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ACTION THRESHOLDS FOR PROCESSING CABBAGE, A SHORT-TERM SOLUTION TO A LONG-TERM PROBLEM

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ABSTRACT

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Action thresholds for management of lepidopteran pests in processing cabbage were developed and refined over a 4-year period. Since research data on the relationship of pest population density to economic loss was not available initially and treatment guidelines were required for a pest management demonstration program, the thresholds were initially based on the experience of an advisory committee including members from industry, extension and research faculty. These thresholds were revised annually, based on the comments of farmers using them, observations of the advisory committee and studies conducted for that purpose. Studies demonstrated considerable interaction between pest population density and other factors affecting yield. Future progress will require the development of a comprehensive economic threshold model, but in the interim the action thresholds provide most of the benefits expected from such a model.

INTRODUCTION

In the last 20 years, considerable research in entomology has been devoted to determining treatment decision criteria for selected pests of specific crops. The common treatment decision rules that relate pest population density to crop loss may be viewed as action thresholds or, when economic analyses have been performed, economic thresholds. The research necessary to establish such thresholds would logically precede their implementation. However, a recent infusion of monetary support into state land grant institutions for extension pest management demonstration programs created, in some cases, a more immediate need for treatment decision rules where none had existed before. Programs were initiated to demonstrate whatever pest management techniques were currently available, sometimes only field

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sampling procedures. Such was the situation for processing cabbage in New York because prior to 1980, action thresholds for management of Lepidoptera [*Plutella xylostella* (L.), *Pieris rapae* (L.), *Trichoplusia ni* (Hübner)] in processing cabbage had not been proposed. In that year, however, the Cornell Cabbage Integrated Pest Management (IPM) Program began providing field monitoring services to interested farmers. The objective was to correct inefficiencies in insecticide use by more careful monitoring for pests. Because data on pest abundance in cabbage fields had been reported to the farmer in quantitative terms, treatment guidelines in similar terms were needed. At the time, we had no research data that would provide the necessary guidelines so development and implementation of treatment guidelines had to proceed simultaneously. The first thresholds in terms of pest population density were proposed by a group of research entomologists, extension personnel and processing industry fieldmen, based on their collective experience and judgement. Since the benefits of the program were under close scrutiny by the growers, the first threshold proposed was designed to minimize the danger of loss in the farmers' return on the crop due to pest damage and was simply a guideline for treatment decisions, an action threshold. It was important to gain the farmers' confidence in and acceptance of pest management techniques. To this end we involved them in the process of developing the action thresholds. Over the following 3 years we revaluated and revised the proposed thresholds annually based on experience gained in the pest management program by the group listed above and the farmers themselves. We also conducted research each year to refine the proposed thresholds further and, we hoped, to lead toward a true economic threshold for processing cabbage.

Herein, we describe how these action thresholds were developed, the results of studies conducted to refine them and the implications of these studies on future research into economic thresholds for processing cabbage.

DEVELOPMENT OF ACTION THRESHOLDS

Implementation and development, 1980

The first threshold proposed was an average of 1—2 lepidopteran larvae of any species per plant, based on the consensus of a committee experienced in cabbage production. However, none of the members of this committee had regularly monitored specific fields; their experience with lepidopteran feeding injury had largely been with the worst cases. The group's and the farmers' theory at this time was that any feeding would result in some loss in yield. The threshold was based on these perceptions, as well as an appreciation of the damage that growers found unacceptable. For example, *P. xylostella* larvae can feed in the heart leaves on young plants, sometimes damaging the meristem; therefore, one *P. xylostella* larva could, in the worst case, prevent head formation, which is unacceptable. Since control measures were assumed to be economically justified, this estimate of the lowest population density that would cause economic damage was consistent with the definition of an economic injury level (EIL) (Stern et al., 1959). It was assumed that the pest population could be effectively controlled by insecticides as soon as it reached this density. These thresholds were provided to farmers for the 1980 growing season in conjunction with the IPM program.

Implementation and development, 1981

During the growing season of 1980, we observed the development of lepidopteran larvae in the field and the relationships of population density to damage and damage to the growth of the plant. Often treatments that were considerably delayed still prevented unacceptable damage. Two of the most obvious reasons were differences in amount of feeding by the 3 species and differences in tolerance of a given amount of feeding by plants at different growth stages. Differences in feeding by each species had been studied by Harcourt (1954). Based partially on this study, we devised a scale of "larval units" as follows:

larval units = No. of 3rd—5th instar *T. ni* + 0.6(No. of 1st—2nd instar *T. ni* + No. of 3rd—5th instar *A. rapae*) + 0.1(No. of 1st—2nd instar *A. rapae* + No. of *P. xylostella*).

The values given to *P. xylostella* and small *A. rapae* and *T. ni* are higher than necessary, which reflected the difficulty of control (e.g., small *T. ni*) and the capacity for increase (e.g., *P. xylostella*). Differences in tolerance to a given amount of damage by various stages of growth of the plant were hypothesized. After infestations in commercial cabbage fields, feeding injury varied from plant to plant. Since plants were grown under identical conditions, qualitative differences in head size, plant vigor, etc. were attributed to feeding injury. Other crops have been shown to tolerate low percentages of defoliation without reducing yield (Bardner and Fletcher, 1974) and we hypothesized that this was the case in cabbage. We expressed this in the thresholds by proposing different thresholds for 4 different crop growth stages for 1981: 10—15 leaves, 0.8 larval units; 16—25 leaves, 1.0 larval units; 26—32 leaves, 1.6 larval units; > 32 leaves, 2.5 larval units. Again, the quantitative step was a matter of judgement and consideration of the growers' comments.

The growers generally considered thresholds to be a useful way to interpret the field monitoring information. Their consensus on the proposed thresholds was that at some of the earlier stages they were approximately correct, but at the later crop stages they were probably somewhat low, requiring treatments sooner than necessary. Lepidoptera have been shown to be primarily indirect pests of processing cabbage (Shelton and Andaloro, 1982). Their injury does not extend farther into the cabbage head than the outer green leaves, ordinarily removed regardless of feeding injury. Another study showed that head weight was not well correlated with lepidopteran larval populations (Shelton et al., 1982). Given the growers' attitudes, we could not suggest that no treatments be applied. The revised thresholds were again provided to the growers involved in the IPM Program in 1981.

Test of 1981 thresholds

Three commercial fields, each 2–4 ha in size and managed in a similar fashion were divided into three sections and each section was treated by the grower at a different action threshold during 1981. Action thresholds consisted of 0.8X, 1.6X and 2.5X, "X" being the threshold proposed above for a particular crop stage. From 13 to 40 plants were inspected weekly in each section from planting until harvest to estimate pest population density. When population densities exceeded the thresholds, growers applied an appropriate insecticide (Andaloro et al., 1983) with their usual ap-

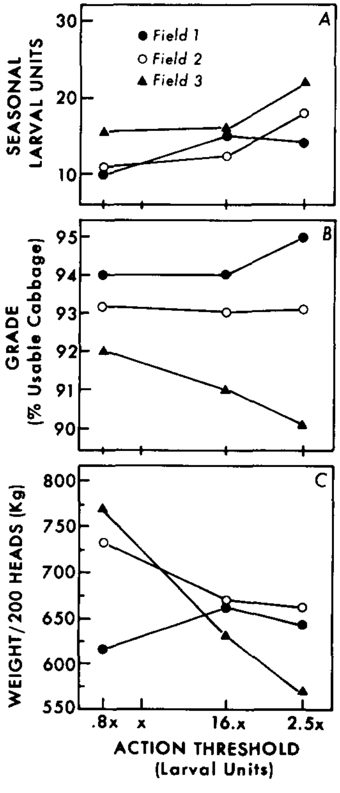

Fig. 1. Relationship of action thresholds for Lepidoptera (expressed in larval units) to resulting larval units, grade and yield of cabbage in three commercial fields. Ontario County, NY, 1981.

plication equipment, gallonage and pressure. When the cabbage was mature, 200 randomly selected heads per section were hand harvested and taken to a sauerkraut processing plant, where they were weighed and graded according to the processor's usual procedures. Analyses of variance were performed to test differences in yield and grade between treatments.

Differences between the three sections were obvious. Lepidopteran feeding was more evident in sections where the highest thresholds were used. However, analysis of grade and yield from the three sections revealed no significant differences. In addition, no relationship could be discerned between the action threshold and resulting larval units (Fig. 1a), or between larval units and either grade (Fig. 1b) or yield (Fig. 1c). Increases in action threshold did not result in consistent corresponding increases or decreases in larval units and increases in larval units did not result in consistent corresponding increases or decreases in head weight. In Field 2, increased larval units actually corresponded with increased head weight. However, average yield was lower in all of the 2.5*X* plots than in the 1.6*X* plots.

Implementation and development, 1982, 1983

During the 1981 growing season, growers realized substantial savings in insecticide costs as well as increased insecticide efficacy (Andaloro et al., 1983). The system of larval units made the thresholds a useful tool for timing, as well as determining the necessity, of insecticide treatments. Since small larvae are given very little weight in the scheme, the threshold in larval units tended to allow most of the eggs in a field to hatch, during periods of rapid population density increase, before an insecticide was applied. The only obvious fault was the discrete nature of the crop stages. In addition, temperatures in the field varied considerably from May to September and have a profound effect on the relationship of pest population density to damage over time.

To address these problems, a pocket computer (TRS80 PC2) was programmed to calculate more dynamic action thresholds in 1982. The 1981 thresholds, as a function of number of leaves on the plant, were fit with a continuous curve, by eye on graph paper and then an equation was fit to the curve using a statistical computing program. Data from the literature for effects of temperature on *T. ni* development (Jackson et al., 1969; Toba et al., 1973) and food consumption by *T. ni* (McEwen and Hervey, 1960) were also used to adjust the thresholds to field temperatures. The computing procedure was as follows: (1) calculate threshold larval units at average summer temperatures as a function of the no. of leaves per plant; (2) convert threshold larval units at average conditions to allowable consumption for the no. of leaves per plant; (3) divide the allowable consumption per day by the consumption per day per larval unit at the temperature encountered in the field. The 1983 thresholds were calculated by the same procedure, except that the function for action thresholds was modified slightly based on the growers' comments (Appendix 1).

Further threshold evaluations

The pest population densities that actually occurred in 10, 21 and 20 commercial sauerkraut cabbage fields in which the thresholds were in use in 1981, 1982 and 1983, respectively, were compared to records of yield and grade. From 11 to 20 plants, according to a variable-intensity sampling procedure (Hoy et al., 1983), were inspected weekly to estimate population densities of the three lepidopteran species. In 1983, each plant was also given separate visual damage ratings from 0 (no injury) to 4 (severe injury) for the frame, wrapper and head leaves. Grower records of yield and grade were collected for each field after harvest. Regression analyses were performed on yield predicted by sum of larval units for the season and the sum of positive deviations from the action threshold, and grade predicted by total larval units after head formation. Additional regression analyses were conducted for yield predicted by average frame damage rating and grade predicted by final head damage rating at harvest for the 1983 data.

Total larval units varied from 1.1 to 24.7 in 1981, from 1.2 to 14.7 in 1982 and from 6.5 to 66.0 in 1983; the sum of the positive deviations from the action threshold varied from 0 to 10.19 in 1981, 0 to 5.7 in 1982 and 0.31 to 44.05 in 1983; and total larval units after heading ranged from 0.5 to 24.31 in 1981, from 1.12 to 12.63 in 1982 and from 5.42 to 56.47 in 1983. However, using linear regression analyses, yield could not be predicted by total larval units or sum of the positive deviations from the threshold and grade could not be predicted by total larval units after head formation. None of the slopes of regression lines were significantly different from zero, even at $P \leqslant 0.4$. No relationships were evident in plots of the above variables, most values of r^2 were less than 5% and the largest value was 11.6% for grade predicted by total larval units after head formation in 1981. Despite the wide variation in total larval units, the average frame damage ranged only from 1.1 to 1.7. Furthermore, damage ratings could not be predicted by total larval units and yield could not be predicted by damage rating. The final damage rating to the cabbage heads ranged from 0 to 1.2 and the regression of grade predicted by final head damage rating gave an r^2 of only 31%.

The consequence of exceeding the proposed threshold was tested by spraying most of a field on 13 September 1985, while leaving 6 rows untreated. On 5 September, the average number of leaves was 32, the average head diameter was 9 cm, the average number of larval units per plant (4.5, mostly small *T. ni*) exceeded the threshold and an average of 11.3 *T. ni* eggs per plant were ready to hatch before the application. The weather over the following weeks was very hot and dry, poor conditions for cabbage growth. At harvest, 11 October, damage to the sprayed portions of the field was minimal, ranging from ratings of 0—1 for both the frame and head leaves, while damage in the unsprayed rows ranged from 2.5 to 3.5 for both the frame and head leaves. To compare frame weight, head weight and grade between relatively injured and uninjured plants, 100 plants with a visual damage rating of 3 were chosen randomly and harvested from the untreated rows. For each of these plants, the nearest plant with a damage rating of 0.5, in the next row where the insecticide had been applied, was also harvested. The cabbage head and plant frame were weighed separately for each plant. A subsample of 25 heads from each damage rating was graded by a processing company grader and the cull material trimmed from each head was weighed. Data for frame and head weight were analyzed using a paired *t*-test and the data for cull material was analyzed using a two-sample *t*-test.

Significant differences were observed in frame weight and head weight ($P < 0.01$) between the heavily damaged and slightly damaged plants in the commercial field. In the more damaged plants, average reduction in frame weight was 5.6% and average reduction in head weight was 8.4%. Average weight of cull material was the same in both treatments. The reduction in head weight was equivalent to a 5.3 tonnes ha^{-1} decrease in yield, costing the farmer approximately $174.30 ha^{-1}, while the cost of the application was approximately $24.70 ha^{-1}.

IMPLICATIONS AND CONCLUSIONS

The studies have demonstrated that Lepidoptera are primarily indirect pests of processing cabbage, as Lepidoptera had no effect on the grade of cabbage, even when populations were dense and damage extensive. Lepidoptera can have an effect on the yield (tonnes per ha), but in combination with other factors, as attested by the 1981 test of threshold levels, in which response of the crop to different population densities varied according to environmental, edaphic and agronomic conditions.

Population dynamics of Lepidoptera will determine the amount of damage incurred when a given threshold is in use. Since eggs are not very susceptible to insecticides, spraying at the beginning of a population increase, when much of the population is still in the egg stage, could allow a second increase. The damage may be almost the same if the population is allowed to develop further before treatment. An example of this is in the 1.6*X* and 2.5*X* sections of Test Field No. 1 in August (Fig. 2). At times, the population can increase so rapidly that either low or high thresholds would be exceeded, as was the case with the 0.8*X* and 1.6*X* sections in Test Field No. 2 in early August (Fig. 2). If larvae reach the action threshold quickly and are controlled promptly with insecticides while they are small, the resulting damage is likely to be slight. However, if larvae reach the action threshold slowly, after they have entered the late instars, insecticides are likely to be less effective and feeding damage is liable to be much greater.

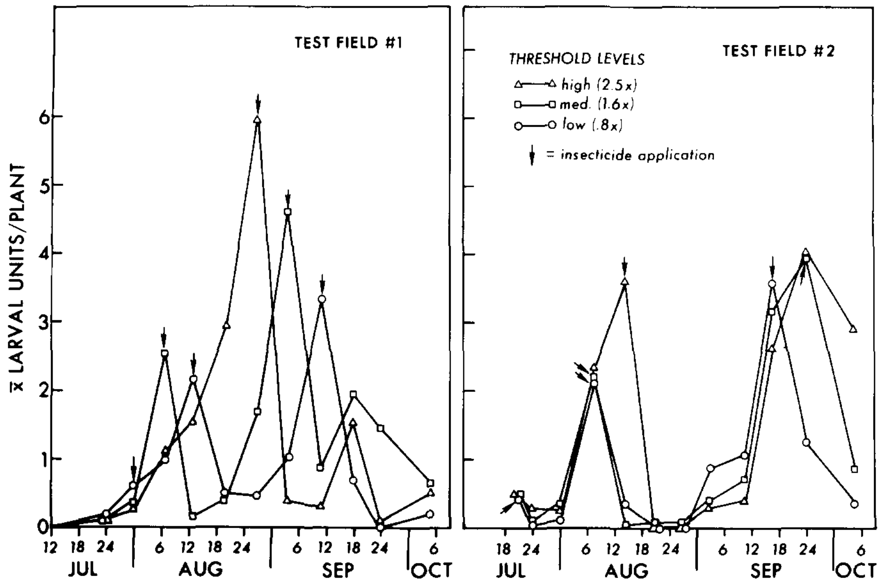

Fig. 2. Population trends of Lepidoptera (expressed in larval units) as a function of action threshold levels and insecticide treatments in three commercial cabbage fields. Ontario County, NY, 1981.

Despite the complexity of the problem, action thresholds were developed that have improved pest management practices of cabbage growers. Andaloro et al. (1983) attributed a 49% reduction in insecticide use and a 54% increase in insecticide effectiveness to the use of field monitoring information and these action thresholds. Because the growers were involved in the development they are satisfied with the action thresholds and have embraced the concept of the true economic threshold as a goal to strive for in their management practice. Thus, the action thresholds, despite their relatively unsophisticated development, seem to provide most of the benefits that a more comprehensive, economically valid threshold model would be expected to provide. However, in the longer term we cannot be satisfied until proposed thresholds can be thoroughly and scientifically evaluated under any conditions encountered by cabbage producers and thereby either refined or proved to be economically sound. Current research is concentrating on developing a model for the relationship between pest population density and the amount and location of foliage consumption on the cabbage plant, the first step in a model to predict yield loss.

APPENDIX I

In 1982, the threshold, in larval units, for average summer temperatures (21°C) was calculated by:

$$\text{action threshold} = 0.2252 + 0.0023(\text{No. of leaves})^2 \quad (2)$$

where the action threshold is in larval units per plant. This function was derived by graphing the discrete thresholds used in 1981 as a continuous function of the number of loose frame and wrapper leaves on the plant and then determining an equation that fit the curve. Based on observation and experience in 1982, the equation for 21°C was further refined in 1983 to:

$$\text{action threshold} = -0.004 + 0.003(\text{No. of leaves})^2 \quad (3)$$

which was very similar to the previous function at the intermediate crop growth stages, but was judged to be more useful when the plants were very small and when they were close to maturity. These thresholds were adjusted for temperature, because the feeding rate of the caterpillars varies with temperature. Temperature—development data reported by Jackson et al. (1969) and Toba et al. (1973) and consumption data by McEwen and Hervey (1960) for *T. ni* were used to approximate the amount of cabbage consumed in one day by one larval unit at a given temperature as:

$$\text{approximate consumption (mg)} = 1450/(12.3 + (84762 \times 1.14^{-(9/5T+32)})) \quad (4)$$

where T = (daily maximum temperature + minimum temperature)/2. The approximate allowable consumption for a given crop stage is calculated by using 21°C for the temperature in (4) (giving the mg consumed per day per larval unit under average summer temperatures in our area) and multiplying by the larval units obtained in (3). The approximate consumption by a larval unit on any given day is calculated by using the forecast maximum and minimum temperature for the day in (4). The adjusted action threshold (in larval units) for a specific field on a specific day is the approximate allowable consumption for the crop stage divided by the approximate consumption per larval unit at that day's temperatures.

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