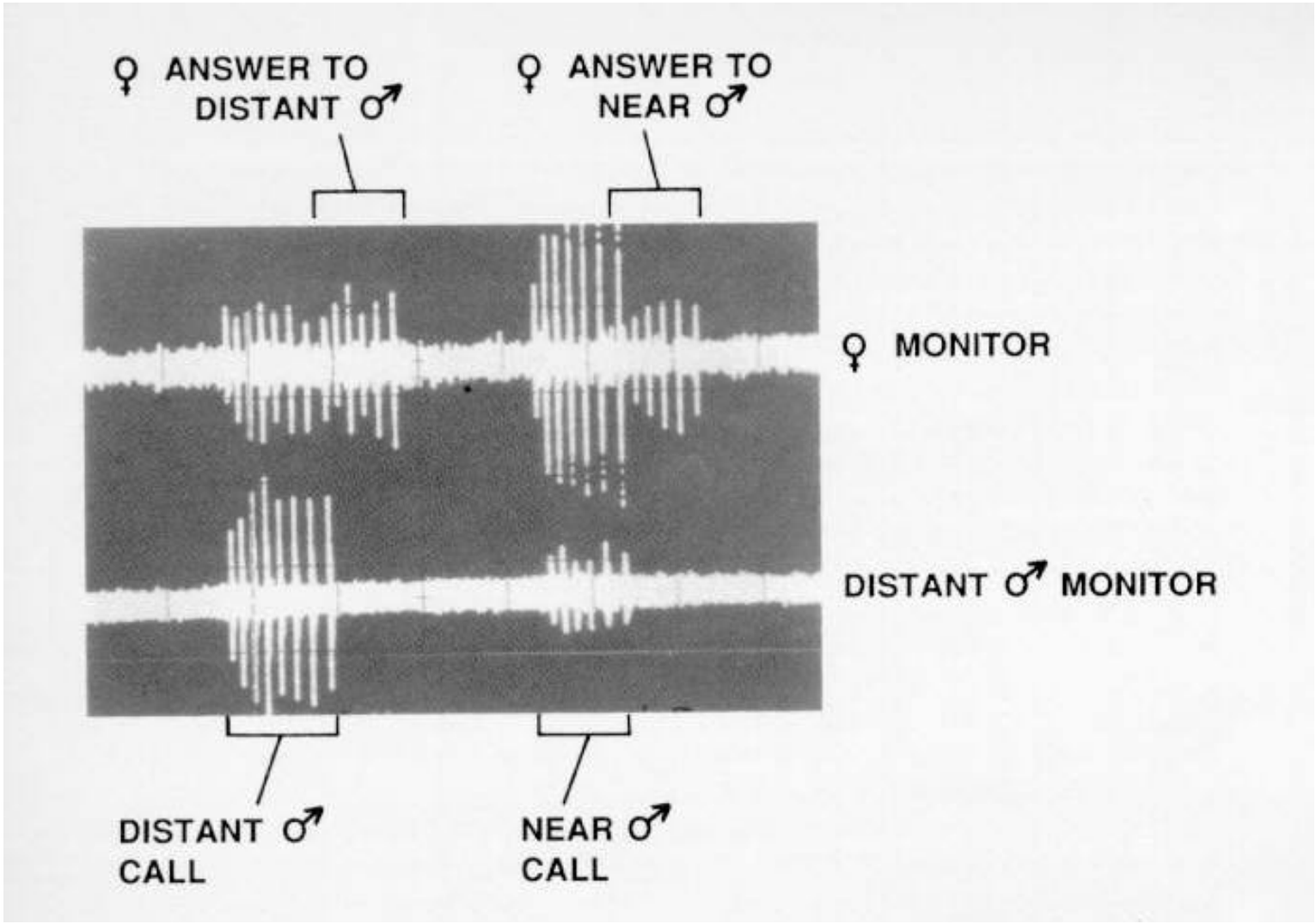
GORDON L. SNODGRASS
Southern Field Crop Insect Management Laboratory
USDA-ARS, Stoneville, Mississippi 38776

ABSTRACT

A population of the predaceous mirid, *Deraecoris nebulosus* (Uhler), was sampled in cotton infested with the cotton aphid, *Aphis gossypii* Glover, at Stoneville, Mississippi during July and August 1988. During this period the population density of this mirid reached 14 nymphs and adults per meter of row (> 137,000 per ha). Adults and nymphs were frequently observed in the field feeding on cotton aphids. In laboratory feeding tests adults averaged feeding on as many as 7 cotton aphids, or 26 eggs of the tobacco budworm, *Heliothis virescens* (F.), per day. First instar larvae of the tobacco budworm and beet armyworm, *Spodoptera exigua* (Hübner), were also accepted as food. These results show that this mirid should be considered a beneficial insect in cotton and that it may occur in numbers large enough to have an impact on populations of pest insects.

RESUMEN

Se muestreó la población del mirido predator *Deraecoris nebulosus* (Uhler), en algodón infestado con el afido del algodón, *Aphis gossypii* Glover, en Stoneville, Mississippi entre Julio a Agosto 1988. En este período la densidad de población de este mirido alcanzó 14 ninfas y adultos por metro de surco (> 137,000 por hectarea). En el campo los adultos y ninfas fueron observados alimentandose frequentemente en afidos de algodón. En el laboratorio las pruebas de alimentación dieron como resultado un promedio de 1 adulto alimentandose diariamente de 7 afidos de el algodón o de 26 huevos del gusano del tabaco *Heliothis virescens* (F.). El primer instar de la larva del gusano del tabaco y del gusano de la remolacha *Spodoptera exigua* (Hubner), fueron también aceptados como alimento. Estos resultados muestran que este mirido puede ser considerado como un insecto benefico en algodón y que puede ocurrir en número suficiente para hacer un impacto en las poblaciones de insectos.


♀ ANSWER TO DISTANT ♂
♀ ANSWER TO NEAR ♂
♀ MONITOR
DISTANT ♂ MONITOR
DISTANT ♂ CALL
NEAR ♂ CALL

STEWART, K. W., AND D. D. ZEIGLER. 1984b. The use of larval morphology and drumming in Plecoptera systematics, and further studies of drumming behavior. Annls. Limnol. 20(1-2): 105-114.

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A population of the predaceous mirid, *Deraecoris nebulosus* (Uhler), was sampled in cotton infested with the cotton aphid, *Aphis gossypii* Glover, at Stoneville, Mississippi during July and August 1988. During this period the population density of this mirid reached 14 nymphs and adults per meter of row (> 137,000 per ha). Adults and nymphs were frequently observed in the field feeding on cotton aphids. In laboratory feeding tests adults averaged feeding on as many as 7 cotton aphids, or 26 eggs of the tobacco budworm, *Heliothis virescens* (F.), per day. First instar larvae of the tobacco budworm and beet armyworm, *Spodoptera exigua* (Hübner), were also accepted as food. These results show that this mirid should be considered a beneficial insect in cotton and that it may occur in numbers large enough to have an impact on populations of pest insects.

RESUMEN

Se muestreó la población del mirido predator *Deraecoris nebulosus* (Uhler), en algodón infestado con el afido del algodón, *Aphis gossypii* Glover, en Stoneville, Mississippi entre Julio a Agosto 1988. En este período la densidad de población de este mirido alcanzó 14 ninfas y adultos por metro de surco (> 137,000 por hectarea). En el campo los adultos y ninfas fueron observados alimentandose frequentemente en afidos de algodón. En el laboratorio las pruebas de alimentación dieron como resultado un promedio de 1 adulto alimentandose diariamente de 7 afidos de el algodón o de 26 huevos del gusano del tabaco *Heliothis virescens* (F.). El primer instar de la larva del gusano del tabaco y del gusano de la remolacha *Spodoptera exigua* (Hubner), fueron también aceptados como alimento. Estos resultados muestran que este mirido puede ser considerado como un insecto benefico en algodón y que puede ocurrir en número suficiente para hacer un impacto en las poblaciones de insectos.

The mirid, *Deraecoris nebulosus* (Uhler), is small (length 3.5-3.9 mm), ovate in shape, and shining olivaceo-testaceous in color darkened with black, or fuscous to black with pale markings (Knight 1941). It was first recognized as being predaceous by Uhler (1876), and is found throughout most of the eastern United States west to Texas and Colorado. It belongs to a genus with 56 species north of Mexico (Slater & Baranowski 1978). Many species in the genus are found most frequently on trees and shrubs (Knight 1941). In the Delta region of Mississippi *D. nebulosus* has been reported from 10 species of trees and 10 species of weeds along with cotton and soybeans (Snodgrass et al. 1984). *Deraecoris nebulosus* was first reported to feed on the cotton aphid, *Aphis gossypii* Glover, in cotton by Whitcomb & Bell (1964). No additional information is available about the feeding habits or occurrence of *D. nebulosus* in cotton. In 1988 a field of cotton located at Stoneville in Washington County, Mississippi, was found to be heavily infested with cotton aphids during July and August (G.L.S., personal observation). *D. nebulosus* was also found in large numbers in the field, and adults and nymphs were observed feeding on cotton aphids. To obtain more information about the predator, laboratory tests were conducted to study its feeding habits. Field sampling was also conducted to determine population levels of the predator in the cotton field. Results of the studies are reported herein.

Materials and Methods

Field Sampling

The cotton field sampled in the study was planted to 'DES 119' cotton on 12 May 1988. The field was 1.6 ha in size and was located at Stoneville in Washington County, Mississippi. The field was treated with dimethoate at 0.22 kg (AI)/ha on 10 June to control tarnished plant bugs, *Lygus lineolaris* (Palisot de Beauvois). Treatments were made on 22 and 28 June, and 8, 18, and 27 July for control of cotton aphids, *Aphis gossypii* Glover, using dimethoate, chlorpyrifos, malathion, methamidophos, and dicrotophos at 0.28, 0.84, 1.12, 0.22, and 0.28 kg (AI)/ha, respectively. On 8 August profenofos and methyl parathion (1.12 + 0.56 kg [AI]/ha) were applied for control of beet armyworm, *Spodoptera exigua* (Hübner), and the boll weevil, *Anthonomous grandis* Boheman.

Cotton aphid and *D. nebulosus* counts were taken weekly from mid-July through August. Numbers of cotton aphids were determined by counting those found on a leaf in the lower one-third of a plant and those found on the first fully expanded leaf below the main terminal of the same plant. Aphid counts on leaves from 2 locations on the plants were made because aphid counts from the upper leaves in cotton treated with insecticides often tend to be much lower than counts taken on bottom leaves (Personal communication, G. L. Andrews, Entomologist, Delta Branch Experiment Station, Stoneville, Miss.). The number of plants on which aphid counts were taken ranged from 25 to 50 depending on the sample date. Fewer plants (25) were sampled during July when the aphid population was high due to the time required to count high numbers of aphids on leaves. In August the number of plants sampled on each date was increased to 50 because the aphid population in the field was much lower. The *D. nebulosus* population was sampled using a drop cloth (1.0 by 0.9 m). Sample sites were selected at random and one sample was taken at each site by placing a drop cloth on the ground at the base of the plants between 2 rows, then vigorously shaking the plants from 1 row over the cloth as described by Kogan & Petri (1980). Numbers of *D. nebulosus* adults and nymphs found on the cloth were immediately counted in the field. Twenty-five to 40 samples were taken on each sample date. Forty samples were taken on each date in July, while 25 were taken on each date in August. Samples taken in August were

decreased in number due to growth of the cotton which made sampling with a drop cloth more difficult. Means (± SE) were calculated for *D. nebulosus* counts on each sample date. Differences in numbers of aphids found on leaves in the lower one-third of the plants and those found on the first fully expanded leaves were examined each week using *t* tests for data with unequal variances (SAS Institute 1985).

Laboratory Tests

Feeding tests were conducted to determine the number of cotton aphids an adult *D. nebulosus* would feed on per day. Tobacco budworm eggs and first instar larvae, and first instar larvae of the beet armyworm, were also tested as prey of *D. nebulosus*. Adult *D. nebulosus* were obtained from the sampled cotton field on the day prior to a test and were provided with water until used in a test. The 24-h period of prey deprivation was used to try and minimize any preconditioning of the test insects to a given prey. Cotton aphids were field collected as needed, and tobacco budworm and beet armyworm larvae were obtained from colonies maintained in the Southern Field Crop Insect Management Laboratory, Stoneville, Miss. Tests were conducted at laboratory conditions of 27 ± 2°C and about 60% RH with a 14:10 (L:D) photoperiod. The test insects, both predator and prey, along with a small cotton leaf were placed in a petri dish (100 x 15 mm). One adult *D. nebulosus* was used per dish.

Cotton aphids were tested using 15 per petri dish, while 35 tobacco budworm eggs (1 or 2 days old) were placed on the cotton leaf in each petri dish when tested. No adhesive was used to stick the eggs to a leaf. First instar larvae of the tobacco budworm and beet armyworm were tested using 5 larvae per petri dish. Number of insect prey consumed, except for tobacco budworm larvae, was determined at 24-h intervals after which the *D. nebulosus* adult was removed from each petri dish and placed into another one containing a new cotton leaf and new insect prey of the same species. The number of tobacco budworm larvae consumed was determined at 1-h intervals. This was performed in 15, 1-h intervals over a 3-day period. Some mortality among the field collected *D. nebulosus* occurred during the tests, and adults that died were not replaced in a test. The tests were performed over a 5-day period for cotton aphids and tobacco budworm eggs, and for a 2-day period for beet armyworm larvae. There were 25 replicates (petri dishes) for each insect tested, except 15 were used for the beet armyworm. Mortality among control insects was also determined. The controls for the tests consisted of 5 petri dishes each containing a cotton leaf and 15 aphids, or 35 tobacco budworm eggs, or 5 tobacco budworm or beet armyworm larvae. New controls were set up for each 24- or 1-h test period. In all laboratory tests means (± SE) were calculated.

Results and Discussion

Field Sampling

Although 6 insecticide applications were made in June and July to control the cotton aphid, the number of *D. nebulosus* remained relatively high during most of July and increased in number each week (Table 1). The *D. nebulosus* population was nearly eliminated by an application of dicrotophos (0.28 kg [AI]/ha) made for cotton aphid control on 27 July (Table 1). However, the population of *D. nebulosus* increased in size during the first 3 weeks of August to reach its peak size of 14 adults and nymphs per meter of row (> 137,000 per ha) on 18 August. The cotton aphid population declined rapidly during the first week in August and remained low during the rest of the month. This was probably the result of the insecticide applications and the increasing numbers of *D. nebulosus* present in the field. Adults and nymphs of *D. nebulosus* were frequently observed feeding on cotton aphids in the field during August.

TABLE 1. NUMBERS (MEAN ± SE) OF COTTON APHIDS AND D. NEBULOSUS FOUND IN A COTTON FIELD LOCATED AT STONEVILLE, MISSISSIPPI 1988[a].

Sample date	Cotton aphids/leaf		*D. nebulosus*/meter of row	
	Top leaf	Bottom leaf	Adults	Nymphs
14 July	29.10 ± 13.01**	110.70 ± 24.37	1.40 ± 0.26	0.00
21 July	39.10 ± 17.96**	120.10 ± 26.42	1.63 ± 0.33	1.00 ± 0.22
27 July	14.90 ± 02.77**	57.10 ± 06.18	3.67 ± 0.34	2.20 ± 0.31
1 August	0.00	0.00	0.23 ± 0.08	0.03 ± 0.04
12 August	0.98 ± 0.24**	6.20 ± 1.61	6.50 ± 0.73	3.00 ± 0.41
18 August	1.93 ± 0.25**	0.43 ± 0.15	5.10 ± 0.43	8.93 ± 0.87
30 August	0.27 ± 0.18*	0.97 ± 0.42	4.23 ± 0.47	6.23 ± 0.49

*, ** Indicate that the mean number of aphids found on the top and bottom leaves on that date were significantly different at $P < 0.05$ and $P < 0.01$, respectively (t test; SAS Institute 1985).

[a]Insecticide applications mainly for control of the cotton aphid were made on 22 and 28 June, 8, 18, and 27 July using dimethoate, chlorpyrifos, malathion, methamidophos, and dicrotophos at 0.28, 0.84, 1.12, 0.22, and 0.28 kg (AI)/ha, respectively. Profenofos + methyl parathion (1.12 + 0.56 kg [AI]/ha) was applied on 8 August for control of the beet armyworm and boll weevil.

Numbers of aphids found on leaves from the bottom one-third of the plants were significantly higher on all but 2 sample dates (1 and 18 August) as compared to numbers of aphids found on the first expanded leaves in the plant terminals (Table 1). The reason(s) for the significantly higher numbers found in the bottom one-third of the plants is unknown. However, counts from leaves collected from either location showed the general pattern for the aphid population to be high in July then a decline during late-July and remain low in August

A heavy infestation of the beet armyworm and a light infestation of the boll weevil developed during the first week of August. A spray mixture of profenofos plus methyl parathion (1.12 + 0.56 kg [AI]/ha, respectively) was applied on 8 August to control these pests. This treatment had little effect on the *D. nebulosus* population which remained high during August. These results suggest that *D. nebulosus* may be tolerent to some organophosphorus insecticides, because populations increased in size in July and August (despite 6 applications of organophosphorus insecticides in June and July). *D. nebulosus* may be more susceptible to dicrotophos than the other organophosphorus insecticides to which it was exposed, because the application of dicrotophos made on 27 July nearly eliminated the *D. nebulosus* population.

LABORATORY TESTS

The adult *D. nebulosus* fed on 4 to 7 cotton aphids per day over the 5 days they were tested (Table 2). Eggs of the tobacco budworm were also readily accepted as food, and each adult averaged feeding on from 16 to 19 eggs per day. First instar larvae of the beet armyworm and tobacco budworm were accepted as food and the adult *D. nebulosus* averaged feeding on 2 to 3 beet armyworm larvae per day. Predation of tobacco budworm larvae was as high as 0.5 larvae per hour.

The laboratory tests indicate that *D. nebulosus* could be a valuable predator in cotton. In taking the cotton aphid counts in the field, adults and nymphs of *D. nebulosus* were commonly observed on the bottom leaves, top leaves, fruit, and terminals of the cotton plants. It appears that *D. nebulosus* can search the entire plant for prey, which would bring it into contact with eggs and larvae of pests such as the tobacco budworm. However, in the field *D. nebulosus* was not observed feeding on eggs or larvae of this pest, or on eggs and larvae of the beet armyworm which was much more numerous. The small size of *D. nebulosus* would make it difficult for it to catch and feed on large larvae or nymphs of pest species.

TABLE 2. NUMBERS (MEAN ± SE) OF COTTON APHIDS, BEET ARMYWORM LARVAE, AND TOBACCO BUDWORM EGGS AND LARVAE FED ON BY *D. NEBULOSUS* ADULTS IN LABORATORY TESTS.

Insect	Day	No. exposed/ petri dish	No. fed on[a]	N[bc]
Cotton aphid	1	15	4.05 ± 0.49	22
	2		5.27 ± 0.71	22
	3		4.43 ± 0.61	21
	4		5.26 ± 0.78	19
	5		6.78 ± 0.83	18
Tobacco budworm	1	35	16.52 ± 1.50	25
eggs	2		26.13 ± 1.63	23
	3		16.52 ± 1.82	23
	4		19.40 ± 2.06	20
	5		17.10 ± 2.13	20
First instar beet	1	5	2.47 ± 0.43	15
armyworm larvae	2		3.27 ± 0.37	15
First instar	1	5	0.45 ± 0.16	23
tobacco budworm	2		0.29 ± 0.13	20
larvae	3		0.48 ± 0.14	19

[a]Determined at 24-h intervals, at which time a new cotton leaf and new prey was added. Number of tobacco budworm larvae fed on is expressed as the mean number per hour, and was determined in 15 1-hour intervals on days 1, 2, and 3 respectively.

[b]Twenty-five petri dishes (100 by 15 mm) each with 1 *D. nebulosus* adult were used in each test, except for the beet armyworm larvae in which 15 were used. Numbers of *D. nebulosus* (N) less than 25 on a test day show mortality among the *D. nebulosus* adults used in the test.

[c]No mortality in the controls occurred.

Nymphs of *D. nebulosus* are about the same size and color as nymphs of the big-eyed bug, *Geocoris* spp., and could be confused with them. However, *D. nebulosus* nymphs are more elongate in shape, have longer antennae and smaller eyes, and can be easily seperated from nymphs of *Geocoris* by a close examination.

In conclusion, adults and nymphs of *D. nebulosus* should be considered beneficial insects when found in cotton, and populations of this predaceous mirid may be large enough at times in cotton to have a beneficial impact on pest populations.

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TOXICITY OF HYDRAMETHYLNON TO LABORATORY AND FIELD STRAINS OF GERMAN COCKROACH (ORTHOPTERA: BLATTELLIDAE)

PHILIP G. KOEHLER
Department of Entomology and Nematology,
Institute of Food and Agricultural Sciences,
University of Florida, Gainesville, FL 32611

RICHARD S. PATTERSON
USDA-ARS Medical and Veterinary Entomology Research Laboratory,
P. O. Box 4565, Gainesville, FL 32604

ABSTRACT

Hydramethylnon was fed nonchoice to German cockroaches, *Blattella germanica* (L.), and LT_{50}s and LC_{50}s were calculated by probit analysis. The LT_{50}s for the Orlando normal strain of German cockroach ranged from 4.47-9.95 days as the concentration of hydramethylnon in the bait decreased from 1.0% to 0.05%. The LC_{50}s of hydramethylnon for the Orlando normal strain decreased from 0.267% to 0.05% as the time to achieve 50% mortality increased from 6 to 10 days. The House of Representatives, DC (HRDC) strain of organophosphate and carbamate insecticide resistant cockroaches had no resistance to hydramethylnon; whereas the Jacksonville strain had low-level resistance at bait concentrations >0.1%, due to avoidance of the treated bait.

RESUMEN

Se suministró hydramethylnon a la cucaracha germana, *Blattella germanica* (L.) y se calcularon las LT_{50} y LC_{50} por medio de el analisis probit. Las LT_{50} para la raza Orlando de la cucaracha germana tuvieron un rango de 4.47 - 9.95 días así como la concentración de hydramethylnon en el cebo decreció desde 1 % a el 0.05. Los LC_{50} de hydramethylnon para la raza normal Orlando decrecieron desde 0.267 % a 0.05 % así como el tiempo de alcanzar mortalidad incremento desde 6 a los 10 días. La raza Camara de Representantes, DC (HRDC) con resistencia a insecticidas organofosforados y carbamatos no mostró resistencia a hydramethylnon, mientras que la raza Jacksonville mostró niveles bajos de resistencia a el cebo con concentraciones menores de 0.1 %, debido a que eludieron el cebo tratado.

Hydramethylnon cockroach bait (Combat® Roach Control System, American Cyanamid, Clifton, N.J.) was introduced to the household consumer market in 1985 for control of German cockroaches, *Blattella germanica* (L.). Hydramethylnon is an inhibitor of mitochondrial respiration (Hollingshaus 1987) and is effective as a stomach poison against a broad spectrum of insects. Laboratory and field tests have demonstrated the efficacy of the product for control of the German cockroach (Bennett et al. 1984, D'Agnese 1984, Reierson & Rust 1984, and Milio et al. 1986), oriental cockroach, *Blatta orientalis* L. (Thoms & Robinson 1987, American cockroach, *Periplaneta americana* (L.) (Milio et al. 1986), Smoky-brown cockroach, *Periplaneta fuliginosa* (Serville), and Florida woods cockroach, *Eurycotis floridana* (Walker) (Patterson & Koehler 1989).

Milio et al. (1986) found that most mortality of German cockroaches exposed to 1.65% hydramethylnon bait occurred between 2-4 days in the laboratory. Field applications of 12 bait stations per apartment resulted in 77% reductions in cockroach populations at

1 month and 98% reductions at 3 months after treatment. In addition to efficacy, hydramethylnon bait stations provide less environmental contamination and greater ease of application for the homeowner than other insecticide products (Rust 1986). Consequently, the product has been widely used throughout the U.S. for German cockroach control in residences.

In 1988, residents at a low income apartment complex in Jacksonville complained that hydramethylnon was no longer working for control of German cockroaches. Field tests (P.G.K, unpublished data) confirmed that only 50-60% percent reduction in cockroach populations was achieved at 3 months with the 1.65% bait station using 12 bait stations per apartment.

The objective of this study was to evaluate the toxicity of hydramethylnon to laboratory strains of German cockroach and compare the toxicity information to data collected from a field strain. Because hydramethylnon is a stomach poison and causes delayed mortality, both LT_{50} and LC_{50} were used to determine its toxicity.

Materials and Methods

Cockroach Strains

Three strains of German cockroach were used in this study. The Orlando normal is an insecticide susceptible strain (Koehler & Patterson 1986) obtained in Orlando, Florida about 40 years ago. The HRDC is an insecticide resistant strain (Milio et al. 1987, Wadleigh et al. 1989) that originated from individuals collected from the U. S. House of Representatives in 1980 and crossed in 1982 with a field strain collected from a Gainesville apartment complex. Selection pressure was initially applied to the HRDC colony by placing a water source on two plywood panels (15 by 15 cm) treated with propoxur (0.11 mg/cm^2) and diazinon (0.11 mg/cm^2) during the cockroaches' third, fourth, and fifth instars. Currently, the colony is pressured with the same chemicals applied at 0.22 mg/cm^2. The Jacksonville strain was collected from low income apartments in Jacksonville, Fla, in 1988 where residents claimed that hydramethylnon bait devices (Combat® Roach Control System, American Cyanamid, Clifton, N.J.) were not providing satisfactory control. First generation offspring of field collected females were used in our experiments.

Adult males that had eclosed three days previously were used for the bioassay. They were removed from the colony by lightly anesthetizing them with CO_2.

Chemicals and Baits

Baits were prepared by dissolving the appropriate amount of technical grade hydramethylnon (92.5%; American Cyanamid, Clifton, N.J.) in 15 ml of acetone. The solution was then pipetted onto 50 g of finely ground Purina rodent chow (22-25% protein, Ralston Purina, St. Louis, Mo.) in a Pyrex beaker (500 ml). The bait was thoroughly mixed and allowed to dry in a fume hood for 24 hours before use. Seven concentrations of baits ranging from 0.005-1.0% (w:w) were used. Finely ground rat chow mixed with acetone was used as a control diet.

Bioassay Method

Cockroaches (N = 25 per jar) were placed in glass utility jars (4.25 liter) that were lightly greased with a 2:3 petrolatum:mineral oil film to prevent escape. A souffle cup containing about 8 g of diet was placed in each jar. Water was provided in a plastic vial with a cotton stopper (20 ml; 5.5 by 2.5 cm i.d.). Cloth covers were placed over each jar.

The Orlando normal and the Jacksonville strains of cockroach were exposed to seven concentrations of hydramethylnon diets (0.005, 0.01, 0.025, 0.05, 0.1, 0.5, and 1.0%) or the control. The HRDC strain was exposed to six hydramethylnon diets (0.005, 0.01, 0.05, 0.1, 0.5, and 1.0%) or the control. Two jars were set up for each treatment. All tests were nonchoice and conducted at 50% RH and 25°C.

Number of dead cockroaches was recorded for each jar at 1, 2, 3, 4, 6, 8, and 10 days of treatment. Data were analyzed by probit analysis (Finney 1971) to determine LC_{50} values for each day of treatment and LT_{50} values for each concentration of bait. Significant differences in LT_{50}'s and LC_{50}'s were determined by nonoverlap of 95% confidence intervals.

Results and Discussion

The LT_{50} of the Orlando normal strain of German cockroach ranged from 4.47-9.95 days as the concentration of hydramethylnon in the bait decreased from 1.0% to 0.05% (Table 1). A similar trend was seen for the HRDC strain with the LT_{50} ranging from 4.12-7.12 days for the same range of concentrations. There is a definite increase in time to mortality as the concentration of hydramethylnon in the bait is decreased. Milio et al. (1986) found that 91% of Orlando normal German cockroaches were killed by 3 days after treatment with 1.65% bait. These values are consistent with the concept that hydramethylnon provides delayed mortality of cockroaches that is dose-related. The HRDC strain's LT_{50}s are not significantly different from the Orlando normal's at the 1.0% concentration but are significantly shorter at lower doses. The HRDC strain was colonized in 1980-1982 (Wadleigh et al. 1989), before any field use of hydramethylnon for cockroach control. Therefore, the HRDC strain was effectively a second susceptible strain as indicated by our results.

The Jacksonville strain's LT_{50}s for the 1.0 and 0.5% concentrations (6.33 and 6.74 days, respectively) were significantly higher than the Orlando normal and the HRDC strains responses (Table 1). However, at lower doses the LT_{50}s did not significantly

TABLE 1. LT_{50}S (DAYS) OF GERMAN COCKROACHES FED HYDRAMETHYLNON FOR VARIOUS BAIT CONCENTRATIONS IN NONCHOICE TESTS.

Percent	LT_{50} (days)[a]	95% CI	Slope ± SE	R/S[b]
Orlando normal strain				
1.0	4.47	4.191–4.767	8.749 ± 0.481	—
0.5	5.08	4.773–5.389	11.048 ± 0.621	—
0.1	8.23	7.769–8.753	9.251 ± 0.628	—
0.05	9.95	9.180–11.473	7.389 ± 0.753	—
HRDC strain				
1.0	4.12	3.800–4.433	6.732 ± 0.402	0.92
0.5	4.42	4.054–4.772	5.902 ± 0.314	0.87
0.1	5.31	4.805–5.866	5.036 ± 0.242	0.64
0.05	7.12	6.655–7.619	7.344 ± 0.406	0.71
Jacksonville strain				
1.0	6.33	5.905–6.753	7.718 ± 0.445	1.41
0.5	6.74	6.266–7.216	6.964 ± 0.422	1.32
0.1	7.68	7.144–8.312	6.497 ± 0.437	0.93
0.05	8.10	7.613–8.652	8.466 ± 0.775	0.81

[a]Data (N = 50) were analyzed by probit analysis (Finney 1971).
[b]R/S = LT_{50} of field strain (R) / LT_{50} of Orlando normal, susceptible (S) strain.

differ. Also for the Jacksonville strain there were no significant differences in LT_{50} between adjacent doses, indicating no strong dose response.

Using the Orlando normal as the susceptible strain, the resistance ratios (R/S) for the HRDC and Jacksonville strains could be calculated (Table 1). The HRDC strain's R/S ratios were all <1.0, indicating that there is no resistance in the strain. However, the Jacksonville strain's R/S values were 1.41 and 1.32 for the 1.0 and 0.5% bait concentrations, respectively. But at concentrations of 0.1 and 0.05%, the R/S values were <1.0.

The LC_{50}s of hydramethylnon for the Orlando normal strain decreased from 0.267% to 0.05% as the time to achieve mortality increased from 6 to 10 days (Table 2). These results are typical of a toxicant that produces time-delayed mortality, in that higher concentrations of toxicant kill faster than lower concentrations. The HRDC strain had significantly lower LC_{50}s at 8 and 10 days than the Orlando normal strain, again indicating that the HRDC strain has no resistance to hydramethylnon. The Jacksonville strain, however, had a significantly higher LC_{50} (0.736%) at 6 days of treatment than the Orlando normal (0.267%) and HRDC (0.131%) strains, but at 8 and 10 days there were no significant differences in LC_{50}s.

The R/S ratio of LC_{50}s was >1.0 for only the Jacksonville strain and decreased as the time for mortality reading increased (Table 2). All R/S values for the HRDC strain and the Jacksonville strain at 10 days were <1.0.

From these data it is clear that there is a low-level resistance to hydramethylnon in the Jacksonville strain of German cockroach. At 1.0% concentration, hydramethylnon takes 1.41 times longer to kill the Jacksonville strain than the susceptible strain. Also the LC_{50} at 6 days was 2.75 times higher than the susceptible strain. Higher doses were required to kill all strains of German cockroaches quickly; however, in the Jacksonville strain, the higher doses require a significantly longer period of time to kill.

These results can best be explained as repellency of bait formulations above 0.1%. Since hydramethylnon was fed as a nonchoice bait, the cockroaches were forced to consume the treated bait in order to survive. If the Jacksonville strain found concentrations of hydramethylnon above 0.1% repellent, the cockroaches would delay consuming the bait for several days, resulting in a higher LC_{50} at 6 days and a higher LT_{50} for the 1.0 and 0.5% concentration.

TABLE 2. LC_{50}S (%) OF GERMAN COCKROACHES FED BAIT WITH HYDRAMETHYLNON FOR VARIOUS EXPOSURE PERIODS.

Day	*n*	LC_{50} (%)[a]	95% CI	Slope ± SE	R/S[b]
Orlando normal strain					
6	250	0.267	0.214–0.335	2.294 ± 0.098	—
8	300	0.101	0.083–0.127	2.591 ± 0.119	—
10	300	0.054	0.045–0.065	2.614 ± 0.126	—
HRDC strain					
6	250	0.131	0.093–0.183	1.554 ± 0.073	0.49
8	300	0.051	0.013–0.245	1.481 ± 0.122	0.50
10	250	0.019	0.014–0.025	1.723 ± 0.076	0.35
Jacksonville strain					
6	250	0.736	0.463–1.496	1.025 ± 0.064	2.75
8	300	0.109	0.037–0.392	0.856 ± 0.076	1.07
10	300	0.041	0.017–0.096	1.231 ± 0.082	0.75

[a]Data were analyzed by probit analysis (Finney 1971).
[b]R/S = LC_{50} of field strain (R) / LC_{50} of Orlando normal, susceptible (S) strain.

Our data indicate that low level resistance to hydramethylnon may be evolving in field populations of the German cockroach. Additional research with preference tests for hydramethylnon baits at concentrations above 0.1% should be conducted. In order to delay or prevent the onset of insecticide resistance, the effect of feeding stimulants and improved bait formulations on efficacy should be investigated.

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RESPONSE OF SWEETPOTATO WEEVIL (COLEOPTERA: APIONIDAE) TO SELECTED INSECTICIDES

L. J. MASON, D. R. SEAL, AND R. K. JANSSON
University of Florida
Institute of Food & Agricultural Sciences
Tropical Research & Education Center
18905 S. W. 280 St.
Homestead, FL USA 33031

ABSTRACT

The contact toxicity of five insecticides against adult male and female sweetpotato weevil, *Cylas formicarius* (F.), was compared using a series of laboratory Petri-dish bioassays. The insecticides tested were chlorpyrifos, parathion, methomyl, carbaryl, and endosulfan. The organophosphates chlorpyrifos and parathion were most toxic, followed by the carbamate methomyl and the chorinated hydrocarbon endosulfan which were moderate in toxicity and the carbamate carbaryl which was least toxic. Slopes differed among insecticides. Parathion exhibited the steepest slope, followed by methomyl, endosulfan, chlorpyrifos and carbaryl, regardless of sex. No differences were found in the susceptibility of males and females to any of the compounds tested. Carbaryl, which had the largest LD_{50} and LD_{90} values, and the shallowest slope, is the only compound that is currently registered for use against *C. formicarius* in Florida.

RESUMEN

En una serie de pruebas en platos Petri, se comparó la toxicidad de contacto de varias dosificaciones de cinco insecticidas contra los machos y hembras adultos del picudo de la batata, *Cylas formicarius* (F.). Los insecticidas utilizados fueron: chlorpyrifos, parathion, methomyl, carbaryl y endosulfan. Los organofosforados chlorpyrifos y parathion fueron mas toxicos, seguidos por el carbamato methomyl y el hidrocarburo chlorinado endosulfan, los cuales fueron moderadamente toxicos, y el carbamato carbaryl el cual fue el menos toxico. La inclinación de las regresiones fue diferente entre insecticidas. Tanto para hembras como para machos el parathion exhibió la linea de regresión con inclinación mas marcada, seguido por el methomyl, endosulfan, chlorpyrifos, y carbaryl. No se encontró diferencia entre la susceptibildad de machos y hembras con ninguno de los insecticidas. Carbaryl, el cual tuvo los valores mas altos de LD_{50} y LD_{90} y la menor inclinacion de la linea de regresión, es el unico insecticida que está registrado en Florida contra *C. formicarius*.

Sweetpotato weevil, *Cylas formicarius* (F.), is the most important biotic factor limiting sweet potato (*Ipomoea batatas* (L.) Lam.) production in the United States, the Caribbean, and other tropical regions of the world (Suah 1981, Pollard 1984, Sutherland 1986, Chalfant et al. 1990). Cultural control has long been recommended (Reinhard 1923, Sherman & Tamashiro 1954, Smee 1965, Talekar 1983), however, early attempts at chemical control met with very limited success (Sherman 1951, Mistric 1955, Wolcott & Perez 1955, Floyd 1955, Kantack & Floyd 1956). More recently, chemical control studies have shown promise (Pillai et al. 1981, Waddill 1982, Rajamma 1983, Sutherland 1985).

The most extensive testing of efficacy of foliar insecticides against *C. formicarius* has been with organophosphates, including fenthion, formothion, fenitrothion and monocrotophos (Johnson et al. 1979, Pillai et al. 1981, Rajamma 1983, Sutherland 1985, Sutherland 1986). Another insecticide that has shown promise in the field is endosulfan (Waddill

1982, Rajamma 1983). One problem with studies on chemical control of this weevil to date is that all were conducted under field conditions and none examined contact toxicity to this weevil. Reported here are results of a study to determine the contact toxicities of five insecticides against adult *C. formicarius*. The data will not only establish the relative susceptibilities of these insecticides, but provide the baseline data to monitor further the development of insecticide resistance in local populations of adult *C. formicarius*.

Materials and Methods

Cylas formicarius used in the bioassays were obtained from weekly collections of infested roots taken from commercial fields and roots infested in the laboratory. Insects were removed from emergence cages daily, sexed, and placed in separate plastic boxes (8 × 13.5 × 19 cm) containing up to approximately 200 individuals per box. Adults were held in a rearing room set at 20 ± 2°C, under a photoperiod of 12:12 (L:D), and provided with fresh sweet potato roots every other day.

Technical grade samples of insecticides were obtained from their respective manufacturers. Insecticides, their purity levels, specific gravity, and sources were as follows: chlorpyrifos (99.8% pure; specific gravity 1.18; Dow Chemical Co., Midland, Mich.), parathion (77% pure; specific gravity 1.27; American Cyanamid Co., Wayne, N.J.), methomyl (98% pure; specific gravity 1.29; E. I. DuPont Nemours, Wilmington, Del.), carbaryl (99.9% pure; specific gravity 1.23; BASF Corp., Chemicals Division, Parsippany, N.J.), and endosulfan (96% pure; specific gravity 1.74; Hoechst AG Agricultural Div., Frankfort, F.R.G.). Acetone (99.5%, class 1B) was used as the solvent for all dilutions.

Petri-dish bioassays were conducted on 2-wk-old adult weevils. Average wet weights of treated groups were used to determine dosage on a per gram wet weight basis. To facilitate handling, weevils were chilled in a refrigerator (2-4°C) for a period of ca. 10 min. Once immobilized, they were treated topically on the dorsal surface of the thorax (1 μl per insect) using a microsyringe. Adults were then placed in Petri-dishes with ventilated lids made by excising a hole (4.25 cm dia.) on top and covering it with nylon mesh. Petri-dishes containing the topically-treated adults were placed on a laboratory bench in the rearing room and provided with a slice of sweet potato. Mortality was determined 48 h after treatment. Moribund individuals were scored as dead if they were unable to move or change position after 5 min. The reason for this extended length of time was due to the fact that adult *C. formicarius* often feign death when disturbed (Chalfant et al. 1990). This period would allow those feigning death ample time to move.

Ten individuals per sex were tested at each concentration per replication, and each test was replicated 3-10 times. Eight concentrations were tested for most insecticides. Adults treated with acetone (1 μl) served as the control.

Data from the Petri-dish bioassays were analyzed by POLO probit analysis (Russell et al. 1977). The lethal dosages that resulted in 50 and 90% mortality (LD_{50} and LD_{90}, respectively) and 95% fiducial limits (FL) were reported as μg per g of wet biomass for both sexes individually, as well as overall lethal dosages for both sexes collectively.

Results and Discussion

The toxicities of the insecticides to adult female and male weevils are given in Table 1. Both organophosphates (chlorpyrifos and parathion) were very toxic to both female and male *C. formicarius*. Probit analysis indicated that LD_{50} values did not differ ($P > 0.05$) for these two compounds, with values ranging between 1.97 and 5.12 μg/g of wet biomass (Table 1). Methomyl, a carbamate, was moderately toxic, as was endosulfan, a cyclodiene. The least toxic of the five compounds tested was the other carbamate,

TABLE 1. RELATIVE TOXICITIES OF VARIOUS INSECTICIDES TO 2-WK-OLD MALE AND FEMALE SWEETPOTATO WEEVILS.

Treatment	N	Slope±SEM[1,3]	t	LD_{50}(95% FL)[1,2,3]	LD_{90}(95% FL)[1,2,3]
			FEMALE		
Chlorpyrifos	300	1.72±0.38ab,A	4.52	3.78(1.89–7.57)a,A	20.81(9.45–145.64)a,A
Parathion	400	2.74±0.42c,A	6.47	4.90(2.45–7.35)a,A	14.71(9.81–29.42)a,A
Methomyl	800	1.82±0.13b,A	13.51	7.70(5.78–9.63)a,A	36.60(28.89–55.86)a,A
Endosulfan	650	1.88±0.15b,A	12.60	64.89(49.16–80.62)b,A	308.71(230.05–452.24)b,A
Carbaryl	600	1.39±0.16a,A	8.62	389.08(252.33–577.84)c,A	3272.52(1822.14–9087.56)c,A
			MALE		
Chlorpyrifos	300	1.27±0.21a,A	5.96	2.06(0.01–4.13)a,A	18.56(8.25–111.38)a,A
Parathion	400	2.75±0.28c,A	9.93	2.67(2.66–5.35)ab,A	10.69(8.02–16.04)a,A
Methomyl	800	2.04±0.15b,A	13.49	6.30(4.20–6.30)b,A	25.21(16.80–37.81)b,A
Endosulfan	660	1.81±0.15b,A	12.28	51.46(38.60–64.33)c,A	259.46(195.13–377.39)c,A
Carbaryl	600	1.39±0.16a,A	8.66	228.96(142.83–333.98)d,A	1911.46(1186.79–4020.37)d,A
			TOTAL		
Chlorpyrifos	600	1.39±0.20a,A	7.06	1.97(1.90–3.97)a,A	21.71(9.88–78.93)a,A
Parathion	800	2.52±0.21c,A	12.22	5.12(2.56–5.12)a,A	12.79(10.23–17.90)a,A
Methomyl	1600	1.93±0.11b,A	18.46	6.03(6.02–8.04)b,A	30.14(24.12–40.19)a,A
Endosulfan	1310	1.89±0.10b,A	18.11	57.44(49.23–67.70)c,A	276.94(471.83–348.74)b,A
Carbaryl	1200	1.35±0.11a,A	12.02	297.41(215.02–393.87)d,A	2636.53(1744.29–4784.74)c,A

[1]Values followed by different lowercase letters indicate significant differences ($P<0.05$) between insecticides within each category (female, male, total). Values followed by different uppercase letters indicated significant differences between categories (female, male, total) for each insecticide.

[2]Values are in μg/g wet weight.

[3]Slopes were compared by the general linear test (Neter and Wasserman 1974). The LD_{50} and LD_{90} values were compared using the 95% fiducial limits.

carbaryl, which had an LD_{50} in the range of 228.96 to 389.08 μg/g of wet biomass. The range of toxicities of the five compounds tested was very wide. Females were 6-fold more susceptible to endosulfan, almost 50-fold more susceptible to methomyl, 80-fold more susceptible to parathion, and over 102-fold more susceptible to chlorpyrifos as compared with the least toxic compound, carbaryl. The order of toxicity to males was similar: chlorpyrifos 111-fold; parathion 86-fold; methomyl 36-fold and endosulfan 4-fold more toxic to males than carbaryl.

In general, female insects are less susceptible to insecticides than males. This has been found in several insect orders, including Diptera (Ikeda et al. 1979) and Homoptera (Horowitz et al. 1988). In the present study, there were no statistical differences between males and females in the toxicities of insecticides that were tested. However, females were 1.2- to 1.8-fold less susceptible (although not significant) than males to the selected insecticides.

Slopes differed among most insecticides (Table 1). Parathion exhibited the steepest slope, regardless of sex, followed by methomyl, endosulfan, chlorpyrifos, and carbaryl. Slopes for carbaryl and chlorpyrifos were 1.9- to 2.0-fold less than that for parathion indicating that carbaryl and chlorpyrifos toxicities were more heterogeneous than parathion. The steepness of the slopes for parathion, methomyl, and endosulfan indicate that the susceptibility of the weevil population was homogeneous, which, in general, is characteristic for insect populations that have not been exposed to insecticide selection pressure (Hoskins 1960). It is interesting to note that carbaryl has the largest LD_{50} and LD_{90} values, in addition to the shallowest slope, and is currently the only insecticide registered for use against *C. formicarius* in Florida (Johnson 1990). This may be indicative of intense carbaryl insecticide pressure on local populations. Future studies should monitor local weevil populations to examine this more fully.

Other insecticides that are registered in Florida for use on sweet potato but not registered for *C. formicarius*, include endosulfan, malathion, methyl parathion, parathion, methoxychlor, ethoprop, chlorpyrifos, fonofos and diazinon (Johnson 1990). Endosulfan, when used for flea beetle control, appears to lower *C. formicarius* populations (Johnson 1990). However our laboratory data indicates that endosulfan is only moderately toxic to *C. formicarius*.

Insecticide field trials conducted during the winter growing season when weevil densities are typically low (Jansson et al. 1990), found that foliar sprays of either permethrin 25WP or endosulfan 50WP resulted in the production of storage roots free of *C. formicarius* (Waddill 1982). In trials conducted during the summer and fall season, adults emerged from all treatments; however, fewer adults were found in permethrin and endosulfan treated plots than in control plots (Waddill 1982). Thus, it appears that although endosulfan was only moderate in toxicity to *C. formicarius* in this study, its effectiveness was enhanced when weevil population levels are low. When weevil population levels are high, such as in summer, endosulfan was less effective at controlling this weevil.

In summary, the range in toxicities of the compounds *C. formicarius* was wide. Carbaryl, which is the only insecticide registered for use against *C. formicarius* on sweet potato in Florida, was the least toxic compound tested. The most toxic compounds, chlorpyrifos and parathion, were over 80-100 fold more toxic than carbaryl. Although slopes were generally steep, the shallowest was carbaryl. *Cylas formicarius* populations should be monitored to determine if insecticide selection pressures increase.

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SCIENTIFIC NOTES

LABORATORY REARING OF *HYDROMETRA AUSTRALIS* (HEMIPTERA: HYDROMETRIDAE)

CARMINE A. LANCIANI
Department of Zoology, University of Florida,
Gainesville, Florida 32611

The surface-dwelling aquatic insect *Hydrometra australis* Say (Hemiptera: Hydrometridae) is difficult to rear. Although most field-collected nymphs reared on a diet of *Drosophila* in the laboratory develop to the adult stage, mate, and reproduce successfully (Lanciani 1975), only a small percentage of individuals reared from the egg stage on this food reach adulthood. In previous laboratory rearing attempts using different container sizes, different substrata, and *Drosophila* as food, the maximum survival I have observed in individuals reared from egg to adult is 40%. The closely related species *Hydrometra martini* Kirkaldy has been cultured on *Drosophila* (Sprague 1956), but its survival rate was not given.

Collembolans have been cited as a common food source of hydrometrids, e.g., *H. martini* (Sprague 1956) and *Hydrometra stagnorum* (Linnaeus) (Arrow 1895). In northern Florida, *H. australis* can be often seen in the field feeding on aquatic collembolans, which are abundant in many shallow aquatic habitats frequented by *H. australis*. These observations suggested a rearing method for *H. australis* using aquatic collembolans as food.

Six female *H. australis* were collected from Lake Alice, Gainesville, Florida, U.S.A. on 17-IX-1989, placed individually in plastic petri plates lined with moistened absorbent paper, and fed 3 frozen *Drosophila melanogaster* Meigen per day. Eggs removed from these plates to establish a laboratory parental generation were placed individually in plastic vials (3 cm in diameter and 7 cm in height) that were half to three-fourths full of water. The water surface was completely covered with plants of 2 species of duckweed, *Lemna minor* Linnaeus and *Spirodela polyrhiza* (Linnaeus). A circular hole cut in each vial cap was covered with a piece of screen. The vials were placed in a constant-temperature chamber held at 28°C with a 12-h light-dark cycle. Approximately 20 or more live collembolans (*Sminthurides* sp.) of various sizes collected from a local temporary pond were added to each vial when the *Hydrometra* eggs hatched. (Collembolans were easily field-collected by slowly skimming the duckweed-covered pond surface with the edge of a plastic box.) As the number of collembolans in the vials dwindled, more were added so that prey were always abundant. Uneaten collembolans survived well, so contamination by death of excess prey did not occur.

As individuals of the parental generation of *H. australis* reached the adult stage, females and males were paired. The first 27 eggs laid, which were from two females, were then placed individually in plastic vials to establish the subject generation. This generation was reared as was the parental generation, except that the vials were removed briefly from the constant-temperature chamber 4 times each day (within the periods 7-9a.m., 11a.m.-1p.m., 4-6p.m., and 8-10p.m.) to be checked for molts.

Twenty-six of the 27 subject-generation eggs successfully developed to the adult stage on an exclusive diet of collembolans. The mean stadium of each of the 5 immature instars is listed in Table 1. These stadia are consistently shorter than those (Lanciani 1975) determined on *Drosophila*-fed individuals (Table 1; $P < 0.001$ for each instar, t-test). The comparisons of instars 2 to 5 are not ideal because in the *Drosophila*-fed group, data for instars 2 to 5 were obtained from field-collected instars 1 to 4, respectively, that were maintained in the laboratory through the next instar only. The Collembola-fed

TABLE 1. THE MEAN STADIUM (IN DAYS) PLUS OR MINUS THE STANDARD ERROR OF EACH NYMPHAL INSTAR OF *H. AUSTRALIS* REARED ON COLLEMBOLA OR *D. MELANOGASTER* AT 28°C WITH A 12-H LIGHT:DARK CYCLE.

	Collembola-fed		*Drosophila*-fed[1]	
Instar	Stadium	N	Stadium	N
1	1.64 ± 0.04	26	2.57 ± 0.05	100
2	1.40 ± 0.02	26	2.19 ± 0.05	96
3	1.61 ± 0.03	26	2.42 ± 0.06	97
4	1.84 ± 0.03	26	2.46 ± 0.05	99
5	2.49 ± 0.03	26	3.23 ± 0.04	97
Male total	8.85 ± 0.09	12	—	—
Female total	9.08 ± 0.06	14	—	—
Total	8.97 ± 0.06	26	—	—

[1]Data for *Drosophila*-fed individuals were originally presented in Lanciani (1975) and were taken as follows: data for instars 2 through 5 were obtained from field-collected instars 1 through 4 that were maintained in the laboratory through their next instar only; data for instar 1 nymphs were obtained from hatched eggs oviposited by field-collected females.

group was reared totally in the laboratory. As a result, the 2 groups did not have a common physical environment in instars younger than the compared instars. However, this reservation may not be serious because it does not apply to first instars, which also developed faster in the Collembola-fed group (see footnote 1, Table 1).

The high (96%) survival rate and rapid development of *H. australis* in this sample of 27 individuals indicate that aquatic collembolans may be an appropriate food. Aquatic collembolans are widely distributed and reasonably easy to collect in large numbers. Also, they can be cultured using a modification of a technique described by Linley (1979) for rearing ceratopogonid larvae. A 1.5 to 2.0% corn meal agar mixture poured into petri plates or plastic boxes is inoculated with small clumps of duckweed. The duckweed provides oviposition sites and introduces fungi and bacteria that grow readily in the nutrient-enriched agar, supplying food for the collembolans.

An exclusive diet of collembolans may not be necessary for high survival of *H. australis* in laboratory cultures. Eleven individuals (offspring of the 26 survivors) were fed collembolans through instar 2 and then were transferred to new collembola-free vials, after which they were fed only *D. melanogaster* (2 per day). Ten survived to the adult stage. However, in a matched, control group of 11 individuals fed exclusively *D. melanogaster*, none survived to the adult stage. In a related observation, 5 first- and second-instar *H. australis* were collected from a small temporary pond abundantly inhabited by Collembola and were then maintained in the laboratory on a diet of *D. melanogaster*. All 5 nymphs, which had most likely fed on Collembola before capture, survived to the adult stage. Thus, aquatic collembolans may provide developing *H. australis* with essential nutrients that are lacking in *D. melanogaster*.

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TIGHTNESS OF THE PERIANTH OF COCOCUTS IN RELATION TO INFESTATION BY COCONUT MITES

F. W. HOWARD
Fort Lauderdale Research & Education Center
University of Florida
Institute of Food & Agriculture
3205 College Avenue, Ft. Lauderdale, Fl. 33314

EDWIN ABREU RODRIGUEZ
Agricultural Experiment Station
University of Puerto Rico
P. O. Box 417, Isabela, P. R. 00662

The coconut mite, *Aceria guerreronis* Keifer (Acari: Eriophyidae) is an economic pest of coconuts, *Cocos nucifera* L., in many countries of the Americas and Africa where these palms are grown (Mariau 1986). Damage occurs when the mites congregate and feed on the meristematic tissue of the coconut, which is the area of the coconut surface that is normally protected by the inner whorl of the perianth (Fig. 1). The tissue growing from beneath the perianth at a point near a coconut mite colony becomes first chlorotic and then crackled and cork-like. Eventually, half or more of the exposed surface of the coconut may be damaged. Coconut mite damage reduces the production of copra, causing losses of up to 30% (Hernandez-Roque 1977).

Adult coconut mites are 36-52 μm thick (Keifer 1965), thus are able to penetrate very minute spaces. There is general agreement in results from several localities [Mariau & Julia (1970) in Ivory Coast, Hall & Espinosa-Becerril (1981) in Mexico, and Moore & Alexander (1987) in St. Lucia] that coconut mites do not infest the meristematic zones of unfertilized female coconut flowers or fruits of less than a few weeks old. According to detailed observations on 'Malayan dwarf' coconuts (Moore & Alexander 1987), coconut mite populations built up rapidly and peaked on coconuts of about 3 to 6 months old. Populations declined on older fruits. Generally, it appeared that fruits of 1 to 4 months old were the most susceptible to attack. The above authors suggested that the perianths of younger coconuts were tightly appressed and thus protected the meristematic zone, but became looser as the coconut developed. Populations declined on larger coconuts, and were virtually absent from coconuts of about 20 cm in length. They suspected that conditions for coconut mites became unfavorable as coconuts matured. We conducted similar sampling and observations at Cabo Rojo, Puerto Rico, and Miami, Florida, and observed a similar relationship between the stages of development of coconuts and coconut mite infestation (unpublished). Moore (1986) reported that the arrangement of the tepals of the inner whorl of the perianth of young coconuts affected the pattern of coconut mite attack, thus providing further evidence that physical access space is important for coconut mite invasion and subsequent population development.

We attempted to determine whether the perianth protects the meristematic zone during young stages of growth of the coconut. A test using marking ink was conducted to determine whether the tepals of smaller coconuts are more tightly appressed to the fruit surface than those of larger coconuts. It was found empirically that a marking ink, Volger's Indelible Ink® (Philadelphia, Pennsylvania), penetrated beneath the perianth of most older coconuts and dried to the surface.

Coconuts were pruned from 5 'Golden Malayan Dwarf' coconut palms. Ten coconuts were in each of the following length classes: 2-3 cm, 7-9 cm, and 11-13 cm, corresponding to developmental stages of approximately the first, fourth and sixth months, respectively.

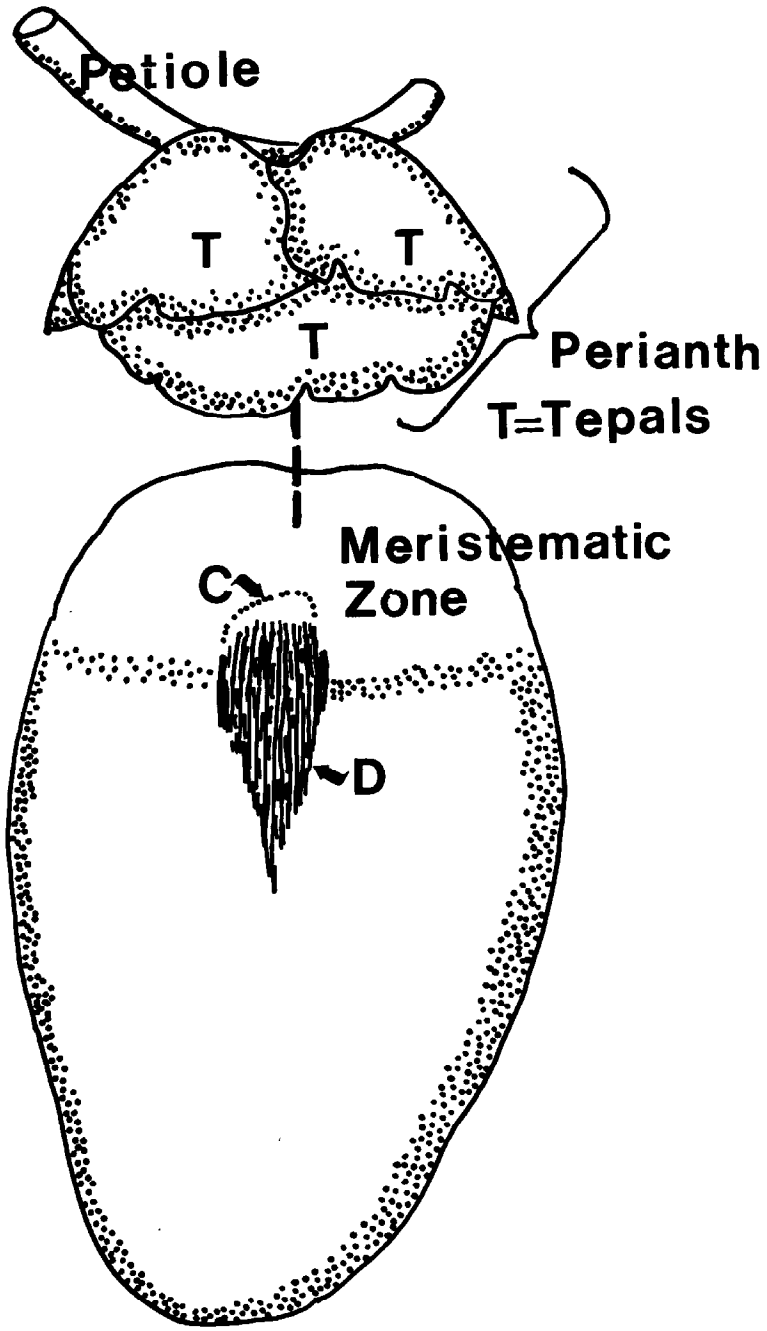

Fig. 1. Young coconut, showing structures referred to in this paper. C = typical feeding site of coconut mite. D = early stage of feeding damage.

Each coconut was dipped in the marking ink for 1 minute and set aside to dry. The following day the surface of the fruit and inner surfaces of tepals were examined for staining location.

In all of the coconuts of the 2 larger size classes (7-9 cm and 11-13 cm) the ink penetrated nearly the entire zone beneath the perianth. In contrast, the ink did not penetrate the meristematic zones of any of the 10 coconuts in the 2-3 cm length class

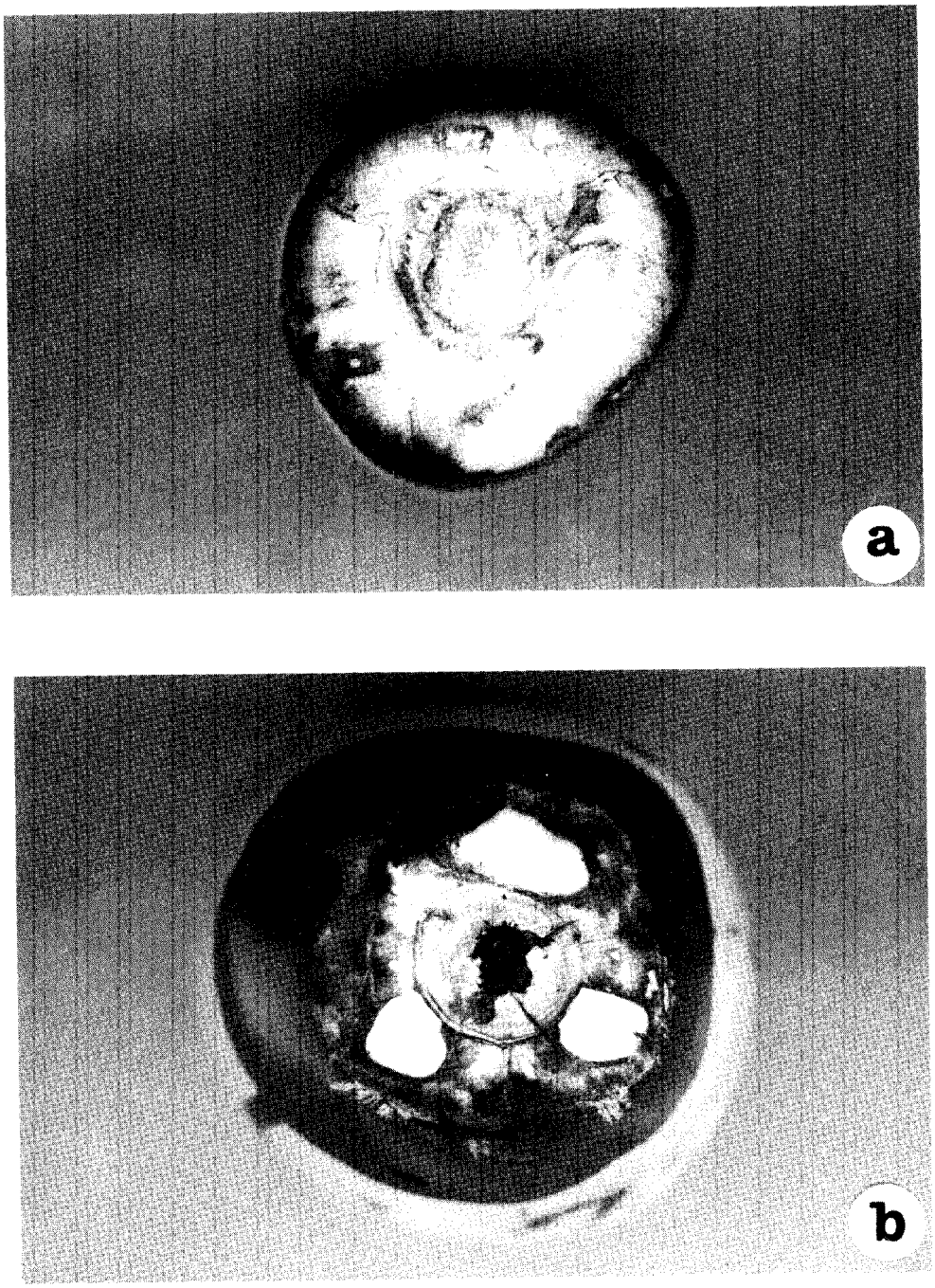

Fig. 2. Coconuts stained with ink to determine the degree of penetration of the ink beneath the perianth. a. coconut of 2-3 cm length class. b. coconut of 7-9 cm length class.

(Fig. 3), that corresponds to the size of fruits in the first month of development. These results indicate that in the coconuts that were in a very young stage of growth the tepals were tightly appressed against the surfaces. At later stages, some pathways of entry were open to ink penetration.

Based on our observations, coconut mites utilize the inner surfaces of tepals as feeding sites as well as the tender meristematic zone. It is the feeding in the latter site which

causes economic damage. The principal function of the perianth in plants is to protect the flower bud and later the tender meristematic zone of the growing fruit. This protective function is maximal in young coconuts (i.e., in the first month of development), which are almost completely covered by the tightly appressed perianth. As the coconut grows, it becomes increasingly larger in proportion to the perianth, and, in the cultivar that we studied, spaces develop between the coconut surface and the perianth, as indicated by the ink penetration test. This apparently allows coconut mites to enter this habitat. Thus, the tightness of the perianth to the coconut appears to be a key factor in its susceptibility or resistance to coconut mite attack.

Mariau (1977) reported that a Cambodian cultivar was apparently resistant to coconut mite, and suggested that the perianth remained tightly appressed to the very round coconuts of this cultivar, preventing penetration by coconut mites. Moore (1986) suggested that in susceptible cultivars adverse growing conditions could possibly result in a loose fit between perianth and coconut, and hence a greater susceptibility to coconut mite. The ink penetration test described in this paper has potential use to explore such questions regarding resistance mechanisms to coconut mites. Additionally, the technique could be developed as a simple screening method to identify coconut cultivars potentially resistant to coconut mite.

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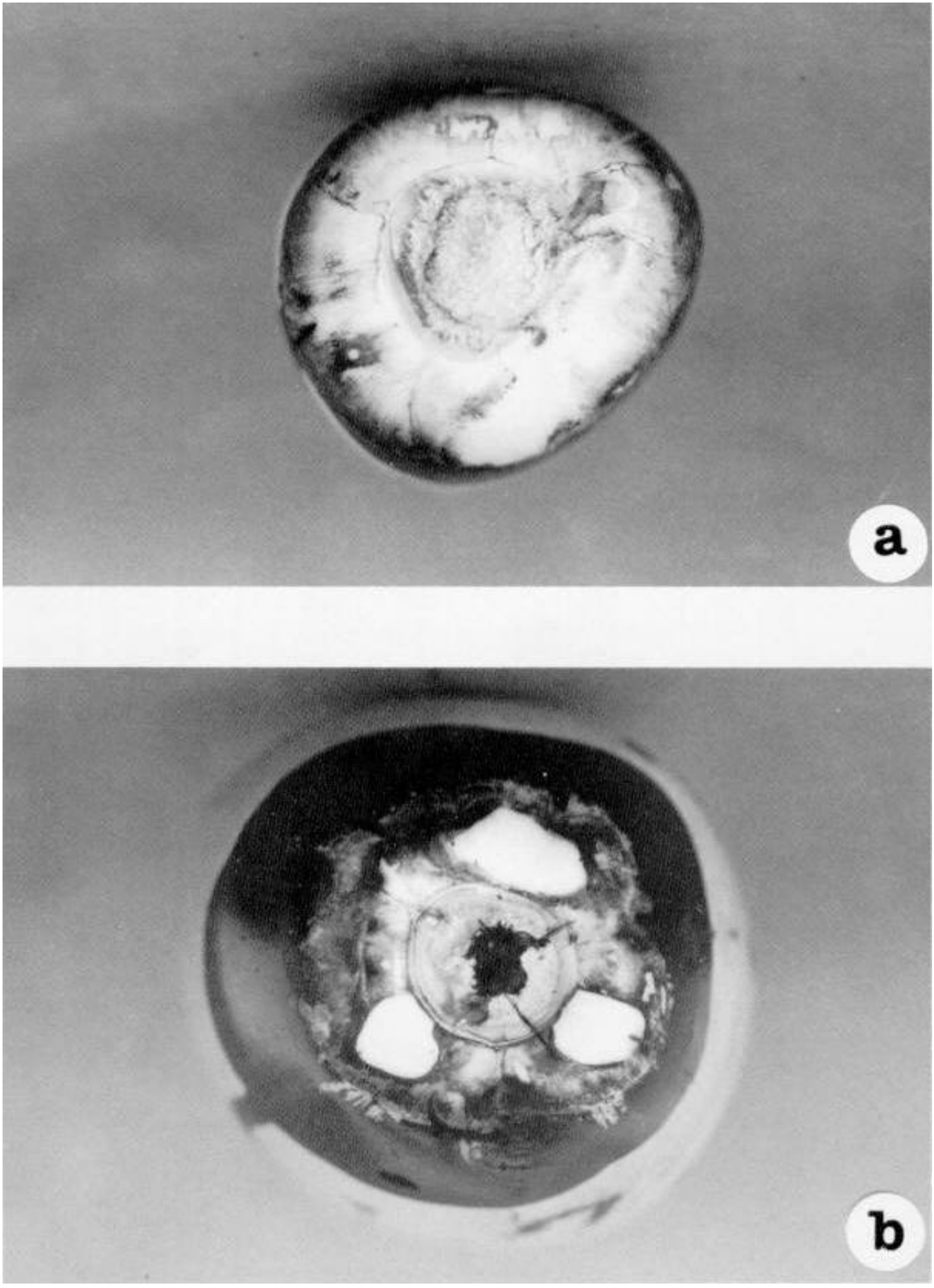
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EFFECT OF BAIT ON CAPTURE OF *HELIOTHIS VIRESCENS* MALES (LEPIDOPTERA: NOCTUIDAE) IN TWO DIFFERENT TRAPS

MOSHE KEHAT[1], EVERETT R. MITCHELL, AND ROBERT R. HEATH
Insect Attractants, Behavior, and Basic Biology Research
Laboratory, Agricultural Research Service
U.S. Department of Agriculture, Gainesville, Florida 32604

Identification of pheromone components for the tobacco budworm, *Heliothis virescens* (F.), (Roelofs et al. 1974, Tumlinson et al. 1975, Klun et al. 1980) in conjunction with the development of the wire cone trap (Hartstack et al. 1979, 1980) have presented opportunities for the development of a pheromone-based trapping system. In insect pest management programs, a durable, inexpensive, easily serviced, and sensitive trap is desirable. The high cost and bulk of the wire cone trap essentially eliminates its use for all but experimental purposes. A commercial version of the wire cone trap, the Scentry *Heliothis* cone (Scentry, Inc., Buckeye, AZ), is available, but it also is unwieldy and expensive. The possibility of using a different trap, the inexpensive and easy to handle bucket trap, was investigated in this study.

An important aspect of *H. virescens* trapping is the development of a suitable pheromone dispenser. For *H. virescens*, initial evaluations of a laminated plastic dispenser were made by Hendricks et al. (1977); later evaluations were reported by Hartstack et al. (1980) and Zvirgzdins & Henneberry (1983). Comparisons of laminated plastic and rubber septum dispensers under desert conditions were reported by Flint et al. (1979). They found that the rubber septa were very effective dispensers and lasted for a longer period of time than laminated plastic dispensers. Polyvinyl-chloride (PVC) substrates for dispensing the pheromone of *H. virescens* have been developed and evaluated by Hendricks (1982, 1983) and Hendricks et al. (1987) and were reported to be more effective than other dispensers tested. Further evaluations of the Ramaswamy, PVC and Flint dispensers were conducted by Lopez et al. (1987).

The objective of the present study was to evaluate the effectiveness of cone and bucket traps for capturing *H. virescens* males when combined with different pheromone dispensing systems. Therefore, the commonly used bait dispensers for *H. virescens*—the laminated plastic Hercon dispensers (Hercon Laboratories, Inc., South Plainfield, NJ) and the Biolure membrane dispenser (Consep Membranes, Inc., Bend, OR)—were compared with other available dispensers in cone and bucket traps.

Scentry cone traps (test 1) and International Pheromones bucket traps (test 2) (Great Lakes IPM, Vestaburg, MI) were positioned 100 m apart and 1 m above ground level in a N-S direction in fallowed fields near Gainesville, FL. The tests were conducted in late September-early October 1989 during a period of relatively low *H. virescens* moth population. The test area was heavily populated with *Desmodium tortuosum* (Swartz) de Candolle, an important weed host for *H. virescens* (Jackson & Mitchell 1984). The traps were baited with different commercial lures (BioLure and Hercon 2- or 7-components) or septa (Israeli-Maavit, Tel Aviv, Israel; A. H. Thomas No. 1780J07, Swedesboro, NJ; Wheaton no. 224091, Millville, NJ) prepared locally by Laboratory personnel.

Load ratios for the experimental lures (1 mg total/septum) were: tetradecenal, 3%; (Z)-9-tetradecenal, 5%; hexadecanal, 8%; (Z)-7-hexadecenal, 1%; (Z)-9-hexadecenal, 1%; and (Z)-11-hexadecenal, 82%. All synthetic compounds used on the septa formulations were obtained from commercial sources and were analyzed on both capillary and GC

[1]Entomology, ARO, The Volcani Center, P. O. Box 6, Bet-Dagan 50-250, ISRAEL.

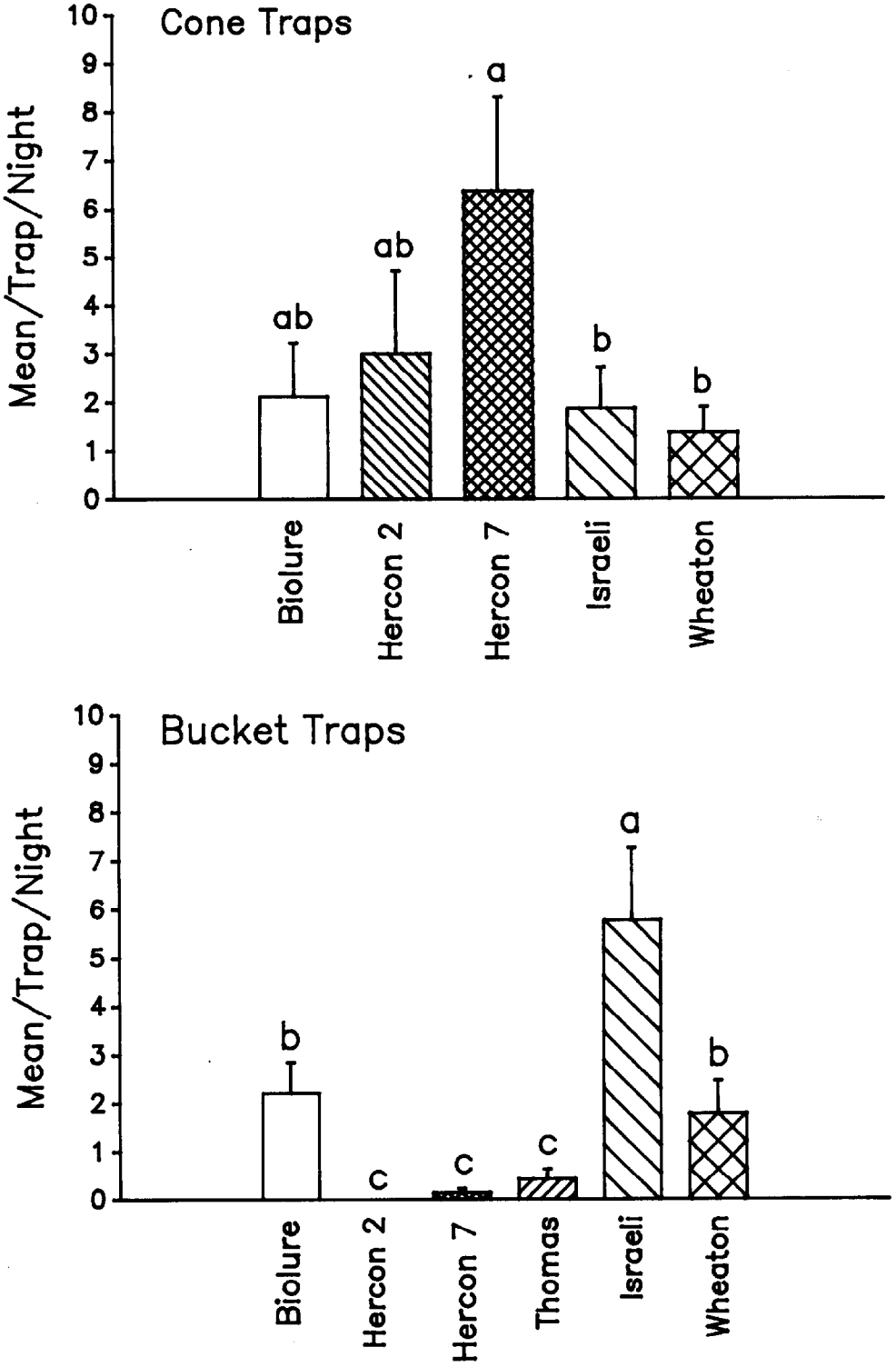

Fig. 1. Capture of *Heliothis virescens* males in cone traps (test 1, 8 replicates; 118 moths captured) or bucket traps (test 2, 14 replicates; 141 moths captured) traps baited with different pheromone dispensers. Bars with different letters are significantly different ($P < 0.05$, Duncan's Multiple Range Test).

columns to determine purity. Compounds that were <98% pure were purified by HPLC on a $AgNO_3$-coated silica column eluted with toluene (Heath et al. 1977) and reanalyzed by GC to ensure that they were >98% pure. The septa used were soxhlet extracted with methylene chloride for 24 h and air dried prior to loading. Each septum was loaded with 100 µl solution of the pheromone blend pipetted onto the wall of the large open reservoir of the septum. Septa were aired for two days at room temperature before use.

The treatments were arranged in a randomized complete block design (1 block/night in test 1; 2 blocks/night in test 2). The distance between traps in blocks was 60 m., the distance between blocks in test 2 was 100 m. Traps were checked daily and captured insects were counted and removed; then the traps were rotated one position. Trap catch data were transformed to $\sqrt{X + 0.1}$ and subjected to ANOVA (Steel & Torrie 1960); significance between means was determined using Duncan's Multiple Range Test (Duncan 1955).

Captures of *H. virescens* in cone traps were highly variable with the highest catch recorded for Hercon's 7-component pheromone blend (Fig. 1). In bucket traps, treatment differences were clear and distinct. The most effective lure was the Israeli septum followed by the Wheaton and Biolure dispensers. The least effective lures in bucket traps were the Thomas septum and the 2- and 7-component pheromone blends in Hercon's laminated plastic strips (Fig. 1).

The results suggest that bucket traps can be used to monitor *H. virescens* populations provided the trap is baited with an effective lure formulation. The reason for the higher efficacy of the Israeli septum in bucket traps as compared with the other dispensers tested is unknown. Nevertheless, these results are encouraging, but clearly indicate need for further research on pheromone dispensing systems for *H. virescens*. It is probable that the efficacy of the bucket trap for capturing *H. virescens* could be enhanced significantly through improvements in the pheromone delivery system.

This article reports research results only. Mention of a proprietary product does not constitute an endorsement or the recommendation of its use by USDA.

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METHYL PALMITATE AND METHYL MYRISTATE REPEL FLIES

G. HENDERSON,[1,2] J. D. WELLS,[3] AND R. L. JEANNE[1]
[1]Department of Entomology
University of Wisconsin
Madison, Wisconsin 53706

[3]Department of Biological Sciences
University of Illinois at Chicago
Box 4348, Chicago, Illinois 60680

We tested the effectiveness of methyl palmitate ($C_{17}H_{34}O_2$) (MP) (Eastman Kodak Co., Rochester, New York), an active ant repellent product of van der Vecht's gland in *Polistes fuscatus* (Post et al. 1984), and methyl myristate ($C_{15}H_{30}O_2$) (MM) (Aldrich Co., Milwaukee), a homolog, also known to be an effective ant deterrent (Post & Jeanne 1981, Post et al. 1984, Henderson & Jeanne 1989), as repellents against two species of flies.

Although ants are the most important predators, they are not the only arthropod enemies of *Polistes* spp. Nelson (1968) provided an extensive list of symbionts and

[2]Present address: Department of Entomology, Louisiana State University, Baton Rouge, Louisiana 70803.

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G. HENDERSON,[1,2] J. D. WELLS,[3] AND R. L. JEANNE[1]
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Although ants are the most important predators, they are not the only arthropod enemies of *Polistes* spp. Nelson (1968) provided an extensive list of symbionts and

[2]Present address: Department of Entomology, Louisiana State University, Baton Rouge, Louisiana 70803.

parasites from *Polistes* nests in or near the U. S. He included two *Sarcophaga* spp. (*S. polistensis* Hall and *S.* sp. near *bullata* Park) as parasites of *Polistes* larvae. Chemical protection against opportunistic flies like *Musca domestica* L. may also be of selective value since the nectar and honeydew stored in exposed wasp nest combs (Strassmann 1979, Hunt et al. 1987, Henderson personal observations) are attractive carbohydrate sources for flies (Downes & Dahlem 1987). Our pupose was to determine if *M. domestica* and *S. bullata* are repelled by the "ant" repellents.

Tests with *Musca domestica*:

Field tests were conducted 8-14 August 1988 on a farm with a high density of house flies in Cross Plains, Wisconsin (Dane Co.). A 500 ml erlenmeyer flask containing a 50:50 honey/water mixture was placed upside down onto a small petri dish that fit snuggly around the flask mouth. Only a small amount of "honeywater" was accessible to flies between the dish half and flask mouth (ca. 1 mm exposure). The food dispenser was supported 0.75 m from the ground using clamps and a chemistry ring stand. Placed directly under and in contact with the petri dish half was a 20 cm by 30 cm glass plate. Flies were highly attracted to the honeywater and they invariably landed on the glass plate (rather than the dish or flask) and walked across the plate to get to the food source.

Six trials were conducted, each consisting of three treatments; MM, MP and a control (untreated plate), presented sequentially in random order. Each treatment consisted of 8 ml of a 1% solution in hexane (containing 80 mg of MP, MM, or hexane alone) poured into the center of the plate where it dried to a thin film having a 6 cm radius. The plate was then placed under the dish. The number of flies that flew away upon tarsal contact with the chemical surface (repelled) and the number that continued toward the food source (not repelled), was recorded for five minute intervals between the hours of 12:00 and 4:00 PM over the seven day study period. Temperature was approximately 30°C.

We found no significant differences between the repellency of MM or MP to *Musca domestica* adults (total not repelled = 4 and 4, total repelled = 47 and 56, respectively; chi-square = 0.048, $p > 0.25$). Only 7.8% of the flies were not repelled by the treatments. We pooled these data for comparison against the control (untreated plate (hexane only); not repelled = 70, repelled = 2). *M. domestica* adults were repelled significantly by the treatments (chi-square = 144; $p < 0.001$).

Tests with *Sarcophaga bullata*:

Four petri dish halves (9 cm diam.), each with 50 g putrid ground beef mixed with 0 ml, 0.25 ml, 0.5 ml, or 1 ml of undiluted MM, were exposed to a colony (> 300 individuals) of *S. bullata*. MP was not used here because it remained a solid at the tested temperatures (22-24°C) and methyl esters do not appear repellent to insects when in a solid state (Henderson and Jeanne, personal observations). The four dishes (treatments) were arranged at random around the center inside of a large (0.6 m on a side) screened cage (BioQuip Products, Gardena, CA) containing adult *S. bullata* of mixed sexes. A 150 W flood bulb was placed 2 cm above the outside center of the cage to help maintain room temperature at ca. 24°C and increase fly activity (they often "sunned" themselves). The number of adult flies on each dish was recorded every 15 min for the next 1.5 h and the mean number per dish was calculated for each of five separate test days. Each test was separated by one week. The degree of MM repellency for each treatment was expressed by the percentage ratio method (Laake et al. 1931). In addition, the number of larvae (*S. bullata* larviposits) in each dish was counted after 48 h. The mean number of adults landed, as well as the number of larvae from each dish, were analyzed using a two-factor ANOVA.

TABLE 1. TWO-FACTOR ANOVA ON THE REPELLENCY OF METHYL MYRISTATE TO *SARCOPHAGA BULLATA*. TESTS ARE BLOCKED ON TIME.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	P
Treatments	3	716.19	238.73	4.64	< 0.05
Blocks	4	680.90	170.22	3.31	< 0.05
Error	12	616.91	51.40	–	–
Total	19	—	—	–	–

A significant difference in repellency of MM to *S. bullata* was found between treatments and between blocks (Table 1). The block (time) effect may be the result of changes in the physiological age (and thus readiness to larviposit) of the flies being tested. Only the 1.0 ml MM treatment was significantly different from the untreated control (Tukey's procedure at alpha = 0.5). However, the treatment effect reflected the correlation between increased repellency with increased treatment dose. Using the percentage ratio method developed by Laake et al. (1931), the highest treatment dose (1.0 ml), had a rating of 3.8, indicating the strongest repellency, while the lowest treatment doses (0.25 and 0.50 ml) had the highest values (ca. 43) and indicated a low degree of repellency (Table 2).

The number of larvae per dish, however, was not affected by MM (two-factor ANOVA, treatments $F_{3,12} = 2.42$, $p > 0.05$, blocks $F_{4,12} = 2.97$, $p > 0.05$). It is possible that MM is not as effective in repelling the flies 48 h after application and that larvae are deposited at that time. Previous studies have shown MM to have a short lifetime (< 24 h) (Henderson and Jeanne, 1989).

In conclusion, we found that the house fly is repelled by MP and MM and that a parasitic fly is repelled by MM. These repellents may have wider application in controlling pestiferous insects than was previously thought. Tests of MM and MP show repellency to yellowjackets and honey bees as well (Henderson and Jeanne, unpublished).

Chemical protection at the wasp nest may involve a fly repellent in addition to its known function as an ant barrier; in the field, paper wasps often rub parts of their nest other than the petiole with their gasters. However, it is not known if a repellent is applied to areas outside of the nest petiole.

TABLE 2. NUMBER OF *SARCOPHAGA BULLATA* ADULTS LANDING ON METHYL MYRISTATE (MM) TREATED BAITS COMPARED WITH THE NUMBER LANDING ON UNTREATED BAIT. THE RESULTS ARE EXPRESSED AS THE PERCENTAGE RATIO OR COEFFICIENT OF EFFICACY (SENSU LAAKE ET AL. 1931). A PERCENT RATIO OF 0 INDICATES PERFECT REPELLENT ACTION, A RATIO EQUAL TO 100 INDICATES NO REPELLENT EFFECT.

Treatment	No. dishes	Total No. landed	Percentage ratio
Control (untreated)	5	567	*
0.25 ml MM	5	243	42.8
0.5 ml MM	5	247	43.6
1.0 ml MM	5	22	3.8

*Percentage ratio is determined by dividing the total number of flies in treated dish by the number in the control dish X 100.

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POLYGYNOUS COLONIES OF *SOLENOPSIS GEMINATA* (HYMENOPTERA: FORMICIDAE) IN THE GALAPAGOS ISLANDS

D. F. WILLIAMS
Insects Affecting Man and Animals Research Laboratory
USDA-ARS
Gainesville, Florida 32604

P. WHELAN
Charles Darwin Research Station
Galapagos Islands, Ecuador

The tropical fire ant, *Solenopsis geminata* (F.), introduced into the Galapagos Islands over 100 years ago (Wheeler 1919) is presently widespread in the islands of the archipelago (Lubin 1984). They are especially abundant in improved pastures, parks, residential yards and gardens, and along National Park trails. These ants sting humans and also can be serious pests on young and weak Galapagos tortoises, and land iguanas (M. H. Wilson, Terrestial Ecologist, Charles Darwin Research Station, Galapagos Islands, unpublished data). Heavy populations exist on the island of Santa Cruz, particularly in the small village of Bellavista (Figure 1), on several of the surrounding farms,

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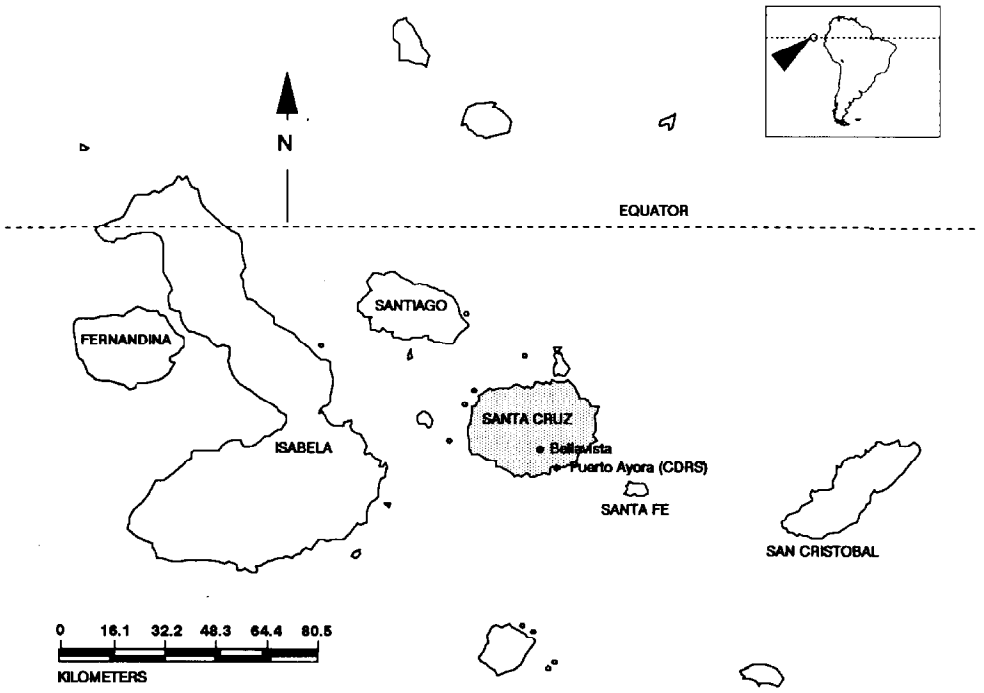

Figure 1. Galapagos Islands.

and in the town of Puerto Ayora, and on the Charles Darwin Research Station (CDRS). In the latter, they have caused problems in the rearing pens of young Galapagos tortoise and in tortoise holding pens, especially the egg-laying and feeding areas.

Attempts have been previously undertaken to control this ant with chemicals. The majority of the chemicals gave only short-term control and some had the potential to cause harm to the environment and affect other animals in the treated areas. Most of the chemicals killed foraging worker ants, but because the queen(s) were not killed, control was only temporary. The treatments appeared to control these pest ants only to have the ants reappear in a short time.

Extensive problems with *S. geminata* and another pest ant, *Wasmannia auropunctata* (Roger), prompted personnel from the CDRS to request assistance and advice from scientists at the USDA-ARS, Gainesville, Florida on methods of control. As a result, the senior author visited the Galapagos Islands to determine the extent of the problem and consult and advise officials of the CDRS and the Galapagos National Park Service on possible measures to use for control.

Trips were made in July 1987 and October 1989. During the first trip, we assessed the distribution of the two pest ants on two of the islands (Santa Cruz and Santa Fe), and conducted field tests of baits for control. During the second trip, we found several residential yards heavily infested with *S. geminata* in the small community of Bellavista north of Puerto Ayora. In addition, a field behind several of the residences also contained numerous *S. geminata* mounds. Closer inspection by digging in these mounds showed that several had characteristics such as high mound density, presence of numerous dealate queens, and the clustering of workers around these dealate queens exhibited by polygynous colonies of the red imported fire ant, *Solenopsis invicta* Buren in the United States (Glancey et al. 1975, Lofgren & Williams 1984). Five moderately physogastric dealate queens were collected from 3 different mounds (N=15) and placed in vials containing 70% isopropyl alcohol. The ants were brought to our laboratory in the U.S.

where all queens were dissected. Four of the 5 queens from each colony contained sperm in their spermathecae (13 of 15), evidence that these queens had been inseminated. We did not determine if these inseminated queens were all functional but they did have well-developed ovaries and degenerate wing muscles. Furthermore, previous studies have repeatedly demonstrated that inseminated queens in polygyne colonies are fully capable of contributing to both worker and sexual production (Ross 1988).

Polygyny has also been observed in *S. invicta* (Glancey et al. 1973, Fletcher 1983, Lofgren & Williams 1984), in *S. invicta/S. richteri* hybrid (Glancey et al. 1989), in *S. richteri* Forel and *S. quinquecuspis* Forel (Jouvenaz et al. 1989) and in *S. xyloni* McCook (Summerlin 1976). It has previously been reported in *S. geminata* in the U.S. (Banks et al. 1973, Adams et al. 1976, Porter et al. 1988) and more recently in Mexico (MacKay et al. in press), however, this is the first time polygyny has been noted in this species in the Galapagos Islands. The polygynous form of *S. invicta* can cause serious ecological problems in the U.S. (Porter & Savignano 1990). It is probable that the polgyne *S. geminata* causes similar problems in a much more fragile island ecosystem such as the Galapagos Islands. However, we only sampled a few colonies in one locality and do not know if polygyny is occurring throughout the population of *S. geminata* in the Galapagos. Although most of the queens were inseminated, we do not know whether they were functional queens in the nest. Holldobler & Wilson (1990) indicated that mature colonies of most ant species are monogynous. During evolution, properties of colony organization in social insects that bias the species towards monogyny change only when unique ecological conditions are imposed on the species (Holldobler & Wilson 1977, Oster & Wilson 1978). Probably the greatest competitor for *S. geminata*, especially on the island of Santa Cruz, is *W. auropunctata*, a true polygynous species with numerous queens and very large colonies. This unicolonial species was brought to the island of Santa Cruz sometime in the early part of this century and now has spread to several of the other islands (Lubin 1984). It is the dominate ant species in the Galapagos Islands and appears to be causing greater problems than *S. geminata*. In fact, it is believed to be causing major ecosystem changes in invertebrate diversity and density (Clark et al. 1982). Few ant species overlap with *W. auropunctata* in areas of high density and only *S. geminata* may be a successful competitor (Lubin 1984). Although we do not know what is occurring in the *S. geminata* populations in Bellavista, the competition between *S. geminata* and W. auropunctata in this area is intense. Is it possible, due to this competition, a unique ecological condition as described by Holldobler & Wilson (1977) has occurred which has initiated polygyny in *S. geminata*?

The authors wish to thank J. C. Trager for the *S. geminata* confirmations and to Terry Krueger for his technical assistance in the dissections of the queens.

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BOOK REVIEWS

PETER D. STILING, 1989: Florida's Butterflies and Other Insects. Pineapple Press, Sarasota. 96 pp. Hardbound. Price $24.95 (plus $1.50 postage. Florida residents add $1.75 sales tax.)

Neither a coffee table book nor a field guide, Peter Stiling's Florida Butterflies and Other Insects still can pass as either.

He begins with an essay on the importance of insects. He recounts killer malaria and yellow fever epidemics as late as 1939 and the story of air conditioning, which now allows Florida's population growth, being invented to cool malaria patients. He discusses the reasons scientists believe mosquitoes cannot transmit AIDS. He includes the tale of the world's first biological control success against aquatic weeds—250 beetles released near Jacksonville which conquered the whole state's alligatorweed infestation. He also provides evolutionary context for Florida's chitinous creatures and a kind word for scientific nomenclature.

Luminous photographs of 154 insects and spiders accompany descriptions of their habits and habitats. Selecting only the flashy and frequently encountered specimens keeps the book short enough to be handy as a backpack reference. The book's value as a guide would be enhanced by sketches or guidelines on the contents page—not all of us know that locusts are Orthoptera not Homoptera.

Other features: creating and visiting butterfly gardens, insect collections, a good index and additional readings.

Best of all, the book can help people be a little more aware of the 26 billion six-legged creatures that share each square mile with us two-legged ones. That's worth doing.

DARCY MEEKER
Institute of Food and Agricultural Sciences
University of Florida

J. A. SLATER AND R. M. BARANOWSKI. Lygaeidae of Florida (Hemiptera: Heteroptera). Arthropods of Florida and Neighboring Land Areas. Vol. 14. 211 p. Gainesville, FL, 1990. Paper-bound. Price $28.00.

Accurate, thorough, useful—these were my thoughts as I glanced at this attractive volume. A careful reading mostly sustained this initial impression.

Among Heteroptera or true bugs, the Lygaeidae is the second largest family (about 3,000 species worldwide). In the North American fauna of more than 300 species are crop pests such as the infamous chinch bug, *Blissus leucopterus* (Say); general predators, *Geocoris* spp., that are important in the natural control of some agricultural pests; and a diversity of litter-inhabiting seed predators (Rhyparochrominae) that may help suppress populations of weed species. The family also is crucial to an understanding of heteropteran phylogeny and relationships within the Pentatomomorpha.

This work, a significant contribution to the knowledge of North American Lygaeidae, is a complete account of the known Floridian fauna: 105 species in 47 genera. It contains keys to the eight subfamilies occurring in Florida and keys to genera and species within these subfamilies. Slater and Baranowski's work not only permits accurate determination of specimens from Florida (and, to a degree, those from the southeastern states and the West Indies), but provides a baseline of current systematic knowledge and identifies the biodiversity of this interesting geographic region. Entomologists, ecologists, and

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biogeographers will find it an invaluable reference. It is hoped that administrators will see its value and support similar projects. In many ways, the Slater-Baranowski work can serve as a model for much-needed regional manuals treating the U.S. insect fauna.

The format is nearly the same as that used in their *Coreidae of Florida* (Baranowski and Slater 1986). Introductory material consists of an overview of the Lygaeidae, a brief summary of the family's economic importance, and a zoogeographic analysis of the fauna. Drs. Slater and Baranowski then place their research in historical context by reviewing previous work and publications on Florida lygaeids.

The taxonomic portion (p. 5-188) is the volume's focal point. All keys are well illustrated and appear workable and usable by the nonspecialist. For each species there is a short section on diagnosis, biology, distribution, and Florida distribution (which includes a map). Excellent habitus drawings of many adults and fifth instars of several species enhance the species write-ups. Also useful are a list of all associated plants and an index that has the principal entry for each taxon in bold type. An abstract highlighting new U.S. records and listing species new for Florida would have been a useful addition.

Few problems were detected in the systematic accounts. Under *Neortholomus jamaicensis*, figures listed as 22 and 23 are actually 22A and 22B. Parentheses should be added to the authors of *Belonochilus numenius* and *Kleidocerys resedae*, i.e., (Say) and (Panzer), respectively; the original description of the latter should read *Lygaeus* (not *Kleidocerys*) *resedae*. *Cistalia signoreti* should read *C. signoretii*, and the type species of *Cryphula* is *parallelogramma* (not *parallogramma*, a typographical error).

In several instances, biological information is attributed to personal communication, but only the observer's last name is given. This would have been sufficient to identify the workers involved if names and institutional affiliations had been listed under Acknowledgments. The personal communication concerning habits of *Eremocoris depressus*, which is attributed to me (p. 104), needs clarification. I collected one specimen of this bug from a Chester Co., Pennsylvania, serpentine barren by beating cones of pitch pine, *Pinus rigida* Mill. But the collection "of numbers of specimens by beating pine cones in New Jersey" should be referred to *Slaterobius quadristriatus* (Barber).

In reviewing the author's *Coreidae of Florida* (Wheeler 1990), I felt compelled to mention what I considered an inordinate number of typographical errors and inconsistencies. The lygaeid work contains similar problems. These begin with the table of contents: parentheses inadvertently placed around the author of a genus (*Lygaeospilus* Barber), author names omitted for three species, parentheses omitted from the authors of two other species, the tribe Orsillini listed as Orsillinae, Guerin-Meneville cited as such but also as Guerin, and Latreille spelled Latrielle.

The text contains numerous misspellings of plant and insect names, one sentence begins with a lowercase letter, periods are omitted from two sentences, the period is consistently omitted from "et al.," and two lines at the top of p. 48 are repeated from the bottom of p. 47. Punctuation often is nonstandard. For example, commas are missing in constructions such as "Small coarsely punctate" and inexplicably inserted before parentheses in recording label data from specimens (e.g., "1-VII-56, (at *Erigeron*), R. A. Morse, (RMB)."

Although the authors must be held accountable for these and other problems, some editorial help could have been expected. Copyediting would have prevented a sentence fragment, several run-on sentences, occasional ones in which subject and verb do not agree, as well as some awkward and ungrammatical sentences.

Certain factors perhaps extenuate the errors, for instance, lack of an opportunity to read galley proofs, deadline for submission of the manuscript, or time limit on the availability of publication funds. It remains, however, that more errors—nearly all trivial when considered individually—occur than in most similar works. It is disappointing to see a potentially outstanding volume marred by lack of attention to detail and an apparent lack of copyediting.

The well-conceived series "Arthropods of Florida and Neighboring Land Areas" is a credit to the Division of Plant Industry and Florida Department of Agriculture and Consumer Services; it is a source of pride for the state. Its volumes represent a useful systematic, ecological, and zoogeographic resource. Authors submitting manuscripts should receive good copyediting to ensure some consistency among the papers and maintain high standards for this series.

Despite the problems noted and ones I refrained from mentioning, the *Lygaeidae of Florida* is a most valuable addition to North American heteropterology. It provides new information on an important and somewhat neglected group of insects from a biogeographically critical area. The authors are to be commended for this considerable achievement.

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A. G. WHEELER, JR.
Bureau of Plant Industry
Pennsylvania Dept. of Agric.
Harrisburg, PA 17110-9408

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Att: Toni Caithness, C.A.E.
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Att: Thomas Minter
1700 DeLeon Street
Oviedo, FL 32765

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Att: Carroll D. Applewhite
Route 3, Box 36
Tifton, GA 31794

Norman Goldenberg
3 Grove Isle Drive #1507
Miami, FL 33133

Helena Chemical Company
Att: Steve McDonald
P.O. Box 5115
Tampa, FL 33675

ICI Americas, Inc.
Att: Henry Yonce
1092 Glenwood Trail
Deland, FL 32720-2130

Integrated Crop Protection
Att: Kevin Short
405 Avenida de Mayo
Sarasota, FL 34242

Martin Pest Control
Att: Michael D. Martin
P.O. Box 610605
North Miami, FL 33161

McCall Service Inc.
Att: Bryan Cooksey
P.O. Box 2221
Jacksonville, FL 32203

Mobay Corporation
Att: B. A. Bustillo
P.O. Box 667
Lutz, FL 33549

MSD AGVET
Attn: Art James
P.O. Box 2000
Rahway, NJ 07065-0912

Mycogen Corporation
Att: Carol Fisher
407 Avenida de Mayo
Sarasota, FL 34242

Nor-Am Chemical Company
Field Station Florida
P.O. Box 7
Cantonment, FL 32533

E. O. Painter Printing Co.
Att: S. Dick Johnston
P.O. Box 877
DeLeon Springs, FL 32130

Plant Products Corporation
Att: Robert Geary
P.O. Box 1149
Vero Beach, FL 32960

Rhone-Poulenc Ag Company
Att: Mel Kyle
P. O. Box 916385
Longwood, FL 32791-6385

Rohm & Haas Company
Att: Stephen E. Crane
3682 Liberty Square
Ft. Myers, FL 33908

Sandoz Crop Protection Corporation
Att: Galen B. Wilson
5511 Highlands Vue Lane
Lakeland, FL 33813

South Bay Growers
Att: Stewart Swanson, Tech. Dir.
P.O. Drawer "A"
South Bay, FL 33493

Sun Refining & Marketing Co.
Att: N. E. H. Wright
P.O. Box 1135
Marcus Hook, PA 19061-0835

Sunshine State R & D Inc.
Att: Robert W. Metz
P.O. Box 2363
Brandon, FL 33509-2363

Uniroyal Chemical
Att: Keith H. Griffith
6233 Ridgeberry Court
Orlando, FL 32819

Van Waters & Rogers
Att: Norman R. Ehmann
2256 Junction Avenue
San Jose, CA 95131

Walt Disney World
Att: Jerry A. Hagedorn
P.O. Box 40
Lake Buena Vista, FL 32830

A. C. "Abe" White R.P.E.
817 W. Fairbanks Avenue
Orlando, FL 32804

Wright Pest Control
Att: M. L. Wright, Jr.
P.O. Box 2185
Winter Haven, FL 33880