REGIONAL MANAGEMENT OF THE
FALL ARMYWORM—A REALISTIC APPROACH?

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ABSTRACT

Little headway has been made during the past several decades in reducing damage (and avoiding ecological disruptions) for most major pests. It appears that a regional approach to preventing fall armyworm, Spodoptera frugiperda (J. E. Smith) problem, rather than attacking the symptoms is the best prospect for a successful solution to this costly pest problem.

The topic assigned to me is posed as a question: Is regional management of the fall armyworm, Spodoptera frugiperda (J. E. Smith) feasible and practical? On the basis of information now available a positive "yes" or "no" answer cannot be given. However, I intend to take the positive viewpoint. There is every justification for undertaking the necessary research efforts to fully explore this possibility. First of all it will be necessary to undertake research on the biology, ecology, dynamics and dispersal characteristics of the pest to make a judgment as to the feasibility of a regional management approach. This will be necessary to consider where, when, and how suppressive measures might be taken. In the meantime, however, I would urge that research efforts be continued and expanded to fully explore every possible avenue of attack that could contribute to regional management.

When we critically analyze the list of major insect pests that for decades have caused heavy losses and have required intensive use of ecologically disruptive chemical insecticides year after year we should ask ourselves: How successful have we been in developing satisfactory solutions for the pests? For the most part the control strategy has been the farm to farm or crop to crop management system, with heavy reliance on chemicals when control measures are necessary.

This defensive strategy is still the central theme of current pest management philosophy. This procedure has been stressed because serious ecological consequences have been experienced in the past by unnecessary or excessive use of insecticides as a preventive measure. However, a matter of grave concern to me is the viewpoint, which seems to prevail at the highest administrative and budgetary levels, where policies, priorities, and goals are established, is that such defensive pest management strategy, is all that is necessary to provide a satisfactory solution to most of the pest problems.

We have had enough experience with many of the important pests to know that despite the value of natural control factors they do not provide adequate and dependable control of the historically important pests. These are the realities of pest control that growers face year after year. The dynamics of most of the major pests affecting crops and livestock, especially in our greatly altered agricultural environments, is so great that the pests are capable dur-

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ing favorable years of increasing from very low to damaging levels within a few generations. It then follows that growers must rely on the defensive strategy. Their only recourse is to apply fast acting and generally broad-spectrum insecticides to cope with damaging populations when they appear. This then nullifies the natural controls we are counting on for help. I have reference in particular to such chronic and costly insect pests as the boll weevil, *Anthonomus grandis* Boheman; tobacco budworm, *Heliothis virescens* (F.); corn earworm, *Heliothis zeae* (Boddie); pink bollworm, *Pectinophora gossypiella* (Saunders); cabbage looper, *Trichoplusia ni* (Hübner); European corn borer, *Ostrinia nubilalis* (Hübner); fall armyworm and others. Such major pests cost our economy several billions of dollars each year and are responsible for the use of most of the ecologically disruptive chemical insecticides used for agricultural purposes.

Progress has been made in more judicious use of insecticides by instituting pest monitoring programs. More effort is being directed toward the development of host plant resistant varieties and to the use of sanitary and cultural measures. Many uninformed people in decision-making roles have been led to believe that such preventive measures are new techniques for use in presently emphasized integrated pest management systems. Yet, these methods have been investigated for years and have been advocated as desirable solutions to a number of the pest problems. While very important and desirable, these methods are not applicable to many major pests attacking plants, animals and man, and even when available they are generally not employed in an organized way.

I have over the years critically analyzed the dynamics and behavior of most of the major pests affecting crops, livestock, and man, for the purpose of considering possible alternatives to major reliance on chemical insecticides. From this analysis I long ago concluded that for most of the major pests the uncoordinated defensive pest management strategy regardless of techniques of suppression used, will not provide a satisfactory and lasting solution. This is why I have advocated more research efforts on ecologically acceptable control measures that eventually can be applied in an organized and coordinated manner for true management of the populations of a number of key pests on a wide area basis before the pests reach damaging numbers. For some species this will require rigid management of populations in large areas in order to maintain subeconomical populations. For others relatively little suppressive effort may be required, so long as it is applied at the appropriate time and place, and against most or all of the population. One of the great fallacies in the reliance on systems of pest management based on treatment at the economic threshold level is that this will assure low losses and at the same time minimize adverse ecological effects. How many of the decision makers at the higher budgetary levels realize that many insects like the *Heliothis* complex can cause several hundred millions of dollars in losses each year before they reach levels that justify the cost of insecticides or other measures after they reach damaging levels. The damage below economic threshold levels together with inevitable losses resulting from miscalculations and neglect can only mean continuing heavy losses year after year. This is one of the reasons why I believe so strongly that we should give more consideration to the development of ecologically acceptable systems of management that will maintain many of our more important pests below
the level of significant damage rather than merely below a defined economic threshold level.

I am more convinced today than ever before that total pest population management on an area wide or ecosystem basis should be the ultimate goal for many of the major pests. I have this conviction for 4 reasons: The first reason is that we have made relatively little headway during the past several decades in reducing damage and avoiding ecological disruptions for most of the major pests despite the efforts made to develop and encourage the use of various integrated pest management techniques on a voluntary basis. In fact, some of the pests such as the *Heliothis* complex seem to be more abundant and damaging today than they were 10 years ago. The second reason is that through the research efforts of many pioneering scientists outstanding progress has been made during the past 1 or 2 decades on new and promising techniques that offer the possibility of maintaining pest populations at very low levels, especially when appropriately integrated with some of the older control methods. I have reference in particular to the progress that has been made on (1) behavioral chemicals such as sex pheromones and kairomones; (2) gradual improvements on sterility methods and certain new genetic manipulations; (3) the outstanding progress that has been made in the mass production of insects which make it operationally and economically feasible to mass produce parasites and predators by the hundreds of millions or billions for augmenting natural biological organisms on an area wide basis. The ability to mass produce insects also makes possible the production of microbial agents that can not be produced in vitro. The third reason, which might be equally as important as the first 2, is a better understanding of the ecology, dynamics, and behavior of most of the pests. This includes a better understanding of the merits and limitations of natural control factors. We also have a much better appreciation of the rate and extent of insect movement and the implications of long range movement in devising the most feasible and rational pest management systems. The fourth reason is that we can hardly afford the risk of continuing to count on an array of chemical insecticides for controlling pests after they reach damaging numbers. The continuing threat of insecticide resistant strains and possible restrictions on the use of chemical insecticides because of potential environmental hazards and the high cost and delays in developing alternative chemicals will limit the choice of chemicals that can be used. It is therefore urgent that entomologists continue to seek alternative ways to control pests that create little or no hazards. Unfortunately, most of the promising alternative methods that are relatively free of hazards are not highly effective when pest populations have already reached moderate to high levels, or their action is too slow to achieve satisfactory control when damage is imminent. In order to make optimum use of most of the new techniques we now have or might envision for the future, it may be necessary that they be used as major components in area wide pest population management programs.

**Characteristics of the Fall Armyworm Problem**

The fall armyworm is one of the most destructive of the agricultural pests. It is difficult to control because of the wide range of host plants and its wide distribution during the crop growing season. Its rapid and long range movement probably provides an escape mechanism from the action of certain
density dependent biological organisms that help regulate the abundance of some of the less mobile pests. The possibility of resistance to available insecticides is also a continuing threat.

Based on early observations by Luginbill (1928), and other investigators, as compiled by Snow and Copeland (1969), there is reason to believe that the fall armyworm population in the southeast and Atlantic coast regions, normally originates from a greatly reduced and restricted overwintering population in Florida and possibly other coastal areas. The size of the area of spread during the summer months may be 10 to 20 times the size of the overwintering area, and the number of moths during the period of peak abundance is likely to exceed the number during the winter or early spring months by as much as 100 to 1,000 fold.

Unfortunately, it is not certain that the fall armyworm population in the Southeastern U.S. originates entirely from the overwintering population in Florida. Enough long range immigrants from the Caribbean Islands, Central America and Mexico may reach the Southeastern U.S. early in the spring to add to the problem. In some years long range migrants could be the major source of moths. This may have been the case during 1977 when an unusually cold winter apparently reduced the fall armyworm population throughout Florida to near extinction. Therefore, investigations designed to determine the source and number of fall armyworm moths that create the problem should receive very high priority in the research on this pest.

Despite the possibility of long range migration in potentially damaging numbers, the probability seems high that during most years Florida is the principle source of economic populations in the Southeast including the Atlantic seaboard. The pest is of such importance and the need for better control methods is so great, I would urge a continuing and greatly expanded research program, not only to determine the primary source of the moths but also to simultaneously conduct research to develop the technology that might be needed for a winter and early spring suppression program in Florida and possibly other states.

The fall armyworm could serve as a model species for developing the concept of managing highly mobile pests by an organized attack on populations at a strategic time and place for the purpose of protecting crops in other and perhaps much larger areas at some later time in the seasonal cycle. A number of other species including the cabbage looper, soybean looper, *Pseudoplasia includens* (Walker), beet armyworm, *Spodoptera exigua* (Hübner), and velvet bean caterpillar, *Anticarsia gemmatalis* (Hübner), apparently also have a greatly restricted overwintering area; and therefore would be good candidates for management on a regional basis by drastically suppressing populations in their greatly restricted overwintering areas.

Thus, the development and implementation of a successful fall armyworm population management program could represent a major advance in pest management concepts and strategies. While this general approach is not a new concept, it has received relatively little serious consideration. The potential advantages of such approach, both economically and environmentally, are so great, however, that it should receive major attention and support not only by entomologists but also by administrators at the highest levels in institutions responsible for establishing pest management priorities, goals and financial support for the future.
INFORMATION NEEDED TO APPRAISE THE FEASIBILITY OF MANAGING THE FALL ARMYWORM POPULATION IN THE OVERWINTERING AREA

About all that we know with reasonable certainty is that the fall armyworm in the Southeastern U.S. is greatly restricted in its area of distribution and in numbers during the winter, as compared with the area of distribution and abundance during the regular crop growing season. To my knowledge, there is no information on absolute numbers of the insect present during the winter or the relative importance of the various host plants that contribute to the overwintering and migrating populations. Also, we have no information on the number of moths that migrate from the overwintering areas to the area of seasonal buildup and spread. Yet, reasonably good information on these 2 vitally important questions is basic to a consideration of the best techniques to develop and employ for a winter and/or early spring population management program.

While good quantitative information on absolute numbers of insects in ecosystems is not easily obtained, techniques are available that can be used to make meaningful estimates of absolute numbers. The release and recapture of marked moths is 1 proven method. Biochemical methods may be useful to identify the source of moths. Intensive surveys should be made to identify important plant hosts that contribute significantly to populations, with estimates of the contribution that each type of plant host makes to the total population. Such surveys would simultaneously provide information on the kinds and amount of host plants where population suppression measures should be applied. Admittedly, such investigations may show that in Florida alone several hundred thousand acres of host plants contribute materially to the overwintering population and that a management program would be difficult and costly. On the other hand, such investigations may also show that most of the moths develop on less that 100,000 accumulative acres of host plants. In fact, in discussing the possible source of most of the moths in Florida during the winter months with E. R. Mitchell (SEA Gainesville, FL), and J. R. Young (SEA, Tifton, GA), they expressed the view that sweet and field corn may be the major source of overwintering moths. The total acreage of corn grown in Florida during the winter where overwintering populations normally occur probably does not exceed 25,000. If this crop is the major source of overwintering and migrating moths, rigid control of the insects on this crop alone could make a major contribution to regional population management. Growers probably do a reasonably good job in protecting sweet corn and seed corn and other possible host crops from fall armyworm attack up to the time of harvest, but corn alone might be responsible for producing many moths after the crop is harvested. Compulsory cultural measures for corn and other cultivated host crops immediately after harvest could be one of the most important and least costly suppressive measures to employ in an integrated population management program. If bermudagrass pastures or wild host plants contribute materially to overwintering and migrating populations, appropriate control measures would of course be necessary also on such plants.

Regardless of the source of most overwintering and migrating fall armyworm moths it is my opinion that it will be necessary to use control measures that cause no significant hazard to people, livestock, livestock products and to beneficial organisms in the environment. Methods of suppression that are
even suspected as hazardous would likely be rejected by property owners, regulatory agencies, environmentalists, or the public in general. Therefore, we must look to some of the newer approaches to fall armyworm management if such program is to be successful. Various possible ecologically acceptable suppressive measures were discussed with a number of my colleagues including W. J. Lewis, E. R. Mitchell, A. N. Sparks, J. K. Young, R. D. Jackson, W. Klassen, and others. Several suppressive measures may be required depending on the nature of the fall armyworm habitats. I would strongly advocate research on such techniques as: (1) the mass production and release of suitable egg and/or larval parasites (perhaps conditioned by the use of kairomones); (2) the possible use of pheromones in mass trapping or confusion techniques; (3) the application of microbial agents under special circumstances; (4) destruction of cultivated or wild hosts by cultural means; and finally, by releasing sterile or partially sterile moths. The appropriate integration of several suppressive measures in habitats of high fall armyworm concentrations could reduce populations throughout the overwintering area to a low level. It might then be feasible to overflood the reduced population by a high ratio by releasing relatively few moths. If Florida is the primary source of fall armyworm moths that create the problem encountered in the areas of spread, I believe that the chances are excellent that it would be feasible and practical to reduce the overwintered and migrating populations to such low levels that the surviving population could not increase to economic population levels in the normal areas of spread before seasons end.

INDIRECT METHOD OF ESTIMATING THE MAGNITUDE OF FALL ARMYWORM POPULATIONS

As noted in prior discussions, definitive information on the number of fall armyworm moths that develop in overwintering areas, and especially the number that subsequently migrate in the critical area of spread, is urgently needed. However, in the absence of such definitive information, indirect methods were used to gain some impression of the number of moths that create the problem in the Southeastern U.S. Over the years I have made extensive use of hypothetical insect population growth models to describe the mechanism of action of various methods of suppression and the impact that the methods and levels of control will have on the dynamics of insect populations (Knipping 1978). These models assign average increase rates per generation for normally low insect populations until they reach the steady density level. Such models have been an invaluable tool for studies on the dynamics of many pests as they may exist under normal conditions and when subjected to suppressive pressure by various methods of control.

The rate of increase of most insect pests will vary from generation to generation, habitat to habitat, and from year to year. However, I make the assumption that many of our economic pests will increase at an average rate of about 5 fold per generation from a normal low to a normal high level in population cycles. For certain dynamic pests a 10 fold increase parameter is used. Observations made by many investigators working on a wide range of pests generally support the validity of a 5 to 10 fold average increase rate per generation, depending on the pest and the conditions under which it is developing. Actual increase rates are likely to be higher than the average in the early generations and lower than the average in later generations, but
the use of a realistic average simplifies models without altering the final result.

Therefore, in my efforts to estimate the magnitude of the fall armyworm population that is responsible for the problem in the Eastern U.S., I will make the assumption that under reasonable normal conditions we can expect a population to grow at an average rate of 5-fold, until the end of the season, but that a 10-fold rate of increase might be expected under highly favorable conditions.

If the basic parameters as stated are reasonably valid we can start with different numbers of migrating moths which can be regarded as the first generation in the area of spread and then calculate the number of moths that will occur throughout a region in succeeding generations. In turn an estimate can be made of the number of acres of crops likely to be damaged by considering the number of moths per acre that will cause significant damage. According to A. N. Sparks (SEA, Tifton, GA) 500 moths per acre could be regarded as a damaging population. This method was used previously (Knipling 1978) for estimating the magnitude of fall armyworm populations and the number of acres of crops subject to damage, but some modifications have been made for this study.

If we assume a 5-fold rate of increase each generation, and a starting population of 5,000,000 moths, the population trend and the number of acres of crops that would be subject to damage as the season progresses seem very realistic. The simulation model is depicted in Table 1.

I believe that the model, although hypothetical, is a reasonably realistic portrayal of a typical fall armyworm season; therefore, it may not be far wrong if we assume that as few as 5,000,000 migrating moths into the southeast each spring can account for the fall armyworm problem in that region. However, the model depicted in Table 2, based on a starting population of 1,000,000 moths and an average 10-fold rate of increase was also developed. This model might be representative of fall armyworm population trends under very favorable conditions. This may have been the circumstance that existed in 1977 when the overwintering population in Florida was very low. A light fall armyworm problem was anticipated that year, but the pest caused extensive damage in the Southeast. No doubt severe winters will greatly reduce the overwintering fall armyworm population. However, such

TABLE 1. THE NUMBER OF FALL ARMYWORM MOTHS IN SUCCESSIVE GENERATIONS AND THE ACREAGE OF CROPS THAT WOULD BE SUBJECTED TO DAMAGE ASSUMING A MIGRANT POPULATION OF 5,000,000 MOTHS AND AN AVERAGE 5 FOLD RATE OF INCREASE EACH GENERATION.

<table>
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<tr>
<th>Generation &amp; period</th>
<th>Moths Number</th>
<th>Acreage of crops subject to damage Number</th>
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<tbody>
<tr>
<td>1. 16 April-15 May</td>
<td>5,000,000</td>
<td>10,000</td>
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<tr>
<td>2. 16 May-15 June</td>
<td>25,000,000</td>
<td>50,000</td>
</tr>
<tr>
<td>3. 16 June-15 July</td>
<td>125,000,000</td>
<td>250,000</td>
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<tr>
<td>4. 16 July-15 August</td>
<td>625,000,000</td>
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<tr>
<td>5. 16 August-15 September</td>
<td>3,125,000,000</td>
<td>6,250,000</td>
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TABLE 2. THE NUMBER OF FALL ARMYWORM MOTHS IN SUCCESSIVE GENERATIONS AND THE ACREAGE OF CROPS THAT WOULD BE SUBJECTED TO DAMAGE ASSUMING A MIGRANT POPULATION OF 1,000,000 MOTHS AND AN AVERAGE 10 FOLD RATE OF INCREASE EACH GENERATION.

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<tbody>
<tr>
<td>1. 16 April-15 May</td>
<td>1,000,000</td>
<td>2,000</td>
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<tr>
<td>2. 16 May-15 June</td>
<td>10,000,000</td>
<td>20,000</td>
</tr>
<tr>
<td>3. 16 June-15 July</td>
<td>100,000,000</td>
<td>200,000</td>
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<tr>
<td>4. 16 July-15 August</td>
<td>1,000,000,000</td>
<td>2,000,000</td>
</tr>
<tr>
<td>5. 16 August-15 September</td>
<td>10,000,000,000</td>
<td>20,000,000</td>
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Winters are also likely to greatly reduce natural enemies. Under such conditions the average rate of increase of certain pests, at least in the early generations, would be much higher than normal. Therefore, a pest population could increase very rapidly to a high level from a very low level.

We should keep in mind the significance of the model depicted in Table 2. If such low starting population does have the capability of increasing to economic damage levels during a single season, we can more readily appreciate the significance of relatively few long range migrants from distant areas. It may not be uncommon for several million fall armyworm moths to reach the Southeast in the spring from Cuba, other islands in the Caribbean or from Central America and Mexico. While the source of moths most years may not be as important as those from Florida, such long range migrants could add to the severity and complexity of the problem and require a different management approach.

The indirect method of estimating the magnitude of fall armyworm migrants that account for the problem in the Southeast is not intended to give an accurate estimate of the migrating population. At the same time, however, such estimates can give us some idea of the dynamics of the pest, the magnitude of populations that we would have to contend with, and what suppressive measures may be feasible in a regional approach to its management. The conventional direct approach for more accurate estimates may require costly research and several years of time, but this will be necessary. In the meantime, I believe the indirect estimates are sufficiently indicative of the magnitude of migrating populations to suggest possible approaches to regional management.

**Estimated Impact of a Suppression Program in the Overwintering Area in Florida**

Definitive information on the dynamics of the fall armyworm in numerical terms can be obtained only by undertaking intensive quantitative ecological studies over a period of several years in the overwintering area and in the initial areas of spread. However, as noted, I have sufficient confidence in the validity of the hypothetical population growth models to conclude that if the overwintering population in Florida is the primary source of the problem, a
rigid suppression program in the overwintering area would largely resolve the fall armyworm population throughout the southeastern and Atlantic coast regions.

Irrespective of the size of the starting population and its increase rate, if the initial population is reduced by a certain degree this should be reflected in a comparable reduction in the population in its usual areas of spread before cold weather again causes the pest to disappear. Therefore, if the starting population is reduced below a certain critical level it cannot increase to serious economic levels before seasons end. If there is a limit to the average growth rate of a population, irrespective of density, we can estimate the degree of suppression necessary to achieve effective management. All preventive control programs such as cultural measures are based on this premise.

Using the basic model depicted in Table 1, I have calculated the effect of a population management program that reduces the overwintered population by 95 percent and in turn reduces the number of migrants by this level. The results are shown in Table 3.

Based on a 5 fold increase parameter and a reduction of a migrant moth population from an estimated normal of 5,000,000 to 250,000, such population should not increase to a level of serious damage before the end of the season. A normal uncontrolled population as depicted in Table 1 might be expected to pose a threat to about 8 million acres of crops, the suppressed population would pose a threat to less than 400,000 acres. If the migrating population is normally as low as 1,000,000, however, and the rate of increase is normally as high as 10 fold (as shown in Table 2) a 95 percent suppressive program should reduce the migrating population to 50,000 and this in turn should prevent serious losses in the usual areas of spread despite the high average increase rate.

**PROPOSED NATURE OF A SUPPRESSION PROGRAM AND THE MAGNITUDE OF COSTS**

It would seem desirable and necessary to develop and employ different suppressive measures that cause little or no ecological hazards with the

**TABLE 3. THE NUMBER OF FALL ARMYWORM MOTHS IN SUCCESSIVE GENERATIONS AND THE ACREAGE OF CROPS THAT WOULD BE SUBJECTED TO DAMAGE, ASSUMING THE NORMAL OVERWINTERING POPULATION AND THE MIGRATING POPULATION HAVE BEEN REDUCED BY 95 PERCENT. THE INCREASE RATE IS ASSUMED TO AVERAGE 5 FOLD PER GENERATION.**

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<td>250,000</td>
<td>500</td>
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<tr>
<td>2. 16 May-15 June</td>
<td>1,250,000</td>
<td>2,500</td>
</tr>
<tr>
<td>3. 16 June-15 July</td>
<td>6,250,000</td>
<td>12,500</td>
</tr>
<tr>
<td>4. 16 July-15 August</td>
<td>31,250,000</td>
<td>62,500</td>
</tr>
<tr>
<td>5. 16 August-15 September</td>
<td>156,250,000</td>
<td>312,500</td>
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intent of reducing migrating populations below the significant damage level. To be effective such programs would have to be well organized and executed in a fully coordinated manner, under the supervision of pest management experts.

The nature and intensity of the suppressive measures to employ in the various habitats would have to be based on very thorough surveys to locate host plants in all areas that contribute significantly to the overwintering population. The period of attack would likely involve 2 generations of the fall armyworm. In order to achieve the goal I estimate that it would be necessary to reduce the usual overwintering population and the potential migrating population by about 95%.

As already stated, such program may not be acceptable, regardless of economic benefits, unless it is virtually without potential hazard to people, livestock and livestock products, fish and wildlife, and to the environment. In my opinion, the use of broad spectrum chemical insecticides by State or Federal agencies would not be acceptable to some land owners, to agencies responsible for maintaining environmental quality, or to the public. This would mean that suppressive measures would be limited to such methods as cultural controls, programmed releases of parasites that are reasonably fall armyworm specific, use of pheromones to inhibit mating by confusion or mass trapping, use of selective microbiol agents, growing resistant crops, if applicable, and the release of sterile or genetically altered moths. I am listing and discussing the major components of an all-out fall armyworm suppression program that I believe would achieve the objective. The magnitude of costs likely to be involved are also estimated.

1) Survey and Monitoring Activities = $250,000

Thorough surveys to locate all areas of significant fall armyworm development would be a vital aspect of a suppression program. Location of all of the important fall armyworm infested-crops and wild plants would serve as a guide to the type and intensity of control measures that would be used in the different habitats.

2) Augmentation of Biological Agents = $1,000,000

The mass production and liberation of 1 or more suitable parasite species in habitats where fall armyworm concentrations occur, in my opinion, can be developed as an effective and desirable method of suppression. While effective suppression by massive releases of parasites has not been demonstrated, the basic technology for such approach is well advanced. Several promising parasites are known based on studies by W. J. Lewis (SEA, Tifton, GA) and others. In personal communication with Dr. Lewis he expressed the opinion that mass production of at least 2 types of parasites could be accomplished at reasonable cost. In my projection, I am proposing the mass production and release of ca. 100,000,000 parasites at an estimated cost of $10 per 1,000. This would permit the release of 2,000 parasites per acre on 50,000 accumulative acres of fall armyworm infestations in the overwintering area. Based on the estimated efficiency of larval parasites for other lepidopterous pests I would expect parasitization rates as high as 90 percent from such a release rate. The activity of the released parasites may have to be manipulated by the use of kairomones. The direct release of the number of parasites proposed should give rise to substantial numbers of natural
parasite progeny during the next parasite generation that would contribute to suppression.

3) **Cultural Measures** = $250,000

Cultural measures may be the most important of the suppressive measures. As noted elsewhere, it is possible that certain crops such as sweet and field corn are the major sources of overwintering populations. While growers are likely to protect such cultivated crops with insecticides until the corn is harvested, abandoned or neglected fields after harvest may be the major source of moths. Such host crops on which most natural biological agents have been destroyed because of the prior intensive use of insecticides could produce millions of moths on a few thousand acres after the use of insecticides is discontinued. The immediate destruction of all cultivated crops that serve as hosts for the fall armyworm after harvest would be mandatory. Destruction by mechanical means would likely be the most effective and least costly procedure to use in most cases. My projections call for the use of cultural measures for cultivated crops, and possibly some wild hosts in certain situations, that aggregate 25,000 acres, at an estimated cost of $10 per acre.

4) **The Rearing and Release of Irradiated Moths** = $1,000,000

The rearing and release of irradiated moths to nullify reproduction of most of the moths escaping other suppressive measures would in my opinion be a very important component in a suppression program. The moths would be distributed throughout the overwintering area to reduce reproduction by native moths originating from widely scattered minor breeding areas. The possibility of using low level irradiation dosages to achieve maximum inherited sterility action and to permit the release of moths having maximum competitiveness should be fully investigated. The inherited sterility feature could be especially important for the fall armyworm. Migrant moths might carry with them the inherited sterility effect and exert considerable suppression during the first and possibly the second generation in the area of spread. My projection allows for the mass rearing, sterilization and release of 100 million moths at an estimated cost of $10 per 1,000 moths. If the native population is held to a level of about 3 million or so, by the use of other suppressive measures, this would provide for 10:1 overflooding rate for 2 successive generations. This final suppressive measure should contribute to further suppression and in turn reduce the migrating population.

5) **Other Suppressive Measures**

No estimates are made for other possible suppressive measures for use in special habitats. However, the use of microbial agents may be useful on certain crops, especially forage grasses being grazed by livestock. Therefore, research on microbial agents should be one of the high priority activities. The possible use of pheromones or mating inhibitors in confusion systems or the use of the pheromone in mass trapping should be considered. If the exact replica of the pheromone were employed, this could provide an effective and desirable way to cope with very low migrating populations by area wide mass trapping.

**General Comments**

There is no way of knowing at this time if the proposed suppressive measures and estimated costs are realistic. Additional research and develop-
ment will be necessary to perfect the proposed or additional technology for operational use. But, research has already advanced sufficiently to assign a high probability of success in the practical development and successful use of the major suppressive components discussed. Also, I consider the overall cost factor of about $3 million per year (excluding facilities) to be a conservative estimate for the type of program outlined.

SECURITY AGAINST LONG RANGE MIGRANTS

As already discussed, the possibility that threatening populations of the fall armyworm moths may enter the Southeast from distant areas should not be discounted. If this is the case, the idea of a regional management program should not be abandoned. Based on the hypothetical models depicted in Tables 1 and 2, if the initial migrating population or their progeny normally do not exceed 5 million moths, the release of as many as 100 million irradiated moths in the critical area, if identified, would achieve a 20:1 overflooding rate. The use of males receiving low dosage irradiation should be highly competitive. If a delayed sterility effect in fall armyworm moths is comparable to the effect in certain other lepidoptera this would provide a very strong deterrent to normal reproduction for at least 2 generations. The cost of such program should not exceed $2 million. Other suppressive measures should of course be considered, as well.

OVERALL COSTS AND BENEFITS, AND PROBABILITY OF SUCCESS

The general approach to fall armyworm management which would involve several suppressive measures may well cost of the order of $5 million per year. The basic technology for the different suppressive measures proposed for consideration seems sufficiently advanced to conclude that the probability of developing them for practical application is high. The cost of such a program if developed may be higher than estimated but there is also the possibility that it would be lower than estimated. But, assuming that the projected cost of $5 million or assuming even double this amount would be required to effectively resolve the fall armyworm problem, what would such costs mean in terms of potential benefits? Before rejecting the regional approach as too costly or too difficult to develop and implement, I consider it urgent that entomologists, administrators, and growers give serious consideration to the potential costs and benefits of regional approaches to the management of some of our major pests versus the costs and benefits of the current farm-to-farm and crop-to-crop management system.

According to a report prepared by the National Program Staff USDA in 1977, the fall armyworm causes an estimated average annual loss in the Southeastern and Atlantic Coastal States ranging from $150-$200 million. In the proceedings of a Fall Armyworm Symposium conducted by the 52nd meeting of the Southeastern Branch of the Entomological Society of America and published in the Florida Entomologist, Vol. 62, No. 2, 1979, the annual loss due to the pest in the U.S. averages about $300 million. The expenditure for insecticide applications to control this pest in the South and Southeast is of the order of $15 million per year (estimated during Biloxi conference discussions). However, the avoidance of most of the direct losses due to the pest would not be the only, or necessarily the most important, benefit of a success-
ful regional program of the nature discussed. The populations of the fall armyworm that develop in the Southeastern region by late summer are generally so high that important forage crops cannot be grown profitably at that time of the year. The fall armyworm is considered the major obstacle to a double cropping system in much of the Southeast. Therefore, if the pest were held to a level of no economic significance, the indirect long range benefits of a double cropping system could be more important than the direct losses.

In addition to the measurable economic benefits of a regional fall armyworm management system, the ecological benefits should also be considered. The ecological problems associated with the use of insecticides are a matter of increasing concern to an environmentally conscious public. Any system of pest management that obviates the need for ecologically destructive insecticides would make an important contribution to environmental improvement.

Perhaps I am overly optimistic that the pest can be effectively managed on a regional basis by the general procedure outlined. Additional ecological information is needed and the technology necessary to accomplish regional management has not been perfected and demonstrated. But I believe the probability of attaining effective regional management is high enough to justify a major research effort to achieve this goal.

The topic assigned to me, as noted in the introduction, was posed as a question. I will conclude this analysis by raising another question: What other approach or approaches that we can now envision offer better prospects for a successful and acceptable solution to this costly pest problem?

**Literature Cited**


