FALL ARMYWORM (LEPIDOPTERA: NOCTUIDAE): POTENTIAL FOR AREA-WIDE MANAGEMENT

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ABSTRACT

The fall armyworm's, *Spodoptera frugiperda* (J. E. Smith), inability to survive extended periods of temperature below 10°C critically limits its overwintering area. This trait renders the pest a model insect on which to research components of pest management systems and select those most suitable for implementing an area-wide management system. An overview of the potential of several components of such a management system for fall armyworm is assessed.

RESUMEN

La inabilidad del gusano cogollero, *Spodoptera frugiperda* (J. E. Smith), a sobrevivir extensos períodos de temperaturas más bajas de 10°, limita criticamente las áreas donde pudieran pasar el invierno. Esta característica rinde a esta plaga como un modelo sobre el cual se pudieran investigar los componentes de un sistema de manejo de plagas, y para seleccionar aquellos más propicios para implementarlos en un sistema de administración de un area. Se evalua una sobrevista del potencial de varios componentes de tal sistema de manejo del gusano cogollero.

Many of our most damaging species of insects of agricultural field crops overwinter in relatively small areas in the South compared to the areas they occupy in mid- to late-summer. Among these species are the corn earworm (CEW), *Heliothis zea* (Boddie), tobacco budworm (TBW), *Heliothis virescens* (Fabricius), fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), beet armyworm, *Spodoptera exigua* (Hübner), cabbage looper, *Trichoplusia ni* (Hübner), soybean looper, *Pseudoplusia includens* (Walker), and velvetbean caterpillar, *Anticarsia gemmatalis* Hübner.

The quantity of annual loss in dollars (actual loss of crop plus control costs) due to these pests is best estimated by the Southeastern Branch of the Entomological Society of America Insect Detection, Evaluation, and Prediction Committee Reports (1977, 1978, 1979, 1980, 1982, 1983a, 1983b). Since 1975, on a yearly basis, entomologists from the nine southeastern states cooperatively estimate losses due to insects. Their estimates of losses for the seven insects mentioned above are shown for the years 1975-1983 in Table 1. Similar data are not available for the entire United States; however, these data suffice to illustrate several points.

1. The average annual loss in the southeastern U.S. due to these seven migratory species approached $370 million.
2. The CEW is the most damaging of the species in the southeastern U.S., inflicting losses ranging from $118 to $248 and averaging almost $160 million annually.

3. The FAW ranks second in order of total losses, ranging from $39 to $297 and averaging ca. $60 million annually.
4. The percent of total loss caused by these seven species over the nine-year period attributed to the CEW and FAW was 63.4%. If TBW losses are added to CEW and FAW, the combined percent loss due to the three species is 77.1%.

Are entomological techniques currently available, or can techniques be developed to suppress overwintering populations of migratory Lepidoptera sufficiently to prevent losses resulting from their annual spring-early summer population expansion and subsequent migration throughout vast areas of agricultural crops? Which of the species would be the best choice for a research project to examine the potential of the phenomenon? Careful examination of the currently documented biology-ecology, distribution, and life history of the seven species reveals that the FAW is the most likely candidate to be used as the model species for such an endeavor.

Luginbill (1928) and Sparks (1979) document several attributes of the FAW that make the species the insect of choice to model the phenomenon of suppressing overwintering populations—

(1) No diapause mechanism has been developed so the species maintains itself in limited areas of the southern extremities of the United States.
(2) Population densities increase yearly in the late winter-early spring and a northward movement occurs that extends into Canada during some years.
(3) Losses due to damage and control costs are significant.
(4) The known overwintering area of the FAW is more restricted than that of the other species.

The overwintering FAW populations are subjected to many natural hazards to their survival. It is generally known that a wide range of biological agents attack various stages of FAW and that agricultural practices and winter hazards further limit survival of the overwintering stages.

Although we cannot identify and quantify all of the different hazards, we know that in sum total a very low proportion of the potential population survives even in the absence of control. Our goal should be to superimpose additional mortality factors on the normally surviving population without interfering with the natural hazards to their survival. It is ironic, however, that the primary method of FAW control now employed negates much of the natural control that nature provides. This system of FAW management by the application of broad-spectrum insecticides is a crude pest management procedure. Yet, this is the approach we have followed for years, and the prospects in the foreseeable future seem dim for major improvement so long as growers must follow the uncoordinated crop-to-crop management system and wait until the pests have already reached damaging or threatening population levels before applying control measures. A change in strategy will be required for major advances in FAW management, regardless of the techniques that may be available.

An alternate to the defensive system described would be to concentrate on the management of FAW populations at strategic times and places for the purpose of maintaining numbers below the level of significant damage throughout a FAW ecosystem. Such an approach would require an attack on the total FAW population in an organized and coordinated manner, and generally well in advance of the existence of economically damaging population levels.

Following the successful eradication of the screwworm, *Cochliomyia hominivorax* (Coquerel) (Baumhover 1966), research on entomological techniques deemed suitable

TABLE 1. ESTIMATED INSECT LOSSES[1] INCURRED IN NINE SOUTHEASTERN STATES DURING 1975-1983 DUE TO SEVEN MIGRATORY SPECIES[2] OF LEPIDOPTERA.

	CEW	TBW	FAW	BAW	CL	SBL	VBC	Totals
1975	118.10	53.20	61.20[3]	4.15	6.60	[4]	38.00	281.25
1976	124.00	54.55	31.95[3]	6.20	13.25	[4]	20.05	250.00
1977	162.80	63.15	297.15	39.00	12.90	10.70	29.80	615.50
1978	135.25	56.45	72.05	8.40	70.15	24.40	16.62	383.32
1979	133.05	43.90	50.15	10.05	12.05	20.60	38.25	308.05
1980	155.50	42.10	46.90	8.55	16.70	31.50	27.50	328.75
1981	134.70	46.65	41.35	6.75	12.35	29.50	7.40	278.70
1982	215.80	46.65	39.80	6.94	15.10	89.09	44.54	457.92
1983	247.75	46.17	39.15	6.29	13.19	31.92	32.15	416.62
Totals	1426.95	452.82	679.70	96.33	172.29	237.71	254.31	3320.11

[1]Losses in millions of dollars.
[2]CEW = corn earworm; TBW = tobacco budworm; FAW = fall armyworm; BAW = beet armyworm; CL = cabbage looper; SBL = soybean looper; VBC = velvetbean caterpillar.
[3]Losses due to FAW and other armyworms, excluding BAW.
[4]Losses not identified.
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for suppression or eradication of entire populations of insects was intensified. The objective of this paper is to examine the current status of control tactics that could possibly be used to suppress the FAW in its south Florida overwintering area. While the opinions expressed are those of the author, senior research entomologists (see Acknowledgments) within each area of expertise were consulted and their evaluations were taken into account. No attempt is made to present a complete literature review of the various areas of research. For that information, the reader is referred to publications resulting from three previous FAW symposia (Mitchell 1979, All 1980, Mitchell and Waddill 1984) as well as the current publication (Wiseman and Gardner 1986).

Biology-Ecology and Population Dynamics

Detailed information on the biology-ecology and population dynamics of the FAW in its overwintering areas is essential prior to the initiation of a program to suppress that overwintering population: Delineation of biotic/abiotic factors governing the size of the overwintering populations is essential to discover the weakest link in the insect's life cycle and to implement a program to successfully attack the vulnerable area effectively to suppress the population.

This researchable area is one in which a significant quantity of information has been obtained in recent years. However, more information is needed. Through cooperative efforts with the Agricultural Research and Education Center of the University of Florida at Homestead, biology-ecology and population dynamics of the FAW have been partially documented. The cooperative effort was initiated in 1981, but the data are fragmented due to a noncontinuous program resulting from ARS personnel actions and ARS policies related to specific cooperative agreements. The south Florida area is the critical area in which to research the potential to suppress overwintering FAW populations. Further, we do not have sufficient continuous data collected over a sufficient period of time to initiate a suppression program, even if we had an outstanding technique in hand.

Farther North, in north Florida, Georgia, Alabama, and South Carolina, Pair et al. (1986) have conducted a coordinated FAW trapping project and larval surveys from 1981-1985 to identify times of occurrence of FAW, identify major host plants, and survey for major biotic factors influencing FAW populations in the southeastern United States.

Harrison (1986) and Linduska and Harrison (1986) have generated additional FAW data concerning times of occurrence, biology-ecology, and damages caused by the insect in Maryland.

In the lower Rio Grande valley of Texas and in northeast Mexico in the State of Tamaulipas, Raulston et al. (1986) have examined time of occurrence and the population dynamics of FAW occurring on about 200,000 ha of corn grown in that area. These data produce evidence that the FAW survives and propagates in sufficient numbers to create problems in that area or to seed other populations when adequate weather transport systems are available.

FAW Migration

In those years in which winter and spring conditions favor FAW in its overwintering range, the pest spreads northward (Walton and Luginbill 1917, Luginbill 1928, Vickery 1929). The rate of movement was estimated at 480 km/generation in some years. The manner in which this migration occurs is speculative, but a convincing hypothesis implicates weather systems as a means of transport. FAW were captured in light traps above 84 m located on a TV tower in South Georgia (Callahan et al. 1972) and in light traps located on unmanned oil platforms located 32, 74, 106, and 160 km in the Gulf of Mexico (Sparks et al. 1986). A cool front moving southward through the Gulf of Mexico was implicated as the transport system for the movement of these insects through the Gulf. Insects and other airborne organisms are known to be concentrated, transported, and deposited great distances from their origin in numbers sufficient to cause serious losses to crops (Greenbank 1957, Greenbank et al. 1980, Rainey 1976, Schaefer 1976, Joyce 1973). There is little reason to doubt that weather systems can assist and/or transport insects northward in the spring-summer in the U.S. and southward in the fall.

Luginbill (1928) speculated that FAW "outbreaks, when general and severe, apparently originate in Mexico and the West Indies." Wolf et al. (1986) captured FAW on a ship operating near the center of the Gulf of Mexico, causing them to speculate that some economic insects can cross the widest part of the Gulf of Mexico with favorable atmospheric conditions. In the proceedings of this Fall Armyworm Symposium, Westbrook and Sparks (1986) computed trajectories that frequently corroborated trajectories hypothesized by Luginbill (1928) which originated in Cuba or south Florida, headed northwestward into the Gulf of Mexico, then veered northeast along the Atlantic seaboard. However, these trajectories failed to show atmospheric transport from the Yucatan peninsula to southern Florida or directly to Georgia as proposed by Young (1979).

The fact remains that we do not know if FAW migrating from Cuba, West Indies, or Mexico, impact FAW populations in the United States. Isozyme studies by Mitchell (USDA-ARS, personal communication) and by Pashley et al. (1985) failed to conclusively implicate FAW migrants from outside the continental U.S. as a source of FAW infestations in the United States. Additional research is needed to make this determination. However, should FAW prove to be a long-range migrant, that fact alone should not discourage the potential for area-wide management using techniques that would disperse deleterious effects throughout the FAW population.

Host Plant Resistance (HPR)

In the early 1960s, USDA-ARS initiated a team approach to produce resistance in corn and sorghum to the FAW at the Southern Grain Insects Research Laboratory, Tifton, GA. Later, a second team effort was initiated at Starkville, MS. At both locations, entomologists and geneticists conduct cooperative research to identify sources of resistant germplasm, identify and define mechanisms of resistance, and then incorporate resistance into germplasm suitable for release to commercial entities for incorporation of the resistance into commercial lines of corn and sorghum.

Wiseman (1985) presented a historical account of HPR terminology according to types and mechanisms of resistance. Although the ARS-Tifton and Starkville programs have evolved into different major thrusts, collectively they have made major advances in techniques and methodology. Through the years, these scientists have developed techniques for rearing insects to insure quantitative insect populations in field plots, methods of infesting field plots, techniques for rating resistance, and developed breeding schemes for incorporating resistance.

High levels of antibiosis and nonpreference resistance to FAW larvae have been demonstrated in the laboratory but remain undeveloped for field use (Wiseman et al. 1981, Wiseman and Widstrom 1986). The ARS-Starkville, MS, team has released eight inbred lines and one population with intermediate resistance to FAW since 1974 (Wiseman 1986). Although the genetics of the resistance has not been studied thoroughly, the mechanisms of the resistance have been described as larval antibiosis and nonpreference (Williams et al. 1983, Wiseman et al. 1983). Hybrids containing the resistant parents significantly out-yield susceptible hybrids when both have comparable numbers of FAW/plant infestations.

Heavily fertilized bermudagrass pastures are not as attractive to the FAW as their preferred host, corn; however, on occasion these pastures support large populations of FAW larvae. One cultivar of bermudagrass, Tift 292, was identified as resistant to FAW by Lynch et al. (1983). During this conference, Quisenberry et al. (unpublished data) reported quite different results when Tift 292 was incorporated in resistance studies with a FAW culture from Louisiana. At this time, the variations in the data from the two locations are inexplicable. Differences may be due to experimental procedures or could be due to strains of insects reared on laboratory vs. bermudagrass diets.

When one compares the current status of HPR/FAW to the status of FAW populations in a limited FAW overwintering area in south Florida, it is difficult to imagine that HPR can function as a tool to suppress those overwintering populations. The majority of the corn planted in the FAW overwintering area is sweet corn for market or seed corn for increase. In both cases, farmers and seed producers decide what to plant, and FAW-resistant germplasm is unavailable/nonfunctional in either case. The only way that FAW populations could be substantially reduced by HPR in the south Florida overwintering area is for all seed corn companies to follow the lead of DeKalb/Pfizer and Funk's and incorporate resistant FAW germplasm into all hybrids undergoing seed-increase in that area. Even then, a program designed to destroy all volunteer corn would have to be followed carefully because the level of currently available resistance is quantified as moderate and will not withstand severe pressure.

At this symposium, Dr. J. L. Overman (1986), DeKalb Agricultural Research, Union City, TN, presented industry's viewpoint of resistance in crop plants to the FAW. DeKalb is one of the commercial companies that is attempting to incorporate FAW-resistant lines developed through the ARS program at Starkville, MS, into commercial hybrids. Dr. Overman reiterated industry's concern for public-supported research groups to find and incorporate resistant germplasm into material suitable for incorporating into commercial lines.

Once commercially available FAW-resistant corn hybrids, sorghum lines, and bermudagrass cultivars are available, the likelihood of coercing all farmers to utilize only resistant varieties is slim, unless there is a yield increase or those resistant varieties are much cheaper to grow. Even then, the process would be a long drawn-out affair with a crop such as bermudagrass. Therefore, the role of HPR in FAW control strategies will probably continue to be most functional in an "on-farm" situation. Farmers with continuous FAW problems can receive considerable relief via use of resistant varieties. However, if the entire corn crop were planted to resistant hybrids, then FAW populations might eventually adapt to those varieties and overcome the resistance.

FAW Pheromone

About 25 years ago, sex pheromones were envisioned by entomologists as tools with great potential to eliminate the entire male population of a species. The female-produced pheromone could supposedly be used to trap out all males, mixed with insecticides to lure males to their death, or dispersed over vast areas to disrupt communication between sexes, thereby eliminating mating and the species. Sparks (1980) reviewed the potential of the FAW pheromone for monitoring and managing populations at that time.

Since that time, Mitchell et al. (1985) have identified three additional components in addition to the two identified by Sekul and Sparks (1967, 1976). Although the female produces a five-component pheromone, a mixture of two components only is required to effectively lure males into traps. Entomologists have yet to correlate trap catch of males with actual populations of FAW in the vicinity of traps. However, pheromone traps remain the tool of choice to determine the relative abundance of FAW populations in a given area.

Numerous field trials have been conducted with components of the FAW pheromone singly and in combination, as well as with chemical pheromone mimics. These chemicals were applied in attempts to disrupt matings. It is convenient to explain the failure to disrupt mating sufficiently to have a biological impact on the high mobility of the FAW. However, I believe that the complexities of noctuid nocturnal behavior and of the pheromones of several insect species of agricultural importance have combined to curtail the enthusiasm for sex pheromones as a major technique for insect population suppression.

At this time, those most familiar with the insect and its pheromone generally recognize and agree that the potential for pheromone mating disruption to suppress populations of FAW is nil.

FAW Predators and Parasites

Very little information is available to assess the potential of FAW predators to suppress FAW populations due to the fact that practically no research has been conducted. This is an obviously neglected area for future research.

Ashley (1979) documented 53 species of parasites attacking FAW populations around the world. Since 1981, data from several surveys have delineated the species and species distribution of FAW parasites in Florida and throughout much of the southeastern U.S. The three most important parasites of FAW in the Southeast, listed in the order of importance, are *Chelonus insularis* Cresson, *Temelucha difficilis* Dasch, and *Cotesia marginiventris* (Cresson) (Ashley et al. 1982, 1983, Mitchell et al. 1984). Occasionally, all of these parasites give high rates of parasitism of FAW larvae. Efforts to introduce two FAW larval parasites, *Eiphosoma vitticole* Cresson and *Telenomus remus* Nixon, into the south Florida overwintering FAW population have been unsuccessful.

Current inabilities to mass rear any of the hymenopterous larval parasites deem the possibility of using them in an area-wide suppression program practically nil. Entomologists most familiar with the FAW and its parasites agree that the possibility of a successful FAW suppression program utilizing hymenopterous parasites is remote at this time.

Entomologists conducting semiochemical research have great hope of using those semiochemicals to manage the parasites' behavior sufficiently to result in population suppression of the host insect (Lewis and Nordlund 1980, 1984, Dmoch et al. 1985, Keller et al., unpublished data); however, the utility of this approach is yet to be demonstrated.

Past experiences with *Trichogramma* indicate that semiochemicals occasionally double to quadruple parasitism rates when normal parasitism is quite low. While increased rates of parasitism are statistically significant, their biological significance is inconsequential as far as insect control is concerned. This being the case with a very general parasite, leaves little hope for success with specific parasites.

However, Gross and co-workers (Gross and Young 1984, Gross and Johnson 1985, Gross et al. 1985) have developed techniques for mass rearing and releasing *Archytas* *marmoratus*—a larviporous endoparasitoid of the Noctuidae, including the FAW. These developments increase tremendously the prospects of using this parasitoid to suppress FAW in its overwintering area.

Pathogens

Gardner et al. (1984) reviewed the potential of microbial agents in managing FAW populations. At this symposium, Hamm (1986) reported on a new virus disease (*Ascovirus*) of FAW making a total of three FAW viruses. All of these viruses have the potential to devastate FAW populations. Their drawbacks are allowing significant damage prior to killing the FAW and inconsistent efficacy. The FAW nuclear polyhedrosis virus is FAW's most virulent pathogen; yet, because of its *low virulence* and its inefficacy against larger larvae, it has not been registered or produced commercially.

FAW are occasionally infected with unidentified species of *Nosema*, but neither virulence nor host range are known.

Gardner (1986) reported that *Bacillus thuringiensis* (BT) gave sporadic results, and the effective dosage rates are too high to be economically feasible. FAW-specific BT isolates have not been developed.

A *Vairimorpha* sp. from Bolivia administered in sublethal doses allows larval maturity and is subsequently transovarially transmitted. Thus, pending acquisition of an EPA required EUP, this *Vairimorpha* sp. has potential for use with other techniques to suppress overwintering FAW populations (J. J. Hamm, USDA-ARS, personal communication).

FAW Sterility

Laboratory and limited field studies with FAW indicate that 8-10 krad ^{60}Co induces partial sterility that could prove to be effective in suppressing FAW populations (Carpenter et al. 1983). However, actual competitiveness of lab-reared, ^{60}Co-treated insects with feral FAW is unknown at this time. The two major holdups are 1) delineating exact population dynamics figures for feral populations, and 2) rearing adequate numbers of high quality FAW for treatment and release.

Perkins (USDA-ARS, personal communication) has estimated that FAW could be reared for $15.10/1000 if and after adequate rearing facilities were developed to house automated equipment and FAW production from the equipment.

Summary

While this summation of results of research in areas considered to have potential for area-wide suppression of the FAW appears gloomy, it represents a rational review of where we stand as seen through the eyes of a 20+-year veteran of this area of research. Some may accuse me of being impatient, and I readily admit that I am concerned about the pace with which we attack the area-wide suppression program.

Our course of action in the future should be dictated by past results. It should be apparent that the management of FAW populations in overwintering areas to prevent migration and subsequent damage throughout a large area cannot be accomplished by scientists working individually in their individual areas of expertise. There were five papers during this symposium dealing with HPR combined with parasites, pathogens and biocontrol. There is a definite need for more cooperation among FAW research projects. Until a collective, effective, noninsecticidal FAW control program can be initiated, we say thanks to all of the entomologists continuing to develop and maintain an effective chemical control program (Pitre 1986, Gonzales and Allen 1986, Young 1986, All et al. 1986).

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