AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

*The World's Largest Open Access Agricultural & Applied Economics Digital Library*

**This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.**

**Help ensure our sustainability.**

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

*No endorsement of AgEcon Search or its fundraising activities by the author(s) of the following work or their employer(s) is intended or implied.*

Pesticides

1977

# ECONOMIC EVALUATION OF ALTERNATIVE PEST MANAGEMENT STRATEGIES UTILIZING SIMULATION MODELLING: FOCUS-MEXICAN BEAN BEETLE ON SOYBEANS*

UNIVERSITY OF CALIFORNIA
DAVIS
AUG 17 1977
Agricultural Economics Library

Katherine H. Reichelderfer and Filmore E. Bender

In recent years, a number of issues concerning the trade-off relationship between agricultural production and environmental quality have led to increasing, interdisciplinary focus on insecticides as both productive inputs and environmental hazards. Entomological research efforts have included numerous studies of alternative insect pest control strategies which reduce or eliminate the need for insecticide inputs. Economic research has focused on the optimization of chemical pest control inputs. The evaluation of both conventional chemical and alternative insect pest control strategies, with respect to the economic efficiency with which each contributes to agricultural productivity, is essential if producers are to make rational control action decisions. Of equal importance is the evaluation of alternatives in terms of social welfare.

Several approaches to the economic evaluation of pest management strategies have been proposed. Headley, who first lent a rigorous definition to the concept of the "economic threshold," devised an aggregated model with four basic elements to evaluate/optimize the single application of a pesticide for an assumed application date. Hall and Norgaard modified Headley's model to account for optimal intraseasonal timing of an insecticide application. Talpaz and Borosh expanded the basic model in order to evaluate the effect of multiple applications

---

*The work reported herein was funded by an EPA sponsored project entitled "A Benefit-Cost Comparison of Alternative Methods for the Control of the Mexican Been Beetle." Funds were provided by EPA under their contract No. 68-01-1938.

Katherine Reichelderfer is a Ph.D. Candidate, and Filmore E. Bender is Professor, Department of Agricultural and Resource Economics, University of Maryland, College Park, Maryland.

Presented at AAEA/WAEA joint meeting,
San Diego, July 31- Aug. 3, 1977.

of pesticides within a single growing season. Regev, et al. applied a unique economic optimization model to the private and social evaluation of interseasonal chemical control of the alfalfa weevil.

All of the studies cited utilized a marginal approach to evaluating or optimizing pest management strategies. While this approach is a useful one when examining the allocation of resources to pest control, certain ever-present biological and current political realities complicate its practical application. The marginal benefit of a pest control action may be a function of the size and age-structure of the pest population, the size and age-structure of non-target species' populations, the stage of development of the crop which is to be protected, and a variety of other factors (e.g., weather) which are independent of the number of units of control action applied to the system. Biological control is not available in discrete units. The marginal analysis of its effectiveness would be highly complicated by its biological interrelationship with the pest population. A further limiting factor is embodied in current federal regulations which prohibit the use of pesticides at any dosage other than a recommended rate of application. In instances where a single application of chemical constitutes the control action, only the time of that application is variable. The producer is not free to vary the intensity of application of insecticide as is implied by previous marginal analysis (Headley; Hall and Norgaard; Talpaz and Borash; Regev, et al.)

While the previously proposed evaluation methods are still excellent bases upon which to elaborate, they are highly abstract and, as such, they cannot take into account all of the biological processes which have definite economic implications. For example, the use of a single, generalized pest population growth curve (Headley; Hall and Norgaard; Talpaz and Borosh) biases the economic evaluation of pest control action by ignoring the possibility that, at some points in time, a large proportion of the pest population may exist in a stage (e.g., pupal) in which it is less vulnerable to pesticide application. In addition, assumptions to the effect that the pest population is homogeneous may bias evaluation/optimization results. Where the pest undergoes a pattern of development in which it proceeds through a number of distinct growth stages, there may exist, in effect, a situation of interdependent yet multiple pests, each with varying effects upon the crop and different responses to control action. The use of a single, generalized damage function may be another source of bias in that it does not reflect the fact that the crop may be more or less vulnerable to insect damage depending upon its stage of development. These are just a few aspects of the "anti-production" relationship between a pest and crop which cannot be accounted for in a generalized model. Hall and Norgaard (p. 201) have aptly pointed out that, "as these additional factors are introduced, mathematical models rapidly become unmanageable." Regev, et al., who did utilize biological data specific to the pest and crop, were forced to simplify several key relationships because the algorithms describing them were so unmanageable as to be inapplicable to their aggregated optimization model.

One well accepted way in which to handle seemingly unmanageable systems is microanalytic simulation (Orcutt; Shubik; Bender). Simulation of this sort specifies each of the basic components of a system and, in doing so, avoids the biases which may arise from aggregation. The specification of all those biological, physical and economic elements which have an impact on pest management strategies and their evaluation improves the validity and greatly increases the applicability of research results. This approach also avoids the problems of formulating complex and perhaps undefinable benefit, cost and profit functions as it does not restrict itself to an aggregate marginal analysis.

The microanalytic simulation approach was utilized in this study to evaluate the private and social cost effectiveness of various alternative methods for the control of the Mexican bean beetle on soybeans in Maryland. A computer simulation model was developed as a tool for the generation of average soybean yield response values resulting from different pest control actions under identical crop-pest conditions. The major objective of its development was the simulation of soybean production as it is affected by Mexican bean beetle populations and their control. Both private and social economic considerations may easily be applied to the data generated by such a simulation model.

The Mexican bean beetle (MBB) specific model simulates a per acre, intra-seasonal dynamic system. The output of the model is deterministic. The values assigned to the input variables are fixed and based upon averages. The output for a simulation of this system under any one set of inputs is single-valued and, invoking certainty equivalence, represents average values. As such, the model is not meant to describe or predict, without uncertainty, the yield benefit of pest control for any particular producer of soybeans in any given year. Rather, it describes the generalized crop-pest situation and the average production response to different pest control inputs.

The simulation program was written in FORTRAN IV computer language and executed on a Univac 1108 computer.

## Simulation of Mexican Bean Beetles on Soybeans

The simulation model utilized in this study was composed of the following major groups of elements: simulation of soybean growth; simulation of the growth and development of a Mexican bean beetle population; simulation of pest damage to soybeans; simulation of insecticide application; simulation of biological control. Each of these is briefly described below.

### Simulation of Soybean Growth

The typical pattern of development for soybeans is one in which the soybean plant goes through a number of distinct growth stages over its total development period. Ten major growth stages were originally identified and classified, according to observable features of the plants' physiogamy, by Kalton et al.

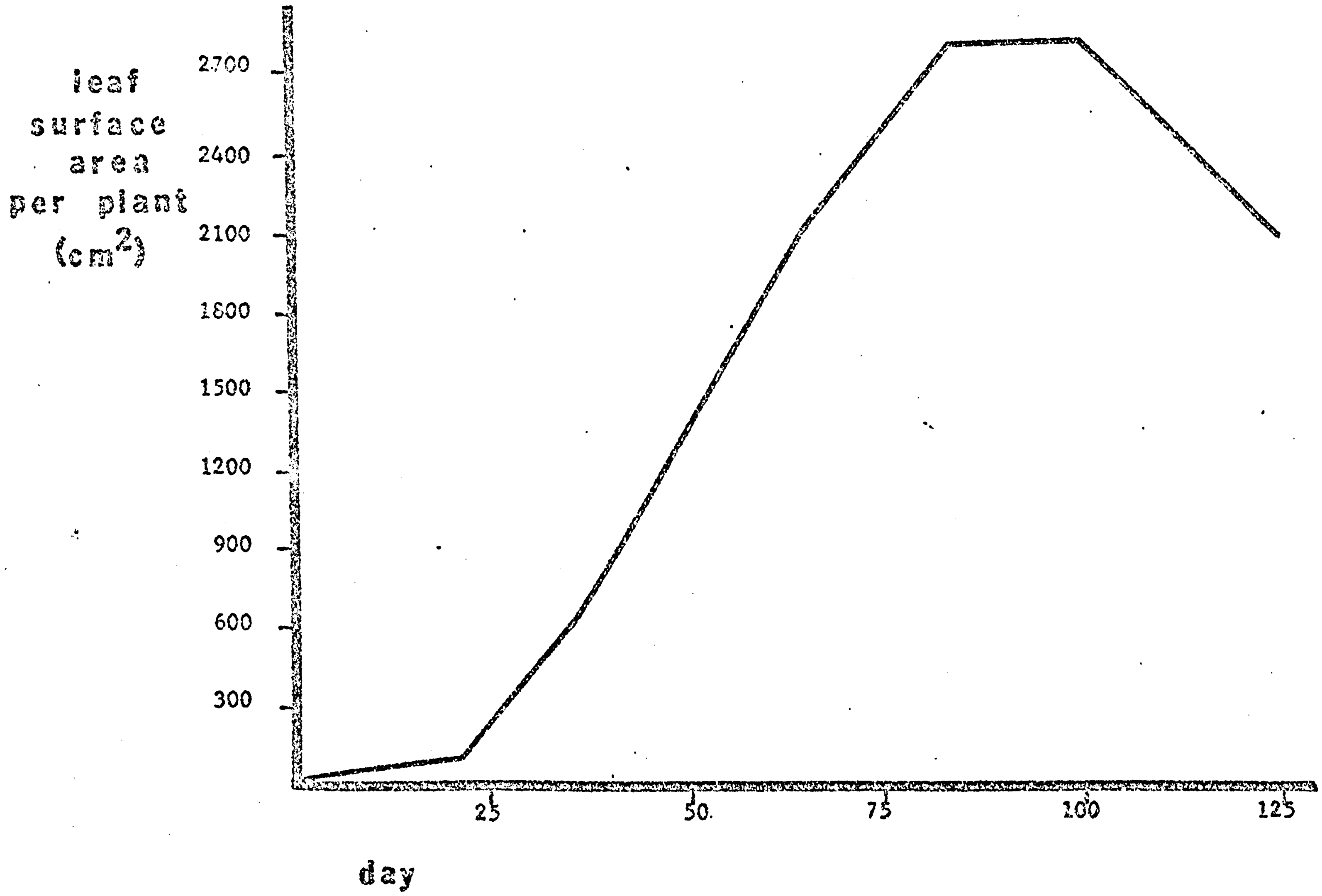
The relevant measure of soybean growth, for this study, is leaf surface area since it is the leaves upon which Mexican bean beetles feed and it is defoliation which can result in soybean yield loss. McAvoy determined the mean leaf surface area for York soybeans, one of three major varieties grown in Maryland, for each of the ten major soybean growth stages. His work also yielded data on the length of time York soybeans remain in each of the ten growth stages and on the duration of the total development period from planting to maturation of that variety. A generalized growth curve (Figure 1), in terms of leaf-surface area over time, was estimated from the data of McAvoy under the assumption that the rate of growth of leaf surface area was constant within each soybean growth stage. The described growth pattern was used in the computer program to simulate soybean growth and development over a 125 day period.

For purposes of simulation, the soybean crop was assumed to be planted in standard 36 inch rows, 8 plants per row foot. This yields an average density of 116,160 plants per acre.

## Simulation of the Growth and Development of a Mexican Bean Beetle Population

The MBB overwinters only in its adult stage. Adult beetles emerge from their overwintering sites in early through late spring. Populations of MBB will migrate into soybean fields when the soybean crop has developed leaves of sufficient size to attract and support the pest population. Although the adults are highly mobile, the population generally remains at a particular site, once established in an area cultivated with an abundance of its food source. Dispersal of adults takes place in late summer or early fall when adults fly from the plants to seek hibernation sites (Metcalf, et al.). In the simulation of MBB on soybeans, the size of the initial, immigrating population of beetles is a key input variable. Further migration, to or from the acre of soybeans, is not considered in the simulation model.

FIGURE 1: SOYBEAN PLANT LEAF-SURFACE AREA OVER TIME



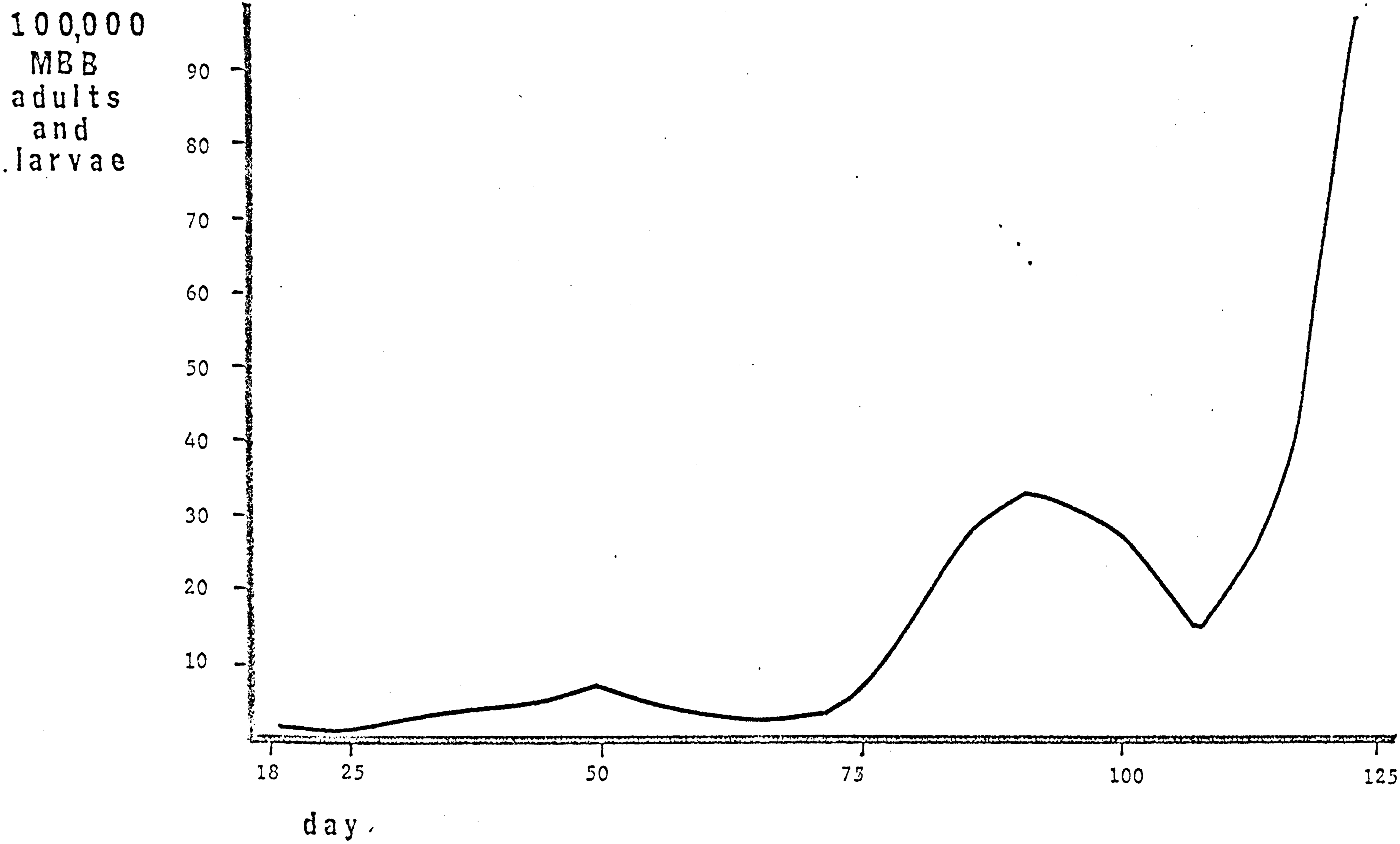
The growth of the pest population from an initial immigrating population is not simulated by the use of a generalized growth curve. Rather, a variety of parameters which describe the life history of the MBB are utilized to follow cohorts of beetles from their egg to adult stages. The review of relevant literature and communication with entomologists provided the data necessary to the development of the simulation of the pest's population growth.

The population of adult beetles which has emerged from winter hibernation is assumed to be composed of 75% females, as hypothesized by Waddill _et al._ The overwintered adults live an average of 30 days after emergence (Waddill, _et al._) and the daily natural mortality rate of that population is assumed to be equal to .01% for each of the 30 days. The egg-laying rate per female in that population is approximated at three eggs per day (Waddill, _et al._). Eggs hatch after an average incubation period of five days at 26.7° C (Van Duyn). By assumption, 50% of the eggs laid will not hatch due to the combined effects of infertility and predation. Larvae emerge from those eggs which do hatch. The larvae feed on soybean leaves and develop through four distinct larval stages: first instar, second instar, third instar and fourth instar larvae. These instars differ in size. Furthermore, both natural mortality rates and leaf consumption rates differ among instars. For that reason, the cohorts of beetles within each instar stage are considered separately from one another within the simulation model. The larval Mexican bean beetle development proceeds over the following average time periods per stage: 1st instar, 5 days; 2nd instar, 4 days; 3rd instar, 4 days; 4th instar, 5 days (Van Duyn). Based upon MBB life-table data collected by Dively (1975) in Maryland, the daily percentage of beetles within the 1st instar stage which are terminated within the model to simulate natural mortality is 8.27% and those beetles within 2nd, 3rd and 4th instar stages are assigned a natural daily mortality rate of 6.37%. After feeding and developing through all four instar stages, the surviving simulated population of fourth instar larvae enter an immobile non-feeding pupal stage. The pupal stage requires seven days under average (26.7° C) conditions (Van Duyn). The population of beetles which are in the pupal stage is not susceptible to direct applications of insecticides. First generation adult beetles emerge from 8-day old pupae and begin laying new eggs after a preoviposition period averaging seven days (Van Duyn). The average egg-laying rate per female Mexican bean beetle in first and later generations is nine eggs per day (Van Duyn) and these first and subsequent adult populations are characterized by a sex ratio of 1 male; 1 female (Waddill, et al.). The total period required for development from newly lain egg to newly emerged adult is thirty days. Therefore, the development of a population through 2 1/2 - 3 generations is simulated over the 125 day period of simulated soybean growth. Figure 2 shows typical simulation results of larval and adult Mexican bean beetles per acre, over that period, for an initial population equal to 4 adult beetles per row foot.

## Simulation of Pest Damage to Soybeans

Both larval and adult Mexican bean beetles feed on soybean leaves. The rate at which leaves are consumed, however, varies among the growth stages of the beetle. McAvoy has estimated the following mean daily consumption rates under average (27° C) conditions: 1st instar, .064 $cm^2$/day; 2nd instar, .256 $cm^2$/day; 3rd instar, .688 $cm^2$/day; 4th instar, 1.814 $cm^2$/day; adult, 1.35 $cm^2$/day. The simulation model determines the absolute amount of defoliation per day by multiplying the number of beetles in each of the five consuming stages on each day by the appropriate daily consumption rate. Defoliation is accumulated over 125 simulated days. Percent defoliation is recalculated for each day since the simulated soybean crop varies in total leaf-surface area according to its generalized growth curve.

Figure 2: Simulated Population of MBB Adults and Larvae Over Time



A number of studies have been conducted on the relationship between soybean defoliation and soybean yield (Stone and Pedigo; Thomas et al.; Todd and Morgan). The results of all of these indicate that yield response to defoliation is largely a function of the period of soybean growth during which defoliation takes place. Post-bloom defoliation has a much greater negative effect on yield than does pre-bloom defoliation. Both Stone and Pedigo and Thomas, et al. have calculated the regression of yield loss on defoliation for various soybean growth stages. Their regression equations are shown in Table 1. These eight equations were utilized in the simulation model to describe the effect of soybean leaf consumption by a Mexican bean beetle population on at-harvest soybean yield. The yield effect of simulated consumption was figured on a daily, incremental basis and was accumulated over simulated time to 125 days. Yield loss as of day 125 was the relevant output of the simulation program.

## Simulation of Insecticide Application

Two different insecticides are commonly used, either singly or in combination, to control Mexican bean beetles on soybeans in Maryland. These two chemicals, disulfoton and carbaryl, are applied by different means and affect Mexican bean beetle populations in different ways.

Disulfoton is applied in the furrows as the soybeans are planted. It is taken up into the plant material as the plant grows and affects insect larvae as they feed on the plants. Disulfoton is a fairly persistent chemical but its on-site effectiveness against Mexican bean beetles decreases over time. By approximately five weeks after planting, it has no effect on insect pests. Webb et al. conducted experiments over several years to determine the rate of loss of effectiveness of a single disulfoton application (at its recommended rate of application) against larval Mexican bean beetles. A line was fitted to their date ($r^2$ = .59) in order to describe the average mortality attributable to the chemical over time. Simulation of a disulfoton application was done by adjusting the chemical mortality rate to include natural mortality, for each larval instar stage, and changing the daily mortality rates utilized in the model to account for higher larval mortality to day 60 of the simulated period. Rates of disulfoton application other than the recommended rate were not considered in this study.

Carbaryl is usually applied aerially in a liquid formulation. It is a relatively short-lived chemical and the total effect of its direct application on the Mexican bean beetle population in the field is achieved within a few days after application. The adult beetle mortality rate attributable to an application of carbaryl, at its recommended rate of application, is 79% (Turnipseed _et al_.). Larval mortality, under the same conditions, is 97% (Turnipseed _et al_.). Simulation of an application of carbaryl was achieved by changing the daily larval and adult mortality rates, for the day of simulated chemical control, to account for the mortality attributable to the carbaryl. Rates of carbaryl applications other than the recommended rate were not considered in this study.

The timing of an application of disulfoton is fixed. The timing of an application, or multiple applications, of carbaryl is an input variable to the simulation model. The decision to use disulfoton and/or carbaryl and the decisions concerning the time(s) at which to apply carbaryl may, in reality, be made according to personal decision-making process of the soybean grower. The basis upon which such chemical control decisions are made will vary from individual to individual. Therefore, simulations of a single application of carbaryl for each of 107 different days, both as the solitary control action and in conjunction with the use of disulfoton, were conducted for this study. In addition, various time-combinations for two separate applications of carbaryl within the single soybean growing season were simulated.

Chemical control may be an integral part of a prescribed spraying pest management strategy. In general, these strategies require a periodic monitoring of the crop and pest population through some "scouting" technique. The application of insecticides is recommended when, and only when, scouting reports reveal that a predetermined "threshold" level of the pest population or of crop damage has been reached. In Maryland, the University of Maryland Prescribed Spraying Pest Management Program is currently operative for the control of Mexican bean beetles on soybeans. This particular program utilizes reports from trained scouts on estimated levels of percent defoliation in area soybean fields. The prescribed spraying strategy involves no use of disulfoton and it advocates the use of carbaryl only when the observed (through sampling) percent defoliation of the soybean crop reaches or exceeds a predetermined "defoliation action threshold". This threshold is defined by the entomologists who direct the program as "the amount of leaf loss allowed at each (soybean) maturity stage before yield is affected" (Dively, 1975). The threshold levels which were determined by the entomologists and are used as the basis for determining whether or not and/or when to apply carbaryl, are shown in Table 2. The simulation of the current University of Maryland prescribed spraying strategy was achieved by the simulation of the application of carbaryl on the day(s) on which simulated defoliation reached the defoliation action threshold.

## Simulation of Biological Control

A parasitic wasp, Pediobius foveolatus (Crawford), may be successfully used to supress Mexican bean beetle populations on soybeans (Stevens, Steinhauer and Coulson). The wasp is unable to overwinter in temperate zones and must be released annually. Its mode os action on Mexican bean beetles is that the adult female wasp deposits eggs (oviposits) into the body of third and fourth (occaisonally second) instar Mexican bean beetle larvae. This kills the larva and also provides a shell (mummy) in which a new generation of wasps develop into adults. The parasite is specific to Mexican bean beetles.

Table 1: Relationships Between Defoliation* and Yield Loss for Soybeans

where: $Y$ = percent yield loss

$X$ = percent defoliation

| Soybean Growth Stage | Regression of Yield Loss on Defoliation |
|---|---|
| 1 | $Y = -0.029X + 0.002X^2$ |
| 3 | $Y = -0.142X + 0.003X^2$ |
| 5 | $Y = -0.002X + 0.004X^2$ |
| 6 | $Y = 2.6 - 0.39X + .009X^2$ |
| 7 | $Y = 0.032X + 0.008X^2$ |
| 8 | $Y = 1.25 + 0.007X^2$ |
| 9 | $Y = 0.05X + 0.002X^2$ |
| 10 | $Y = -0.096 + 0.084X$ |

*those regression equations for soybean growth stages 1,3,5,7 and 9 are from Stone and Pedigo; those for soybean growth stages 6,8, and 10 are from Thomas _et al_.

Table 2: Defoliation Action Thresholds for Mexican Bean Beetle on Soybeans

| Soybean Growth Stage | Action Threshold ( % Defoliation) |
|---|---|
| 1 | 35 |
| 2 | 35 |
| 3 | 35 |
| 4 | 35 |
| 5 | 35 |
| 6 | 20 |
| 7 | 20 |
| 8 | 20 |
| 9 | 20 |

The use of Pediobius foveolatus populations as a measure for the control of Mexican bean beetles on soybeans in Maryland was first tested 1972-1974. The average percent parasitism of Mexican bean beetle larvae achieved in soybean fields sampled in twelve Maryland counties reached 84% by the latter part of the 1974 growing season (Stevens, Steinhauer and Coulson). The use of the parasite was subsequently incorporated into the University of Maryland Soybean Pest Management Program. In 1976, observed average percent parasitism of Mexican bean beetles on soybeans ranged from 0-50% in eight Maryland counties (Dively, 1976).

Under current Maryland pest management program, parasites are released each year into strategically placed "nurse plots" of early growing garden variety beans on which early populations of Mexican bean beetles are developing. The nurse plots are cultivated and provided for this use by soybean growers who are voluntary participants in the pest management program. The wasp population expands in the nurse plots and migrates into neighboring soybean fields when a sufficient Mexican bean beetle larvae population is available, there, for parasitization. The simulation of biological control is based upon current Maryland pest management procedures for the release of the parasite.

The simulation of biological control utilized a sub-model to describe the growth and development of the parasite population as a function of the simulated population of Mexican bean beetles. The size of an initial immigrating parasite population is an input variable to the simulation program. In describing current biological control procedures, the immigrating population size is assumed to be equal to 264 wasps per acre. This estimated size of the parasite population is figured by assuming that the first generation progeny of the 600 female wasps released in one nurse plot, which serves 200 acres of soybeans, distribute themselves equally among the 200 acres of soybeans.

The parasite prefers third and fourth instar larvae, over second instar larvae, as hosts (Stevens, Steinhauer and Elden). It is assumed in the simulation model that the parasite has no preference between third and fourth instar larvae. The simulated wasp population "parasitizes" second instar larvae only when the proportion of available third and fourth instars is less than 20% of all larvae present in the field. Additionally, it is assumed that when second instar larvae are parasitized, they serve as hosts in the same proportion to their total number as do third and fourth instars to their respective numbers.

Laboratory experimentation yielded an average of 20.3 MBB larvae parasitized per female wasp (Stevens, Steinhauer and Elden). All parasitized larvae die approximately five days after parasitization but not all parasitized larvae eventually yield new adult wasps. The phrase, "successful parasitization", refers to cases in which new adult wasps do emerge from the MBB mummy. Successful parasitization is, in part, a function of the age of the ovipositing parasite. Only parasites of ages 1-24 days are included in the simulations model as field studies (Stevens, Steinhauer and Elden) indicate that the great majority of active wasps in the field are under 24 days old. The average percent of parasitized MBB larvae which are successfully parasitized by 1-12 day old wasps is 58.4% and the same figure for 13-24 day old wasps is 26% (Stevens, Steinhauer and Elden). The average number of wasps which emerge from each successfully parasitized larvae was found to be 11.1 (Stevens, Steinhauer and Elden). The biological data on which the simulation variables related to the growth and development of the parasite population are based are derived from the research of Stevens _et al_. The effect of simulated biological control makes itself felt by indirectly increasing the mortality of third and fourth instar larvae.

## Utilization of Simulation Output to Construct Benefit-Cost Ratios for Pest Control Alternatives

Yield loss, the relevant output of the simulation model presented here, may be used to construct benefit-cost ratios which reflect the cost-effectiveness of alternative pest control actions. If average yield in the absence of damage from the pest in questions is known, the amount of yield loss prevented by the control of a simulated pest population is easily obtained by:

$$V(\alpha) - V(\beta) = Y$$

where

$V$ = average yield per acre in the absence of any pest population

$\alpha$ = percent yield loss in the presence of an uncontrolled pest population.

$\beta$ = percent yield loss in the presence of a controlled pest population

$Y$ = per acre yield loss prevented by control action.

The value of the yield loss prevented is simply:

$Y \cdot P$, where $P$ = the unit price of the crop

The benefit-cost ratio which reflects the private cost effectiveness of control equals:

$\frac{Y \cdot P}{C}$, where $C$ = per acre cost of control.

The benefit-cost ratio which reflects the social cost-effectiveness of control equals:

$$\frac{(Y \cdot P) + B}{S}$$

where

$B$ = additional social benefits

$S$ = social cost of control expressed on a per acre basis

## Private Cost of Mexican Bean Beetle Control Alternatives

For 1976 data, the per acre unit costs of insecticide application in Maryland were equal to $4.87 per application of carbaryl at its recommended rate of application and $4.00 per application of disulfoton at its recommended rate of application.

Prescribed spraying techniques involve a fixed cost of either the time spent by the farmer to scout his own fields or the wage paid to a person hired to conduct scouting duties. Maryland soybean grower participants in the University of Maryland Pilot Prescribed Spraying Program were surveyed to determine both the opportunity cost of their own time and their willingness to pay others to perform scouting for them. The mean value of the former was $7.32 per hour (S.D. = 2.50) and the mean value of the latter was $4.40 per hour (S.D. = 2.46). According to Dively (personal communication), the average time required for the scouting of each 30 acre area of soybeans equals 1/2 hours per week over 16 weeks. As the average size of soybean acreage planted by the surveyed growers equaled 484 acres, the approximate annual, per acre fixed cost of scouting was estimated to be approximately $1.95 per acre for grower conducted scouting and $1.17 per acre for hired scouting services. Applications of carbaryl, if prescribed, are additional costs of this control technique but are variable depending upon the Mexican bean beetle population level in the field.

Maryland soybean grower participants in the biological control program must contribute the nurse plots required for early release of the parasite. Each nurse plot is set up at a fixed private cost of approximately $50.00 and serves 200 surrounding acres. Assuming that all of the 200 acres to receive biological control are owned by the provider of the nurse plot, the fixed private cost of biological control is equal to $0.25 per acre, per year.

## Social Cost of Mexican Bean Beetle Control Alternatives

The social costs of chemical control of the Mexican bean beetle on soybeans are environmental in nature. Disulfoton's mode of action is the inhibition of cholinesterase, a common and necessary component of the central nervous systems of insects, fish and mammals. Disulfoton is relatively persistent, and so may reach and affect non-target organisms by leaching into ground water or running off into terrestrial, aquatic or marine ecosystems other than the soybean field. As local (to Maryland) ecosystems and organisms have not been monitored or tested for the presence of disulfoton or other cholinesterase inhibitors, neither the existence nor the severity of any environmental effects of the use of disulfoton on soybeans is in evidence. While some social environmental costs of its use may be expected, they cannot be quantified at this time.

Carbaryl is extremely toxic to fish and bees. Since it is applied aerially, it is often possible for it to "drift" to or be accidently sprayed directly on non-target areas where its presence constitutes an environmental hazard. The effect of carbaryl usage on Maryland fish and shellfish populations is not known. Even if such information were available, it would be extremely difficult, if not impossible, to determine whether the source of the environmental damage was the application of carbaryl on soybeans or on other crops. The value of honey bee losses related to the use of carbaryl on soybeans has been estimated. Consultation of Federal Bee Indemnification Program records along with the results of a survey (Reichelderfer and Caron) of beekeepers in the four major soybean producing counties in Maryland provided the data for the estimation. Between 1967 and 1976, the market value of domestic and commercial honey bee colonies which were damaged or destroyed by exposure to carbaryl applied to soybeans was equal to at least $6818.50. The average yearly value of estimated losses equals $975.86 for the four Maryland counties. As beekeeper response to the survey was only 70% and the survey population did not include non-registered owners of domestic bee colonies, this figure represents a lower bound to the value of the loss of domestic and commercial honey bees. It is reasonable to assume that wild bee populations are killed in at least the same proportion as are domestic and commercial bees since they are just as likely to be exposed to carbaryl which was applied to soybeans. The pollination benefit of wild bees is actively captured by Maryland growers of cucumbers and other cash crops but neither the value of that benefit nor the value of that benefit which is lost through carbaryl poisoning of the wild bees is quantified. For this additional reason the estimated annual social cost of the use of carbaryl on soybeans must be considered a minimum.

Biological control of the Mexican bean beetle is assumed to have no environmental costs associated with it. However, biological control necessitates some annual regional expenditure for rearing and distributing the parasites. State funds are used for this purpose in Maryland. The fixed, capital costs of rearing the parasite are estimated at approximately $3860.00. Assuming a discount rate of 12% over a 20 year period, annual ammortized fixed costs equal $516.66. Annual operating costs of the biological control program were equal to $41,492.30 for 1976-1977. This figure includes costs of materials and transportation, the salaries of two full-time employees, wages for temporary help in distributing the parasite, various contractual services, the value of 20% of one scientist man-year, and the value of 240 agricultural extension agent man-hours. In Maryland, the 1977 target acreage for biological control was estimated at 30,000 acres. Therefore, the total, annual, per acre social cost of biological control is equal to approximately $1.40/acre.

### Value of Soybean Yield Benefits of Mexican Bean Beetle Control in Maryland

The average soybean yield per acre harvested in Maryland between 1966 and 1975 equaled 26.81 bushels per acre. For the purpose of this study, it is assumed that this average yield resulted under conditions of 100% control of Mexican bean beetle damage. This assumption is supported by Maryland agricultural extension agents who feel that local Mexican bean beetle control had, in that 10 year period, been initiated at such a high intensity that yield losses due to Mexican bean beetles were negligible. The amount of yield benefit attributable to each control alternative was calculated by subtracting the percent yield loss simulated under conditions of control, from that percent yield loss simulated for an uncontrolled pest population, and multiplying the difference by 26.81 bushels per acre. The value of the yield benefit of control was determined by multiplying the amount of yield loss prevented by $6.02, the October 1976 mid-month average soybean price received by farmers in Maryland. This particular soybean price was chosen because it represented the market value of a bushel of soybeans at harvest time of the study period. The utilization of other prices would change the absolute value of the yield benefits determined but would not alter the relative differences between yield benefit values of alternative control strategies.

## Analysis of Results

The results presented here were obtained by conducting various pest control simulations for three different input levels of the immigrating Mexican bean beetle population. An original population equal to one adult MBB per row foot was considered a "low" population level, that equal to four per row foot represented a "medium" population level and that equal to eight per row foot represented a "high" population level. The yield loss output of the simulations was used with soybean price data and pest control cost data to construct private, annual per acre benefit cost ratios for each control alternative. The same simulation output was utilized, in conjunction with social cost estimation, to construct societal, annual benefit-cost ratios for each control alternative.

Tables 3 and 4 summarize selected research results.

## Private Cost-Effectiveness of Control Alternatives

The yield effect of chemical control varies both according to the number and type of insecticide applications and in accordance with the date(s) of carbaryl application(s).

The optimal date for a single simulated application of carbaryl was found to be day 50 (see Figure 3). This result is based on a fixed dosage application but is independent of the population level of immigrating MBBs, the price of carbaryl, and the price of soybeans. This is consistent with the finding of Hall and Norgaard.

The private benefit-cost ratios obtained from the simulation of two intra-seasonal applications of carbaryl, at various combinations of dates, are shown in Table 5 for the high MBB population level. All time combinations of two applications of carbaryl on the low-level MBB population resulted in 100% control of the pest and no yield loss. Yield losses under conditions of a medium-level MBB population controlled by two carbaryl applications were found to be less than or equal to 2% for all simulated time combinations.

The simulated use of disulfoton as the only control action yielded private benefit-cost ratios of values close to those obtained for a single simulated optimal application of carbaryl.

1974 insecticide use data was utilized to construct benefit-cost ratios for a typical, conventional chemical use pattern. According to Dively (1975), approximately 201,500 acres of soybeans in the Delmarva region (38.55% of all acres of Delmarva soybeans) were treated with insecticides in 1974. Dively (1975) reported that carbaryl and disulfoton were used on 64% and 36% of the treated

Table 3: Private Costs and Yield Benefits of Selected Alternative Control Strategies

| Control Strategy | Level of MBB Infestation | | | | | |
|---|---|---|---|---|---|---|
| | low | | medium | | high | |
| | per acre yield benefit (bushels) | per acre private cost | per acre yield benefit (bushels) | per acre private cost | per acre yield benefit (bushels) | per acre private cost |
| 1 appl. of carbaryl | .03 to .16 | $4.87 | .03 to 1.4 | $4.87 | .075 to 4.95 | $4.87 |
| 2 appl. of[1] carbaryl | .16 | $9.74 | 1.45 | $9.74 | 5.11 | $9.74 |
| 1 appl. of disulfoton | .11 | $4.00 | 1.15 | $4.00 | 4.21 | $4.00 |
| carbaryl[1] + disulfoton | .16 | $8.87 | 1.44 | $8.87 | 5.11 | $8.87 |
| conv. chem.[1,2] control | .002 | $2.23 | .52 | $2.23 | 1.85 | $2.23 |
| presc. spray. (grower scouted) | ------- | $1.95 | .35 | $6.82 | 3.26 | $6.82 |
| presc. spray. (hired scouts) | ------- | $1.17 | .35 | $6.04 | 3.26 | $6.04 |
| biological control | .16 | $ .25 | .99 | $ .25 | 2.89 | $ .25 |
| bio. control + disulfoton | .16 | $4.25 | 1.39 | $4.25 | 4.76 | $4.25 |
| intgr. p.m. (grower scouted) | .16 | $2.20 | .99 | $2.20 | 3.99 | $7.07 |
| intgr. p.m. (hired scouts) | .16 | $1.42 | .99 | $1.42 | 3.99 | $6.29 |

[1] assuming optimal timing of carbaryl application(s)

[2] based on 1974 insecticide use data

Table 4: Benefit-Cost Ratios for Alternative MBB Control Strategies

| Control Strategy | Level of MBB Infestation | | | | | |
|---|---|---|---|---|---|---|
| | low | | medium | | high | |
| | private B/C | social B/C | private B/C | social B/C | private B/C | social B/C |
| 1 appl. carbaryl | .04 to .20 | ----- | .04 to 1.73 | ----- | .09 to 6.12 | ----- |
| 2 appl. carbaryl[1] | .099 | ----- | .90 | ----- | 3.16 | ----- |
| 1 appl. disulfoton | .165 | ----- | 1.73 | ----- | 6.33 | ----- |
| carb. + disulfoton[1] | .109 | ----- | .98 | ----- | 3.47 | ----- |
| conv. chem. control pattern (1,2) | .15 | <10.48 | 1.40 | <95.64 | 4.99 | <338.73 |
| presc. spraying (grower scouting) | ----- | ----- | .31 | ----- | 2.88 | ----- |
| presc. spraying (hired scouting) | ----- | ----- | .35 | ----- | 3.25 | ----- |
| biological control | 3.85 | .69 | 23.84 | 4.26 | 69.59 | 12.43 |
| bio. control + disulfoton | .23 | <.69 | 1.97 | <5.98 | 6.74 | <20.47 |
| intgr. pest mgt. (grower scouting) | .44 | .69 | 2.71 | 4.26 | 3.40 | <13.88 |
| intgr. pest mgt. (hired scouting) | .68 | 1.52 | 4.20 | 5.09 | 3.82 | <17.99 |

[1] assuming optimal timing of carbaryl application(s)

[2] based on 1974 data for four Maryland counties

FIGURE 3: SOYBEAN YIELD LOSS GIVEN VARIABLE DATES FOR A SINGLE APPLICATION OF CARBARYL

(initial immigrating MBB pop. = 8 per row ft.)

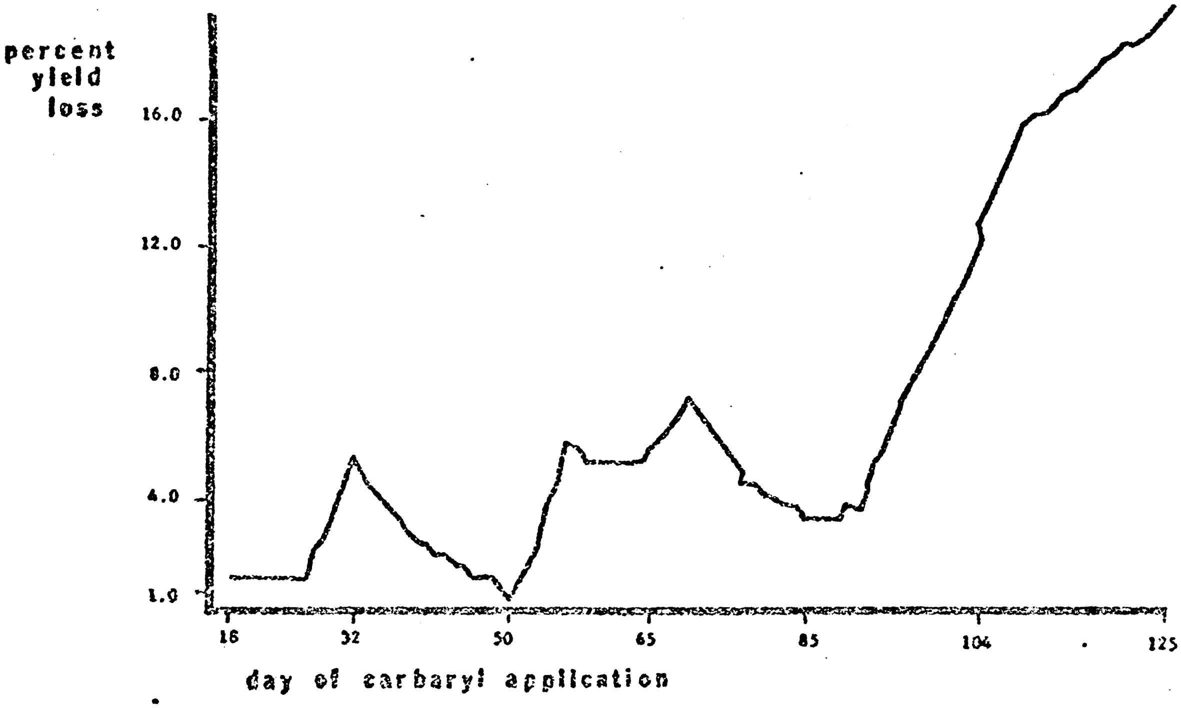


FIGURE 4: SOYBEAN YIELD LOSS GIVEN VARIABLE DATES FOR A SINGLE RELEASE/MIGRATION OF 264 PARASITES PER ACRE

(initial immigrating MBB pop. = 8 per row ft.)

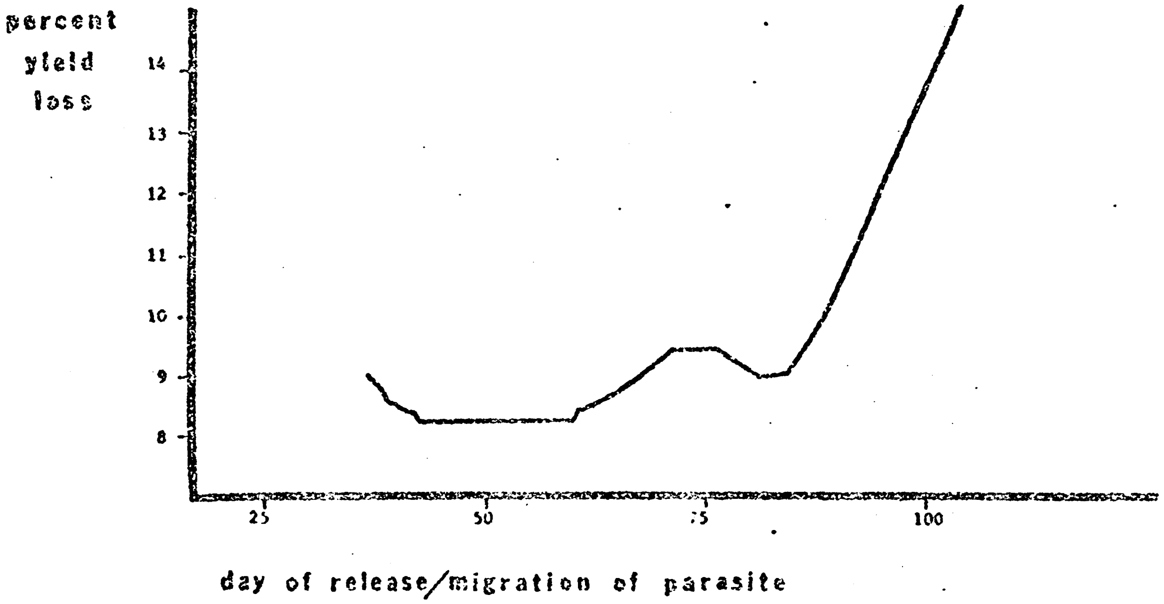


Table 5: Percent Yield Loss for Two Intraseasonal Applications of Carbaryl to a High MBB Population

| day of 2nd application | day of first application | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 22 | 30 | 41 | 54 | 65 | 76 | 90 | 104 | 114 |
| 30 | .3 | | | | | | | | |
| 41 | .2 | .2 | | | | | | | |
| 54 | .3 | 1.6 | 0 | | | | | | |
| 65 | .4 | .7 | 1.7 | .3 | | | | | |
| 76 | .4 | .9 | .5 | .7 | 1.2 | | | | |
| 90 | .2 | .6 | .5 | .5 | 1.0 | .9 | | | |
| 104 | .7 | 2.0 | 1.4 | 1.6 | 3.4 | 3.2 | 2.1 | | |
| 114 | 1.0 | 2.5 | 1.9 | 1.9 | 4.2 | 4.3 | 3.5 | 10.9 | |
| 122 | 1.2 | 3.0 | 2.1 | 2.3 | 4.7 | 4.7 | 3.5 | 11.7 | 16.4 |

acreage, respectively, and that about 25% of the treated acreage received two applications of insecticides. Assuming that half of the double treatments represented the joint use of one applicaton each of carbaryl and disulfoton and that the other half represented double applications of carbaryl, the pattern of insecticide usage on soybeans against MBB in 1974 was estimated as:

4.82% of all acreage treated with 2 applications of carbaryl

4.82% of all acreage treated with one application each of disulfoton and carbaryl

19.85% of all acreage treated with one application of carbaryl

9.06% of all acreage treated with one application of disulfoton

61.45% of all acreage not treated with insecticides

Assuming this use pattern, the yield benefit data generated by the simulation model for each of the combinations of chemical treatment above, was employed to calculate the average expected per acre yield benefit of that control pattern against each of the three MBB population levels. Optimal timing of all carbaryl applications was assumed. The expected cost of the control pattern was utilized to construct the upper-limit private benefit-cost ratios shown in Table 4. Under these assumptions, and utilizing the same soybean price of $6.02 per bushel, the simulation of a conventional pattern of chemical control of the MBB resulted in private benefit-cost ratios greater than 1.0 for both the medium and high-level MBB infestations. When the assumption of optimal application date(s) is dropped, the resultant benefit-cost ratios decrease. Given a number of different simulated combinations of less than optimal application dates, the private benefit-cost ratios decrease to values less than 1.0 for both the medium and high-level MBB populations.

When current prescribed spraying decision-making procedures were incorporated into the model, the use of disulfoton was not simulated. No application of carbaryl to the low-level MBB population was prescribed. The simulation of prescribed spraying pest management did result in the simulation of the application of carbaryl to the medium-level MBB population on day 109 and to the high-level MBB population on day 96.

The soybean yield effect of simulated biological control of the MBB was found to vary somewhat according to the timing of the release or migration of the parasite population into the soybean field. Figure 4 illustrates this variance for the high-level original MBB population. The early, optimal release of the parasite, as the sole simulated control measure, yielded the highest private benefit-cost ratios of all control strategies evaluated. The biological control alternative is the only one which results in a private benefit-cost ratio greater than 1.0 for the simulated low-level infestation of MBB. When the use of disulfoton was simulated in conjunction with biological control, lower yield losses were achieved but at greater costs.

Prescribed spraying procedures were simulated in conjunction with the optimal use of biological control to represent an integrated pest management strategy. Under this set of simulation circumstances, the application of carbaryl was not prescribed for either the low-level or the medium-level MBB population. Spraying was prescribed on day 97 for the high-level MBB population and this simulated control action resulted in a private benefit-cost ratio greater than 1.0 using assumed prices. Next to biological control, the integrated pest management strategy is the most cost-effective alternative, from the private standpoint, for controlling the low or medium-level MBB populations.

In general, the private cost-effectiveness of each control alternative is greater for its implementation on higher levels of MBB infestation. This is due to the fact that, for a given control action at a given cost, the management of a larger pest population has a greater percent yield benefit.

The use of a different soybean price does not affect the relative comparison of alternatives. The use of a lower price does decrease the values of all of the private benefit-cost ratios obtained. It is interesting to note, however, that the utilization of the lowest soybean price received by Maryland farmers since the 1972 escalation of prices ($4.39/bushel) did not act to decrease any of the benefit-cost ratios which, using soybean price equal to $6.02/bushel, were greater than 1.0, to less than 1.0.

## Social Cost-Effectiveness of Control Alternatives

No statistical relationship between the quantity of insecticides used on soybeans and the value of social environmental costs accrued within a season has been specified. For this reason, it was not possible to construct social benefit-cost ratios for each of the separate chemical control alternatives for which private benefit-cost ratios were constructed.

One representative ratio of social benefits to social costs was generated using 1974 insecticide use data and the reports of domestic and commerical honey bee losses for that same year. Assuming the chemical use pattern reported by Dively (1975), the values of expected per acre yield benefits were divided by the ratio of the total value of reported bee losses to the total acreage of soybeans harvested in the four Maryland counties for which bee losses were reported in 1974. The resultant benefit-cost ratios are quite high but since the optimal timing of insecticide application was assumed and the social cost estimation employed was assumed to represent minimum costs, the social benefit-cost ratios obtained for the conventional chemical use pattern must be considered upper bounds. If the known minimum environmental costs of insecticide usage which were used in this analysis represent less than or equal to 10% of actual environmental costs, then that control strategy would yield a social benefit-cost ratio equal to some value less than 1.0 for use on the low MBB population. An underestimation (of costs) of this degree is thought to be entirely possible. The estimated minimum environmental costs of conventional chemical control must be less than 1.0% and less than 0.3% of actual environmental costs if the control of medium and high-level MBB populations, respectively, by than method, were to yield social benefit-cost ratios which approach values less than 1.0.

The benefit-cost ratios representing the social cost-effectiveness of prescribed spraying techniques are likely to be greater than or equal to those determined for the conventional chemical control pattern. The prescribed spraying technique acts to reduce social environmental costs since it results in an insecticide use pattern which employs fewer inputs of the chemicals than does the conventional use pattern. Additionally, where local labor is hired to perform scouting duties, the region benefits from an expanded employment opportunity. Hence, social benefits may be greater than are those under the conventional chemical use pattern. Neither a precise nor a proxy social benefit-cost ratio has been determined for the prescribed spraying technique since the value of environmental costs which would accrue under the utilization of that alternative are not known.

The annual social cost of biological control of the Mexican bean beetle equals $1.40 per target acre. Assuming optimal, early release of the parasite, the values of the yield benefits of the control program are such that the societal benefit-cost ratios of its utilization as the sole control action are equal to .688 for the low-level MBB population, 4.26 for the medium-level MBB population, and 12.43 for the high-level MBB population.

If disulfoton usage is simulated in conjunction with biological control, the yield effect of that control of the medium and high-level MBB populations is greater than for biological control alone. Social cost, however, may be higher due to possible environmental costs of the use of disulfoton.

Integrated pest management, which is assumed to utilize both biological control and prescribed spraying procedures, has, for grower conducted scouting of low and medium-level MBB populations, social benefit-cost ratios equal to those ratios representing the cost-effectiveness of biological control alone. The integrated approach prescribes one application of carbaryl to the high level MBB population, thereby increasing both social costs and social benefits to some degree. Where scouting is assumed to be carried out by local labor other than the grower, the social benefits of the integrated pest management alternative increase by $1.17 per acre. Incorporation of the wage benefit into the determination of cost-effectiveness yielded benefit-cost ratios which are greater than 1.0 for all three MBB population levels.

## An Additional Consideration: Free-rider benefits of Biological Control

The implementation of the biological control program may result in an additional economic benefit which was not included in the evaluations above. Although the current program is aimed at 30,000 target acres, it is probable that the highly mobile parasite population has an effect on soybean acreage outside the target areas. The result of this is some ammassing of "free-rider" benefits (e.g., soybean growers who are not participants in the biological control program, and hence are not paying its private costs, may realize a yield benefit from the migration of parasites into their soybean acreage). The extent to which some proportion of the parasite population within the biological control program target areas does migrate to other acreage is not known. The inclusion of free-rider benefits would alter the evaluation of the biological control option and might have some inherent policy implications.

For purposes of illustration, assume that, as planned under the current biological control program, parasites are released or migrate into target acreage at an early date, e.g., day 40. If we further assume that after the period required for two full generations of parasite development (32 days), an average of 264 wasps (the number assumed to migrate into each target acre originally) migrate from each target acre to a non-target acre, hypothesized free-rider benefits may be quantified. Simulation of this assumed parasite exodus was carried out with the result that the yield-effect of biological control on target acres was not reduced. Non-target acres which received simulated late-season immigration of the parasite realized a lesser benefit from biological control (see Figure 4). Under the assumptions outlined above, the values of the free-rider benefits were found to equal $0.81/acre under conditions of a low-level MBB infestation, $5.33/acre for the medium-level infestation, and $15.78 for the high-level infestation. Including these hypothesized values into the social benefit-cost calculation reduced the per acre cost of biological control by 50% and reduced average per acre yield benefit of biological control by less than 50%. Social benefit-cost ratios for biological control increased from .69, 4.26 and 12.43, to 1.27, 8.07 and 23.70 for low, medium and high level MBB populations,respectively, when free-rider benefits of assumed quantity were accounted for. The recalculated ratios justify public expenditure on biological control even in seasons during which the average MBB infestation occurs at a low level.

The private costs of biological control are not changed by the inclusion of free-rider benefits to the evaluation of that alternative. This does indicate, however, that participants in the biological control program are subsidizing non-participants' soybean production. This situation may result in a less than socially optimal use of biological control by private decision makers.

An oft-suggested (Buchanan; Singer) method by which an undesirable free-riders situation may be rectified is that all private costs of the action which result in free-rider benefits be assumed by a public body. If the private costs of biological control are paid by the state of Maryland, the additions to total cost would equal $7500.00 per year. Assuming twice the target acreage, so as to account for hypothesized formerly free-rider acreage, per acre social costs of biological control would increase by $0.125 per acre. Social benefit-cost ratios calculated under these assumptions equal 1.07, 6.95 and 20.42 for the low, medium and high-level MBB populations, respectively. The additional public expenditure is justified at the assumed soybean price, for all levels of pest infestation.

## Shortcomings

The producers' risks of utilizing unneccessary preventative Mexican bean beetle control inputs at the start of the soybean growing season (e.g. biological control or the use of disulfoton) were not considered in this study. The examination and comparison of each alternative pest control strategy over each level of Mexican bean beetle infestation would not have been necessary if the probability of infestation at each level was known. This information was not available from either objective or subjective sources. The Mexican bean beetle pest problem had not been studied over a long enough period of time for such probabilities to have been objectively estimated. The mean values of grower responses to a survey to determine their estimations of the probabilities of various levels of Mexican bean beetle infestation had exceptionally high standard deviations attached to them. It was felt, by the authors and by collaborating entomologists, that the soybean growers were operating under a great deal of uncertainty regarding the Mexican bean beetle pest problem.

If a probability distribution had been available, the ratio of expected yield benefits to expected control costs could have been calculated for each alternative pest management strategy. These benefit-cost ratios would have been more useful as they would have accounted for the risk aspects of pest control action decisions.

The exclusion of additional risk-related factors may have biased the evaluation of prescribed spraying pest management alternatives. These particular factors are related to weather. This study assumed constant, average weather conditions. Instances in which potentially damaging early or mid-season populations of Mexican bean beetles are subsequently reduced by conditions of drought or other exogenous factors, thereby reducing or eliminating the need for later-date insecticide applications, were not considered. The utilization of scouting to take note of such incidences has benefits which were not accounted for in the analysis.

The intraseasonal nature of this analysis is a further shortcoming. Both the use of insecticides and the implementation of biological control could have long range positive or negative consequences which were not examined in this study.

## Conclusions

The application of a specific microanalytic simulation to determining the relative private and social economic advantages of selected alternative methods for controlling MBB on soybeans in Maryland yielded data which is useful to decision-makers in both the private and public sectors. It provided evidence that biological control of the pest is more than competitive, from the private standpoint, with its alternative chemical control. Results also showed that an integrated pest management strategy which utilizes locally recruited labor has identifiable private and social returns which are great enough, at assumed prices, to justify expenditure at both levels.

The authors feel that the microanalytic simulation technique is an improvement over previously proposed methods for evaluating pest control alternatives. The approach utilized in this study enabled the researchers to evaluate alternative pest control strategies on a comparable basis. The adaptability and flexibility of the microanalytic simulation approach enhances its value as a tool for examining the economic aspects of pest control. The shortcomings of this particular study were due primarily to a lack of biological data. Given data on more specific environmental effects of pesticide usage, on the probabilities associated with various levels of pest infestation, on the effects of environmental variables on the pest population, and on interseasonal aspects of the pest's control, the simulation model may easily be modified to account for the additional factors.

A lack of entomological data on the basic dynamics of specific insect pest populations may limit attempts by economists to evaluate the economic implications of the presence of a particular pest population and the control or management thereof. This implies a need for cooperative research efforts between biologists and economists.

## References

Bender, Filmore E. "Performance of the Broiler Industry - A Simulative Approach." J. Farm Econ. 48 (1966): 1467-1476.

Buchanan, James M. The Demand and Supply of Public Goods. Chicago, Rand McNally, 1968.

Dively, Galen P. "Joint Proposal: Delaware and Maryland Integrated Pest Management Pilot Application Program." Project Proposal. University of Maryland, College Park, Md., 1975

Dively, Galen P. "Maryland-Delaware Coop. Extension Service Blacklight Trap Report No. 8." University of Maryland, College Park, Md., June 1975.

Dively, Galen P. unpublished MBB life-table data. 1975

Dively, Galen P. Maryland Multicrop Pest Management Program, 1976 Progress Report and Proposed Changes. University of Maryland, College Park, Md., 1976.

Hall, Darwin C., and Richard B. Norgaard. "On the Timing and Application of Pesticides." Amer. J. Agr. Econ. 55 (1973): 198-201.

Headley, J. C. "Defining the Economic Threshold." Pest Control Strategies for the Future, prepared by the National Academy of Sciences, pp. 100-108. Washington, D. C., 1972.

Kalton, R. R., C. R. Weber and J. C. Eldredge. The Effect of Injury Simulating Hail Damage to Soybeans. Iowa Agri. Home Econ. Exp. Sta. Res. Bull. 359, 1949.

McAvoy, Thomas J. Personal Communication. Department of Entomology, VPI and SU, Blacksburg, Va., April, 1977.

Metcalf, C. L., W. P. Flint and R. L. Metcalf. Destructive and Useful Insects. New York, McGraw-Hill Book Co., 1962.

Orcutt, Guy H. "Simulation of Economic Systems." Amer. Econ. Rev. 50 (1960): 893-907.

Regev, Uri, Andrew P. Gutierrez, and Gershon Feder. "Pests as a Common Property Resource: A Case Study of Alfalfa Weevil Control." Amer J. Agr. Econ. 58 (1976): 186-197.

Reichelderfer, K. H. and Dewey Caron. Unpublished Depts. Agri. & Res. Econ. and Entm., University of Maryland, College Park, Md. 1976.

Shubik, M. "Simulation of the Industry and the Firm." Amer. Econ. Rev. 50 (1960): 908-917.

Singer, Neil M. Public Microeconomics. Boston, Little Brown and Co., 1976.

Stevens, L. M., A. L. Steinhauer and J. R. Coulson. "Suppression of Mexican Bean Beetle on Soybeans with Annual Inoculative Releases of *Pediobius foveolatus*." Env. Entm. 4 (1975): 947-952.