STATE-OF-THE-ART FOR PREDICTING DAMAGING INFESTATIONS OF FALL ARMYWORM

C. S. Barfield, J. L. Stima, and M. A. Keller
Department of Entomology and Nematology
University of Florida
Gainesville, FL 32611

ABSTRACT

Information necessary for predicting infestations of the fall armyworm (FAW), Spodoptera frugiperda (J. E. Smith), is detailed. Distinction is made on the level of knowledge necessary for predictions of FAW infestations which are short-term, seasonal at 1 site, and seasonal over a wide area. Polyphagy and mobility are emphasized as processes in the dynamics of FAW which make prediction of infestation patterns difficult. Four hypotheses on FAW seasonal survival strategies are presented and evaluated relative to existing information on FAW abundance and distribution.

The fall armyworm (FAW), Spodoptera frugiperda (J. E. Smith), is a member of a complex of Lepidoptera inflicting damage to annual crops in the southeastern and central United States (Luginbill 1928). Documentation of general aspects of FAW biology and natural history is available (e.g. Hinds and Dew 1915, Vickery 1929, Sparks 1979). However, data sufficient for quantitative description of some FAW ecological processes (mortality, movement) are scarce. Ashley (1979) discusses parasites of FAW but does not present or cite data useable in quantifying age-specific FAW mortality. A conceptual model has been presented (Snow and Copeland 1969, Knipling 1978) which depicts continuous breeding FAW populations that re-populate northward areas from southern latitudes each spring. Wood et al. (1979) presented experimental results that appear to support this conceptual model. However, data presented in support of this model do not distinguish between moths emerging locally at trap sites and moths trapped after long-distance movement. FAW adults caught in traps (Snow and Copeland 1969) may have emerged in close proximity to traps. Similarly, FAW immature stages (cf. Wood et al. 1979) may survive cold temperatures in non-crop habitats as yet unsearched.

Barfield et al. (1978) presented a temperature-dependent development model for FAW, and Barfield, Smith, Carlyle, and Mitchell (1980) investigated the impact of qualitative nutritional changes on FAW development, consumption and oviposition. Unpublished data are available for evaluation of FAW development, consumption and oviposition as a function of corn, Zea mays L., phenology. Barfield and Jones (1979) described further needs for modeling FAW dynamics.

The FAW represents a "life style" where polyphagy and mobility seem
extremely important to population survival (Barfield and Stimac 1980). The erratic occurrence of FAW “outbreak years” (see Sparks 1979) and the irregular distribution of heavy infestations lead us to believe non-crop host plant availability, timing of crop host availability, and natural mortality play dominant roles in the FAW’s survival strategy. The polyphagous nature of FAW would permit utilization of variable sequences of non-crop host plants at different sites and years. Each sequence might expose FAW populations to variable amounts of natural mortality, consistent with the heterogeneity in parasite and predator spatial and temporal distribution. A conceptual model relating polyphagy, host plant availability and natural mortality as effectors of movement is presented by Barfield and Stimac (1980). Yet, virtually no data exist which could be used to test hypotheses on how FAW populations utilize mobility and polyphagy to respond to environmental variation. The lack of such information places severe constraints on our ability to predict FAW infestations. To focus on where we are relative to predicting site and time of damaging infestations of FAW, we must:

1. distinguish between the levels of knowledge needed for predicting damaging infestations and for imposing post-damage suppression,
2. elucidate the roles of polyphagy and mobility in FAW dynamics, and,
3. provide a conceptual model which identifies ecosystem components responsible for FAW dynamics and which allows a test of alternative hypotheses on how FAW infestations occur.

**Monitoring and Predicting FAW Infestations**

Personal observations, discussions with various extension personnel and literature sources (e.g., Luginbill 1928, Sparks 1979) lead us to make 5 qualitative observations on the FAW. First, the FAW is a “boom-or-bust” pest. In some years, larval densities are low and not economically important; in other years, infestations are orders-of-magnitude greater and inflict serious economic losses (see Sparks 1979). Second, “boom” years tend to follow winters which, by standards of temperature and moisture, are qualitatively “more severe” than winters before “bust” FAW years (Luginbill 1928). Third, most FAW infestation patterns are unpredictable; i.e., outbreaks move through space and time for reasons that are not understood. Fourth, the absence of data of FAW mortality precludes evaluation of hypotheses on reproductive strategies employed by FAW (see Barfield and Jones 1979).

The fifth observation focuses on corn, the primary host plant for FAW (e.g. Luginbill 1928, Wiseman and Davis 1979). Biomonitoring in corn or any other crop or non-crop host plants is necessary for quantitative evaluation of “boom” or “bust” FAW population status. However, field corn is typically not scouted for FAW infestation due to the rationale that scouting services are not economically feasible in field corn production and to the lack of adequate sampling methods. Sweet corn is not scouted because economic thresholds are so low that pesticides are applied automatically regardless of FAW presence. Close to silking, insecticide applications may be used daily until harvest. As in field corn, however, no reliable sampling methods for determination of FAW densities and economic thresholds have been developed. In short, monitoring of FAW densities in corn is not practiced, has not been developed, or is ignored in lieu of calendar insecticide applications.
Some crops (e.g., alfalfa, pasturegrasses, sorghum) do not suffer from the pressure of high cash value markets as do most vegetables, and progress has been made toward developing biomonitoring schemes for FAW in these crops. These lower value commodities provide the opportunity for initial development of monitoring programs which may become transferable to high cash value crops as petrochemicals become more costly, less available or less useful. Substantial effort has been directed at the use of light and pheromone traps as monitors of adult FAW populations in these commodities (Mitchell 1979). The utility of these trapping methods has been restricted due to the lack of reliable methods for relating trap catches to absolute densities of either adults or immature stages. Differential responses of FAW adults to traps as a function of food resources, density, physical environment and trap design have not been researched adequately (Mitchell 1979, 1979a; Roelofs 1979, Carde 1979, Croft 1979, Hartstack 1979). These responses may be very important for a polyphagous organism which may be subjected to variable sequences of crop and non-crop host plants, variable intraspecific densities, and non-uniform physical environments among sites and fields. In short, few data are available that can be used to evaluate traps as “predictors” of FAW infestations.

We must separate needs for detection from needs for evaluation if progress is to be made toward identifying our capabilities to predict infestations. What appears to be needed is a reliable “early warning” system which alerts growers/pest management specialists to a potentially damaging FAW infestation. Trap catches of adults apparently have not been used successfully in this manner for reasons elucidated in the previous paragraph. Efforts focused on determination of relationships between trap catches and density estimates of absolute populations of immature stages would be a good first-step toward overcoming this problem. Most “early warning” systems utilize trap crops, not light or pheromone traps (see IIunut, this symp.).

Once an infestation occurs, we must be able to evaluate the potential of that infestation to inflict damage. Time and space dimensions of this evaluation fall into 3 distinct phases, and we must focus on the relative difficulties to be encountered in each phase. First, we need to be able to make short-term local predictions (e.g., 1 week) of FAW’s pest status. Second, we would like to progress to making seasonal predictions at a particular site, given specific initial conditions at that site. Third, we would like to be able to predict occurrences of FAW infestations over a wide area.

Achievement of phase 1 involves a re-orientation of many on-going efforts. In this phase, emphasis must be placed on the development of reliable sampling methods for adult and immature stages of FAW. A knowledge of FAW development, consumption and mortality is essential even to making 1-week predictions of FAW damage relative to some density threshold. Functionally, periodic samples would be taken weekly for determination of FAW density and densities of relevant natural enemies. At least ambient temperature would be required between sample dates. Knowledge of consumption rates and potential mortality would be used to project the FAW population trajectory and potential damage over the subsequent week. At the end of that week, new samples would be taken to (1) compare FAW densities and damage levels to those predicted and (2) determine inputs for predictions the next week. These short-term predictions could serve to expose what
is not known about FAW population dynamics relevant to determination of pest status. We see completion of phase 1 as possible in a relatively short time. Re-orientation of ongoing research efforts to provide data on adequate FAW sampling methods, sampling methods for pertinent mortality agents, and consumption will be necessary.

Phase 2, within-season predictions at a given site, demands more detailed information. Here, we want to be able to sample at the onset of a FAW infestation, and without any additional samples, predict the potential damage to that field so that action(s) may be taken at appropriate times. A knowledge of ecological/biological mechanisms dictating the population dynamics of FAW is a prerequisite to completion of this phase. Variation in population consumption, development, mortality, and oviposition and how those processes fluctuate with crop phenology and physical environment would need to be known. Specific assumptions as to net immigration rates would be necessary. The point is that completion of phase 2 will require in-depth knowledge of FAW dynamics and the ecological mechanisms responsible for those dynamics at a given site.

In phase 3, we desire to predict where in space and time FAW infestations will occur. Obviously, this would be beneficial for allocation of resources to combat these infestations as well as for use of preventative tactics. The polyphagous and highly mobile nature of FAW must be understood prior to accomplishment of this phase. Barfield and Stimac (1980) presented a conceptual model for relating environment, host plant availability and natural mortality to insect mobility. Rabb (1978) presented information supporting these concepts. The FAW appears to be ideal as a model to study how these interactions might occur. Suppose physical factors of a given winter reduced the availability of alternate FAW host plants by a significant percentage. The unavailability of these components could result in the production of FAW adult populations with higher proportions of more mobile individuals which disperse to less limiting environments. Fewer host plants might also mean fewer habitats for natural enemies which can attack FAW. In either case, the process of mobility could be affected, and this would re-define spatial boundaries of the FAW's life system. Availability of select non-crop hosts in fall and spring may well determine the site-specific "over-wintering capabilities" of FAW populations. As no published data exist on availability of FAW life stages (especially pupae) in non-crop habitats during colder periods, this possibility remains as a plausible explanation to why the FAW is a "boom-or-bust" pest. As environmental factors impact directly or indirectly (through host plants and/or natural enemies) on FAW populations, sequences of host plants and natural mortality factors change. Currently, we do not understand how such ecosystem dynamics impact on FAW populations. We only know that FAW abundance may vary tremendously between any 2 years or sites, and that our current monitoring tools may vary in reliability among these sites and years. The polyphagous nature of the FAW opens several avenues of research that bear directly on our ability to predict infestations.

Numbers of organisms infesting individual fields from reservoirs of mobile individuals have been conceptualized as a partitioning process (Barfield and Stimac 1979, Stimac and Barfield 1979). Individual fields are coupled by both pest and beneficial flows. A good example of this can be
found in the corn-peanut-soybean production system of north Florida-south Georgia. FAW populations invade corn (from unknown sources) in early spring. Subsequent generations move onto peanuts and, in some years (e.g., 1977) soybean. Cues utilized to initiate movement and the direction of such movement are not understood. Unpublished data indicate natural enemy populations also move sequentially through crops coupled by pest flows. The point is that numbers of FAW infesting a given crop field are determined mostly by processes outside the boundary of that field. Yet, research has been conducted almost totally within the infested field. This is analogous to treatment of symptoms, not causes. What results is a haphazard success rate of anticipation of infestations and management of FAW. Some years a given strategy works; other years it does not. We feel these inconsistencies are related directly to the highly mobile and polyphagous nature of FAW. We see little hope for progressing to step 3 until these processes are understood as related to FAW population dynamics and pest status.

Each phase has requisites for completion, and these requisites should be met sequentially. If phase 1 cannot be completed successfully, we see little hope for achievement of phase 3. Yet, what pest management specialists appear to desire is knowledge and prediction capabilities consistent with our phase 3. Hopefully, we have outlined the difficulty in moving from where we are to completion of phase 3. This should not minimize efforts to complete phase 1, as being able to detect FAW infestations and evaluate pest status over short time intervals would be of tremendous benefit in allocation of management tactics.

In summary, the “life style” employed by FAW is, at best, poorly understood. Does it overwinter where continuous breeding is impossible? Does it disperse from continuously breeding populations in southern latitudes? Does it have the capability to do either depending on select environmental signals? How does this “life style” affect our ability to predict damaging infestations of FAW? We propose a conceptual model of FAW dynamics as a tool for viewing the consequences of all 3 above survival strategies. Two items will emerge from this effort: (1) identification of needed research and (2) a focus on survival strategies which yield results most consistent with qualitative observations of FAW population changes.

A CHOICE OF HYPOTHESES

At least 4 hypotheses can be formulated on the seasonal survival strategies of the FAW. As 2 of these are variations on the same hypothesis, we shall refer to these as A1, A2, B, and C. We shall attempt to show how each 1 of these hypotheses affects our perception of FAW as a pest and how we manage that pest. All 4 hypotheses involve variable FAW mobility, natural mortality, host plant acceptability, and “overwintering” periods. Existing evidence will point to 1 of these hypotheses as “most promising,” and we will attempt to describe experiments necessary to make prediction of infestations possible.

HYPOTHESIS A1: CONFINED CONTINUOUS BREEDING—PARTITIONED DISPERsal

This is, by far, the most popular conception of FAW winter and spring dynamics. Data in Snow and Copeland (1969) and Wood et al. (1979) have

---

been used as evidence for this model. Simply, this model states that FAW populations are continuously breeding in southern latitudes (e.g., south Florida and Texas), and that individuals from these populations disperse northward each spring to invade crop and non-crop host plants. Two possible sequences of host plants attacked are presented in Fig. 1. Regardless of the host plant sequence, populations outside the continuous breeding range ultimately perish because of the lack of requisites for sustained population growth. Variation in natural mortality and host plant availability is possible along each route.

If this occurs, we might expect to see a wave of movement northward each spring and resultant populations breeding as far north in the winter as environmental conditions allow. This northward latitude would vary among years.

**Hypotheses A₂: Confined Continuous Breeding—Long Range Transport**

This hypothesis is presented as a sub-set of A₁ and focuses on weather conditions at the continuous breeding sites. Here, weather fronts and prevailing winds may transport FAW for deposition in areas far removed from the source population. Figure 1 depicts this model. A₂ is distinct from A₁ in the emphasis placed on the incidence of physical conditions conducive to FAW transport. As in A₁, however, death results when colder periods onset.

**Hypothesis B: Wide Area Survival—Dispersal**

This hypothesis differs from A₁ and A₂ in that it assumes FAW popula-

---

**Fig. 1.** Conceptual model for partitioning of a continuously breeding fall armyworm population by dispersal (solid lines) and by long-range transport due to weather phenomena (dashed lines).
tions are capable of surviving winter conditions farther north than the continuous breeding zones. Subsequent spring populations then employ short range dispersal to invade crop and non-crop host plants (Figure 2). Crops invaded would depend upon proximity to areas (crops or non-crops) where FAW survival occurred. Survival could occur as a "true diapause" or simply a temperature-dependent, lengthened developmental period for a given life stage. The main differences from the A₁, A₂ models are in the existence of some mechanism for "overwintering" at areas farther north than zones where continuous breeding is known to occur and in the lack of immigration as the sole process for crop infestation outside the continuous breeding zone.

**HYPOTHESIS C: COMBINATION OF A₁, A₂ AND B**

In this model, either partitioned or long range dispersal from continuous breeding populations or "overwintering" may be utilized by the FAW in any given year. Which strategy is used depends upon physical environment and how that environment impacts directly on FAW populations or indirectly through alternate host plant availability and natural mortality. Obviously, this is the most complex hypothesis proposed. Figure 3 depicts a possible three-year scenario.

**SUMMARY OF HYPOTHESES**

We know that FAW population abundance varies widely in space and time. We suspect that the polyphagous, highly mobile nature of FAW indicates that predictions of infestations depend upon understanding various components of the FAW's life system outside managed crops. To reiterate, we either know or suspect the following from observational data:

1. Continuously breeding populations of FAW occur in both south Florida and Texas,
2. FAW varies greatly in timing and abundance in crops north and west of areas in (1),

---

![Conceptual model for fall armyworm site dynamics where overwintering is predominant. Here, short-range dispersal from crop and/or non-crop overwintering sites is predominately responsible for infestations.](image-url)
Fig. 3. Conceptual model of a given 3-year period in fall armyworm seasonal dynamics. In Year 1, dispersal from continuously breeding populations is the major source of infestation. In Year 2, a pattern similar to Year 1 occurs; however, not all site infestations die. In Year 3, dispersal from continuously breeding populations is minimal relative to infestations from sites housing surviving fall armyworm stages from Year 2.

3. FAW appear to be carried by weather fronts to places extremely far north of continuous breeding zones.

4. FAW is highly mobile and can feed on a wide variety of host plants.

Model A₁ appears inadequate to account for these observations. Here, infestation would need to come from the south annually. Pheromone trap catches as far north as Hastings, FL in “typical” winters (Mitchell⁵, pers. comm.) indicate that either moths are capable of long distance flights during cold periods and against prevailing winds or FAW populations often survive north of zones in extreme south Florida. FAW biological characteristics conducive to upwind dispersal are not accounted for in A. Weather fronts (A₂) certainly remain plausible as a mechanism for long range transport. However, such movement of adults (see Wellington 1979, Rainey 1979) would most likely deposit FAW in concentrations atypical of the spatial arrangements qualitatively observed seasonally. A₃ does not appear reasonable to explain fluctuations in FAW abundance between years.

Hypothesis B demands the existence of an “overwintering” mechanism. No data have been published to demonstrate diapause in FAW; however, Barfield et al. (1979, unpub. data) demonstrated that FAW larvae and pupae could withstand winter cold typical of north Florida. We feel B is a step closer to reality but is not sufficient to explain FAW seasonal fluctuations. Perhaps select combinations of nutrition influence the expression of an “overwintering” mechanism. B does not account for this.

Hypothesis C allows the components of the FAW’s life system to change from year to year. The severity of a given winter may be reflected by the absence of some sub-set of FAW non-crop hosts and FAW natural mortality.

⁵E. R. Mitchell, USDA-SEA/FR, Insect Attractants Laboratory, Gainesville, FL 32602.
factors sustained by those hosts. The subsequent spring would mean that main crop infestations would result from "hop-sketching" (A₁) through less acceptable host plant communities or by long-range transport and drop-out (A₂). The next winter may be "milder" and more alternate hosts may survive. As FAW populations could withstand those winter conditions, populations would persist throughout the year. However, select natural mortality factors survive also; and spring FAW populations may be very low, despite winter survival much farther north than usual. Depending upon which non-crop hosts and which natural enemies act in a given year, FAW populations may appear earlier or later, in higher or lower densities, throughout the southeastern USA. Long-range transport from sources outside the continental USA may add to the complications.

Hypothesis C encompasses the complexity we feel is necessary to account for the seasonal variation in FAW abundance. C is consistent with the conceptualization of Barfield and Stimac (1980) and contains the ingredients to explain, and thus predict, the timing and magnitude of FAW infestations. C is also consistent with complexities in movement and effects of movement on pest management strategies as outlined by Rabb and Stinner (1978) and Walker (1980).

**Conclusions**

The lack of detailed knowledge of FAW population dynamics places severe limitations on predicting when and where damaging infestations of FAW will occur. Prediction capabilities should be developed through phases of detection and evaluation on short-term, within-season and between-season intervals and then over a wide area. We see completion of detection and phase 1 evaluation as possible in a relatively short time, provided on-going research efforts are oriented to this end. Completion of phases 2 and 3 will demand more time and a definite change in the way we perceive FAW dynamics relative to a given crop to be protected.

Data appear insufficient to test any of the 4 (A₁, A₂, B, C) hypotheses on FAW survival strategy. Qualitatively, C appears to be most promising because data sufficient to test C could be used to test all 4 hypotheses. C also appears to encompass the complexity necessary to accommodate observational data on FAW abundance and distribution.

Specific experiments needed to test hypothesis C are:

1. development of markers for determining the origins of northward and/or southward moving FAW populations,
2. derivation of meaningful statistical relationships between relative density estimators and absolute FAW densities,
3. reliable "overwintering" experiments based on response of FAW to temperature and moisture as a function of larval food sources(s),
4. R&D of methods to detect FAW life stages at low densities,
5. systematic use of methods in 4 in non-crop host plant communities up the Eastern Seaboard.
6. reliable experiments to determine age-specific FAW mortality in select crop and non-crop host plant communities, and
7. determination of FAW development, consumption, oviposition, and mobility rates as a function of larval nutrition.
Much discussion has been generated toward intensive management of the FAW in south Florida as a preventative measure for infestation in crops farther north (e.g., Knipling 1978). If hypotheses A, or A₂ are realistic and if A₃ sources do not exist outside Florida, such a plan might work. However, if B or C (or components thereof) are realistic, such a plan might not work. Determination of the proportion of a total FAW infestation attributable to continuous breeding reservoirs versus overwintering populations is needed prior to evaluation of any intensive management program. Further, since many of the FAW's natural enemies also attack other predominant pests (e.g. Heliothis zea Boddie), the consequences of an "eradication" program might result in a typical "secondary outbreak" phenomenon. Simply, we know so little about FAW biology/ecology that robust management strategies are not yet possible. We feel a precursor to management is prediction and to prediction is understanding. The lack of sufficient understanding of FAW dynamics is why current FAW pest management programs have not been more reliable. To predict FAW infestations and invoke ecologically and economically reliable management strategies, we must understand FAW dynamics. From all indications, we are a long way from that level of understanding.

ACKNOWLEDGMENTS

We wish to thank Drs. E. R. Mitchell and T. R. Ashley, USDA/SEA-FR, Insect Attractants Laboratory, Gainesville, FL, for critically reviewing this manuscript.

LITERATURE CITED


WALKER, T. J. 1980. Migrating Lepidoptera: are butterflies better than moths. Fla. Ent. 63:


ACTION THRESHOLDS FOR FALL ARMYWORM ON GRAIN SORGHUM AND COASTAL BERMUDAGRASS

P. E. Martin, B. R. Wiseman, and R. E. Lynch
Department of Entomology and Fisheries,
Coastal Plain Experiment Station,
University of Georgia,
and Southern Grain Insects Research Laboratory,
AR/SEA, U. S. Department of Agriculture,
Tifton, GA 31793

ABSTRACT

Under the present (1980) economic conditions, action thresholds for fall armyworm Spodoptera frugiperda (J. E. Smith), on grain sorghum have been estimated to be (1) 10% of seedling sorghum possessing egg masses, (2) 1 larva/shoot in the whorl stage, and (3) 2 larvae/head after flowering. In coastal bermudagrass the action threshold is between 2-10 larvae < 3/8 in. long/ft². It is common for economic or action thresholds to range from guesses to thoroughly-tested management tactics initiation guidelines. Nevertheless, the action threshold concept is needed in high-energy, fossil-fuel dependent agriculture systems to increase short-term profits and reduce conventional pesticide usage. Important factors to consider in the development of action thresholds for fall armyworm are: weather, soil types, crop culture, other herbivores, and entomophagous arthropods which affect both the fall armyworm and the host crop, as well as the ecosystem in which they are found. An alternative to the development of complex dynamic action thresholds for use in high energy systems is the use of insect insurance; this should be considered in conjunction with or in place of action thresholds. As we transcend to low-energy, holistically-managed systems, there should be much less of a need for action thresholds in our agroecosystems since these systems must be designed to prevent, avoid, evade, circumvent, and suppress pest problems.

Fall armyworms, Spodoptera frugiperda (J. E. Smith), are a serious pest of several grass crops in the Western Hemisphere (Sparks 1979). Grain sorghum (GS) planted in July or early August and coastal bermudagrass (CBG) hay grown during these months and in September in the southern U. S. are particularly susceptible to fall armyworm (FAW) especially if fields are heavily fertilized and possess adequate moisture. The FAW are capable of destroying seedling GS and reducing grain developing in the

Lepidoptera: Noctuidae.