COMPUTER MODEL AIDS in Weevil Control

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During the late 1950's, the Egyptian alfalfa weevil invaded alfalfa in the desert regions of the southwestern United States. In 1974, it caused in excess of 18 million dollars in damage (1974 California Department of Food and Agriculture Report). This is not surprising as, under certain circumstances, this pest can completely defoliate a crop. In addition, the routine pesticide applications which have been directed against this pest appear to have induced secondary pest outbreaks of other formerly innocuous pests (*e.g.*, aphids, mites, and various *Lepidoptera*), which also require further pesticide applications to control them. The problems of increasing pesticide applications and the associated costs are so severe that they jeopardize the economical cultivation of alfalfa in the central valley of California.

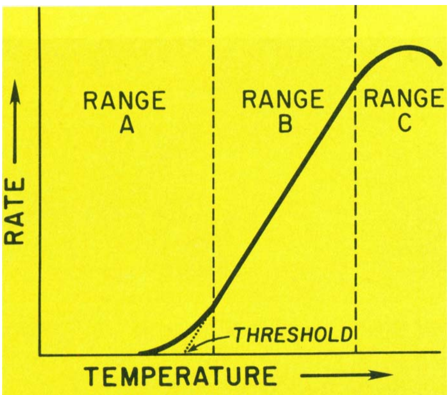


Fig. 1

The problem of assessing the need for pest control is not apparent to the grower until weevil damage appears, in which case economic damage may already have been sustained, not only to the current crop due to insect injury, but also to later cuttings because of depleted plant reserves and induced secondary pest outbreaks. Farmers tend to be "risk averters," and spray as insurance when they feel crop loss may occur. Because of the complexity of the problem, it has not been possible to accurately assess the problem and make the appropriate control decisions.

Computer simulation of a pest/crop system

The recent advent of computer simulation models of crop/pest/weather interactions has enabled researchers to examine the workings of the alfalfa ecosystem. The simulation model is a set of mathematical equations which describe the biology of each component of the system—the weevil population and the host plant as influenced by weather. Such a model has been developed for the Egyptian alfalfa weevil and alfalfa.

It is well known in agronomy and zoology that temperature determines to a large degree the rate of development of microorganisms, plants, and cold blooded animals, provided that other factors are non-limiting. The concept is generally as

Fig. 2

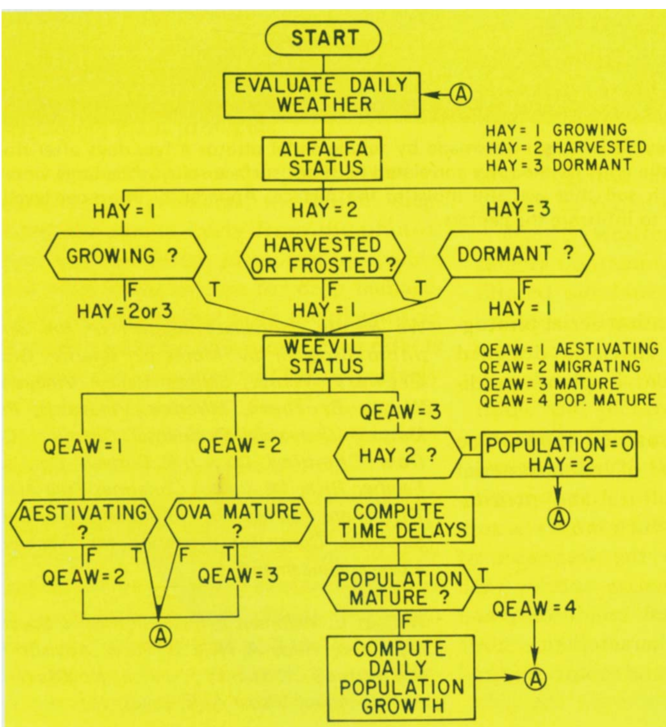
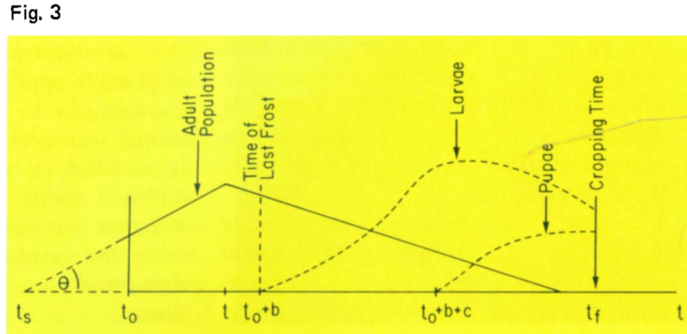


Fig. 3



follows: If we grow an insect at several different temperatures, it will require fewer days to develop through some life stages at high temperatures than at low (fig. 1). At some temperature (T*), the development ceases. (N.B. T* is an approximation of the real zero point.) In general, the equation

$$D^\circ_t = \int_0^t (T(t')\text{-}T^*dt')$$

describes the calculation of physiological time (D°), where T(t') is the temperature at time t' and T* is the lower thermal threshold. The value of D° is approximately constant for each species (*i.e.*, each life stage) and given daily temperature patterns, can be used to estimate the timing of various events in the development of a population. The computer model driven by physiological time predicts the developmental course of both the weevil population (based upon early season counts) and the alfalfa crop, as well as their interaction (fig. 2). In addition to temperature, the model also evaluates the effects of other weather parameters (*e.g.*, solar radiation, rainfall, day length, and wind) on crop growth and development.

Considerable biological complexity is built into the simulation model. It covers the migration of the weevils into the field, the growth of the egg and larval populations, the growth of the crop, defoliation of the crop, the effect of the defoliation on larval survival and adult fecundity, and various other factors as modified by weather.

Whereas weather is quite variable, the biological relationships are similar from year to year, and are used to formulate a generalized economic model for this system. Furthermore, this crop/pest relationship has several biological and economic aspects in common with other crop/pest or man/pest systems; hence the economic model is more general in theory and has much wider application, as, for example, to weeds in pastures or pinworms in dogs and children.

The economic model

The economic model is a concise mathematical distillate of the simulation model which not only captures the essence of the relevant biology, but, in addition, asks economic questions. The economic model includes an analysis of the subleties of the phenologies of the pest and plant (fig. 3), the insect population dynamics, plant growth/pest damage interaction, the effect of quantity and timing of pesticide applications on weevil control and on secondary pest outbreaks, and many other factors. The field of operations research provides the mathematical techniques for handling the complexity inherent in this type of problem.

The model is used to examine pest strategy from the single grower point of view or from a societal point of view. In the first case, the model seeks to find the optimal timing and quantity of pesticide applications to maximize grower profit (a single season solution). The model indicates that control measures should be directed against the adult population, which is contrary to the current grower practice of applying material against the larvae when damage is visible. This procedure will require some sophisticated sampling methods to help the farmers assess the level of adult pest infestation early in the season, and more effective all-weather pesticides must be developed before the results of this model can have practical utility.

From the societal viewpoint, the model recognizes specifically the fact that individual farmers have little regional control on either the within-season pest population levels or the interseasonal dynamics of the pest. A central decision agency (or pest consultants), on the other hand, could enhance the farmers' income by considering the effects of pest control practices by all farmers in the region on the level of pest infestation in the following seasons. The model indicates that for an optimal societal policy, growers should *spray heavily during the first few seasons* to suppress the weevil populations to a low level where it can be more profitably maintained thereafter. On the surface, this would appear to be a good policy, but it ignores the very real threat of the development of pesticide resistance in the weevil population.

A model incorporating insecticide resistance

When a new economic pest enters an area, the usual practice is to attempt suppression using chemical pesticides and cultural and biotic practices. In most cases, adequate practical integrated control procedures are either not found or are not utilized for a variety of reasons. Hence there tends to be a heavy reliance on pesticides with the resultant development of resistance.

The economic model was altered to incorporate the development of pesticide resistance in the population. In this case, some Russian work on a very closely related species indicates that nearly total resistance to heptachlor developed within a period of six years. They found that resistant individuals tended to have more than one generation per year and had higher fecundity. If the resistant individuals had the same "fitness" (progeny surviving per females in the absence of pesticides), the resistant genes would obviously be selected, once the trait appeared. Genetic theory, however, indicates that a new gene—that for resistance, for example—would not be well integrated into the genome immediately, and, as a result, total fitness would be initially lower. However, fitness of a resistance gene does increase with time and continued pesticide selection pressure. The model was altered in the following way: A genetic mechanism for the selection of resistance genes due to pesticide pressures (the Hardy–Weinberg Law) was introduced into the model along with a low mutation rate, increasing fitness of the resistance gene(s) with time, higher fecundity of resistant females, and different genotype pesticide mortality relationships for both larvae and adults.

The above concepts were incorporated into an economic framework of profit maximization, and the following results emerged. Because of pest mobility, the pest resistance level in each field results from chemical pesticide application in the preceding season by *all* farmers. Since the individual farmer does not consider the external effect of his pest control policies on the development of pest resistance, it is only through a joint action by a central body (*e.g.*, cooperatives, legislature, etc.) that the optimal pest control policy can be obtained. This policy is likely to call for reduction in chemical pesticide use, and encourage biological control that does not increase pest resistance. More importantly, it will be possible to estimate the implicit costs of increasing pest resistance, which in turn could be used as an indicator of the amount of money that should be spent by society on research for such non-chemical control methods as host plant resistance, biological control, and cultural methods.

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