INTRODUCTION

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ABSTRACT

A discussion is presented on the need for alternative control strategies for *Helicoverpa zea* (Boddie) and other noctuids to supplement traditional insecticidal control that targets larval stages of the insects. A rationale is presented for developing control strategies focusing on adult control which use attracticide formulations comprised of feeding attractants, stimulants, and toxicants. Volatile chemicals identified from blooms of natural adult food sources of *H. zea* adults, including *Gaura* spp. and other plants, would provide the basis for the attractant. This control technology could be implemented on an area-wide basis as a means of effecting an efficient insect control mechanism having less dependence on insecticides.

INTRODUCTION

Information contained in this supplement is based on presentations at an informal conference entitled "Potential for Development of Adult Control Technology of Noctuid Pests with Plant Attractants" held in conjunction with the Annual meeting of the Entomological Society of America, December 1988 in Louisville, KY. The presentations have been updated to include developments through 1994. This conference addressed the need to develop insect control technology that is consistent with the increased realization of the detrimental effects of insecticides to the environment and human and animal health.

Heliothis/Helicoverpa spp. are among the most injurious pests of food and fiber crops in the world (Schwartz and Klassen 1981). In the United States alone, damage and control of *Heliothis/Helicoverpa* spp. cause an annual loss of at least $1.5 billion (King and Rogers 1986). Insecticide control costs for cotton were estimated at nearly $350 million in 1989 (Head, 1990). Much of this cost was attributed to insecticides used for control of corn earworm, *Helicoverpa* zea (Boddie), (corn earworm, bollworm, tomato fruitworm). The corn earworm causes annual losses of over $125 million to horticultural crops in the United States. In addition, cabbage looper and other noctuid species account for an equal or even greater cost for production of such crops. Consequently, the development of effective control systems based on an attract and kill technology could significantly decrease the use of insecticides to control these noctuid pests, reduce contamination of food and water, provide a cleaner and safer environment, and result in increased economic benefits to

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producers.

Traditional insect control programs normally target the larval stages of the insects. The feeding behavior of larvae, especially in crops such as sweet corn, provides a major constraint to control with conventional procedures. Since larvae feed primarily on the fruit, insecticides must be applied at rates sufficient to provide adequate coverage of the fruiting forms to obtain acceptable control. This has created a major concern for the perceived safety of food from consumers. Development of an alternative technology utilizing attractants and feeding stimulants that target the adult stage could effectively suppress populations prior to oviposition and subsequent larval infestation of crops. Further, the adult female offers a population density 1000X less than her potential larval progeny. Adults are 10-100X more susceptible to insecticides and 10-100X less likely to develop insecticide resistance than larvae (Joyce 1982). Also, potential adult female exposure to treated plant surfaces is high because they must contact the plant to oviposit and feed.

The question then arises, why are control procedures aimed at the larval stage? Other than the fact that larvae are the destructive stage, they are also visible and not highly mobile. Additional key factors are as follows: 1) Larval control procedures have been relatively effective and production, sales, and delivery systems have been developed that can be implemented by individual growers on a field by field basis, requiring little input from organizational or governmental bodies; 2) Research has not defined an economically viable alternative control system; 3) Adults are nocturnal and until the last few years, little was known concerning their nocturnal activities; and 4) Adults are highly mobile (Raulston et al. 1982, Raulston et al. 1986a) and efforts to control them would likely require area-wide implementation.

In a review of insect attractants, pheromones and related compounds, Inscoe (1982) lists 323 compounds and 889 different references. Klassen et al. (1982) listed 674 arthropod species for which some type of attractant has been chemically defined. A large number (475) of those species are in the order Lepidoptera and the attractants are primarily sex pheromones. Other reviews by Plimmer (1985) and Matsumoto et al. (1985) show that volatiles from natural protein hydrolysates contain feeding attractants for several species of insects which suggest that naturally occurring plant products can play a major role in the development of insect pest control. Natural food attractants are primarily found in material on which the adults feed (Matsumoto et al. 1985). A majority of these act as attractants to insects in the order Diptera (Knipling 1979). Some are considered food lures but attract only males that need protein for reproductive development. None of these compounds were identified from flowers or nectar which are important adult food sources for *Heliothis* spp.

Empirical screening of both natural and synthesized compounds has resulted in the identification of numerous compounds which show some attractancy to certain species of insects (Beroza and Green 1963). These studies show the potential for the presence of attractants in various natural products, including plants. Indeed, Coppedge et al. (1977, 1978) demonstrated that attracticide baits containing natural and synthetic products were effective in suppressing adult screwworm populations. Metcalf and Kogan (1987) point out that there are more than 200,000 species of flowering plants and at least 500,000 species of insects that interact with them. They estimated that 50,000 to 100,000 secondary plant compounds are produced during the growth and development of these plants. Only about 12,000 of these compounds have been characterized and most are not essential for the normal physiology of the plants. Within this group of compounds, 64 have been characterized as plant odorants attractive to more than 300 insect species in 5 orders. However, only phenylacetaldehyde is listed as attractive to adult corn earworms.

Phenylacetaldehyde has been identified from constituents in corn silk (Cantelo and Jacobson 1979a), corn tassel (Buttery et al. 1980), bladder flower, citrus oil, and tomato

(Cantelo and Jacobson 1979b) as well as numerous other plants. The compound is attractive to numerous noctuid pest species (Smith et al. 1943, Cantelo and Jacobson 1979b, Creighton et al. 1973) in addition to both sexes of adult corn earworm. The type(s) of attraction to this compound has not been classified; however, it is more than an oviposition attractant, since it attracts moths of both sexes. Presently, no feeding attractant has been clearly identified for the adult corn earworm, although some have shown low levels of attractancy (Shaver, Lingren, Raulston; unpublished).

Knipling (1979) postulated that competing natural food sources rather than insect population density would govern the efficiency of applied food attractants. He further theorized that competition from natural feeding attractants could be minimized by timing and placement of the attractant source. The potency of the attractant will also influence the effectiveness of attracticide formulations.

The more recent work of Lingren and Raulston (1986a), Lingren et al. (1986b) and Lingren et al. (1988), demonstrated that the feeding behavior of emerging corn earworm moths could be employed to minimize competition from natural food sources. Adult population control could be effective in areas containing competitive levels of natural food sources or in decaying habitats if the emerging adults were targeted. Lingren et al. 1990 obtained nearly 100% mortality of emerging corn earworm moths in small field plots using a bait containing a feeding stimulant and killing agent placed in a band around the base of corn stubble. A slow release formulation of such a bait containing a feeding attractant could potentially control emerging populations when applied to other locations on the corn plant or to other crops. Lingren et al. (1987, 1988) observed that newly emerged moths move to the top of the plants before taking flight. If they were induced to feed prior to taking flight, then suppression would be possible if baits were applied near the top of the canopy.

Corn earworm adults feed on floral nectar from numerous flowering plants (Raulston et al., 1997, this supplement), on moisture, and on sugar containing exudates of plants and insects. Tietz (1972) lists 102 food plants as food sources for the corn earworm and there are likely many more. More recent studies by the authors of this report have shown that adult corn earworms are attracted to blooms, bloom extracts and head space volatiles of *Gaura* spp. (Onagraceae). The genus contains 21 species which are widely distributed across the North American Continent (Raven and Gregory 1972). All but two of the species bloom at night and produce fragrant odors. Odor tests and corresponding trap captures, using plant parts as baits, show that the attractant is present in the fragrance released primarily from the petals of the bloom. The nectar is essentially nonattractive but stimulates corn earworm and other noctuid moth feeding. *Gaura* spp. are insect pollinated and apparently secrete the attractant to induce moths to feed on the floral nectars where they become contaminated with pollen. Adults of six orders of insects including 22 families and 82 species, primarily Lepidoptera (68 species) and family noctuidae (37 species) have been captured feeding on blooms and bloom extracts of *Gaura longiflora*. Honey bees feed on nectar and pollen of *Gaura* spp. during the early morning but have not been captured in traps baited with extracts or volatiles from blooms. Therefore, use of baits containing attractants isolated from *Gaura* spp. should not result in major honey bee mortality.

Our research efforts have focused on three species of *Gaura* (*drummondii*, *longiflora* and *suffulta*) which are presently under greenhouse and field plot propagation. *G. drummondii* is a perennial rhizomatous herbaceous weed that grows primarily in subtropical zones. The plant flowers from late March to June and flowering is short-to-long day sensitive. During peak flowering, it produces about 100 blooms per night per plant and about 7mg of nectar per bloom. It is more attractive to corn earworm than either *longiflora* or *suffulta*. *G. longiflora* is a robust, winter annual or biennial that blooms from July through September. Flowering is long-to-short day sensitive, and an individual plant produces about

1000 blooms per night during peak bloom. Nectar production is about 5 mg per bloom each night. The plant is distributed primarily from East Texas, north through Nebraska and east through Mississippi. *G. suffulta* is a summer annual that blooms from April through June and flowering is day neutral. It produces about 100 blooms per night per plant during peak bloom and each bloom produces about 5 mg of nectar. This species is distributed throughout most of Texas and Oklahoma with some specimens found in Eastern New Mexico. Several volatile chemicals that may be useful candidates for attractants have been identified from these species (Teranishi et al. 1991, Kint et al. 1993).

Numerous studies have demonstrated the migratory capabilities of corn earworm moths. Raulston et al. (1986b) reported that 1.3 to 6.5 billion corn earworm moths are produced from 200,000 ha of corn grown in a relatively small area concentrated in the Lower Rio Grande Valley (LGRV) of Texas and Northern Tamaulipas, Mexico, and suggested the area was a source of migratory moths. Peak emergence of moths from fruiting corn occurred over a 2-3 week period in June. Multi-disciplinary migration studies consisting of radar, meteorological and ecological components have tracked the displacement of corn earworm moths from the LRGV 482 km to the northwest where a subsequent oviposition peak occurred on cotton (Raulston et al. 1982, Raulston et al. 1986a, Wolf et al. 1990). Pollen analysis of moths collected in Lane, Oklahoma in early spring (1-1/2 months prior to diapause emergence), showed the presence of pollens from plants blooming only at the time in South Texas or further south (Lingren et al. 1994). This information demonstrates the presence of concentrated source populations of corn earworm moths and some of their migratory capabilities. Identification of pollen adhering to nocturnal feeding moths could be an important tool for identifying candidate plants that may contain feeding attractants.

It is likely that numerous primary source populations of corn earworm can be identified and their subsequent emergence predicted. Planting dates primarily control the times of emergence and the periodicity of nocturnal emergence is known (Lingren et al. 1988). The influence of migration on the spatial redistribution and infestation potential of corn earworm is not fully known. However, it is likely that suppression of adults in source populations located in southern latitudes could offer potential protection to crops in temperate zones where overwintering populations are very low or non-existent. The location of source populations should change as the growing season progresses from subtropical through temperate zones.

Several years of research conducted by the authors and cooperators on the nocturnal behavior and population dynamics of corn earworm and other nocturnal moths has led to the concept of adult control technology for corn earworm and other noctuid insects which uses feeding attractants and stimulants incorporated in a slow release attracticide formulation. The concept is based on observations of the following activity patterns: 1) Adults exit their pupal cells at night and immediately move to an upright object where they expand and dry their wings; 2) They remain at the emergence site for at least 2.5 hours and part of the population (10%) remains throughout the following day prior to taking flight early the next evening; 3) If a food source is available, the newly emerged moths will feed even prior to wing expansion; 4) 100% mortality of emerging moths has been attained in laboratory and field tests with baits consisting of a feeding stimulant and an insecticide [sorghum-water (3-1) plus 2% larvin] banded around the base of corn stubble; 5) Plants of the genus *Gaura* produce volatiles that attract corn earworm and many other noctuids, including cabbage looper and armyworms; 6) Bouquets of blooms, extracts of blooms, and head-space volatiles have been used as baits in Hartstack traps (Hartstack et al. 1979) and captured both sexes of corn earworms plus numerous other noctuid species, as well as numerous families in several other orders; 7) The attractant is released from the petals of *Gaura* spp. blooms while the associated nectar stimulates feeding; 8) Both males and mated and virgin females are attracted and will feed; 9) Isolation, identification, and synthesis of attractants for use in attracticide formulations should result in a reasonable level of control of source populations; 10) Control of immigrant or dispersing moths on fruiting corn or other crops has not been demonstrated but an attracticide formulation should provide adequate kill of moths, especially on crops that do not produce a feeding attractant or nectar. This is so because the first nightly activity of moths one day old or older is to feed and this appears to be true even when they are functionally reproductive (Alder 1987, Lingren et al. 1979, 1990). *H. zea* moths do not migrate during the daytime. Therefore, it is likely that many immigrant moths will feed before oviposition each night. Feeding activity during oviposition and other behavioral activities will likely depend on the power of attraction and placement of the feeding attractant; 11) The honey bee collects nectar and pollen from *Gaura* plants during early morning but is not attracted to extracts or volatiles. Therefore, a formulation utilizing the attractant should not produce major mortality of honey bees; and 12) The *Gaura* plant offers considerable potential for erosion control, honey production, game bird farming and possibly soil building capabilities. This should be extremely important to areas with low economic bases such as southeastern Oklahoma.

Based on information presented, we are proposing that an attracticide formulation can be developed using the *Gaura* attractant, a killing agent, a feeding stimulant, and slow release capability that can be used to control corn earworm adults in fruiting sweet corn and other crops. The attracticide may have control capabilities for numerous other pest species including the cabbage looper, soybean looper, and true armyworm. Major source population mortality of newly emerged adults on mature corn has already been demonstrated but a slow release formulation and a delivery system is needed for practical applications. Development of a source population control program will require some type of action agency involvement, and may be quite difficult to develop. On the other hand, corn earworm control in sweet corn during the fruit production season should be attainable on a field by field basis requiring no more than 2 applications of the attracticide at insecticide rates no higher than those already recommended. In sweet corn and other horticultural crops such as cabbage and lettuce, suppression can likely be attained without directly contacting edible portions of the fruit with the insecticides and it may be possible to obtain suppression without contacting the plant.

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