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A pest management program for variegated cutworm (VC), *Peridroma saucia* (Hübner), in Oregon peppermint was developed based on studies of pheromone trapping, sampling methods, and economic thresholds.

Pheromone traps effectively trapped VC males and were used to reflect development and oviposition trends. Trap height was linearly correlated to moth catch ($P < 0.001$); the largest catch occurred at a height of 80 cm.

Male moths caught from mid-May through June, the number of egg masses collected on pheromone traps, and estimates of peppermint canopy height were used to estimate third and fourth instar larval densities by regression analysis ($r^2 = 0.64$). A discriminant analysis based on similar independent variables correctly placed 16 out of 18 fields into two threshold density classes by a validation procedure.

Parasitism rates of variegated cutworm and peppermint leaf consumption rates of parasitized and unparasitized larvae were measured. Instars 4 to 6 consumed an average of 184 cm^2, equivalent to 888 mg (dry weight) of peppermint foliage. Consumption by VC larvae parasitized by *Meteorus communis* (Cresson) was reduced by 93%.

Parasitism rates averaged 35.1% for instars 2 to 4 and 5.4% for instar 5.

Addition of peppermint mainstem and lateral leaves, rates of leaf senescence, leaf specific oil yields, VC larval development, feeding behavior, feeding injury, and parasitism rates were all simulated by a computer model to determine economic threshold values. Significant injury occurred when fifth and sixth instar larvae were present in early August just prior to harvest. Fields harvested later in August had higher thresholds because of increased time for regrowth following cutworm injury. Economic threshold values calculated from this study ranged from 1.7 to 3.0 times higher than the previously used threshold of 0.9 larvae per 1000 cm^2. Larval damage units (LDUs) were used to express individual instar damage potential (kg/ha oil per cutworm) at various times in the growing season.

Sweep-net samples (n = 10, 180° sweeps) were most efficient for sampling VC instars 2 to 4. Ground search (GS) samples (1000 cm^2 for 10 minutes) were more efficient for instars 5 and 6. Sweep-net sample means were regressed against GS sample means for each VC instar. Efficiency of GS sampling for each instar was determined by vacuuming and searching the soil surface sampled. Slope values from sampling method regressions were used with GS recovery efficiency percentages to derive approximate economic threshold (ET) estimates for instars 2 to 4 using the sweep-net method. Sample size requirements and sequential sampling plans for each sampling method also were developed.

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VARIEGATED CUTWORM IN PEPPERMINT

INTRODUCTION AND LITERATURE REVIEW

The variegated cutworm (VC), *Peridroma saucia* (Hübner), (Lepidoptera: Noctuidae), has been cited as a pest of at least 37 vegetable crops and reported from 85 other host plants in four continents including North America (Rings et al. 1976a). This insect was first described as *Noctua saucia* between 1803 and 1808 (Hemming 1937). VC can cause rapid and serious defoliation in crops not closely monitored for early larval stages. Major outbreaks of this pest were reported during 1900, 1905, 1914, and 1925 (Lovett 1915, Snyder 1951). An estimated 2.5 million dollars were lost due to the outbreak in 1900, about half of which was recorded in Washington state (Lovett 1915). In peppermint, larvae cause direct damage by feeding on leaves which have the peppermint oil glands on their surface. Feeding injury occurs during mid to late July and in early August just prior to peppermint harvest (Berry and Shields 1980). Of the species found in peppermint, the variegated cutworm causes the most serious damage. Other species present include the Bertha armyworm, *Mamestra configurata* (Walker) the alfalfa looper, *Autographa californica* (Speyer), and the redbacked cutworm, *Euxoa ochrogaster* (Gúenée) (Berry 1977). Even though an OSU Extension sponsored pilot insect pest management (IPM) program for peppermint was conducted during 1977 to 1980, neither comprehensive economic threshold values or well-defined sampling programs were developed for cutworms.

Variegated Cutworm Biology

Accounts of the life history, feeding habits, and description of the life stages of VC were given by Lovett (1915), Crumb (1929), Snyder (1957), and Bierne (1971). VC are usually nocturnal feeders and remain on or just under the soil surface during warm daylight hours (Crumb 1929). In Oregon, two to three generations per year were reported (Lovett 1915). Overwintering in the larval, pupal, and adult stages has been noted, with the majority of the population overwintering either as half grown larvae (Lovett 1915) or as pupae (Crumb 1929). No diapausing stage was reported for VC, and overlapping generations are liking to occur. Larvae are consistently reported during July and early August, the period they are most injurious to peppermint. VC causes damage to many crops. Of these, tobacco, alfalfa, tomatoes, potatoes, table beets, grapes, greenhouse plants, and tree fruits are among the most severely affected (Lovett 1915, Crumb 1929, Snyder 1957, Bierne 1971).

Eggs are deposited in masses of 300 to 700 eggs on twigs and leaves, and require 4.0 days to develop at 25°C. Six larval instars normally occur, and at 25°C, require 17.6 days for development when reared on artificial diet (Shields 1983). Supernumerary molts can occur when larvae are reared on certain hosts plants. For example, Snyder (1954) found that 11% of larvae reared on alfalfa exhibited a seventh instar. Foliage consumption varies with host plant. Berry and Shields (1980) reported an average consumption of peppermint foliage of 172 cm^2 by instars 4 to 6, and found 94% of the total foliage consumed was by instars 5 and 6. Capinera (1978) found that instars 4 to 6 consumed 131 cm^2 of sugarbeet foliage. Buntin and

Pedigo (1985) reported that, for larvae exhibiting six instars, instars 4 to 6 consumed 343 mg dry weight of alfalfa. Shields (1984) reported that 159 cm^2 of potato foliage was consumed by instars 4 to 6. Because specific leaf weights (leaf dry weight ÷ leaf area) vary for different plants, leaf area consumption values are not directly comparable for different hosts.

Prepupae tunnel 5 to 15 cm into the soil and require at least 3 days before the onset of pupation. The depth of the pupal stage in the soil has been associated with soil type, in heavier soils pupation occurs at depths of about 5 cm. The pupal stage lasts 13 days at 25°C (Shields 1984).

In Oregon, adults emerge during April, May, and June, and again during late August, September, and October (Lovett 1915). A preoviposition period of 8 days was reported by Crumb (1929). Simonet et al. (1981) found that the preoviposition and ovipostion periods depended on temperature; 128 degree days at a threshold of 3.5°C were necessary before oviposition occurred, and the oviposition period was 13 days at 23.9°C and 5 days at 27.4°C. Snyder (1951) reported the sex ratio of the adult stage was ca. 1:1. Struble et al. (1976) reported that equal amounts of (*Z*)-9-tetradecen-1-yl acetate and (*Z*)-11-hexadecen-1-yl acetate was an effective adult male VC sex attractant (pheromone) for VC. Willson et al. (1981) suggested that pheromone baited sticky traps had potential for predicting VC density levels.

Reports of natural enemies of VC have included various predators, parasitoids, and diseases. Tachinid flies were largely responsible for an 80% rate of parasitism observed near Halsey, Oregon on July 22, 1914 (Lovett 1915). In Ohio alfalfa fields, 19.5% of VC larvae were parasitized by 22 parasitoid species (Soteres et al. 1984). Beetles of the genus *Calosoma* have been observed to be active predators of VC (Burgess and Collins 1917). Numerous spiders occur in peppermint but their effect on VC is unknown (McIver and Belnavis 1986). Birds and domestic fowls also have been mentioned as predators of VC (Lovett 1915). Diseases reported for VC include viruses of the types NPV (Harper 1971) and CPV (Wilson and Ramoska 1980), and a microsporidian *Nosema* (Lipa 1979). No quantitative studies of natural enemy activities in peppermint have been reported.

Economic Thresholds

Peppermint was ranked 16th among the leading Oregon agricultural commodities and was valued at 25.6 million dollars in gross sales in 1986. Total area of peppermint harvested in Oregon in 1986 was estimated at 14,090 ha (Miles 1987). Insecticide applications were required for cutworm control on an estimated 50% of the production area. At an estimated average yield of 72.85 kg/ha, an average oil price of $24.70/kg (Miles 1987), cost of control of $45/ha (Berry and Shields 1980), and frequency of control, 1.25% of the oil value or $320,000 was spent for cutworm and looper control in Oregon peppermint in 1986.

Numerous accounts reporting the occurrence and damage impact of the variegated cutworm have been compiled (Rings et al. 1976b), but relatively little research has focused on management of this pest. Most studies on VC control have concentrated on developing economic injury levels (EILs); the population density of a pest that causes economic damage (Stern et al. 1959). EIL studies based on foliage consumption by VC larvae have been reported for sugarbeets (Capinera 1978), peppermint (Berry and Shields 1980), potatoes (Shields et al. 1985), and alfalfa (Buntin and Pedigo 1985). Calculation of EILs has been based on a formula modified from Tamaki and Butt (1977) and Capinera (1978) and can be derived beginning with the equation modified from Norton (1976):

Cost of Control = Benefit of control

$$C = VDK\Theta$$

where:

V = Value of the crop (\$/ha), equal to the oil price (\$/kg) × Yield (kg/ha)

D = Damage rate (assumed linear) (% yield loss/1000 cm^2/Larva)

K = Control efficacy (%)

Θ = EIL (# Larvae/1000 cm^2)

C = Cost of control (\$/ha)

and is rearranged to give:

$$\Theta = C \div VDK$$

To modify this EIL equation in accordance with Berry and Shields (1980), V = \$22/kg oil price × 85.7 kg/ha yield, C = \$45/ha control cost, K was assumed to be 100%, yield (y) was expressed as mint leaf area per 1000 cm^2 ground surface area (15 locations, average yield = 85.3 kg/ha, and average y = 6247 cm^2leaf area/1000), damage (d) was expressed as cm^2 foliage consumption for instars 5 and 6; d = 164.9 cm^2 giving:

$$\theta = (100(C \div V)y) \div 100d$$

or expressed in terms used by Berry and Shields (1980):

$$\text{\# Larvae/1000 cm}^2 = \frac{\text{\% defoliation} \times \text{total leaf area/1000 cm}^2}{\text{consumption (instars 5-6)} \times 100}$$

where % defoliation was determined by the cost of control divided by the value of the crop × 100 ($100C \div V$).

To use EIL values in pest management programs, they must be converted into a working economic threshold (ET) value, which is the population density (or time) when control measures need to be applied to prevent increasing pest populations from causing economic damage (Stern et al. 1959). The task of developing ET values is not simple, requiring an understanding of the interactions between the population dynamics of the pest and the crop, the environment, and agronomic practices (Poston et al. 1983).

Because of the complexities of this problem, a systems approach to developing ET values has been suggested (Shoemaker 1980, Getz and Gutierrez 1983). A systems approach can be summarized as a process where the many components of a problem are analyzed singly and together, beginning with the simplest and most easily investigated processes and proceeding with more complex behaviors, once they are understood. A systems approach also requires that this process has an end point specified by the objectives set fourth at the beginning of the project (Overton 1979).

Objectives

The overall goal of this project was to develop improved management practices for variegated cutworm in peppermint and to reduce the frequency of inaccurate decisions concerning cutworm control. My primary objective was to develop more comprehensive ET values for VC in peppermint than were previously available. Information on VC field recruitment, development rates, mortality, feeding behavior, and peppermint growth and yields was required to refine the ET values of Berry and Shields (1980).

I adopted a basic premise to improve VC ET values; positional aspects of VC feeding behavior impacted yield loss; foliage lost to other factors such as leaf abscission reduced the yield losses attributable to VC. These positional aspects included the position (distribution) and timing of feeding in relation to harvest, the rates of leaf addition and senescence, and the distribution of oil yield with respect to leaf position on the plant. The effect of feeding injury on growth of the crop was not considered important in this system because the regrowth potential of peppermint greatly outweighs any physiological injury that cutworms may cause at densities near the EIL. Currently, the EIL is set between two and three percent of the value of oil yield. Danielson (1977) found that yield reductions could not be attributed to redbacked cutworm densities up to 7 larvae/1000 cm^2 in fields from two to five years in age. The redbacked cutworm causes injury during April and May, allowing sufficient time for compensatory regrowth to occur. Some growers have mowed their mint fields to control rust. One grower mowed on 9 June, 1983 and yielded 81 kg/ha (72 lbs/acre) on 22 August (Elmer Cook, personal communication). I suggest that vigorously growing peppermint fields may not show yield reductions due to physiological (indirect) injury at cutworm defoliation levels below ca. 10%.

Other questions addressed in my research concerned monitoring techniques: how can VC densities be sampled efficiently, and can damaging populations be predicted before economic injury levels are reached? Pheromones for VC were recently developed (Struble et al. 1976) but have not been tested for usefulness in cutworm management programs. Two sampling methods for VC, sweep-net and ground search, also were studied to develop sampling programs.

The following studies were conducted to help develop a more comprehensive VC management program in peppermint:

(1) Evaluate the effectiveness of pheromone traps to detect VC flight and oviposition in peppermint.

(2) Determine whether males caught in pheromone traps could be used with crop development data to predict larval density in peppermint.

(3) Develop estimates of VC foliage consumption rates based on units of mg dry weight and cm^2.

(4) Evaluate the effect of parasitoids on VC larval foliage consumption rates.

(5) Determine how larval parasitoid rates affected interpretation of VC sample densities.

(6) Measurement of peppermint leaf growth and abscission rates in several fields and years.

(7) Determine peppermint oil yield values from mainstem and lateral leaves and flower buds by gas chromatography (GC) analysis.

(8) Determine VC larval development rates in the peppermint

canopy.

(9) Evaluate VC feeding behavior with respect to orientation to the peppermint plant.

(10) Determine recruitment rates of VC in peppermint.

(11) Develop a simulation model to study the factors affecting the impact of VC on peppermint yields in relation to one another.

(12) Use the simulation model to generate economic threshold values under typical conditions and to answer questions about behavior of the system.

(13) Using the simulation model, develop larval instar- and time-specific damage unit estimates as an alternative to the concept of single ET values.

(14) Determine the mean-variance relationships of the sweep-net and ground search sampling methods for development of VC sampling programs.

(15) Determine the relationship between the sweep-net and ground search sampling methods for each larval instar and how sample estimates from the two methods could be converted to absolute density estimates.

The first two studies are discussed in Chapter I - Predicting variegated cutworm infestations in peppermint using pheromone traps and crop phenology. The next three studies are discussed in Chapter II - Reduction in variegated cutworm (Lepidoptera: Noctuidae) injury to peppermint by larval parasitoids. The next seven studies are discussed as part of Chapter III - An economic threshold simulation model for variegated cutworm in peppermint. The last two studies are discussed in Chapter IV - Sweep-net and ground search sampling methods for variegated cutworm in peppermint.

CHAPTER I

PREDICTING VARIEGATED CUTWORM INFESTATIONS IN PEPPERMINT USING PHEROMONE TRAPS AND CROP PHENOLOGY

ABSTRACT

Pheromone traps (Pherocon 1C) effectively reflected variegated cutworm (*Peridroma saucia* Hübner) development and were used to detect oviposition in western Oregon peppermint fields in 1983 and 1984. Final overwintering generation peaks in moth catch coincided with 50% oviposition on pheromone traps in both years. Initial flight peaks occurred up to two months prior to significant oviposition, suggesting that alternate host plants are used during early generation flight. Of the four trap heights tested: 20, 40, 60, and 80 cm, a positive linear relationship occurred between trap height and moths captured. Trap height was linearly correlated to moth catch ($P < 0.001$); the largest catch occurred at a height of 80 cm.

Males caught from mid-May through June and the number of egg masses collected on pheromone traps were correlated with third and fourth instar larval densities estimated by sweep-net samples. The equation: $-8.24 + 0.120(\beta_1) + 1.119(\beta_2) + 0.605(\beta_3)$ was derived to estimate larval densities where β_1 = peppermint plant height on 15 June; β_2 = no. egg masses collected per trap; and β_3 = moths captured in the trap between 15 May and 30 June ($r^2 = 0.64$). Validation of a discriminant function based on trap catch, no. of egg masses on traps, and the rate of peppermint growth correctly classified 16 of 18 fields

either above or below the estimated treatment threshold.

Egg hatch distributions estimated from egg masses collected on pheromone traps were similar to, but ended slightly earlier than, hatch distributions estimated from field collected larvae in most fields studied. There was a significant correlation between time of 50% hatch and plant height on 15 June. Both earlier and larger infestations of cutworms were associated with mint stands of earlier phenologies.

INTRODUCTION

The variegated cutworm (VC), *Peridroma saucia* Hübner, is often a serious pest of peppermint in Oregon. VC are seldom detected in mint fields prior to the last week in June. This may be partially due to the practice of flaming mint in early May in western Oregon to suppress *Puccinia* rust. Larvae are usually controlled during July by insecticides. Timing of insecticides can be important due to decreased susceptibility of 6th instar VC to insecticides (Yu et al. 1979, Berry et al. 1980). Intensities of larval infestations are usually assessed by either sweep-net or ground search sample methods, and a sampling program based on these sample methods is presently being developed (Chapter IV). A synthetic pheromone which attracts VC males has been field tested and could be used to detect VC flight trends (Struble et al. 1976). Willson et al. (1981) reported that pheromone traps were nearly equivalent to blacklight traps in attracting VC during overwintering generation flight and suggested that future work may allow pheromone traps to be used as an aid in predicting cutworm density levels.

Developmental requirements reported for VC total development are 858 degree days (threshold 4.2°C, oviposition to adult emergence) (Shields 1983), and 775 degree days (threshold 7.2°C, oviposition to oviposition) (Simonet et al. 1981). Assuming that these midwestern studies apply to VC populations in Oregon, only two complete generations per year would be expected in Oregon (30 year average temperature data, NOAA weather station, Corvallis, Oregon). Simonet et al. (1981) reported two VC generations per year based on analysis of light trap data in Ohio.

Initial use of pheromone traps during my studies resulted in the frequent collection of VC egg masses on the traps. These collections represented a possible new source of information which could be used in management programs. The objectives of this study were to: 1) use pheromone traps to monitor VC flight phenology for several generations in mint fields; 2) determine the importance of trap height on trap performance; 3) determine whether moth catch, egg mass collections, and peppermint phenology could be used to predict subsequent larval densities; and 4) determine if egg hatch estimated from egg mass collections on pheromone traps matched hatch estimated by backtracking sweep-net larval sample densities. Meeting these objectives would fulfill some of the basic research requirements needed to demonstrate that cutworm management programs may benefit from the use of pheromone traps.

MATERIALS AND METHODS

Flight Phenology

To study VC flight phenology, rubber septa impregnated with equal amounts of (*Z*)-9-tetradecen-1-yl acetate and (*Z*)-11-hexadecen-1-yl acetate (Trece Inc.) were placed in Pherocon 1C^R traps at four sites for 20 months. One trap per field was placed at field borders in commercial peppermint fields located within 45 km of Corvallis, Oregon. The traps were supported on wooden stakes 60 cm from the soil surface. Moths were counted in the traps weekly except between December and February when monthly counts were taken. Sticky liners were replaced every 3 to 4 weeks or sooner during peak flight periods. Pheromone impregnated septa were replaced every 5 weeks.

Pheromone Trap Height Evaluation

To determine the influence of trap height on number of moths captured, a randomized complete block experiment was conducted. Four heights were tested (20, 40, 60 and 80 cm from the soil surface) in five peppermint fields treated as blocks. The four traps of different heights were placed at least 100 m apart in a random pattern in each field. Fields were all located within 50 km of Corvallis. The traps were checked weekly for four weeks and were maintained as described earlier. Untransformed catch totals taken over the four week study period were used as the dependent variable. Orthogonal polynomial contrasts (Steel and Torrie 1980) were used to test for response patterns among the treatment levels.

Prediction of Larval Populations

Several variables used to predict VC larval populations were measured weekly or biweekly in 15 different commercial peppermint fields located within 50 km of Corvallis, Oregon (four sites during 1983 and 14 sites during 1984). These variables were: 1) number of moths caught in pheromone traps between 15 May and 30 June; 2) number of egg masses and eggs collected on pheromone traps during the same period; and, 3) average peppermint plant height on 1 and 15 June and the rate of increasing plant height. To estimate the number of eggs per egg mass, the masses were cut off the traps. Areas of the egg masses were estimated gravimetrically by cutting out and weighing the tracings made around egg mass perimeters. Areas (mm^2) were multiplied by 3.84, the number of eggs in a 1.0 mm^2 area measured with an ocular micrometer of a dissection microscope, to estimate the number of eggs in each egg mass.

Degree day forwardtracking and backtracking (Hogg et al. 1982) were used to estimate the phenology of egg hatch from eggs collected on traps and from sweep-net samples for larvae. VC egg masses collected from pheromone traps were placed in constant temperature chambers (16°C) and examined daily until they hatched. Field oviposition and hatch dates for VC were estimated using egg thermal requirements of 92.2 degree days at a threshold of 5.0°C (Shields 1983). Temperature data from a weather station located within 45 km of the fields were used to calculate field degree days by a modified sine-curve method (Baskerville and Emin 1969).

Beginning on 26 May, peppermint plant heights were measured every two weeks at each location. I observed that the greatest oviposition occurs on taller mint plants which are the result of improper flaming (skips) for control of *Puccinia* rust in the spring. Therefore, only randomly selected plants ($n = 25$) from the taller clumps of peppermint were measured in each field. To reduce the effect of sampling error and to allow interpolation of plant heights between sample dates, mean plant canopy heights were regressed against four sample dates between 26 May and 6 July, an interval when plant growth was linear and when considerable oviposition occurred. Plant canopy heights on 1 June and 15 June were estimated from these regression equations. These dates were chosen because they represented 20% and 70% of the cumulative total number of eggs laid in 1983 and 25% and 50% in 1984 estimated by the larval backtracking procedure.

Sweep-net samples were taken to estimate VC larvae in the 20 acres nearest pheromone trap locations in each field every two weeks using a minimum of 12 sets of 20 sweeps (180° sweeps, 38 cm diameter net). Larval instars 1 to 6 were identified using relative head capsule sizes (Coop and Berry 1986). Dependent variables used in the stepwise multiple regression analyses were: 1) mean larval densities per 20 sweeps (instars 3 and 4) for dates when densities were highest in each field, and 2) growing date (days after 1 June) when highest densities were obtained. Larval instars 3 and 4 were used because they were the instars most efficiently sampled by the sweep-net method that could also be converted to absolute density estimates (Chapter IV).

Discriminant analysis was used to determine the likelihood that these variables would correctly discriminate between fields which were above or below a certain level of larval infestation. Fields were categorized as class one (below economic threshold or ET) if fewer than a mean of four larvae (instars 3 and 4) per 20 sweeps were present or class 2 (above ET) if the mean number of larvae exceeded four. This threshold density was selected because it corresponded generally with the threshold growers used to apply insecticides during this study. However, in two of the 18 fields studied, insecticides were applied even though larval densities were below this ET.

Stepwise discriminant analysis was used to derive the best classification rule for the data set. A MANOVA approximate F-value was used to test the significance of each variable included in the discriminant function. Validation of the rule was by the Jackknife procedure (BMDP7M statistical software, Dixon and Brown 1983), in which each sample observation was successively excluded from calculations used to derive the rule and subsequently tested for correct classification.

Comparison of Egg Hatch Events

Seven fields were used to compare forwardtrack estimated VC hatch times using egg masses collected on pheromone traps with backtracked hatch times estimated from sweep-net samples. Methods for forwardtracking and sampling were described previously. Thermal requirements used for larval backtracking are reported in Chapter III.

The backtracking method assumed that larvae of each instar were collected at the midpoint of their development, and that mortality rates were 5% for each molt between instars except between the fourth and fifth instars when mortality reached 30%, due to parasitoids (Coop and Berry 1986). Sweep-net sample estimates were converted to absolute sample estimates using methods detailed in Chapter IV. Daily degree days within the peppermint canopy used for backtracking were estimated by subtracting 1.7°C from daily minimum temperatures from local NOAA climatological data. This value was the average difference in daily minimum temperatures between a hygrothermograph in the peppermint canopy (15 cm from the soil surface) and weather data measured for 21 days. Maximum temperatures were not adjusted because there was no significant difference in daily maximum temperatures between the peppermint canopy and weather data.

RESULTS AND DISCUSSION

Flight Phenology

Male VC were collected in pheromone traps beginning in mid-April in 1983, one week after the traps were placed in the field. The overwintered generation flight continued from April through the end of July (Fig. I.1). Significant first generation flight began in late August and continued until early December. Both generations were distributed over several months, indicating a lack of synchrony in adult emergence of the overwintered generation. Simonet et al. (1981) similarly reported, based on light trap data in Ohio, that VC has two generations per year and that flight activity was spread over nearly the entire year. Unlike my study results, Willson et al. (1981) found that pheromone traps performed poorly during late season first generation flight as compared to blacklight traps.

Trapping in 1984 continued only through the end of the overwintering generation flight, and significant flight for this generation occurred between early March and early July. Variegated cutworm flight occurred as early as March, well before peppermint initiates rapid vegetative growth which normally begins in June each season. Based on such an early, yet extended flight pattern, and relatively late oviposition as indicated by egg masses on pheromone traps, it appears that only the final period of the overwintering generation flight is of significance to mint growers.

No moth species other than VC were collected in appreciable numbers in the traps during this study. A maximum of 44 moths were collected in a one week interval. Evidence of partial remains of moths in freshly replaced trap liners indicated that moths either escaped or were taken by birds. More frequent trap maintenance, or alternate trap designs such as a water and antifreeze pan trap may partially solve these problems.

Variegated cutworm egg masses were collected on pheromone traps during the latter portion of the overwintering generation flights, but none were collected during the first generation flight. The lack of egg masses collected during first generation flight suggests that ovipositing VC females were not attracted to peppermint just prior to or after harvest in August. Peppermint regrows a small amount after harvest but usually does not reach a height of 32 cm, the average height of taller clumps of mint in my sites on 15 June. The lack of significant regrowth and the practice of flaming mint shortly after harvest might contribute to the lack of VC activity in mint. Delaying harvest could be used to test whether these management practices deter first generation VC oviposition activity in peppermint.

During overwintered generation flight, some egg masses also were collected on traps supplied with bertha armyworm (*Mamestra configurata* Walker) pheromone capsules and on traps without pheromones indicating that the Pherocon 1C traps attracted the egg-laying moths. Oviposition trends estimated from egg masses collected on pheromone traps in peppermint fields were similar in 1983 and 1984 with less than 25% of the total eggs deposited before the end of May (Fig. I.1). The 50th percentile of oviposition occurred during the same weeks as final overwintering generation peak trap catches in June 1983 and 1984.

Effect of Trap Height

Moth catch differed among the trap heights tested (F = 5.6, P < 0.01, ANOVA). Mean weekly catches were 6.3, 9.5, 9.8, and 12.0 for trap heights 20, 40, 60, and 80 cm, respectively. Using orthogonal polynomial contrasts, moth catch was a significant linear function of trap height (F = 15.5, P < 0.001). Higher order polynomial contrasts were not significant. Moth catch in traps placed at 20 cm may have been adversely affected because they were obscured by mint foliage by mid-June. The mean weekly catches for all four heights tested were higher than counts reported by Willson et al. for the same Pherocon 1C trap used in New York State. Few egg masses were collected during this experiment; a total of 0, 2, 3, and 2 egg masses were collected on traps placed at 20, 40, 60, and 80 cm, respectively.

Prediction of Larval Populations

Densities of VC larvae (instars 3 and 4) were correlated with the egg masses collected on traps (r = 0.65, $P < 0.001$) and with the moths collected in traps (r = 0.54, $P < 0.02$). Variables not significantly correlated with larval density included peppermint canopy height on 15 June (r = 0.34, $P = 0.16$) and peppermint growth rate (PGR) (r = 0.27, $P = 0.28$).

The best multiple regression model to predict the density of larval instars 3 and 4 was; $y = -8.24 + (0.120 \times \text{plant height on June 15}) + (1.12 \times \text{\# egg masses}) + (0.605 \times \text{moth catch})$ ($r^2 = 0.64$, $P < 0.005$). This model was used on the same data set to classify fields as either below or above the estimated treatment threshold (4.0 instar 3 and 4 larvae per 20 sweeps). Three fields were incorrectly classified as below or above the threshold (regions A and D, Fig. I.2). Of three fields, only one field was predicted to have a much lower larval population than was actually sampled (region A, Fig. I.2). An independent set of observations is required to validate the regression model.

The date of highest mean larval density of instars 3 and 4 also was regressed against the predictor variables described above for all 18 fields. No significant correlations or regression models were obtained for date of highest mean larval density from these studies. The lack of correlation between plant height and dates of peak larval densities in this study may be due to a relatively infrequent sampling interval. Results of larval backtracking estimates of egg hatch (discussed below) indicated that earlier VC populations may be expected in fields with early, vigorous growth.

Number of egg masses on traps, cumulative number of moths collected in traps between 15 May and 30 June, and plant growth rate

(PGR) were variables selected using stepwise discriminant analysis (Table I.1). One field was incorrectly classified using the discriminant function derived from these variables. Using the Jackknife validation procedure, two of the 18 fields were incorrectly classified. In one of the fields (classified incorrectly as below the threshold), the plant canopy was tall in late May and early June, which may account for the high larval densities in the field. This field had a very low PGR during June due to dry weather and a lack of irrigation (personal communication with grower) which contributed to the missclassification of the field by the model. In the other field, also incorrectly classified as below the threshold, no egg masses were found on the pheromone traps, possibly because of unusually tall plants which may have competed with the traps as oviposition sites.

Comparison of Egg Hatch Events

Estimated VC egg hatch trends, estimated from sweep-net samples and egg mass collections on pheromone traps in peppermint fields, were roughly similar (Fig. I.3). One difference observed in most of the fields studied and from the data combined for 1983 and 1984 (Fig. I.3), was that egg- laying moths were not attracted to pheromone traps as late in the season as might be expected. This may indicate that oviposition on pheromone traps ceased when the plant canopy reached a height sufficient to more favorably compete for egg-laying moths. No other consistent differences were evident between the two methods of estimating hatch trends. The period of greatest hatch occurred from ca. 8 June - 5 July using backtracking of larval samples and from 1 June - 5 July using forwardtracking of egg masses collected. There were no significant differences between peak week of hatch or 50% hatch estimated by the two methods ($t = 2.19$, $P = 0.23$, paired difference t-test). In general, egg hatch events estimated from egg masses collected on pheromone traps appeared to be representative of egg hatch occurring on the peppermint foliage estimated by backtracking from field collected larvae.

Evidence of a trend between plant height on 15 June and 50% hatch date estimated by larval sampling was found for nine fields that had sufficient data for the analysis ($r = -76$, $P = 0.02$). These results indicate that larval populations may be expected to occur earlier in taller mint stands. This is apparently related to my observations that egg masses are often deposited on taller clumps of mint, and with the significant contribution of plant height in the multiple regression model for larval density prediction discussed earlier. These results suggest that earlier and larger VC outbreaks can be expected in fields managed for early, vigorous growth. Crop management practices should therefore be selected that take into consideration their potential effects on VC colonization. Growers with especially severe, perennial cutworm populations may want to manage their mint fields for later canopy development, e. g. by delaying flaming time and limiting irrigation and fertilizer applications.

Pheromone traps have not yet been incorporated into peppermint pest management programs in Oregon. The results of my study indicate that they may provide useful information about the timing and potential density of VC larval populations in advance of actual outbreaks. VC moth catch during May and June and egg counts on traps were correlated with subsequent VC larval density levels. These counts, when coupled with estimates of peppermint canopy growth, may be used to help pest managers anticipate the requirements for cutworm sampling programs. After further refinement and validation of either the multiple regression or discriminant analysis models used in this study, it may be possible to predict the occurrence of populations above economic threshold densities with a more reasonable degree of certainty.

Pheromone traps may be used to collect egg masses for marking potential infestation loci within fields and, if egg masses are allowed to develop on the traps, periods of peak hatch may be monitored. The use of pheromone traps in conjunction with measurements of crop phenology to predict larval densities may increase the practicality of VC pheromone traps in peppermint integrated pest management programs.

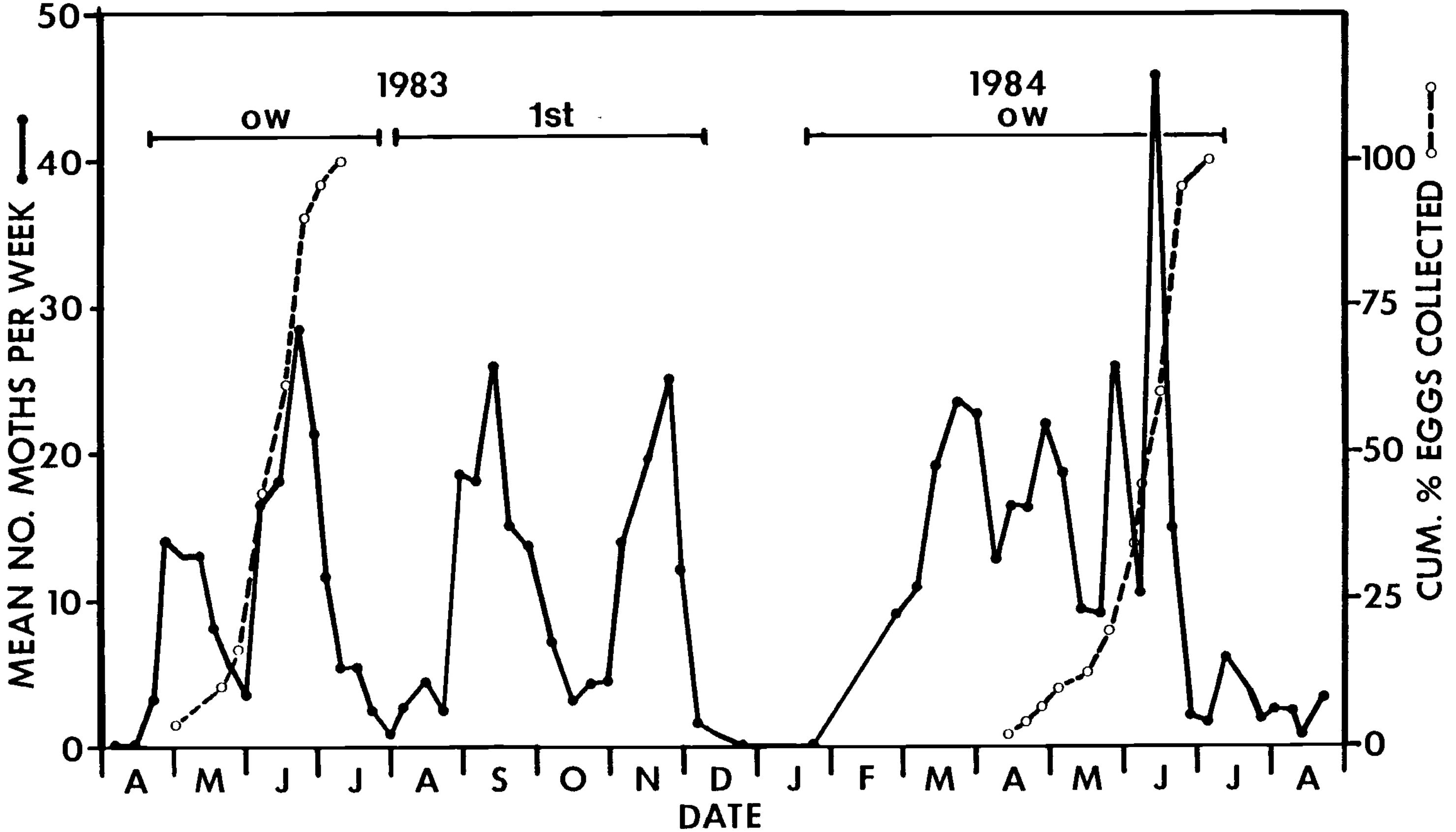

Fig. 1.1. Flight and oviposition activity of variegated cutworm monitored using pheromone traps in western Oregon, 1983-84. "OW" means overwintering generation flight; "1st" means first generation flight.

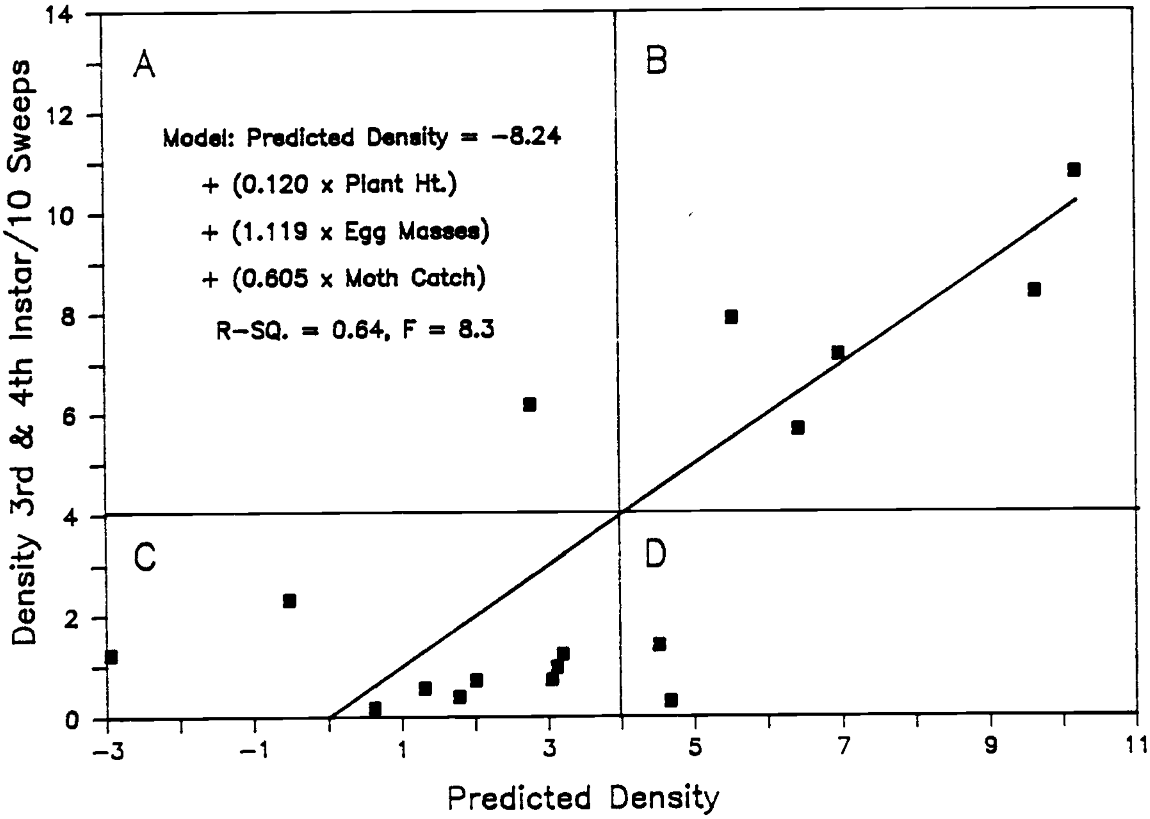

Fig. I.2. Density of variegated cutworm instars 3 and 4 per 20 sweeps sampled in western Oregon in 1983-84 and as predicted by multiple regression. Regions B and C contain fields correctly placed above or below the treatment threshold, respectively. Regions A and D contain fields incorrectly placed below or above the treatment threshold, respectively.

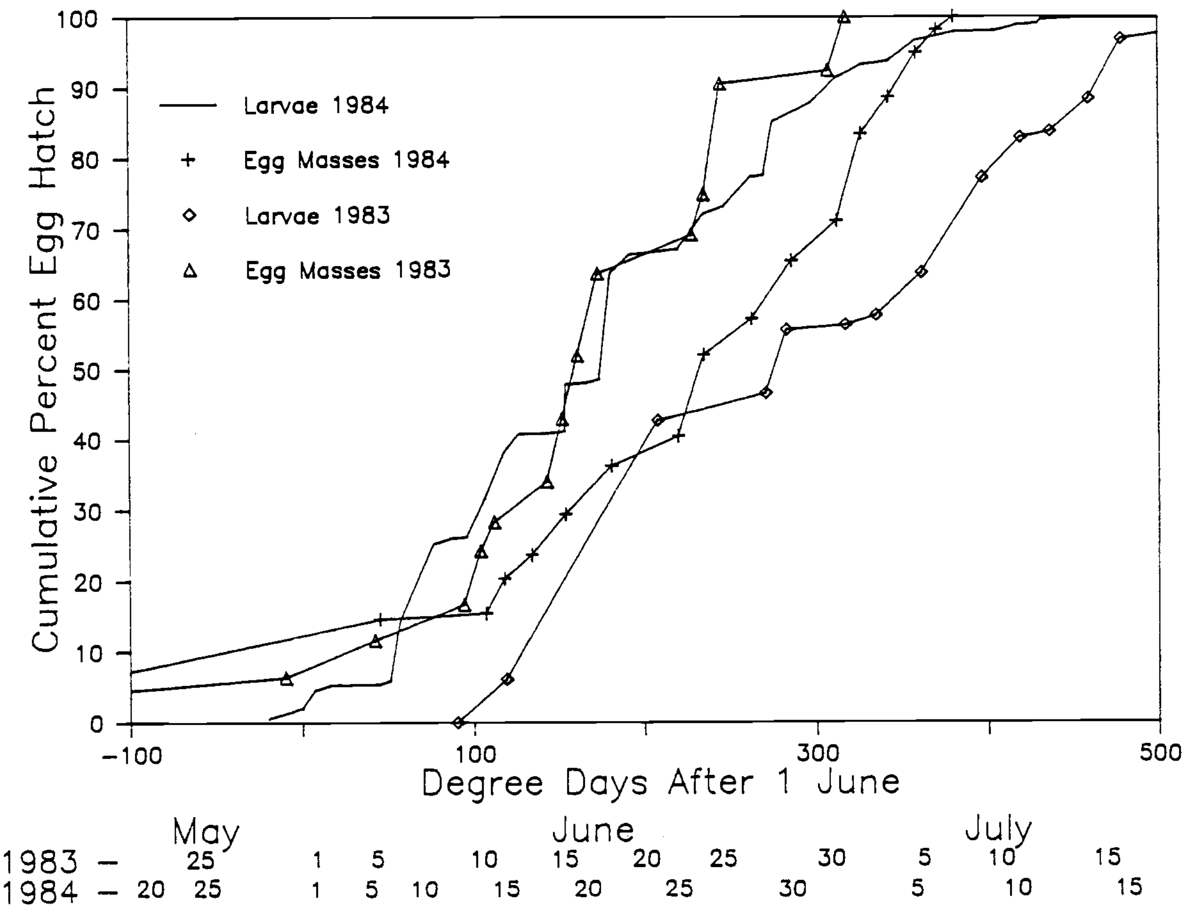

Fig. I.3. Comparison of variegated cutworm egg hatch events in two western Oregon peppermint fields from 1983 and six fields from 1984. Egg hatch estimated from egg masses collected on pheromone traps by degree day forwardtracking; egg hatch estimated from larval samples by degree day backtracking.

Table I.1. Discriminant analysis between variegated cutworm density class and peppermint growth rate, pheromone trap catch, and egg mass recovery from 18 western Oregon peppermint fields sampled during 1983 and 1984.

Variable	Coefficients[1] F_1	F_2	prob. $F = 0$
Constant	1.966	-.966	-
Mint growth rate (PGR)	-.6273	.6273	.003
No. egg masses	-.0852	.0852	.062
Moth catch	-.0058	.0058	.014

[1]Field classified as below treatment threshold of 4 larvae/20 sweeps if $F_1 > F_2$; above if $F_2 > F_1$.

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CHAPTER II

REDUCTION IN VARIEGATED CUTWORM (LEPIDOPTERA: NOCTUIDAE) INJURY TO PEPPERMINT BY LARVAL PARASITOIDS

ABSTRACT

Variegated cutworm (VC), *Peridroma saucia* (Hübner), parasitism rates in western Oregon and peppermint leaf consumption rates of parasitized and unparasitized larvae were measured for use in a VC economic threshold model. Instars 4 to 6 consumed an average of 184 cm^2, equivalent to 888 mg (dry weight) of peppermint foliage. Total consumption by larvae parasitized by *Meteorus communis* (Cresson) was reduced by 93%. Total parasitism rates averaged 35.1% for instars 2 to 4 and 5.4% for instar 5. Parasitism rates were related to time of season and inversely related to the $\log_e$ of larval instar 2 to 4 host density. *M. communis* comprised 11% of parasitoids reared, while *Nepiera* sp. and *Campoletis* sp. (Hymenoptera: Ichneumonidae) comprised 84% of parasitoids reared from field-collected larvae. Based on final VC head capsule measurements, only 2% of all larval parasitoids reared allowed hosts to cause significant damage that occurs during the final two instars. Accounting for natural biological control by these early instar larval parasitoids will permit a ca. 34% increase in economic thresholds for VC in peppermint.

INTRODUCTION

The variegated cutworm (VC), *Peridroma saucia* (Hübner), can be a serious pest of peppermint, *Mentha piperita* L., in western Oregon. Berry and Shields (1980) measured consumption of peppermint foliage by VC and estimated an economic injury level (EIL) (Stern 1973). Their EIL value has been used directly as a working economic threshold (ET) in peppermint integrated pest management (IPM) programs. However, these ET estimates have not included effects of natural enemies on VC injury. Solitary larval parasitoids have reduced consumption by noctuid larvae from 17 to 78% (Guillot and Vinson 1973, Schoenbohm and Turpin 1977, Sajap et al. 1978, Brewer and King 1980, Rohlfs and Mack 1983, Hopper and King 1984, Grant and Shepard 1984). Soteres et al. (1984) reported 19.5% parasitism of VC in alfalfa in Oklahoma. Several solitary larval parasitoids have been observed from VC collected in Oregon peppermint, but their abundance and effect on crop damage by VC are unknown.

We chose the braconid *Meteorus communis* (Cresson) to study the effects of parasitism on VC consumption because it is one of the solitary larval parasitoids that can be reared from VC in peppermint. Here, I report the consumption of peppermint foliage by unparasitized VC and larvae parasitized by *M. communis* and rates of parasitism of VC larvae in western Oregon commercial peppermint fields. Sampling estimates of parasitism rates were combined with estimates of parasitism impact on foliage consumption to reflect a more comprehensive approach to estimation of VC economic thresholds.

MATERIALS AND METHODS

Larval Head Capsule Widths

First-generation VC larvae were reared on a lima bean diet (Harper 1970) modified from Shorey and Hale (1965) for measurement of head capsule widths of instars 1 to 6. Fifty larvae of each instar were measured to the nearest 0.02 mm with an ocular micrometer.

Parasitism Rate Estimation

A survey of VC parasitism rates in selected peppermint fields within 50 km of Corvallis was conducted during June to August 1983 and 1984 using 180° sweep net samples (20 sweeps per sample). During 1983, seven locations were sampled on one to three dates with a minimum of 10 samples per sampling date at each location. During 1984, eight locations were sampled on one to four dates with a minimum of 15 samples per sampling date at each location. At least 35 larvae each of instars 2 to 5 were collected per sample date at each location in 1984. During collection, densities of individual instars were recorded. Larvae were placed in waxed paper cups (250 ml) in a cooler and taken to the laboratory. Lima bean diet was used to rear the larvae individually in plastic cups (30 ml). Larvae were observed daily for pupation and parasitization. Rearing conditions were 25°C with a photoperiod of 16L:8D. Larvae that died of unknown causes before the prepupal stage constituted 3.4% of larvae collected and were not counted in percent parasitism calculations. Larvae that died during or after the prepupal stage were counted as unparasitized individuals because they had successfully completed the feeding period. Parasitoids were allowed to complete development and were retained with host remains for identification. Final head capsule widths of hosts were measured to the nearest 0.05 mm. Parasitism rates were analyzed by instar collected, sample date, and host sample density using least squares regression or 95% confidence intervals of the normal approximation to the binomial distribution (Steel and Torrie 1980). Throughout this paper, means ($\bar{x}$) will be reported with standard deviations (SD) unless otherwise noted.

Consumption Studies

Since my unpublished data showed that peppermint leaf weights (unit weight per unit leaf area) vary considerably depending on leaf age and growing conditions, I attempted to estimate consumption of leaf dry weight in addition to leaf area.

First-generation VC larvae were fed peppermint leaves obtained from an unsprayed commercial mint field located in Corvallis. Young (not fully expanded) and old, senescent leaves were not fed to VC larvae because my observations of VC feeding behavior suggested that these types of leaves are not usually consumed (unpublished data). Each pair of leaves used was measured for length and width, weighed to the nearest 0.1 mg, and tagged. Leaf area, as measured by an area meter (Li-cor Inc.), was estimated using a regression model developed using leaves from the same fields:

$$\text{Leaf area} = -0.0519 + 0.80157 \times \text{length} \times \text{width (cm)}$$

$$(r^2 = 0.99,\ n = 65 \text{ leaves})$$

One leaf of the pair was placed in a petri dish (75 ml) containing one instar 3 VC and the other was placed in an empty petri dish to serve as a control. Depending on their size, larvae were provided with one or more leaves daily. Leaf remains were dried in an oven at 37°C overnight and weighed again. Leaf petioles were left intact by the larvae even when whole leaves were consumed. Larval molts were recorded when shed head capsules of the previous instars were found. The sex of pupae was determined; they were weighed 5 days after pupation and again after they were dried in an oven. Linear regression was used to determine if there was a relationship between consumption and pupal weights.

Our method of estimating dry weight consumption was based on a regression model that relies on two relationships: 1) the ratios of wet to dry weights of opposite leaves are similar ($r^2 = 0.94$, $n = 44$) and 2) the specific leaf weights (mg leaf dry weight ÷ cm^2 leaf area) of opposite leaves are similar ($r^2 = 0.86$, $n = 44$). The model was:

$$\text{Estimated leaf dry weight} = 2.192 + (1.465 \times X_1) - (0.498 \times X_2)$$

where:

X_1 = wet weight leaf ÷ (wet weight ÷ dry weight control leaf) and

X_2 = specific leaf weight of control leaf.

This model was developed using 50 randomly selected leaf pairs. Both independent variables were significant (analysis of variance, $F = 957$, df = 47, $P < 0.01$, $r^2 = 0.99$). The estimate for leaf dry weight consumed was then made by subtracting the dry leaf remainder (if any) from the estimated leaf dry weight. Leaf area consumed was estimated as the ratio of the estimated dry weight consumed divided by the specific leaf weight of the control leaf.

To determine if field conditions resulted in pupal weights similar to those observed in the laboratory, VC pupae were obtained from either commercial peppermint fields or from larvae reared individually on peppermint in outdoor weather shelters. Dry weights of the pupae from the field and weather shelters were then compared with weights of pupae from the consumption studies (Student's t test).

To determine the effect of parasitism on VC consumption, 40 late instar 3 VC were exposed for 24 h to 15 *M. communis* adults that had been reared from field-collected VC larvae. The exposed larvae were treated the same as larvae in the consumption study. The final head capsule widths of VC larvae were measured for comparison with host head capsule widths from parasitized larvae collected from the field.

RESULTS AND DISCUSSION

Larval Head Capsule Widths

The head capsule widths of VC larvae reared on an artificial diet were distinct for each of instars 1 to 6 ($\bar{x} \pm$ SD): 0.30 $\pm$ 0.01, 0.50 $\pm$ 0.01, 0.82 $\pm$ 0.03, 1.26 $\pm$ 0.05, 1.97 $\pm$ 0.09, and 3.05 $\pm$ 0.11 mm, respectively. These values are similar to VC head capsule width measurements reported by Snyder (1951), except for instars 1 to 3 where the means I present are slightly higher.

Field Parasitism Rates

Eight hymenopteran parasitoid species were reared from 2,158 VC larvae collected from peppermint (Table II.1). The genera *Nepiera* and *Campoletis* (family Ichneumonidae: subfamily Porizontinae) comprised the majority (84%) of the parasites reared from instars 2 to 4. The solitary braconids *M. communis* and *Cotesia* sp. comprised 11.1% and 1.8%, respectively, of the total parasites reared. The hyperparasitoid *Mesochorus* sp. emerged from 1.5% of all parasitoids reared. Porizontinae spp. and *Cotesia* sp. were the primary parasitoids attacked by *Mesochorus*. A few gregarious larval parasitoids also were reared from VC, including *Euplectrus* sp. (family Eulophidae), and *Meteorus rubens* (Nees von Eisenbeck).

Most final head capsule widths of parasitized VC were within the range typical of unparasitized VC instars 3 or 4 (Tab. II.1). Only 2% of all larval parasitoids reared left VC head capsule widths that could be classified as representing large instars 5 or 6. These parasitoids included the gregarious species *M. rubens* and a few *M. communis*. Since 94% of peppermint consumption is caused by instars 5 to 6 (Berry and Shields 1980), hosts parasitized by species that prevent attainment of instar 5 will decrease consumption by a similar amount. Thus, 98% of the larval parasitoids reared during this study prevented VC from causing all but 6-7% of the usual consumption of unparasitized larvae.

Apparent parasitism rates in the field increased for all instars studied during the 4 weeks of the study (Fig. II.1). Parasitism of instar 5 was considerably lower (5.4%) than for other instars (35.1% for instars 2 to 4 combined), which could be expected from the data on final host head capsule widths. With the exception of week 2, parasitism rates did not significantly differ among instars 2, 3, and 4 (Fig. II.1). When results were combined for instars 2 to 4 and percent parasitism was regressed against the number of days the collection was made after 1 June, the linear model was as follows:

percent parasitism = -28.23 + 1.506 × (days after 1 June) ($r = 0.71$, $P < 0.001$, $n = 22$). Parasitism rates were highest during the last week in July, when ca. 60% of VC instars 2 to 4 were parasitized. The higher rates of apparent parasitism observed later in the season may be attributed to cumulative effects of parasitism, to prolonged development of parasitized hosts, or a combination of these factors (Simmonds 1948, Marston 1980, Van Driesche 1983).

Parasitism rates of instars 2 to 4 combined were inversely related to host larval density ($r = -0.65$, $P < 0.02$) (Fig. II.2). Since larval densities also were inversely correlated with sampling date ($r = -0.72$, $P < 0.001$), the trend observed in Fig. II.2 may be attributed to the sampling date. VC larval density was not significant in predicting parasitism rates in a multiple regression model that included sampling date as a variable.

Consumption Studies

Consumption of peppermint leaves averaged 36.1 ± 12.5, 143.0 ± 54.0, and 708.8 ± 174.9 mg dry weight for unparasitized larval instars 4, 5, and 6, respectively. The leaf area consumed was 7.4 ± 2.1, 26.7 ± 8.3, and 149.9 ± 30.2 cm^2 for the same instars. Total leaf area consumption for instars 4 to 6 combined was slightly greater than that reported by Berry and Shields (1980) ($t = 1.97$, df = 110, $P = 0.05$).

Females consumed 203.6 ± 36.4 cm^2 of peppermint foliage versus 171.7 ± 25.4 cm^2 by males, a significantly greater amount ($t = 2.64$, df = 25, $P < 0.01$). Final pupal dry weights were 114.4 ± 23.3 mg for females and 98.2 ± 12.5 mg for males and were correlated with the quantity of mint foliage consumed (model: expected pupal dry weight =

25.81 + 0.4280 × area consumed, r^2 = 0.57, df = 24, $P < 0.001$). Pupal dry weights of 60 VC larvae reared in the field were 105.5 ± 13.1 for females and 91.5 ± 12.8 for males and were not significantly different from those reared in the laboratory (females; $t = 1.64$, df = 47, $P = 0.11$, males; $t = 1.58$, df = 37, $P = 0.12$), so no adjustment to estimate field consumption was made. In contrast, significant differences between male and female consumption ($t = 2.64$, df = 25, $P = 0.01$) and pupal dry weights ($t = 4.14$, df = 85, $P < 0.001$) indicated that consumption estimates should be corrected for sex ratio, which is approximately 1:1 (Snyder 1951). Dry weights of pupae reared on peppermint foliage (corrected for sex ratio) were 3.2 times greater than those reported for pupae reared on alfalfa foliage, and peppermint dry weight consumption values for instars 4 and later were 2.0 times greater than the dry weight of alfalfa consumed (Buntin and Pedigo 1985). Peppermint may be a much more satisfactory diet for VC than is alfalfa, despite the generally much higher detoxification enzyme activity levels found for VC reared on peppermint than on alfalfa and several other diets (Berry et al. 1980). In addition to an increased tolerance of VC larvae to some insecticides in peppermint conferred by these higher induced detoxification enzyme levels (Yu et al. 1979, Berry et al. 1980), insect pest management programs should consider that VC can cause more injury per insect and have a higher fecundity in peppermint than in alfalfa fields.

Consumption rates of unparasitized VC larvae were not constant within individual stadia, and were highest during the middle and latter portion of stadium 6 (Fig. II.3). At 25°C, 2.9, 4.0, and 6.6

days were spent on average in the feeding period of stadia 4 through 6. An average of 3.8 days was spent in the prepupal stage, during which no feeding occurred.

Larvae parasitized by *M. communis* required 10.1 days before parasite cocoons appeared, and a small amount of feeding occurred during the first 8.1 days of this period. Ten days into the study the unparasitized larvae were in stadium 6 (Fig. II.3). Parasitized VC consumed an average of only 58.8 mg dry weight, which was equivalent to 12.8 cm^2 leaf area during the entire developmental period. The amounts consumed represent a reduction in consumption of 93% compared with unparasitized larvae. Although all parasitized VC molted at least once and 56% molted twice before parasitoids emerged, consumption rates did not increase appreciably following these molts (Fig. II.3).

Economic Threshold Estimation

Although real mortality rate estimation is often implied as the purpose of percent parasitism studies (Van Driesche 1983), real mortality estimates are not always useful for pest-management purposes. When only a single generation of the pest can develop on the crop or the pest is highly mobile (or both), the impact of parasitoids on the damage potential of the current generation is of greatest interest. For cases when parasitoids kill the host or suppress host feeding activity before the final instars are reached, apparent larval percent parasitism estimates are then of direct importance. Percent parasitism estimates will then represent the percentage of larvae present in the sample that have (to date) been attacked by such parasitoids and will not reach a size capable of causing significant crop injury.

If replicated rearings of sampled larvae show significant and consistent levels of injury-preventing parasitism, then a standard discounting of the population size may be applied to field counts. An adjustment of ET estimates for VC in peppermint due to the action of larval parasitoids can be calculated by using the same assumptions, oil value of $22/kg, total insecticide treatment cost of $45/ha, amount of defoliation equivalent to total control cost of 2.4%, and EIL formula reported by Berry and Shields (1980). Although parasitism rates were variable during the month of July, I could conservatively use the average rate of 27% obtained for instars 2 to 4 during the second week shown in Fig. II.1, since most sampling for treatment decisions takes place during this period, and rates can be expected to increase thereafter. My study indicated that parasitized VC larvae would be expected to consume an average of 7% of the foliage of the unparasitized larvae. This would result in a reduction in injury by field populations to 74.9% of that expected without parasitism ($[0.27 \times 0.07] + [0.73 \times 1.0] = 0.749$), which would cause an increase in the ET by a factor of $1 \div 0.749 = 1.34$. The resulting adjustment to the ET of 0.91 larvae (Berry and Shields 1980), then becomes 1.21 larvae per 1,000 cm^2. Although I showed that high density VC populations are more likely to have parasitism levels lower than 27%, such densities would be well above the ET, so mistakes due to over-reliance on parasitoids would be unusual. The other major assumption needing further study before a more comprehensive ET can be developed is the relationship of oil losses due to VC and losses due to leaf senescence and abscission. These data can be used to calculate higher ET values and further reduce the need for the overly conservative threshold estimates used previously in peppermint pest management programs.

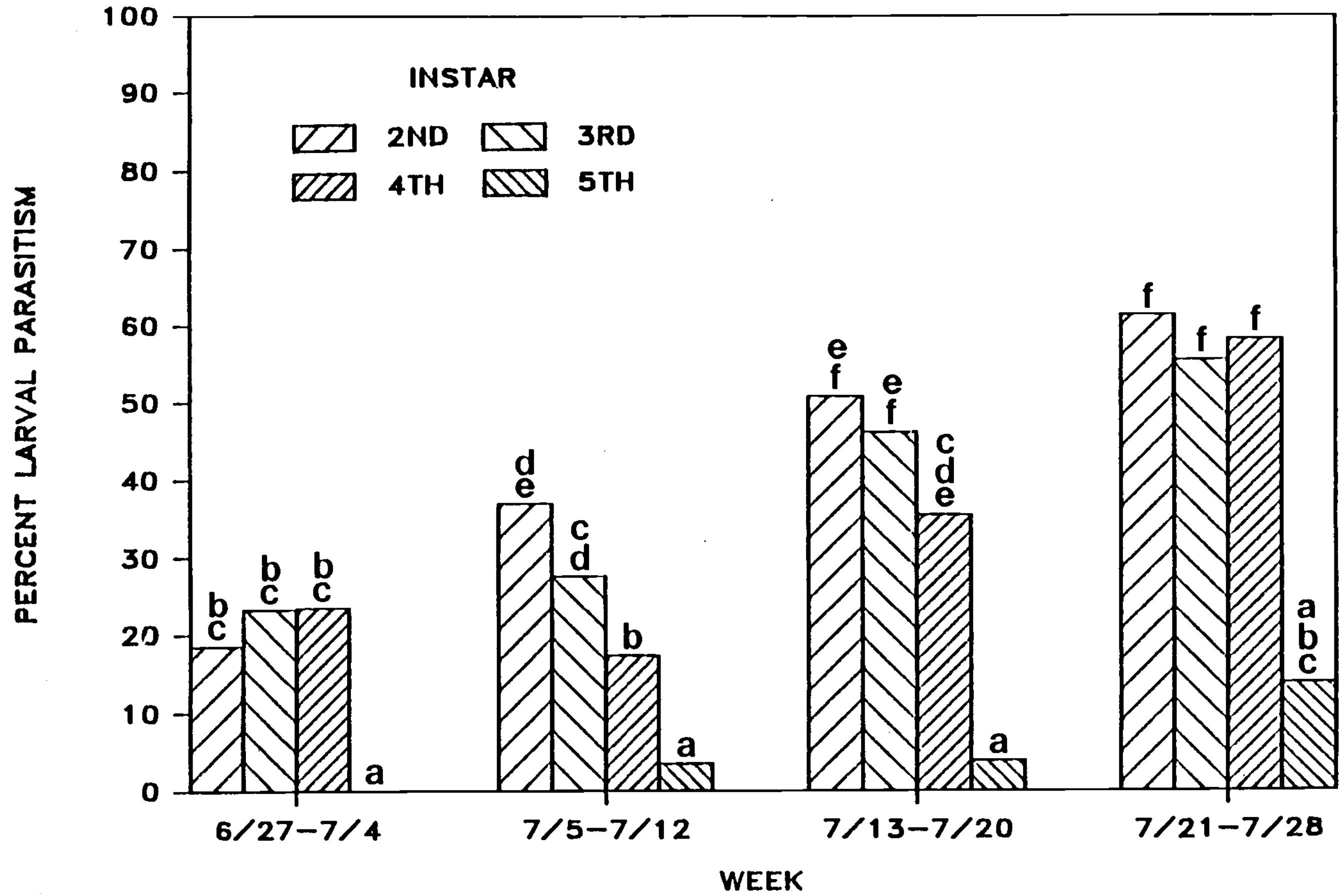

Fig. II.1. Parasitism rates of *Peridroma saucia* in western Oregon in 1983-84 averaged by host instar collected and week of collection. Any two columns not headed by the same letter represent nonoverlapping 95% confidence levels.

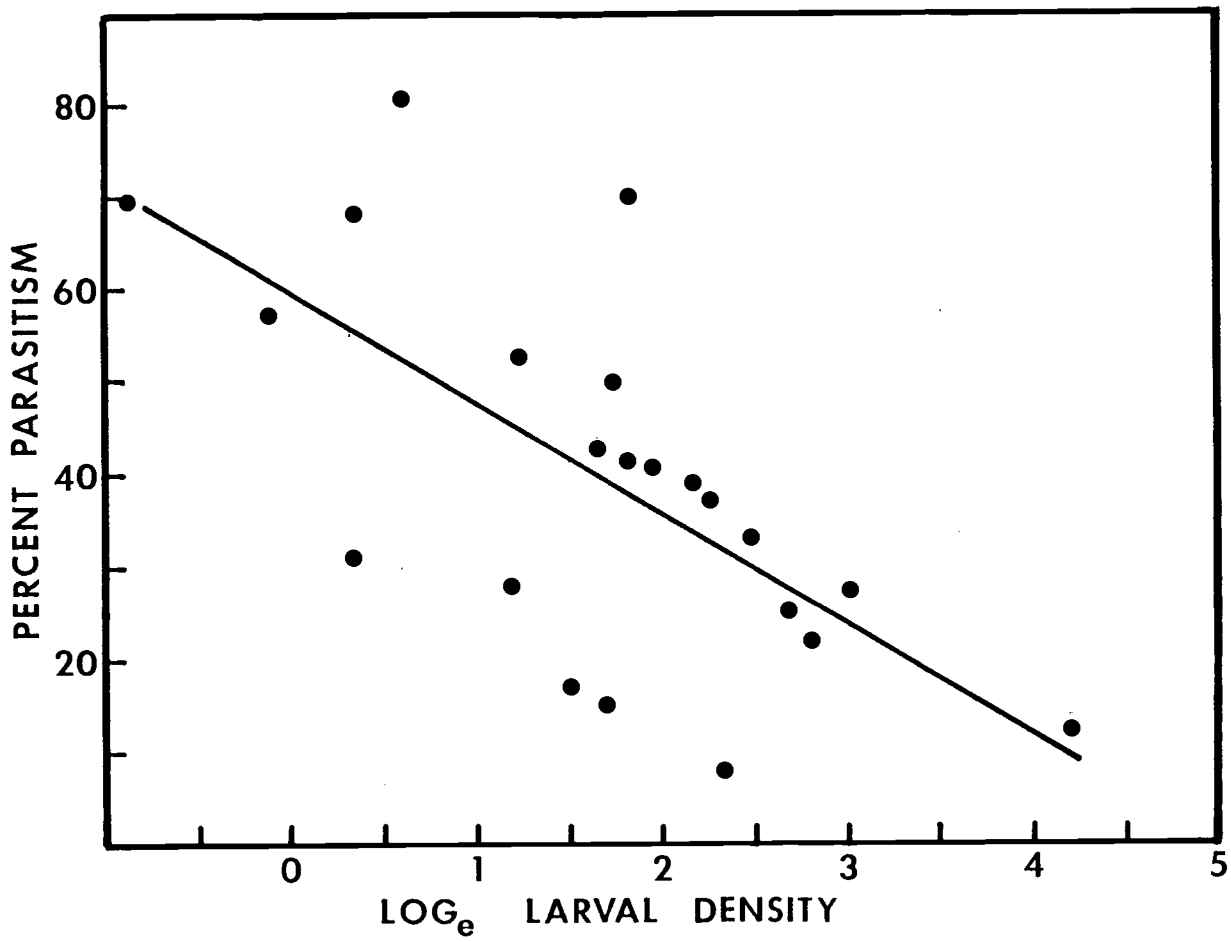

Fig. II.2. Relationship between percent parasitism and density of variegated cutworm samples ($\log_e \bar{x}$ no. instars 2 to 4 per 20 sweeps) in western Oregon peppermint in 1983-84 ($r^2 = 0.65$).

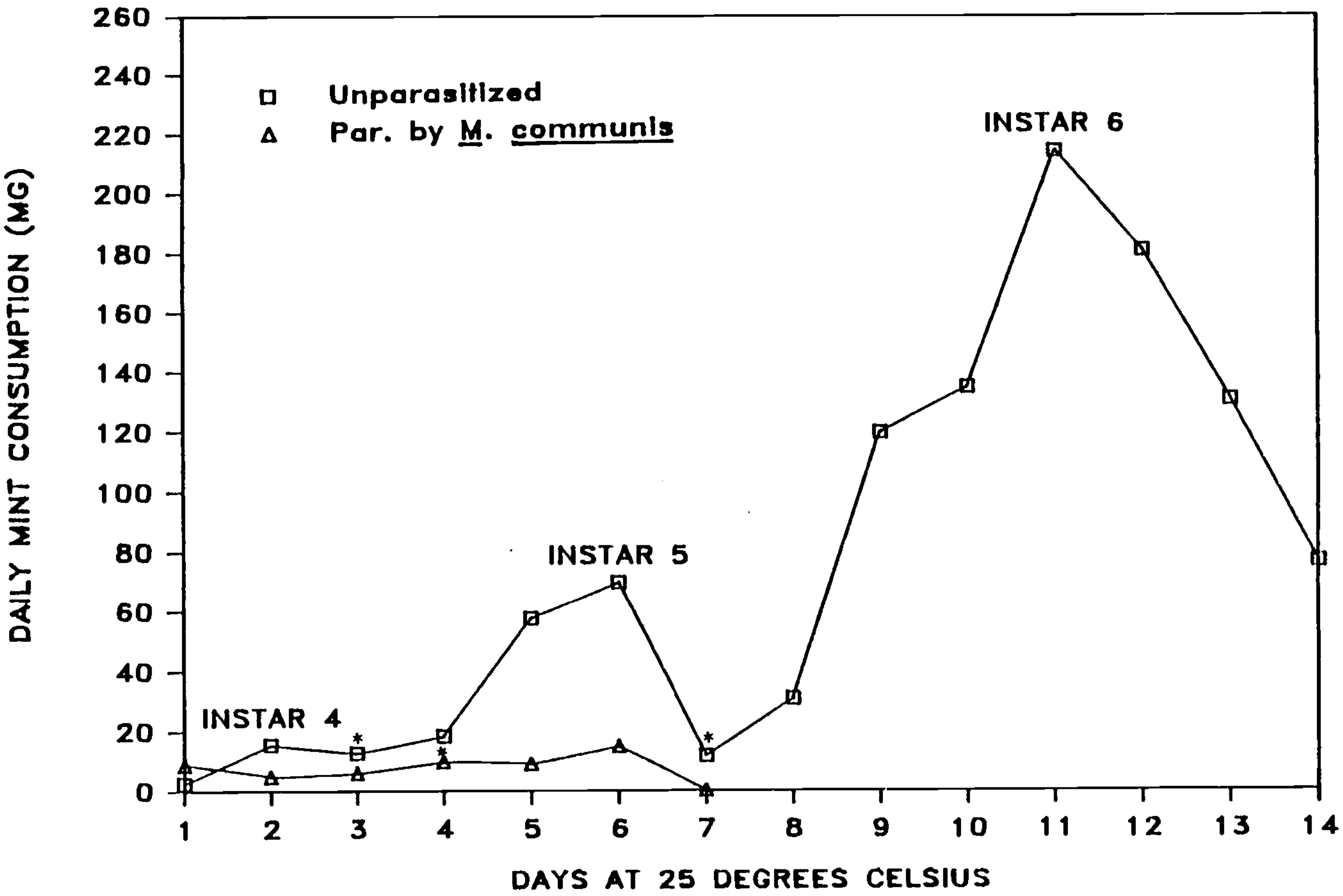

Fig. II.3. Median daily peppermint foliage consumption patterns of parasitized and unparasitized variegated cutworm larvae. Molting times are indicated by asterisks (*).

Table II.1. Parasitoids reared from variegated cutworm larvae collected from peppermint near Corvallis, Oregon in 1983 and 1984.

Species name	No. Reared 1983	No. Reared 1984	% of total	Host Final Head Capsule Width (mm) $\bar{x} \pm SD$	Range
Campoletis sp.	71	253	48.0	1.07 ± 0.11	0.75-1.35
Nepiera sp.	44	100	21.3	1.04 ± 0.18	0.65-1.75
Porizontinae spp.[1]	29	72	15.0	1.07 ± 0.20	0.75-1.45
Cotesia sp.	2	10	1.8	0.95 ± 0.20	0.75-1.25
Mesochorus sp.	3	7	1.5	1.03 ± 0.31	0.85-1.05
Microgaster sp.	2	1	0.4	- -	- -
Meteorus communis (Cresson)	41	34	11.1	1.60 ± 0.51	0.85-2.85
M. rubens (Nees von Esenbeck)	0	3	0.4	2.73 ± 0.04	2.70-2.75
Euplectrus sp.	1	2	0.4	1.07 ± 0.23	0.80-1.20

[1]Porizontinae consist of either *Nepiera* sp. or *Campoletis* sp. that did not successfully complete development.

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CHAPTER III

AN ECONOMIC THRESHOLD SIMULATION MODEL FOR VARIEGATED CUTWORM IN PEPPERMINT

ABSTRACT

Addition of mainstem and lateral leaves, rates of leaf senescence, and oil yields of the peppermint plant, and development, feeding behavior, feeding injury, and parasitism rates of the variegated cutworm, *Peridroma saucia* (Hübner) were simulated by a computer model to determine economic threshold values. Model processes and parameters were estimated from field data collected in western Oregon from 1983 to 1985.

Significant injury occurred when fifth and sixth instar larvae were present in early August just prior to harvest. Fields harvested later in August had higher thresholds because of increased time for regrowth following injury. Final economic threshold values ranged from 1.7 to 3.0 times higher than the previously used threshold of 0.9 larvae per 1000 cm^2.

INTRODUCTION

The variegated cutworm (VC), *Peridroma saucia* (Hübner), is an important defoliating pest of peppermint in Oregon. The economic injury level (EIL) is the pest population level causing the amount of damage equal to the cost of preventing that damage, and the economic threshold (ET) is the time or population level at which to apply control to prevent populations from reaching the EIL (Stern et al.

1959). The EIL and ET are both used as guidelines for making decisions on the need to control cutworms in peppermint pest management programs. An EIL for VC of 0.91 early instar larvae per 1000 cm^2 (Berry and Shields 1980) was developed based on consumption of mint leaves, but Berry and Shields did not consider VC mortality, developmental rates or feeding behavior, or peppermint leaf senescence. Their EIL resulted in conservative ET values that have been adopted by pest management consultants in peppermint. My approach was to refine existing economic threshold values by including more of the biological and dynamic factors in a simulation model. Shoemaker (1980) discussed the use of simulation models in pest management.

There are several biological considerations that are relevant for the construction of an ET simulation model for VC. VC is bivoltine with only one generation developing in peppermint. Eggs are deposited in June and mature larvae are present by the end of July and early August. Sampling third and fourth instar larvae in early and middle July allows sufficient time to make decisions about control before significant injury occurs (Berry and Shields 1980). One factor recently used to refine VC ET estimates was the consistent parasitism rates of 27% or more for fourth instar larvae (Coop and Berry 1986). Hollingsworth (1981) demonstrated that senescence and abscission of the lower leaves is significant, thus reducing the direct injury caused by defoliating pests.

The goal of this research was to simulate the behaviors of variegated cutworms in western Oregon which are of greatest significance to peppermint yield reductions. Model objectives included the ability to generate economic threshold values over a typical range of field conditions for certain factors including the timing of defoliation, harvest date, temperature regimens, and peppermint growth rates.

The simulation model presented here (referred to as MINTSIM) is a discrete, deterministic, time and temperature-driven (seasonal, daily, and degree day resolution), yield-loss estimation model. The model estimates peppermint and cutworm development, calculates leaf injury during the season, and converts leaf injury to yield loss and economic threshold estimates at harvest.

PARAMETER ESTIMATION

Peppermint Growth and Leaf Senescence

Peppermint plant height, number of leaves and leaf nodes, lateral stems, lateral leaves, and percent flower bud development were monitored during the growing season in four fields in 1983, two fields in 1984, and one field in 1985. The fields were all located within 45 km of Corvallis, Oregon. Weekly samples of 20 stems were taken in 1983 and 25 stems in 1984 and 1985. Plant stems were randomly selected and damaged or diseased stems were discarded.

Addition and abscission of mainstem leaves and addition of lateral leaves was regressed against growing days after 1 June and degree days (5°C threshold). Both growing days and degree days correlated well with an increase of leaf nodes (average r^2 values for six fields were 0.94 and 0.95) and leafless nodes (average r^2 values were 0.96 and 0.95). Growing days were selected as the independent variable to determine mint growth rates in the model. Results of leaf node addition and abscission rates for the six fields sampled in 1983 and 1984 were smoothed by linear regression and ranked in order of phenology. Subsets of the fields were averaged to represent three different mint growth classes, early (fields 1 to 3), average (fields 2 to 5), and late (fields 4 to 6). The average harvest date for the fields used to calculate the early field class was 2 days later than 5 August, the nominally chosen harvest date. The y-intercept of the equations describing the early field class leaf node addition, abscission, and lateral growth were adjusted by subtracting 2 to account for this difference. The late field class growth equations were treated similarly by adjusting the y-intercept so that the x-intercept was increased by 8 days to agree with the nominally chosen harvest date of 25 August. The average field class growth equations were not adjusted because the average harvest date of the subset used was equal to the targeted nominal harvest date of 15 August. Lateral leaf addition rates were analyzed the same as mainstem leaves except trends were smoothed to exponential functions using the simplex curve fitting algorithm (Caceci and Cacheris 1984).

Rates of mainstem leaf addition and senescence of fields 1 to 5 and rates calculated for the average field class are shown in Fig. III.1a. Growth in field 1 was very early because it had been heavily watered and fertilized throughout the season. Mainstem leaf growth and abscission rates of early, average, and late field classes plus three validation measurements are shown in Fig. III.1b. Field 1 sampled in 1985 (Fig. III.1b) was harvested August 18 and was classed as an average to late field in terms of phenology. Validation data sets 2 and 3 (Fig. III.1b) were from Hollingsworth (1981). Data set 2 was averaged for 10 fields in the Willamette Valley and appeared to underestimate the number of leaf nodes, presumably because stems were not clipped close enough to the crown. Data set 3 was from a single field near Corvallis and closely agreed with my results. Rates of addition of lateral leaves are shown in Fig. III.2 for the three field classes. Again, validation of data set 1 was representative of an average or late field as the harvest date would indicate. Data in Hollingsworth (1981) did not include rates of addition of lateral leaves in the Willamette Valley.

Oil Yields with Respect to Leaf Node

While leaf node-specific damage at the time of harvest is dependent on leaf position and time of VC feeding, the potential oil yield in terms of both quality and quantity also is dependent on leaf position. Gas chromatography (GC) analysis was used to determine the total oil and amounts of individual monoterpenes in each leaf stratum. Six fields, located within 40 km of Albany, Oregon, were analyzed for leaf stratum-dependent oil content in 1983 and 1984. In 1983, four fields were sampled 0 and 3 days prior to commercial harvest dates on August 1, 5, 6, and 12 by randomly selecting three peppermint plants. Leaves were removed from each plant and numbered according to its position on the stem: 0 = top leaf pair, not yet fully expanded, 1 = next leaf pair down the stem, etc. The leaves were measured for length and width, dried and weighed. Mint oil was extracted from each leaf in pentane with mortar and pestle. An internal standard of 200 μl n-tridecane was added and the samples were analyzed quantitatively for monoterpene content using a Hewlet-Packard 5710A gas chromatograph. Samples of eight lateral leaves were randomly chosen from each of 10 plants and handled in the same way as mainstem leaves. Lateral leaves from position 0-3 also were analyzed from five lateral stems. Flower buds on lateral stems were included with leaf pair 0.

In 1984, analysis of monoterpenes differed in several ways to allow larger leaf sample sizes. Six samples of 25 plants each were taken in two fields. Thirty plants per sample were used for flower bud and lateral leaf analyses. Oil was extracted from 25 to 30 leaves at a time for each leaf stratum and the analysis was conducted in split mode (1:50) to reduce sample volume.

Results for total monoterpene quantity from each leaf stratum were similar in 1983 and 1984 (Table III.1). Since oil quality characteristics were not incorporated in the current version of MINTSIM, results of individual monoterpene content, except percent menthol and menthofuran, are not discussed here. In both 1983 and 1984 samples, oil quantity per leaf increased initially in the first three leaf strata and remained nearly uniform in older leaves. Oil content per leaf increased for lateral leaves 0 to 3. Mainstem leaves had higher oil amounts per leaf than lateral leaves. Oil per mg leaf dry weight, which is important for the calculation of cutworm injury (assessed as mg leaf dry weight), decreased from young to old leaves and was higher in lateral leaves than in mainstem leaves. Senescent leaves contained as much oil as lower non-senescent leaves, indicating that senescent leaves and even newly abscissed leaves contribute to total oil yields. Menthol content increased from less than 20% in new leaves to 50% in the fourth leaf pair and was similar in lateral and mainstem leaves but was only 6% in flower buds. Menthofuran was less than 1% except in young leaves in 1983 (1-2%) and in flower buds in 1983 (40%) and 1984 (35%). Because oil quality varied with leaf position and VC feeding was not evenly distributed along the plant, cutworm damage affected overall yield quality to some degree. Given the current cost of controlling cutworms of 2-3% of the value of the peppermint crop, a typical allowable impact that cutworm populations have on oil quality would be relatively unimportant, especially since slight variations in oil quality generally have no affect on the price of mint oil.

Variegated Cutworm Development Rates

Requirements for development of VC larvae were determined largely by rearing studies conducted out-of-doors on peppermint. On six occasions (15 June, 2 July, and 1 August of 1983, and 15 June, 5 July, and 19 July of 1984), 20 to 30 newly hatched VC larvae were placed in 27 ml plastic cups in a Stevensen screen weather shelter located at the Entomology research farm in Corvallis, Oregon. Fresh field-grown peppermint foliage was added to the cups as required. Larvae were checked daily for signs of prepupal behavior. Degree days were calculated for the temperature thresholds 0, 2.5, 5, 7.5, 10.0, and 12.5°C using a modified sine curve method (Baskerville and Emin 1969) for the interval between hatch and average date of the beginning of the prepupal stage for the six replicates. Weather data was from Hyslop Field Laboratory, a NOAA station, located 10 km from the study site. Means, standard deviations, and coefficient of variations (CVs) for accumulated degree days were calculated for each temperature threshold to determine which threshold to use in a developmental model. Two additional studies were conducted to augment results obtained from the weather shelter and to determine if development would be different within the peppermint canopy. A hygrothermograph was placed 15 cm above the ground on a concrete block in the peppermint canopy for three weeks to compare temperature in the canopy with data collected in the weather shelter. Thirty newly hatched VC larvae were placed under a 1.6 m^3 cage and checked regularly until the prepupal date approached; larvae were then placed in 27 ml cups supplied with peppermint foliage. The degree days accumulated from the local NOAA weather site for the period of development were then compared with the average development degree days obtained from cutworms reared in the weather shelter using a *t*-test. Differences in development in the weather shelter and the cage were used as a basis for correcting development requirements in the simulation model.

Larval fed an average of 36.9 days (CV = 14.5) in the weather shelter. Degree day totals at all threshold temperatures evaluated had lower CV values than when daily temperatures were used. CV values ranged from 5.4 to 9.0, the lowest occurred at a threshold of 10°C. The mean developmental degree days at 10°C equaled 313.9. At a threshold of 5°C the CV was 7.3 ($\bar{x}$ degree days = 492), which was used as the threshold for modeling larval development. The mean degree days for larval development in the weather shelter was corrected to provide a better estimate of development in the canopy. Larval development in the caged study required a significantly greater number of degree days ($t = 4.0$, $P < 0.01$). The difference in daily maximum temperatures between the weather shelter and the mint canopy was near 0.0°C ($n = 22$, 95% C. I. = -0.8, 0.8). The mean difference for daily minimum temperatures in the two environments was -1.7°C ($n = 21$, 95% C. I. = -2.2, -1.2). Based on the difference in daily minimum temperatures, the degree days required for development in the mint canopy was adjusted by adding 33 degree days to 492, the mean degree days required for development in weather shelters. The 525 degree days required for the entire larval feeding period was divided into individual instar development requirements using the average proportion of larval development that each stadium required at 10, 15, 20, and 25°C (Shields 1983), resulting in development requirements of 96, 64, 66, 68, 90, and 140 degree days for instars 1 to 6.

Recruitment, Mortality and Consumption Rates

Egg hatch in the field, referred to as recruitment, was estimated from observations of field collected egg masses and by backtracking larval samples (Chapter I). The results of backtracking larval samples from five fields, and the recruitment schedules parameterized using the normal distribution in the MINTSIM model are shown in Fig. III.3. Since early season mint growth rates affected time of egg deposition, different recruitment trajectories for egg hatch in early, average, and late field phenology classes were represented using different egg hatch distribution means. The recruitment trajectories in MINTSIM were designed to be alterable by the user to match any VC population trends observed other than those preselected.

Mortality due to parasitoids was estimated by rearing larvae collected in samples from several fields (Coop and Berry 1986). A consistent trend of increasing parasitism during the growing season for larval instars 2 to 4 was used as a basis for setting the parasitism rate at 27%; other VC rearing studies have confirmed this rate (L. Coop, unpublished data; Ken West, personal communication). The majority (97%) of larvae parasitized were killed before reaching the final two instars (Coop and Berry 1986). These results were taken into account in the MINTSIM model by setting larval survival at 73% during the transition from the fourth to fifth instar. Predator related mortality data were not available and no predator related mortality rates were used in MINTSIM. A list of spider fauna found in peppermint has been published (McIver and Belnavis 1986), but the impact of these species on VC larvae has not been studied. The number of insect and spider predators found in sweep samples was highly variable between different fields (unpublished data). Consumption of peppermint foliage (cm^2) for individual instars was reported by Berry and Shields (1980) and confirmed by Coop and Berry 1986 (Chapter II) (cm^2 and mg dry weight consumed). Total consumption per two degree days for each instar used in MINTSIM was estimated by dividing mg dry weight consumed by half the degree day development requirements. Consumption rates were 0.04, 0.11, 0.34, 1.02, 3.36, and 9.21 mg foliage per two degree days for instars 1 to 6.

Variegated Cutworm Feeding Behavior

Variegated cutworm feeding distributions on peppermint stems were studied by caging larvae in seven different commercial mint fields. Fields were all located within 30 km of Albany, Oregon. A total of 40 to 50 fifth and sixth instar cutworms were distributed in each 160 cm^3 screen cage and observed for seven days. Cages were placed in the fields on 28 June, 28 July, and 11 August in 1983 and on 28 June and 19 July in 1984. Two additional cages were set up on 28 June 1984; one was shaded and the other unshaded to determine whether daily temperatures affected feeding distribution. Hygrothermographs were placed in the shaded and unshaded cages; otherwise, ambient maximum and minimum temperature data from Hyslop field station near Corvallis, Oregon were used to determine the influence of temperature on feeding distributions.

Random samples of 100 stems from each cage were taken to the laboratory and feeding injury on each leaf stratum and lateral leaves was measured with a Li-cor leaf area meter. The amount of leaf area removed was estimated by subtracting the injured leaf area from the whole leaf area. Whole leaf area was estimated by reconstructing injured leaves using masking tape or measuring undamaged leaves of the same size. The distribution of feeding injury for each leaf node was expressed as a percent of the total leaf area damaged. The influence of temperature and growing date on the mean of the feeding distribution were examined using linear regression. The normal and binomial distributions were tested to represent feeding behavior in the MINTSIM model by chi-square analysis (Steel and Torrie 1980).

The observed and fitted feeding distributions along mint mainstems from the seven caged field studies are shown in Fig. III.4. The binomial distribution was selected for use in the model to generate daily feeding distributions because it produced the best chi-square fit ($\bar{x}$ chi-square = 2.8) in five of the seven tests and gave a very close fit in most of the tests (Fig. III.4). Feeding distribution means were linearly correlated with mean daily maximum temperatures ($r = 0.67$, $n = 7$). The relationship, mean of feeding distribution = 0.0286 + 0.0195 × daily maximum temperature, was used in the model with bounds placed at the feeding midpoint = 0.45 when the daily temperature exceeded 28.3°C and at 0.58 when the daily temperature was below 21.6°C. Placing bounds on this relationship prevented feeding behavior from being affected beyond the region of known predictability. The theoretical basis for temperature-mediated VC feeding activity has been a consideration for cutworm sampling programs (Chapter IV). Shields and Wyman (1985) found that VC instars 1 and 2 were photopositive, instar 3 was photoneutral, while instars 4 to 6 were photonegative. The degree of negative phototaxis of instars 4 to 6 increased with light intensity. In the field, temperature and levels of solar illumination are related, so that VC larvae would be expected to feed lower within the plant canopy on hot and sunny days than on cool and cloudy days. One grower interviewed concerning VC management methods observed that cool cloudy weather "brings up" the cutworms on the plants, resulting in increasing damage from the cutworms (Dave Gilmour, personal communication). The function in MINTSIM of temperatures affecting VC feeding distribution was meant to reflect these observed behaviors.

Consumption of lateral leaves in the caged studies varied between 0 and 9% of the area of mainstem leaves consumed, which was less than the amount expected based on the total leaf area available. In two cages, when lateral leaf consumption was 9% of mainstem leaf consumption, lateral leaf area represented 22% and 34% of the total area available, indicating that mainstem leaves were preferred over lateral leaves by factors of 2.4 and 3.7 to 1, respectively. Since these results have not been satisfactorily validated, a more conservative mainstem leaf preference over laterals of 1.5 to 1 was used in MINTSIM.

MODEL EXECUTION

Initiation

A flowchart of the major model events is shown in Fig. III.5. Initial variables and parameters are read in from an external parameter file. The file includes seven parameters: 1) the field phenology class (early, average, or late) which is a simple classification used to describe general field characteristics with respect to mint flaming dates, crop phenology class, and timing of cutworm infestation; 2) expected harvest date, where default values are 5, 15, and 25 August for early, average, and late field classes; 3) if a specific harvest date other than the default values are desired, this value is read in from the parameter file as well; 4) the population density of cutworms per 1000 cm^2; 5) choice of model output (text, graphics, or neither); 6) whether the degree days should be recalculated since the last model run; and 7) the expected cost of control for one insecticide application, expected value of the crop, and expected yield. Since the ET value calculated by this model is closely tied to the EIL, the cost of control and oil price is used to determine the ET, while the yield is used only to determine the percent crop loss.

The plant record-arrays are initiated next. Different numbers of attached and abscissed leaves are initialized for 1 June according to the field class. The model optionally calculates daily degree days using historical weather data and a modified sine curve integration method (Baskerville and Emin 1977). The degree days are stored in a file and are read daily by the model.

Daily Iteration

The events which take place every day of the simulation from 1 June until the harvest date (Fig. III.5) are as follows. The degree days for each day are read from a file. The growing date of the simulation (days since 1 June) is used to calculate whether it is time to add or absciss leaves based on the field class and the linear equations which describe plant leaf addition and abscission for that field class. If either of these flags is true then nodes are added, abscissed, or both. When nodes are added, the new node is initialized after all previous node variables are transferred down one node. Node variables include the amount of foliage consumed (dry weight), the date the node originated, whether the leaves on that node have abscissed and the abscission date. When a leaf node has abscissed the record for the last (bottom-most) leaf pair present is set to abscissed and the date recorded. The number of lateral leaves present is then calculated based on the growing date, the field class and an exponential function developed for each field class.

The daily proportional egg hatch is calculated next by integrating the area under a truncated normal distribution of egg hatch from the previous cumulative degree days to the current daily degree days according to parameters estimated for each field class. Density of first instar larvae is set equal to the initial VC density times the proportion of the total density hatching for the day. Larvae develop in the model by assignment of the density from one substage to the next (later) substage. The total density of each instar is added and the amount of foliage consumed is calculated by multiplying the density of each instar by its consumption rate per two degree days.

Actual defoliation of the plant is not applied to the plant until the end of the day using the cumulative consumption for the day. Total consumption is distributed along the plant according to: 1) the number of lateral leaves present relative to the mainstem leaves (both weighted by leaf area); 2) a lateral leaf preference factor which was estimated to be 60% relative to the preference for mainstem leaf foliage on a dry weight basis; 3) the midpoint of feeding (= p of the binomial mass distribution) which varies between 0.45 and 0.58 as a linear function of the daily maximum temperature; 4) the binomial distribution with parameters K = the number of leaf pairs present on the plant and p = the feeding midpoint; 5) the small amount of consumption calculated for the youngest leaf pair is added to that for leaf pair one and then reset to 0. Cumulative consumption is calculated in addition to the daily consumption for each leaf pair present and for lateral leaves. A daily report can be sent to the screen or to a compatible spreadsheet file as specified in the initial parameter file. The report includes VC daily and cumulative egg hatch, density of each VC instar, distribution of feeding, daily and cumulative consumption of each leaf stratum and of lateral leaves, number of mainstem leaf pairs present and abscissed, and number of lateral leaves present.

Harvest Events

After the daily iterations are completed and the harvest date has occurred, the final plant profile and amount of injury are used to determine loss of oil yield. The harvest submodel begins by initializing the amount of oil per leaf for each leaf pair as determined from GC studies. The proportion of total oil per plant in each leaf pair and lateral leaves is determined from the amount of oil per leaf and the number of mainstem and lateral leaves. Hypothetical oil amounts from abscissed leaves also are calculated based on GC analysis of recently senescent leaves.

Potential oil yield per 1000 cm^2 is calculated next by multiplying the proportion of total oil in each leaf pair and lateral leaves by the total potential oil yield which is nominally 679,537 μg oil/1000 cm^2 (equal to 85.29 kg/ha). Oil yield can be changed but will only influence the ET on a percent yield loss basis, not in terms of oil loss or cutworm density. The amount of oil consumed on a $\mu g/1000\ cm^2$ basis is determined by multiplying the cumulative dry weight consumed for each leaf pair and lateral leaves by the amount of oil per mg dry weight obtained from the GC studies.

The harvest report is issued to both the screen and a file. Primary results of the model are the percent yield reduction attributed to cutworm injury, the oil loss in kg per ha, and the ET value. In addition, the oil consumed, oil potential, and percent reduction are output for each leaf pair, abscissed leaves (hypothetically), and lateral leaves. The percent consumption to leaves attached at harvest (i. e., not abscissed) also is output which gives the user an idea of the effect of leaf abscission on increasing thresholds. For each mainstem leaf pair, a marker indicating the presence or abscission of the leaf pair, the date the pair was added, and the date the pair was abscissed also is reported.

VERIFICATION AND VALIDATION STUDIES

Model Verification

Verification of MINTSIM was based on a stepwise process where changes from the simple threshold model of Berry and Shields (1980) were added sequentially and the model outputs compared to previous steps. This allowed examination of each model component for correctness and accordance to its expected influence on model behavior. The primary criteria used to judge the effects of the new components on model behavior were the change in whole plant oil damage (yield loss), adjustment of the VC population required to cause the nominal 2.42% yield loss (ET values), and the shift in the relative injury to attached leaves compared with abscissed leaves.

Step 1. Nominal conditions or emulation of the threshold model of Berry and Shields (1980). All model components were adapted to assumptions of Berry and Shields (1980) to verify basic model performance. These components included: EIL = 2.42% damage caused by 0.91 larvae (instars 5 and 6, earlier instar injury not included); oil yield 85.29 kg/ha (76.1 lb/acre); price of oil \$22.00/kg (\$10/lb); cost of control \$45/ha (\$18.22/acre); no cutworm mortality; all consumption completed by harvest; all leaf injury present at harvest; all leaves of equal value at harvest; consumption expressed in terms of cm^2 leaf area; no positional effects such as feeding position or time of injury.

Results obtained agreed with Berry and Shields (1980), with a percent loss of 2.42 attributed to a density of VC instars 5-6 of 0.91 per 1000 cm^2 (Table IV.2).

Step 2. Positional effects when only leaf abscission was included. Distribution of feeding behavior and addition and abscission of leaves were added to the model. Feeding distribution was calculated by the binomial distribution using a constant feeding midpoint (p) of 0.525.

Adding leaf abscission to the model resulted in a decrease in percent yield reduction by 71-84% depending on field class. Late-class field damage was the lowest because there was a longer period between heaviest VC defoliation and harvest, which allowed the plant to produce leaves to replace the injured leaves.

Step 3. Feeding midpoint as a function of temperature. This component produced a downward shift in feeding distribution during the late season when heaviest defoliation occurred. Injury to leaves at harvest decreased from 84% to 81% for the early field class and from 71 to 64% for the late field class. This downward shift in feeding behavior resulted in increases in threshold populations from 1.08 to 1.12 larvae per 1000 cm^2 for early class fields and from 1.28 to 1.41 for late class fields.

Step 4. Decreased preference for lateral leaves relative to mainstem leaves to 60%. The addition of this factor to the model shifted injury more to mainstem leaves and further decreased the percent yield loss by three to five percent. The lowered preference for lateral leaves also resulted in a three to five percent decrease in injury to leaves present at harvest.

Step 5. Differences in oil yield between individual leaves included. The decreased preference for lateral leaves added to the model in step 4 was more important when yield loss was figured on a positional basis. The lowered amounts of laterals consumed resulted in decreased overall yield loss and increased threshold values by 35% (early fields) and 31% (late fields).

Step 6. Addition of leaf consumption by instars 1-4. Adding this factor resulted in a slight decrease in the threshold population as expected.

Step 7. Addition of mortality attributable to parasitoids (73% survival during development from instar 4 to 5). This simplified mortality factor resulted in a decrease in percent yield reduction by about 1/3. The threshold population size was increased to 2.06 larvae/1000 cm^2 (early field class) and 2.58 (late field class). In keeping with the conservative approach to developing this model, mortality due to predators and other factors was not included since it has not been documented.

Step 8. Cutworm development and mortality processes were set at two degree day (instead of one degree day) intervals, to reduce the number of instar substages and improve model performance. This model alteration speeded execution by almost 50% and caused a small and consistent change in output (1%) measured as ET values. This change was calibrated in step 9.

Step 9. Calibrated the model to diminish the 1% change caused by step 8. Multiplying the total consumption each day by 0.9906 used to bring threshold estimates to within 0.5% of the values obtained prior to step 8.

Step 10. Use of different average weather data. The average weather data used previously was based on smoothing 40 year weekly maximum and minimum temperatures from Corvallis. The new average weather data added to the model was based on 16 year (1970-1985) mean daily degree days which had 1416.5 cumulative degree days between 1 May and 31 August compared with 1448.1 degree days for the older average weather data. The change in the weather data used in the model resulted in a three to four percent reduction of threshold values, depending on field class.

Step 11. Leaf abscission rates corrected to be more conservative, based on results obtained from GC analyses which showed that senescent leaves contained full amounts of oil. This correction factor decreased threshold values by 6.9 to 10.5%, depending on field class.

Step 12. Final leaf profile calculations adjusted to include partial leaf abscission. This improvement in model accuracy was made because of an observed sensitivity of model results to harvest date. The change reduced the sensitivity and resulted in increased threshold values of 6.0%, 11.1%, and 11.3% for the default harvest dates; 5, 15, and 25 August for average, and late field classes.

Step 13. Use of different oil price and control costs to reflect 1986 values. The oil price was changed from $22.00/kg ($10/lb) to $24.20/kg ($11/lb) and the cost of control increased from $45.00/ha ($18.22/acre) to $49.40/ha ($20/acre). The cost of control as a percentage of crop value decreased from 2.42% to 2.39% and ET values decreased to 1.91, 2.07, and 2.44 larvae/1000 cm^2, depending on field class.

Step 14. The degree days for development for VC were increased by 7.8% to account for the difference between development in weather shelters and in the mint canopy. When this factor was changed, ET values decreased to 1.83, 1.96, and 2.24 larvae/1000 cm^2, depending on field class.

Model Validation

Direct validation of the MINTSIM model by field experimentation was not part of the scope of this project, since the model was conceived as an alternative to experimentally estimating yield losses. The model construction process reflected a conservative approach in estimating model components. Individual components of the model were each validated experimentally, and the component effects were each verified when incorporated into the model. Validating whole model behavior would require that either artificial defoliation or caging studies in the field be performed to determine effects of artificial or actual VC defoliation on yield loss. Significant problems in interpreting results of artificial defoliation studies would occur because they would differ substantially from natural cutworm defoliation. Caging and inoculation studies might be helpful to determine how conservative the model output is, and to show the effects of predators on reducing VC injury. However, the precision of measuring yield loss from caging studies would be low, and confidence intervals for damage estimates would be wide in proportion to the degree of actual damage being considered. Currently the cost of control as a percent of the crop value is ca. 2.5%, meaning that caging studies to experimentally validate the model would not be particularly valuable. A better approach to improve the model would be to continue examining model assumptions and refining the details of model components. Examples of this approach may include adding a peppermint population heterogeneity (growth variance) factor, making leaf oil yields dependent on harvest date, having parasitism-induced mortality dependent on field class, or separating the three field classes into more specific classes associated with certain management decisions such as flaming time, field rolling, and irrigation scheduling.

Model Sensitivity Analysis

A simple sensitivity analysis was performed to help identify selected model parameters that may require more accurate estimation in further MINTSIM model development and to help validate model performance under prescribed model alterations. Model sensitivity analysis usually involves multiple model runs with changes to one or more parameters and observing the difference in specified model output variables. I chose to vary each parameter by 80, 90, 110, and 120 percent and then express output differences as the percentage change in ET values. Sensitivity analysis results from early and late class fields were graphed (Fig. III.6), and the sensitivity score of each parameter was obtained by calculating the slope of a regression line for percent change in the ET compared with the percent change in the parameter value. This technique is nearly equivalent to the method of ranking partial derivative values, but using slopes over a given range simplifies calculations and provides an estimated average sensitivity rank rather than a point estimate. This method presupposes linear model behavior about the nominal parameter value, which is principally true for the MINTSIM parameters shown in Fig. III.6. The interpretation of these sensitivity scores is straightforward since a slope of 1.0 indicates that a percent change in ET values would be a direct result (in a 1:1 ratio) of a similar percent change in the parameter value. Parameter sensitivities are compared in Table III.3, with parameters sorted in descending order by absolute values of slopes of the average field class. A more complete sensitivity analysis should include an estimate of sampling error for each parameter with confidence levels, if available. The highest ranking parameter sensitivity score was harvest date (Table III.3). This result was unexpected and prompted correction by adding partial leaf abscission at harvest time (step 12 in the verification studies).

Sensitivity scores for the rate of leaf abscission were relatively high, ranging from 0.91 to 2.21, which indicates that growers with fields having especially high rates of leaf abscission may be less concerned with cutworm populations than if they had minimal abscission problems. In general, variance characteristics of parameter measurements should be inversely related to the sensitivity scores to insure that model inaccuracies are kept within acceptable limits.

MODEL BEHAVIOR

The questions asked of the model were specified early in the modeling process and are as follows. 1) What are the economic threshold values for VC in peppermint under a range of growing and management conditions expected in western Oregon, including: a) temperature regimes during the past 16 years; b) three different peppermint field classes based on different management practices and time of harvest; and, c) differing VC recruitment schedules. 2) Would it be economically feasible to alter harvest dates to reduce cutworm impact given the current cost of control and price of oil?

Effect of Field Class on ET Values

Field class had some effect on ET values (Table III.4) for various oil prices and control costs. The late field class (harvest date 25 August) always had higher VC thresholds than early and average field classes (harvest dates 5 and 15 August). Although cutworm recruitment schedules were parameterized to each field class, 50% recruitment varied only ca. 10 days between early and late field classes, while the harvest dates differed by 20 days. As a result, the late field class had a longer interval to regrow injury and had higher threshold values. Because field class did impact ET values, the model may be run several times when fields not matching any one field class are being simulated, resulting in ET values that can be averaged to give more precise results.

Effect of Variable Weather on ET Values

Temperature affects both the rate of development and feeding behavior of VC in MINTSIM. To determine the effect of different temperature regimes on ET values (expressed as number of larvae/1000 cm^2), the model was run using 17 years of temperature data (1970 to 1986) recorded at Hyslop station, Corvallis. A nominal set of input variables was used (Step 12, Table III.3). The model estimated ET values that ranged from 1.76 to 2.50 for early class fields, 1.80 to 2.63 for average fields, and from 1.98 to 2.99 for late fields. When the effect of low temperature on feeding distribution was removed from the model and the analysis repeated, the ET values ranged from 1.71 to 2.30 for early fields, 1.78 to 2.42 for average fields, and 1.91 to 2.87 for late fields. These differences suggest that the impact of warm temperatures on cutworm feeding behavior is greatest during the latter part of the season which is when warmer temperatures often occur. The fluctuations in ET values found here indicate the importance of weather which influences the synchrony of harvest with injury trends and the distribution of VC feeding injury on the plant.

To examine trends relating relatively cool or warm growing seasons to ET values, cumulative degree days (5°C threshold) from May through August were regressed on ET values for the 17 years of weather data tested. There were significant relationships between cumulative degree days and ET values for all three field classes (r^2 = 0.55, 0.59, 0.68; $P < 0.001$)(early field class shown in Fig. III.7). If this relationship is true, in future years a warm growing season may result in higher ET values. Situations also were identified for some years such as 1983 when relatively cool temperatures in July slowed VC development but were followed by warmer temperatures just before harvest, resulting in accelerated feeding by sixth instar larvae which produced low thresholds (ET = 1.7, early field class).

Effect of Varying VC Recruitment Schedules

Egg hatch distributions were altered by changing mean egg hatch in 20 degree day increments to minus 200 and plus 300 degree days to determine effects on ET values (Fig. III.8). Degree days may be approximately converted to days by dividing by the average of 11.5 degree days per day found for the period from June 1 through June 30. Altering the distribution of VC egg hatch, and thus subsequent injury trends, showed that ET values were minimized at mean egg hatch times of plus 100, 160, and 220 degree days and were 9.7, 17.6, and 29.6% lower than the default ET values for early, average, and late field classes. ET values were most sensitive to changes in mean egg hatch distribution for late harvested fields. This indicates that model output is relatively insensitive to changing egg hatch for fields harvested early, while fields harvested later have a greater potential for reducing damage by delaying the harvest date, and increasing damage when accelerating the harvest date.

Effect of Varying Harvest Date

The effect of altering the harvest date on ET values also was studied. Harvest dates were changed by one to seven days plus or minus the default dates of 5, 15 and 25 August for the three field classes (Fig. III.9). With few exceptions, for each day harvest was delayed, threshold values increased slightly. The effect was more influential for the later field classes, and less important for accelerating harvest than for delaying it in all three field classes. Based on the nominal model conditions which included an oil price of \$26.40/kg (\$12.00/lb), and a density of 3.0 larvae per 1000 cm^2, a one day delay in harvest increased crop value due to plant regrowth by \$0.40, \$0.37, \$0.43 per ha (\$0.98, \$0.91, and \$1.05 per acre) for early, average, and late field classes. A seven day delay in harvest increased crop value by \$2.45, \$2.46, \$2.75 per ha (\$6.06, \$6.08, and \$6.79 per acre). Increases in crop value due to harvest delays were less than 1% of the total crop value of \$370 per ha (\$913 per acre) for a field yielding 88.66 kg/ha (79.1 lb/acre). Delaying harvest to allow the crop to recover would be economically justified only at VC densities much higher than current ET levels.

Calculation of Larval Damage Units (LDUs)

MINTSIM was designed primarily to calculate ET values by simulating injury during the entire growing season and expressing damage at harvest as a percent yield loss. MINTSIM also was modified slightly to run in an on-line mode during the growing season. The major differences to the user of this optional on-line version are that: 1) VC densities estimated from field samples may be entered for a specified sample date and the simulation proceeds from that point. This allows exclusion of VC injury prior to the sample date, which is appropriate because ETs must be calculated for preventable, not past injury; 2) final damage units were changed to kg oil per ha (lbs of oil per acre), so that oil price, cost of control, and expected yield could remain independent from damage expression.

These model modifications allowed MINTSIM to be used in two additional ways: 1) by making the model available for on-line use to pest managers for predictions based on current conditions; 2) by allowing construction of tables of damage units specific to each instar for average conditions, bringing some of the benefits of on-line use without the need for a computer. The concept of using damage units extends the ET concept (Stern et al. 1959) by making ETs dynamic with respect to time and pest stage, and may be applied to other crops and pests. The term larval damage units (LDUs) is proposed, which is defined as the amount of yield loss (in units of yield measurement) attributable to one individual of a specific development stage at a certain time during the development of the crop. For VC in peppermint, an LDU would be the expected yield loss in kg/ha (lb/acre) that is attributable at a specific time to one cutworm larva of a specific instar per 1000 cm^2 (ft^2).

Model modifications and assumptions used to calculate LDUs included: 1) plant growth was simulated as usual but cutworm injury was not calculated until the day after samples for larvae were taken; 2) larval density of each instar was uniformly distributed over all instar substages; 3) damage in units of kg of oil per ha (lb/acre) were calculated by dividing the damage in μg oil/1000 cm^2 by the conversion factor 10,000 (8930).

To calculate LDUs, MINTSIM was run with a VC larval density of 1.0 per 1000 cm^2, one instar at a time on the dates July 1, 5, 10, 15, 20, and 25, and for each field class (early, average and late).

The LDU values observed (Table III.5) may be used in the field by: 1) looking up the LDU values for the appropriate sample date and field class from a table; 2) multiplying the LDU values by the density of each larval instar per 1000 cm^2 and summing the results for all instars to give the total expected yield loss in kg/ha (lbs/acre); and 3) comparing that result with the value of control expressed as kg/ha (lbs/acre) which can be calculated as the the cost of control $/ha ($/acre) divided by the current oil price $/kg ($/lb). If the expected yield loss is greater than the value of control, then the ET has been exceeded and control is warranted. For example, for a sample taken 15 July and an expected harvest date of 15 August, and sample densities of 1.3 3rd instar and 0.7 4th instar larvae per 1000 cm^2, (1.05 LDUs × 1.3) + (1.29 LDUs × 0.7) = 2.27 LDUs total, which is greater than the value of control of 1.87 kg/ha ($49.40/ha cost of control divided by an oil price of $26.40/kg). Although the use of LDUs requires some calculation in the field, it has the advantage of being sensitive to last minute adjustments in oil price, cost of control, expected harvest date, and larval sample estimates. Also, the approach of using LDUs takes into consideration that all instars are not equal in their capacity to damage the crop. If LDUs are used early during the growing season when mostly early instars are present, the damage estimates will be very conservative because only phenological and parasitoid induced mortality factors were considered in this version of MINTSIM (mortality estimates for early instars due to predators were not included).

CONCLUSION

The approach to refine economic threshold levels for VC in peppermint discussed in this chapter may be referred to as a systems analysis simulation approach (Shoemaker 1980), or as a step towards more comprehensive economic thresholds (Poston et al. 1983), rather than as an experimental or empirical approach.

The principle benefits of using this economic threshold model on VC management include: 1) increasing ET values from 70% to 300% over previously used values, primarily because VC feeding behavior, larval mortality due to parasitoids, and peppermint leaf abscission were added to the model; 2) allowing ET values to be generated for different field and market conditions; 3) reducing misconceptions about VC biology and the importance that peppermint leaf longevity has on interpreting damage caused by defoliating insects; and 4) allowing 'what-if' questions to be simulated to test assumptions about system behavior.

Changes to the model to make it more comprehensive and useful might include: adding a control function where date of control and control efficacy are user-specified; adding additional defoliating species such as bertha armyworm; including predator caused mortality, including information on oil quality in the model output; using plant growth rates that are dynamically dependent on crop management practices; parameterizing the model for other peppermint growing regions; including on-line weather forecast information, automatic conversion of data from the two cutworm sampling methods to absolute area estimates (Chapter IV); and incorporating information known about predicting larval infestations using pheromone traps (Chapter I). Even though none of these extensions to the model were specified in the original objectives, some data are available and may be added to the model in the future.

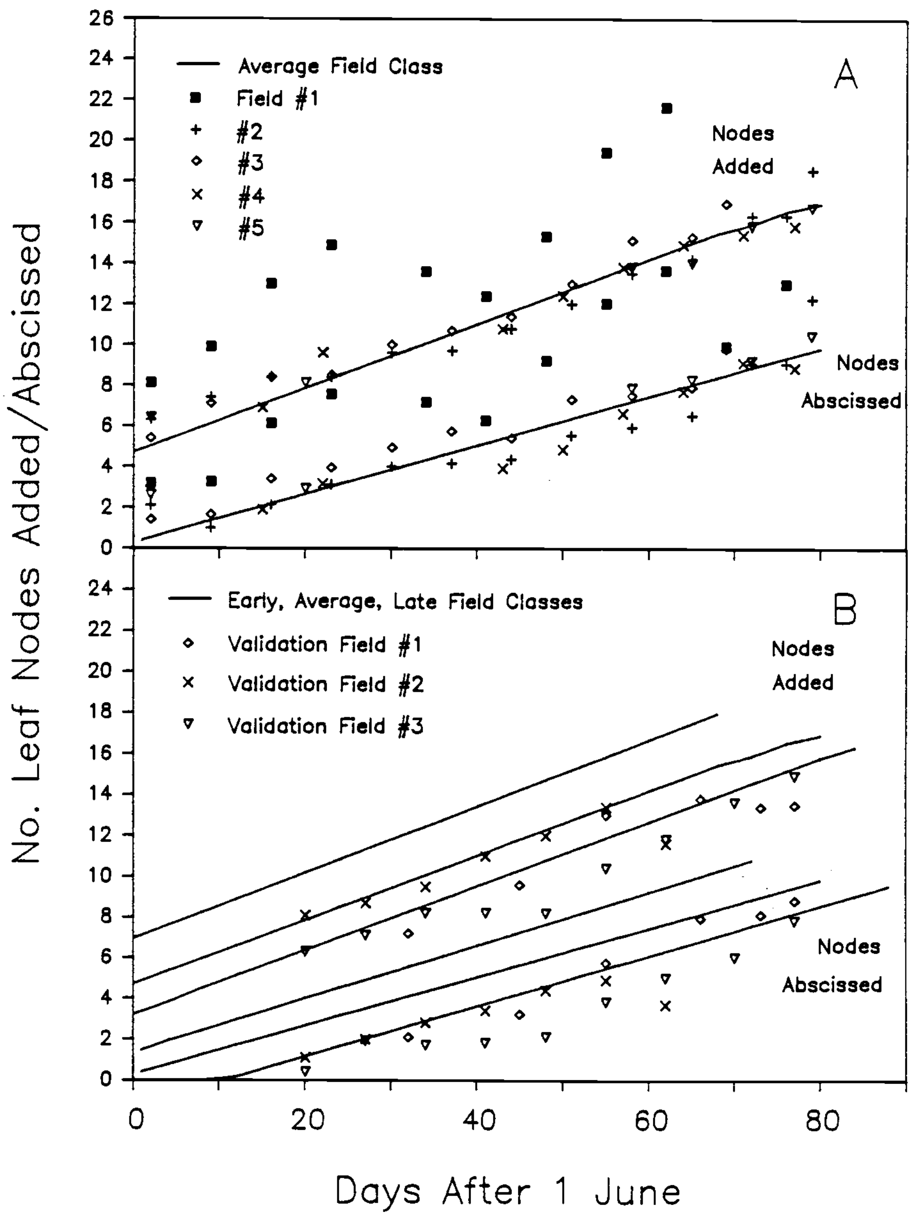

Fig. III.1. Rates of mainstem leaf growth and abscission in western Oregon peppermint in 1983-84 from; A) sampled fields 1 to 5, plus average field class; B) early, average, and late field classes plus validation sampled fields 1 to 3. Regression equations used in leaf node addition for early field class: leaf node = 6.50 + 0.161 × date, average field class: leaf node = 4.70 + 0.158 × date, late field class: leaf node = 3.43 + 0.154 × date. Regression equations used in leaf abscission for early field class: leaf pairs abscissed = 0.30 + 0.14 × date, average field class: leaf pairs abscissed = -0.70 + 0.12 × date, late field class: leaf pairs abscissed = -2.28 + 0.12 × date.

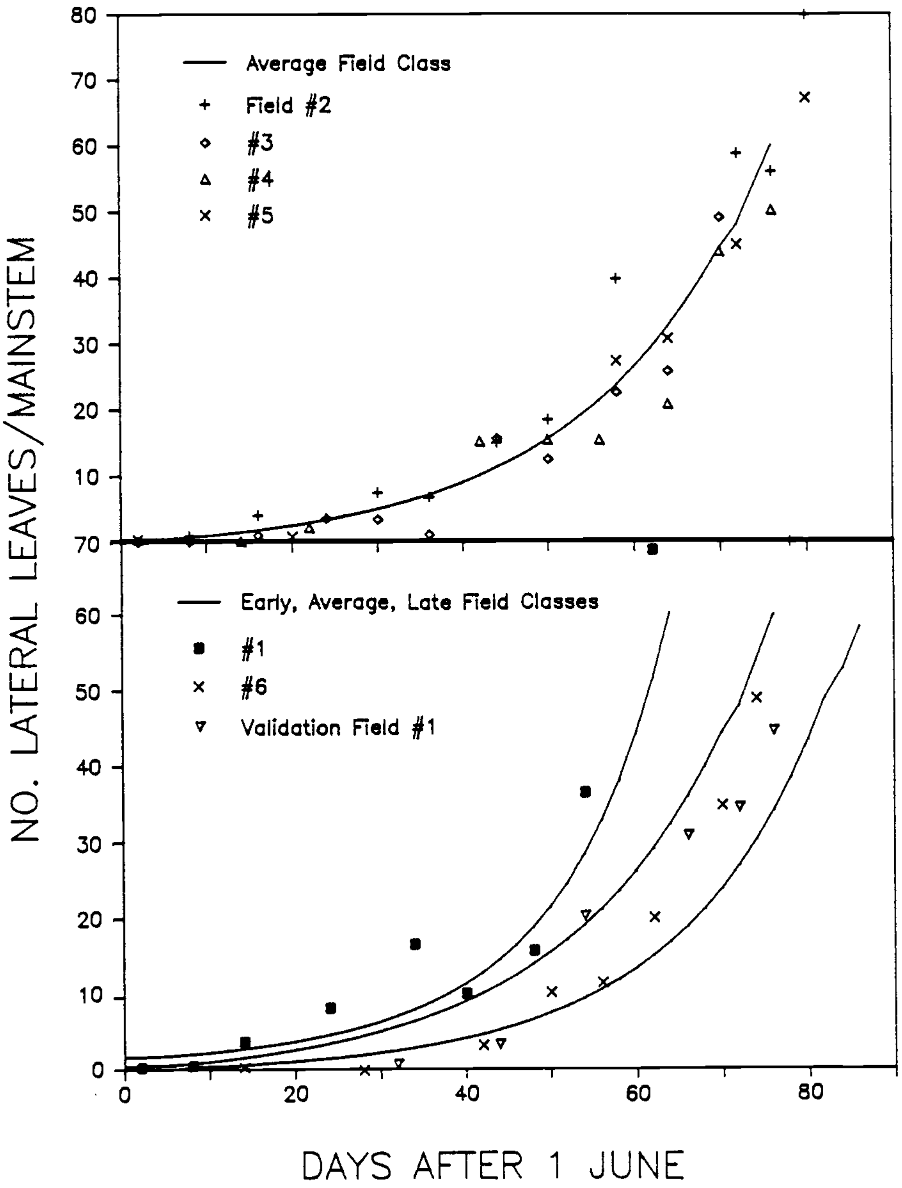

Fig. III.2. Lateral leaf growth rates in western Oregon peppermint in 1983-84 from; A) sampled fields 1 to 5, plus average field class; B) early, average, and late field classes used in MINTSIM model plus validation sampled field 1. Equations for lateral leaf growth for early field class: lateral leaves = $0.58 + 0.82 \times e^{(0.07 \times \text{days})}$, average field class: lateral leaves = $-1.40 + 1.09 \times e^{(0.05 \times \text{days})}$, late field class: lateral leaves = $-0.67 + 0.52 \times e^{(0.06 \times \text{days})}$.

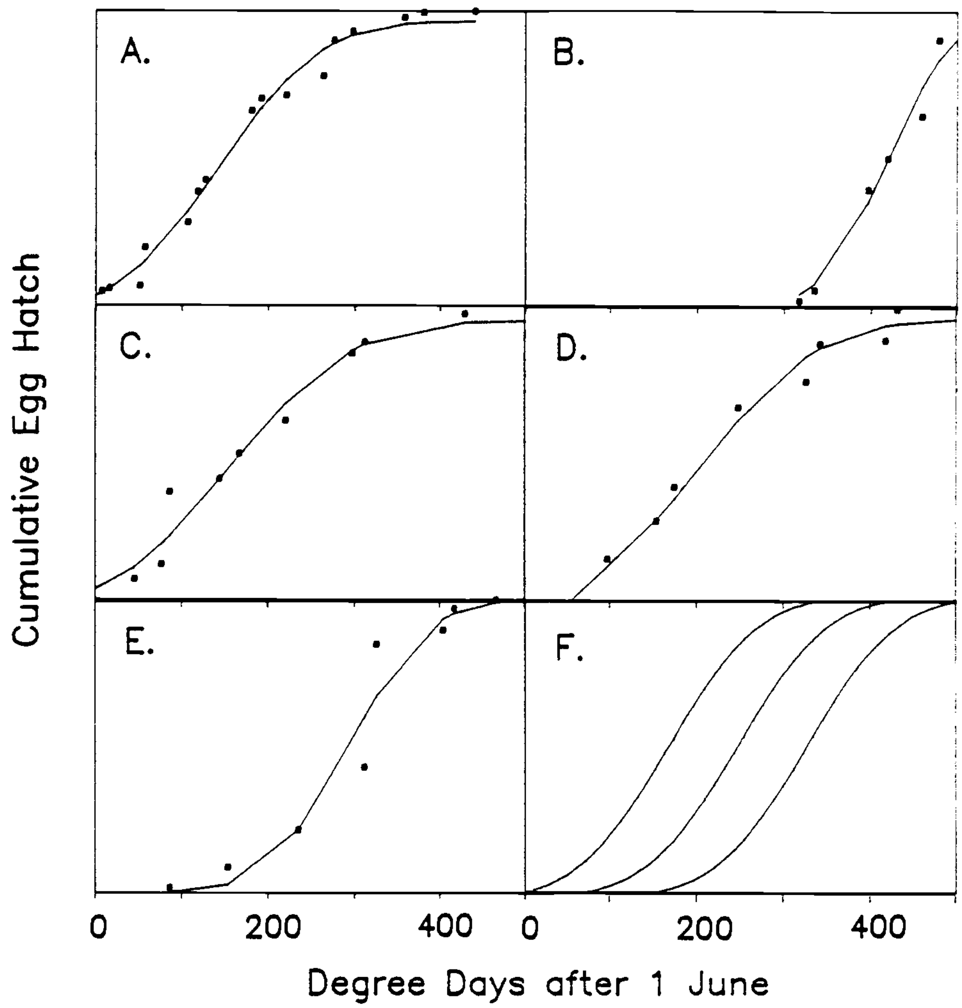

Fig. III.3. Variegated cutworm egg hatch distribution in western Oregon peppermint in 1983-84 from; A-E) five fields as estimated from larval sampling; F) early, average, and late field classes used in MINTSIM model.

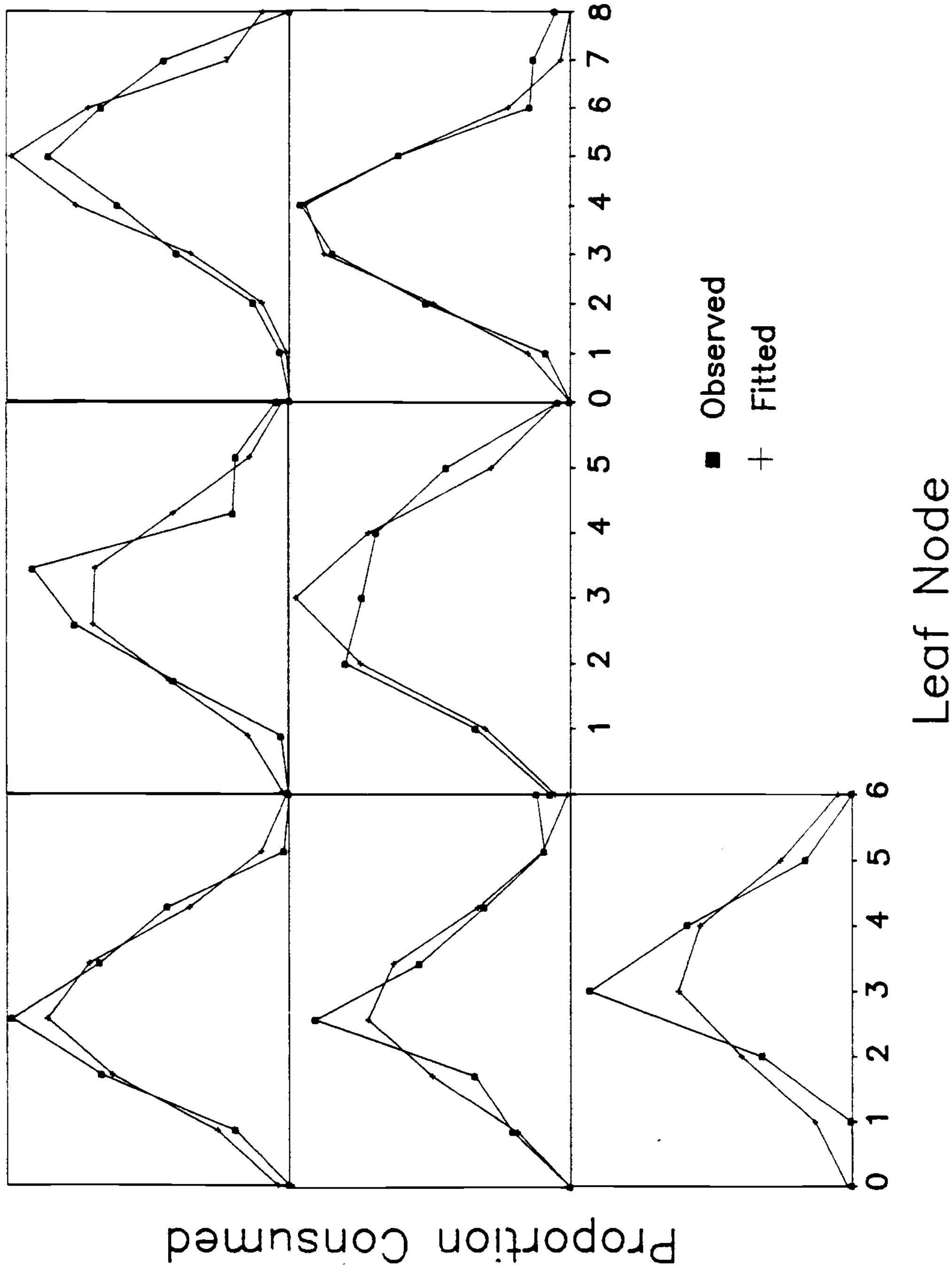

Fig. III.4. Variegated cutworm feeding behavior on mainstem peppermint leaves in western Oregon in 1983-84 as observed in field behavior studies and fitted using the binomial distribution.

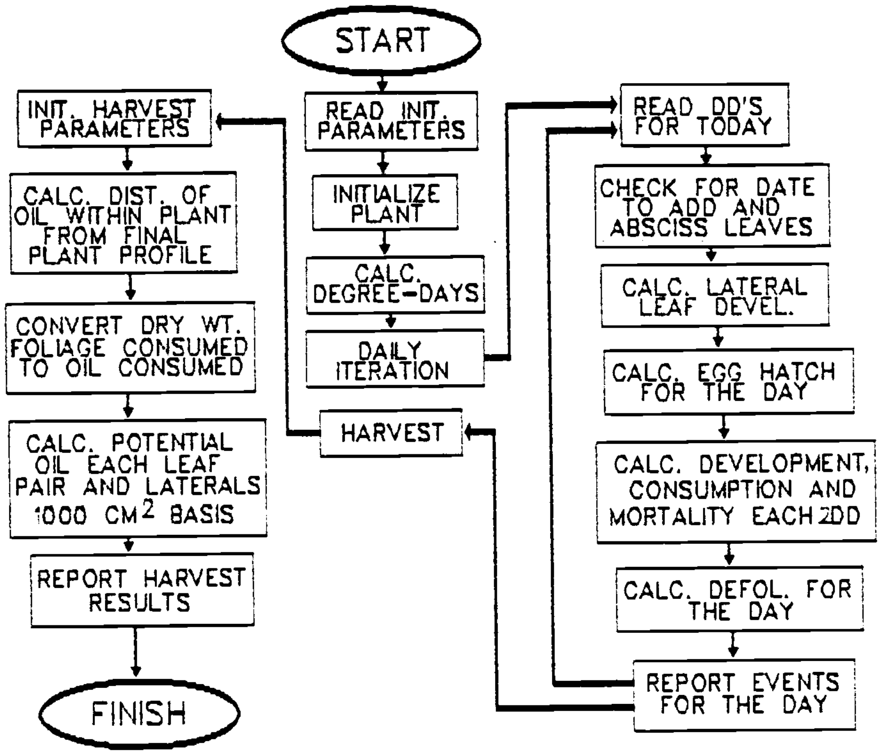

Fig. III.5. Major steps taken during execution of the MINTSIM peppermint defoliation model.

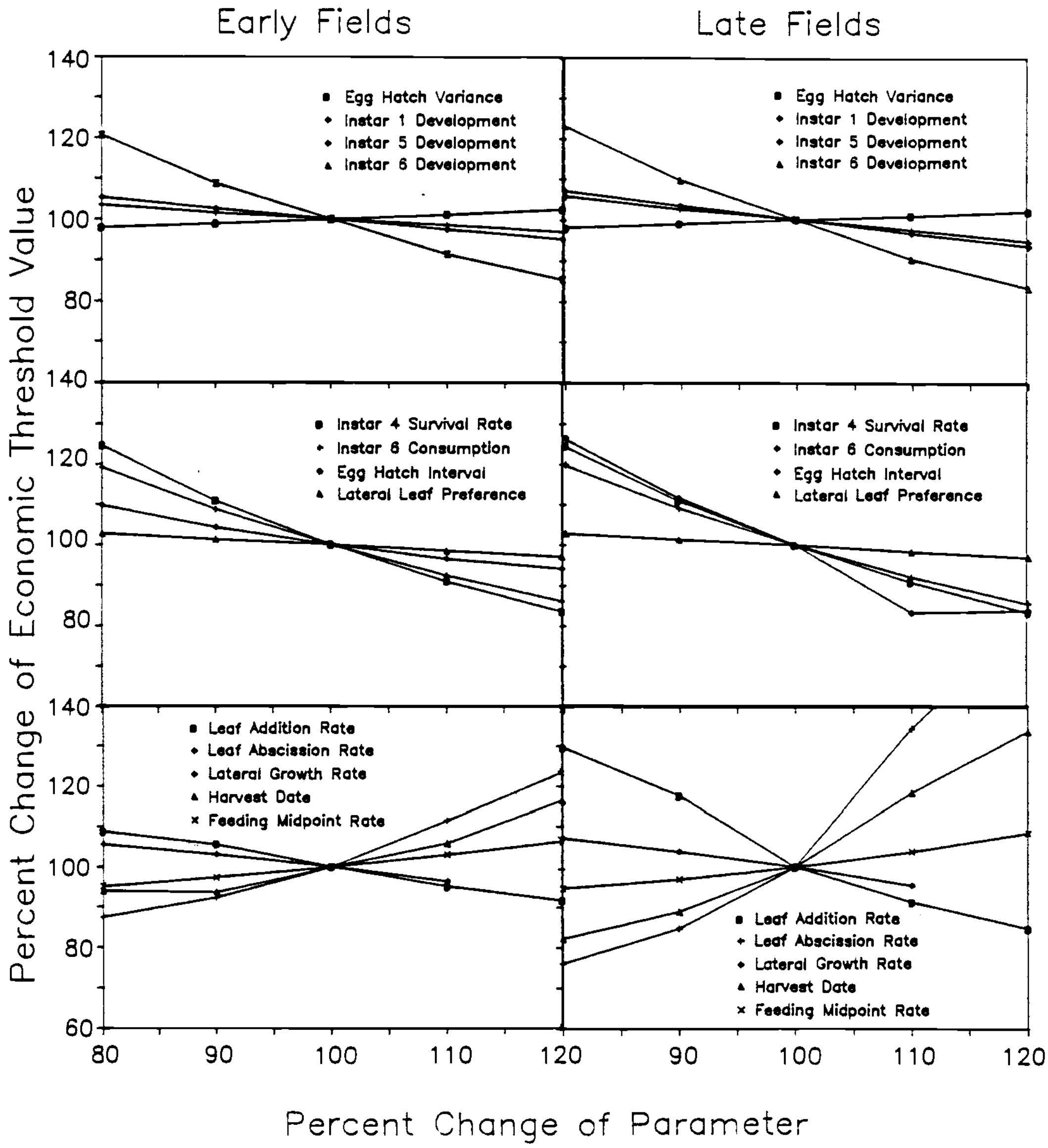

Fig. III.6. Sensitivity of MINTSIM model expressed as percent change in variegated cutworm economic threshold values due to prescribed percent changes of the model variable or parameter.

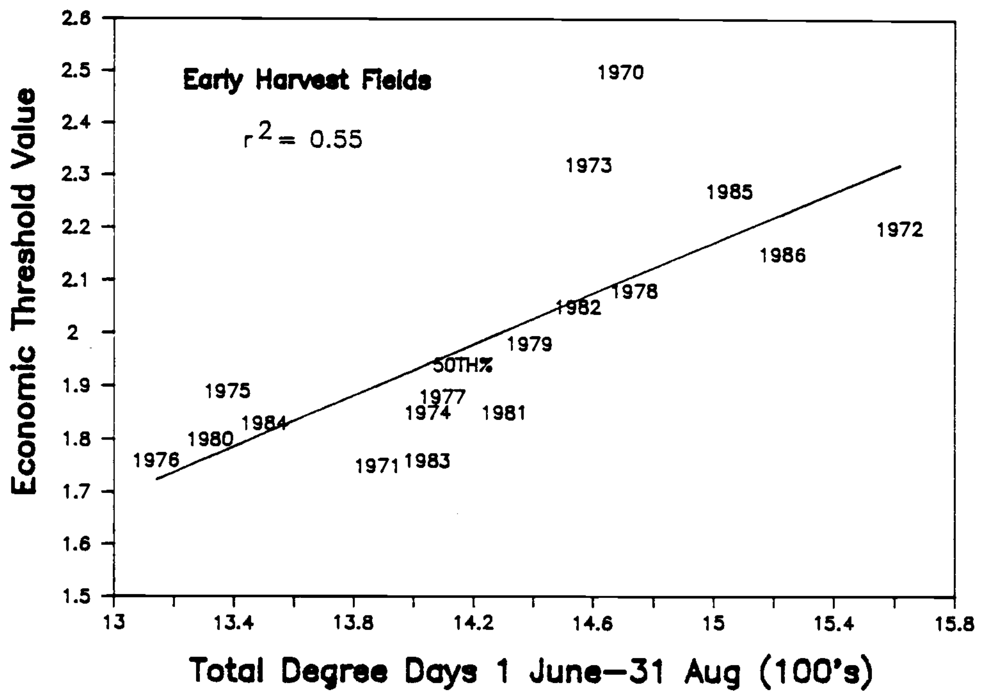

Fig. III.7. Regression of early field class economic threshold values on cumulative degree days (5°C threshold) from 1 June to 31 August between 1970 and 1986, Corvallis Oregon.

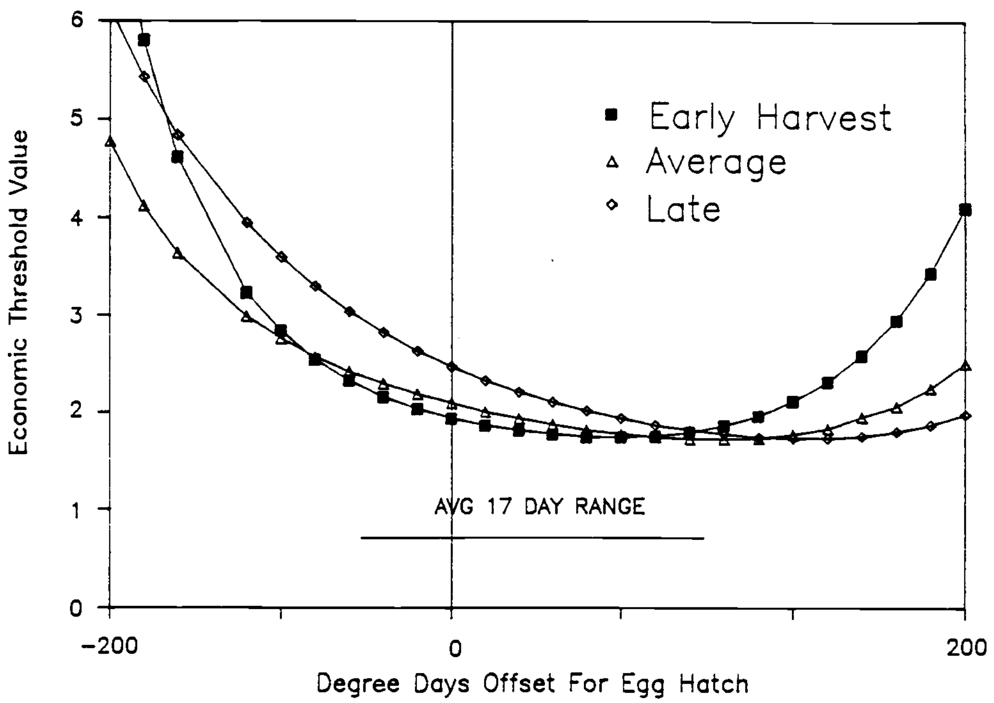

Fig. III.8. MINTSIM peppermint defoliation model change in economic threshold values in response to varying variegated cutworm recruitment schedules for early, average, and late field classes.

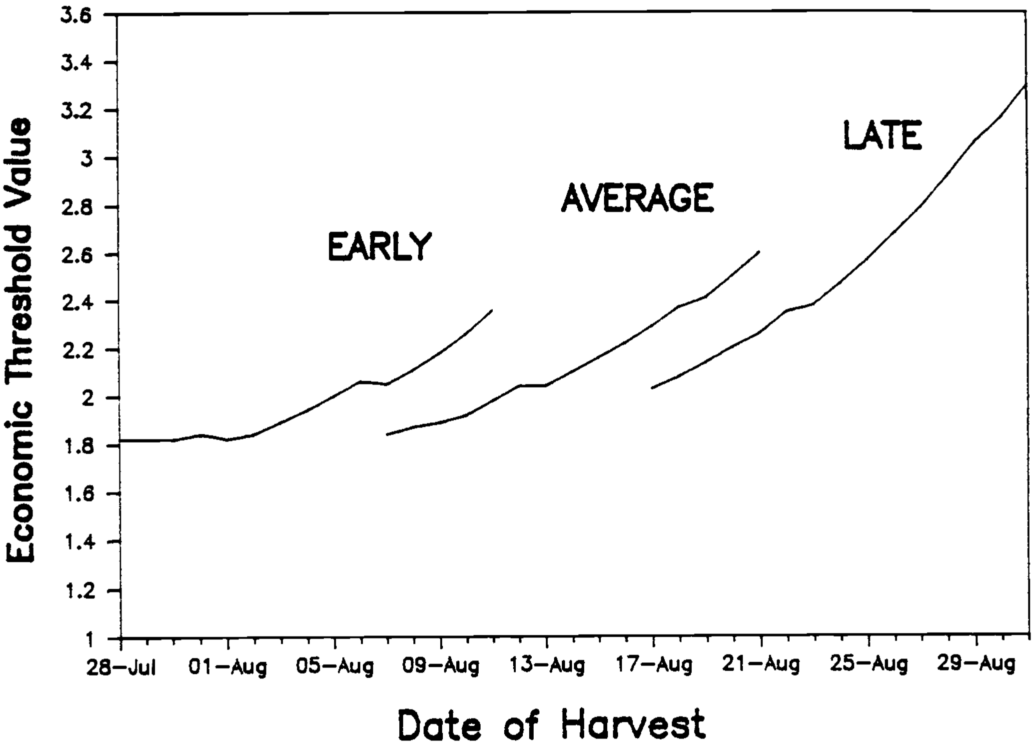

Fig. III.9. Effect of varying peppermint harvest dates on variegated cutworm economic threshold values for early, average, and late field classes.

Table III.1. Average leaf weights, essential oil content and menthol and menthofuran contents in different peppermint plant parts from four western Oregon fields in 1983 and two fields in 1984.

Plant Part[1]	*n*	Avg Leaf wt. mg	± sd	Avg Oil/Leaf µg	± sd	Oil/mg Leaf µg	± sd	% Menthol	% Menthofuran
				1983 Samples - 1 leaf per sample					
Mainstem leaves:									
0	12	12.3	4.9	376.9	182.4	31.4	11.0	20.6	2.44
1	12	31.2	7.6	661.4	190.3	22.3	8.0	30.3	1.58
2	12	44.7	8.0	832.5	313.4	18.9	7.1	47.5	1.66
3	12	54.1	9.9	716.6	272.6	13.9	6.3	46.1	0.91
4	12	59.1	14.9	941.0	192.1	16.6	4.2	50.4	0.52
5	11	60.6	17.3	924.9	231.8	16.6	6.3	53.0	0.31
6	10	65.7	18.4	828.6	304.9	14.3	7.5	55.3	0.33
7	6	68.8	17.6	943.5	313.4	15.0	7.7	53.5	0.32
Flower buds									
	12	53.3	33.9	1936.0	840.0	47.0	23.6	6.1	39.90
Lateral leaves:									
L0	5	23.5	9.2	1552.8	782.9	69.1	33.4	9.2	6.17
L1	5	11.3	3.8	520.5	299.4	59.8	23.2	23.8	1.67
L2	5	17.7	4.1	615.3	213.8	37.8	20.2	37.0	0.87
L3	2	22.4	0.1	883.3	336.2	39.6	15.4	47.3	0.56
Random	10	13.6	4.1	444.8	235.5	33.0	16.3	36.7	0.85
				1984 Samples - 30 leaves per sample					
Mainstem leaves:									
0	12	10.7	1.3	230.3	32.3	21.6	2.5	17.7	0.53
1	12	27.1	4.5	584.9	71.8	22.3	5.5	28.5	0.63
2	12	41.4	4.7	741.4	117.3	17.9	2.3	37.2	0.31
3	12	48.0	6.8	790.2	199.0	16.4	3.1	43.8	0.22
4	12	65.4	47.9	818.0	240.1	14.7	4.5	47.7	0.29
5	12	52.8	7.7	839.0	204.7	15.8	2.4	50.2	0.23
6	12	52.5	7.7	812.2	184.6	15.5	3.1	51.2	0.17
7	12	51.6	9.6	753.6	220.4	14.7	3.8	52.4	0.25
Flower buds									
	12	42.0	10.6	1578.5	418.8	37.6	4.5	7.3	35.50
Lateral leaves:									
L0	2	2.9	-	106.6	-	36.2	-	4.8	1.06
L1	2	8.6	-	272.3	-	31.6	-	13.9	0.50
L2	2	13.9	-	412.7	-	29.6	-	32.1	0.59
L3	2	22.2	-	563.3	-	25.4	-	44.8	0.54
Random	12	11.3	1.4	247.3	50.9	21.9	4.0	29.4	0.53
Senescent leaves 1									
	2	47.1	-	797.8	-	17.8	-	51.2	0.41
Senescent leaves 2									
	2	49.9	-	885.5	-	18.3	-	48.5	0.49

[1]Mainstem leaf pair 0 is from top of stem, lateral leaf pair L0 is from top of lateral stem. Senescent leaves 1 refers to leaves more than 50% yellowed, senescent leaves 2 refers to leaves more than 50% browned.

Table III.2. Steps taken to verify MINTSIM peppermint defoliation model accuracy. Results of each major model change expressed for early, average, and late field classes as percent damage caused by 0.909 variegated cutworm larvae per 1000 cm^2, percent injury to leaves present at harvest, and economic threshold (ET) values (no. larvae per 1000 cm^2).

#	Description of model change	Early fields % Damage	Early fields % leaf pres.	Early fields ET level	Average fields % Damage	Average fields % leaf pres.	Average fields ET level	Late fields % Damage	Late fields % leaf pres.	Late fields ET level
1	Emulation of Berry and Shields (1980)	2.42	100.0	0.91	2.42	100.0	0.91	2.42	100.0	0.91
2	Add leaf senescence	2.04	84.4	1.08	2.01	83.2	1.09	1.72	71.1	1.28
3	Midpt. of feeding is function of temp.	1.97	81.4	1.12	1.92	78.8	1.16	1.56	64.3	1.41
4	Lateral preference = 0.6	1.92	79.4	1.15	1.86	77.0	1.18	1.49	61.7	1.47
5	Influence of leaf position on harvest	1.42	79.6	1.55	1.39	78.1	1.58	1.14	63.7	1.93
6	Include consumption by instars 1 to 4	1.46	77.0	1.51	1.44	75.7	1.53	1.17	61.3	1.89
7	Instar 4 survivorship = 0.73	1.07	76.7	2.06	1.05	75.4	2.09	0.85	61.0	2.58
8	Use 2 degree day substages for VC	1.08	76.8	2.04	1.06	75.4	2.07	0.86	61.2	2.55
9	Add correction factor step 8	1.07	76.8	2.05	1.05	75.4	2.09	0.86	61.2	2.57
10	Use different avg. weather data	1.12	80.0	1.97	1.08	77.6	2.03	0.89	63.3	2.48
11	Adjustment of leaf growth formulae	1.20	86.0	1.83	1.17	83.4	1.89	0.99	70.1	2.22
12	Partial leaf abscission at harvest	1.14	81.3	1.94	1.05	75.0	2.10	0.89	63.8	2.47
13	Adjust control cost and oil price	1.14	81.3	1.91	1.05	75.0	2.07	0.89	63.8	2.44
14	Adjust VC development requirements	1.19	85.0	1.83	1.11	79.5	1.96	0.97	69.3	2.24

Table III.3. MINTSIM peppermint defoliation model sensitivity analysis of selected variables. Sensitivity scores are the slope of the relationship between percent change in a variable or parameter and the percent change in the output variable which is the economic threshold.

	Field Type		
Variable Name	EARLY	MID	LATE
Harvest date	1.15	2.04	3.17
Slope of leaf absciss.	0.91	1.31	2.21
Survival rate of instar 4	-1.02	-1.02	-1.03
Development rate of instar 6	-0.88	-0.91	-0.98
Consumption rate of instar 6	-0.82	-0.83	-0.86
Slope of leaf addition	-0.45	-0.71	-1.16
Egg hatch interval	-0.39	-0.55	-1.14
Lateral growth rate	-0.31	-0.29	-0.39
Development rate of instar 5	-0.26	-0.28	-0.33
Development rate of instar 1	-0.16	-0.19	-0.27
Midpoint of feeding	0.28	0.18	0.34
Lateral preference	-0.14	-0.13	-0.15
Egghatch variance	0.11	0.10	0.10

Table III.4. Variegated cutworm economic thresholds (number of larvae/1000 cm^2) as a function of peppermint oil price, cost of control, and field class.

Oil Price ($/kg)	Cost of Control ($/ha) 26.5	30.9	35.3	39.7	44.2	48.6	53.0	57.4	61.8
	Early Field Class (Harvest 5 August)								
19.8	1.5	1.8	2.0	2.3	2.5	2.8	3.0	3.3	3.5
24.7	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8
29.7	1.0	1.2	1.3	1.5	1.7	1.9	2.0	2.2	2.4
34.6	0.9	1.0	1.2	1.3	1.4	1.6	1.7	1.9	2.0
39.5	0.8	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.8
44.5	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.6
49.4	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
	Average Field Class (Harvest 15 August)								
19.8	1.6	1.9	2.2	2.4	2.7	3.0	3.2	3.5	3.8
24.7	1.3	1.5	1.7	1.9	2.2	2.4	2.6	2.8	3.0
29.7	1.1	1.3	1.4	1.6	1.8	2.0	2.2	2.3	2.5
34.6	0.9	1.1	1.7	1.4	1.5	1.7	1.9	2.0	2.2
39.5	0.8	0.9	1.1	1.2	1.3	1.5	1.6	1.8	1.9
44.5	0.7	0.8	1.0	1.1	1.2	1.3	1.4	1.6	1.7
49.4	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
	Late Field Class (Harvest 25 August)								
19.8	1.9	2.2	2.5	2.8	3.1	3.4	3.7	4.0	4.3
24.7	1.5	1.7	2.0	2.2	2.5	2.7	3.0	3.2	3.5
29.7	1.2	1.4	1.6	1.9	2.1	2.3	2.5	2.7	2.9
34.6	1.1	1.2	1.4	1.6	1.8	1.9	2.1	2.3	2.5
39.5	0.9	1.1	1.2	1.4	1.5	1.7	1.9	2.0	1.8
44.5	0.8	1.0	1.1	1.2	1.4	1.5	1.7	1.8	1.9
49.4	0.7	0.9	1.0	1.1	1.2	1.4	1.5	1.6	1.7

Table III.5. Larval damage units (LDUs)[1] for variegated cutworm larval instars in early, average, and late field classes for varying sample dates. LDUs are damage units expected in kg/ha.

Sample Date	Instar 1	2	3	4	5	6
Early Field Class (Harvest 5 August)						
July 1	1.28	1.17	1.05	1.23	0.93	0.34
July 5	1.17	1.26	1.17	1.42	1.12	0.43
July 10	0.76	1.26	1.24	1.56	1.26	0.50
July 15	0.31	0.78	1.20	1.68	1.40	0.58
July 20	0.10	0.29	0.67	1.51	1.51	0.65
July 25	0.03	0.09	0.24	0.74	1.30	0.68
Average Field Class (Harvest 15 August)						
July 1	1.09	0.93	0.77	0.84	0.59	0.18
July 5	1.19	1.06	0.93	1.05	0.77	0.29
July 10	1.26	1.17	1.06	1.26	0.94	0.36
July 15	1.23	1.26	1.18	1.45	1.13	0.43
July 20	0.77	1.26	1.26	1.60	1.32	0.55
July 25	0.30	0.77	1.19	1.69	1.43	0.61
Late Field Class (Harvest 25 August)						
July 1	0.75	0.54	0.38	0.36	0.20	0.06
July 5	0.92	0.72	0.54	0.52	0.33	0.10
July 10	1.06	0.89	0.72	0.73	0.46	0.15
July 15	1.18	1.05	0.91	1.00	0.67	0.22
July 20	1.27	1.18	1.08	1.27	0.93	0.33
July 25	1.17	1.27	1.19	1.48	1.17	0.45
July 30	0.63	1.18	1.28	1.63	1.34	0.56

[1]Predicted oil yield loss (kg/ha) = density 1st instar/1000 cm^2 × LDU for instar 1) + (density 2nd instar/1000 cm^2 × LDU for instar 2) + ...

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CHAPTER IV

SWEEP-NET AND GROUND SEARCH SAMPLING METHODS FOR VARIEGATED CUTWORM IN PEPPERMINT

ABSTRACT

Sweep-net samples (10, 180° sweeps) were suitable for sampling variegated cutworm (VC), *Peridroma saucia* (Hübner) instars 2 to 4 in peppermint. The mean to variance relationship was described using Taylor's power law ($s^2 = \alpha\bar{x}^\beta$), where $\alpha = 1.129$, $\beta = 1.609$ ($r^2 = 0.95$). Ground search (GS) samples (1000 cm^2 for 10 minutes) were suitable to sample instars 5 to 6; power law parameters were $\alpha = 1.37$, $\beta = 1.72$ ($r^2 = 0.89$). Sweep-net sample means were regressed against GS sample means for each VC instar. Efficiency of GS sampling for each instar was determined by vacuuming and searching the soil surface sampled. Sampling method regression slope values were used with GS recovery efficiency percentages to derive approximate economic threshold (ET) estimates for the sweep-net method.

The *k* values of the negative binomial distribution, used as the sampling distribution were fitted at ET densities. The ET for sweep-net samples was 4.0 larvae/10 sweeps and $k = 2.46$; for GS samples the ET was 1.9 larvae/1000 cm^2 and $k = 1.65$. Using Taylor's power law to estimate variances, sample size curves were generated for fixed standard error (SE) values and SE as a proportion of the mean. Sample size requirements at the threshold densities were 18 for GS and 11 for sweep-net samples with the SE set at 25% of the mean. Sequential sampling plans for each sampling method also were developed.

INTRODUCTION

The variegated cutworm (VC), *Peridroma saucia* (Hübner), is an important defoliating pest of peppermint (Berry 1977) and many vegetable crops (Rings et al. 1976). It is often classified as a "climbing cutworm" because larvae feed on foliage during the night and cooler daylight hours but otherwise remain near the soil surface. Shields and Wyman (1984) reported that instars 1 to 3 were positively phototaxic and instars 4 to 6 were negatively phototaxic. In peppermint, sweep-nets have been used to sample early larval instars, suggesting that sweep samples may be used in a sampling program for early detection and management of potentially damaging VC populations.

Research reported here describes a sampling program for VC larvae in mint, including a description of spatial distributions for the sweep-net and ground search (GS) methods, sample size requirements and a sequential sampling program based on economic threshold model studies (Chapter III).

MATERIALS AND METHODS

Sampling Methods

Fields were located in the mid-Willamette valley of western Oregon and were commercial black Mitcham peppermint with no recent insecticide applications. Fields were at least 6 ha in size, and only 12 ha were included in the sampling universe for fields of greater sizes. Fields were sampled by walking nearly the entire field and stopping every 30 to 60 paces to take samples to minimize sampling costs while assuring as near a complete sample coverage of the fields as possible. Standard sweep-nets (38 cm diameter) were used to take 180° sweeps, ten sweeps per set, in peppermint foliage. Samples were placed on a light colored ground cloth and each VC instar was counted. Instars of field collected larvae were verified in the lab by measuring head capsule widths (Coop and Berry 1986) with an ocular micrometer on a dissecting microscope. Ground search samples were taken near sweep sample sites by placing a 3 sided 1000 cm^2 iron frame on the ground, vigorously shaking the foliage above and next to the frame, and searching the area enclosed in the sampling frame for at least ten minutes. The searches included checking dead leaves and other debris that may harbor cutworms. On several sampling occasions, the foliage within the frame also was clipped and shaken over a ground cloth to check that all larvae had been dislodged, and in no instance was a significant number of larvae recovered by this procedure.

Because sweep-net performance can be greatly influenced by environmental conditions (Southwood 1978), samples were not taken during wet conditions early in the morning or in irrigated portions of the field, and sampling was not conducted when ambient temperatures exceeded 27°C on sunny days, or 29°C on days with 80% cloud cover.

Ground Search Recovery Efficiency

To check the efficiency of the GS samples, I used a power vacuum to examine debris on the soil surface. Thirty samples were taken in four different commercial fields over two years to include a variety of soil surface conditions. For these samples, the foliage was clipped from each sample plot and shaken over a ground cloth to be sure the foliage was free of larvae; the soil surface within the 1000 cm^2 frame was searched for ten minutes; and the area was vacuumed for one minute to remove all loose dirt and debris. The vacuum contents were spread on a ground cloth and examined for all VC larval instars for ten minutes. The results were expressed as the proportion of the total of each instar recovered by both methods that were initially found through the GS technique. I estimated 95% confidence intervals for the proportion recovered using either the normal approximation to the binomial distribution or binomial confidence interval tables (Steel and Torrie 1980).

Sampling Methods Comparison

To compare sweep-net and ground search sampling methods, sweep and GS methods were tested in 1983 using 20 samples per field. Results from all but one field proved to be too imprecise to evaluate VC spatial distribution patterns. Beginning in 1984, 40 samples were taken per field. Sample data used for the sweep-net and ground search comparison were from one field in 1983 with 20 samples, one field in 1984 with 30 samples, and eight fields in 1984 with 40 samples. Sample times were recorded for the two sampling methods at each field. Methods were compared for means ($\bar{x}$), standard deviation (SD), relative variations, (RV), average cost of sampling in hours (Cs), and relative net precision (RNP, 100 ÷ RV × Cs)(Ruesink 1980). Regression through the origin also was used to compare the efficiency of each sampling method in collecting each VC instar and as a potential method to convert counts from one method to the other.

Larval Spatial Pattern Characteristics

Twenty-two fields were sampled with a sweep net to define spatial distributions of larvae and to develop sequential sampling plans for the total number of instars 2 to 4. Sample numbers varied for these fields from 20 to 40 sets of ten sweeps per set. Eleven fields (n = 20 to 40) were sampled for analysis of spatial patterns of instars 4 to 6 per 1000 cm^2 in GS samples. Taylor's power equation (Taylor 1961) was used to describe sample mean - variance relationships, degree of aggregation, sample size requirements, and k of the negative binomial distribution (NBD) (Ruesink 1980). Taylor's power equation is: $y = \alpha\bar{x}^{\beta}$, where y is the sample variance, $\bar{x}$ is the sample mean, and α and β are parameters of the equation. Sequential sampling plans were developed using equations described by Waters (1955) and Onsager (1976).

RESULTS AND DISCUSSION

Comparison of Sampling Methods

Larval recovery efficiency for the ground search sampling method was 14% (95% C. I. = 2.5, 40) for instar 1, 70% (59, 82) for instar 2, 92% (86, 98) for instar 3, 95% (88, 98) for instar 4, 97% (82, 99) for instar 5, and 100% (80, 100) for instar 6 based on vacuum samples. Recovery of instars 3 to 6 exceeded 90% suggesting that this method could be considered nearly absolute for these instars. However, the 10 minute GS samples were more thorough than might be expected in an IPM program, and I have not included instar 3 in the GS sampling program described below.

The sweep-net and GS sampling methods were compared to determine the relative efficiency of each method in sampling each VC instar. Efficiency was based on high sample means, low standard errors relative to the mean, and low sample costs. Average sample means from the ten fields, SDs, RVs, RNPs, and β from Taylor's power law analysis are presented in Table IV.1. Average sample costs used to calculate RNPs were 0.140 and 0.238 person-hours per sweep set and GS sample, respectively. The sweep-net method had higher means, lower RVs, and higher RNPs than ground searches for instars 1 to 4. Ground search samples were ineffective for sampling first and second instar larvae. In sweep-net and GS samples, first instar larvae were too small to expect reliable counts from pest management personnel, and are recommended to be used primarily as an indicator of a recent hatch. Ground search samples were better than sweep samples for instars 5 and 6, resulting in RVs of 25 and 41 compared with 45 and 91 for sweep-net samples. RVs for samples separated into individual instars tended to be high overall as compared to values given by Southwood (1978), who suggested RV values should be around 10 for parameter estimation and 25 for decision making.

The β values (slopes) from Taylor's power law (Taylor 1961) were slightly greater than 1.0, except for GS samples for instars 1 and 5 (Table IV.1). According to Southwood (1978), the higher the β value, the more aggregated the distribution, and values greater than 1.0 indicate aggregated (non-Poisson or non-random) distributions. Our results indicate that VC larvae exhibit slightly clumped or aggregated distributions. The β values and other indices of spatial patterns (not presented here) showed no indication that early instar larval populations were more clumped initially than later instars, which was expected because larval populations would disperse in an area around initial egg masses as they develop.

Regressing the means for both sample methods from the ten fields resulted in significant regressions for all instars except the sixth instar. The sixth instar was under-represented in our samples because all fields with significant populations had been treated by the time instar 6 became abundant. Regression coefficient of determination values for instars 2 to 4 were considered high enough to develop approximate conversion factors for estimating one sampling method mean from the other.

The average cost of sampling a site using both methods when $n = 40$ was 15.1 hours in our study. Achieving greater precision by increasing sample size would be prohibitive for pest management purposes. The requirement for high sample numbers to achieve acceptable precision when separating individual instars in the samples and the likelihood that field scout personnel may not be able to easily differentiate each instar led to a combining of counts of instars 2 to 4 for sweep-net samples and instars 4 to 6 for GS samples for sampling programs developed here.

Adapting Economic Threshold Values

Because the two sampling methods used for VC in mint are more appropriate for certain instars than others, economic threshold values were estimated with this consideration in mind. ET values for VC larvae in peppermint were estimated using a model which simulated VC development rates, consumption rates, feeding behavior, parasitoid induced larval mortality and effects on consumption and peppermint growth rates and yield characteristics (Chapter 3). The ET values from the model were based on nominal conditions, including a price of peppermint oil of \$26.4/kg, insecticide cost of \$49.4/ha, 16 year historical average weather data, and the second of three field phenology classes, which represented a field with average mint growth rates and a harvest date of 15 August. The ET value obtained by the model was 1.9 larvae/1000 cm^2, which should be considered conservative because I did not include predator induced mortality. This ET value should be interpreted as the absolute density threshold of instars 1 to 4 which will cause damage equivalent to the cost of preventing these larval instars from reaching the more damaging instars 5 and 6.

For instars 5 and 6, ET values were decreased because larval parasitoids usually no longer impact these instars (Coop and Berry 1986). Model output was 1.4/1000 cm^2 when larval parasitoid mortality was not included. However, ET values of instars 5 and 6 would be slightly higher because insecticides would not prevent the damage already caused by these larger larvae. GS recovery efficiencies of less than 100% would decrease threshold values slightly, but could vary with the individual taking samples. Because of these trade-offs, 1.9 larvae/1000^2 will be used in calculations of the following example.

Based on an ET of 1.9 larvae per 1000 cm^2 (absolute density), I estimated a sweep-net sample ET for instars 2 to 4. One necessary assumption was that the sweep-net sampled instars 2 to 4 with equal efficiency. For instar 4, the GS recovery efficiency was 95%, so an

ET converted for GS samples was 1.9 × 0.95 = 1.8. Using the slope of the regression between sweep-net and GS samples of 0.48, an ET converted to the sweep-net method was 1.8 ÷ 0.48 = 3.7. Repeating the same steps for instar 3, the sweep-net ET was 1.9 × 0.92 ÷ 0.43 = 4.1, and for instar 2; 1.9 × 0.70 ÷ 0.30 = 4.5. Averaging these threshold values gave an ET of 4.1 larvae/10 sweeps for instars 2 to 4, which was conservatively rounded to 4.0 larvae/10 sweeps to calculate the example sampling program below.

Larval Spatial Pattern Characteristics

Sweep-net samples of instars 2 to 4 ($n = 22$) and GS samples of instars 4 to 6 ($n = 11$) were used to calculate sample means, variances, RVs, and k value estimates of the negative binomial distribution (NBD) (Table IV.2). Sample means plotted against sample variances and the line of best fit for the Taylor's power law model are plotted for sweep-net samples (Fig. IV.1) and GS samples (Fig. IV.2). For sweep-net samples, parameters of Taylor's power law were $\alpha = 1.13$ and $\beta = 1.61$, and for GS samples, $\alpha = 1.35$ and $\beta = 1.72$. The β value is often a consistent and reliable index of aggregation (Taylor 1961, 1978). It is common for β to fall between 1.4 and 2.0 for field pests (Ruesink 1980), which is consistent with my results. When β falls between 1.0 and 2.0 the population may be described using the NBD as long as a narrow range of densities is being considered (Taylor 1984). The two parameters of the NBD are $\bar{x}$ and k. Estimating k is difficult because it may not be constant, especially when the mean varies over one order of magnitude (Ruesink 1980). When developing sampling programs for pest management programs, estimates of k should therefore be within a range surrounding ET values (Onsager 1976). Two common methods for estimating k were used (Table IV.2). Method 1 was $k = \bar{x}^2 \div (S^2 - \bar{x})$ (Southwood 1978), and method two used Taylor's coefficients α and β where $k = \bar{x} \div (\alpha(\bar{x}^{\beta - 1})) - 1$ (Ruesink 1980). For ground searches, where the nominal ET was set at 1.9 larvae/1000 cm^2, and the range of densities around the ET set at 1 to 3.25 larvae/1000 cm^2, k values averaged 2.27 ($n = 8$), or excluding 1 out-of-range sample, $k = 1.64$. Using method two, k ranged from 2.80 to 1.50 and was 1.65 at 1.9 larvae/1000 cm^2. For sweep-net samples, the ET density for instars 2 to 4 was set at 4.0 larvae/10 sweeps; the range of densities around the ET was set at 2.5 to 5.5 larvae/10 sweeps. The k values for this range of densities using the first method averaged 2.79 ($n = 10$). The k values ranged from 2.57 to 2.51 using the second method. At a mean density of 4.0 larvae/10 sweeps, the second method resulted in a k estimate of 2.46. The k values of 1.65 and 2.46 derived from Taylor's power law were used in the sequential sampling plans discussed below.

Sample size curves can be drawn once aggregation characteristics are known and an appropriate equation selected. Sample reliability was defined using the standard error rather than probabilistic statements because sample sizes greater than 30 would be expected using probabilistic statements, which is unreasonable for cutworm IPM programs in mint. Sample size curves were drawn for the GS and SW methods (Figs. IV.3 and IV.4) where the standard error is a constant (g); $n = \alpha\bar{x}^{\beta}/g^2$ and where the standard error is a fraction of the mean (c); $n = \alpha\bar{x}^{(\beta-2)}/c^2$. For sweep-net samples, when the SE is 1.0 or 25% of the mean, a sample size of 11 (10 sweeps/sample) is required at the ET density (Fig. IV.3). For ground search samples, when the SE is 0.48 or 25% of the mean, 18 1000 cm^2 samples are required at the ET density (Fig. IV.4). At higher precision levels, considerably more samples are required; 16 sweep or 28 GS samples when the SE is 20% of the mean and 29 sweep or 50 GS samples when the SE is 15% of the mean. Figures IV.3 and IV.4 can supplement sequential sample plans by showing the average sample number required for a given level of precision.

Sequential Sampling Plans

Sampling insects for control decisions may be expensive. When population levels are not near ET levels, the mean does not require as precise an estimate and fewer samples may be required. Sequential sampling plans may help minimize sampling costs while allowing precise mean population estimates when required. I determined the NBD using formulae reported by Waters (1955) and Onsager (1976). The *k* values of the NBD were 2.46 for sweep-net samples and 1.65 for GS samples. The sequential sampling method requires hypotheses for two population levels; H_1: $\bar{x} \leq \bar{x}_1$, where the mean population $\bar{x}_1$ is low enough to stop sampling and no control is recommended; and H_2: $\bar{x} \geq \bar{x}_2$, where $\bar{x}_2$ is the ET; the population at or above which control is recommended. I used the ET levels for $\bar{x}_2$ of 1.9 larvae/1000 cm^2 for GS, and 4.0 larvae for sweep-net samples. I chose $\bar{x}_1$ levels to be 75% of the ET as a compromise between the greater risk that Type 1 errors occur when larger percentages of the ET are used and the longer sampling time required when lower percentages of the ET are used. Type I (α) error levels (the probability that H_2 is accepted when H_1 is true) were set at 0.05 and type II (β) error levels (the probability that H_1 is accepted when H_2 is true) at 0.10. The resulting equations of the stop lines were $d_1 = 1.65 \times n - 10.44$ and $d_2 = 1.65 \times n + 14.44$ for the GS method (Fig. IV.6) and $d_1 = 3.46 \times n - 12.59$ and $d_2 = 3.46 \times n + 17.40$ for the sweep-net method (Fig. IV.5). Definitions are d = cumulative number of larvae samples, and n is the number of samples taken. Although these sampling schemes offer the potential to quit sampling after only a few samples are taken, the sample number curves for a given precision level (Figs. IV.3 and IV.4), and the necessity of sampling all parts of a field should be considered when determining minimum sample size numbers for each sampling method.

I determined which larval instars were collected in sweep-net samples and ground search samples, applied Taylor's power law to define mean to variance relationships and developed sampling plans for each sampling method. This approach recognized the constraints inherent in sampling programs for pest management decisions; programs must be simple and adaptable to changing conditions. The implementation of a sequential sampling plan for VC in mint should improve acceptance of the more precise sampling program reported here, by reducing sampling costs and by incorporating economic threshold values in the plan. For situations when ET values change, sequential sampling plans may be easily modified to allow flexibility in the sampling program.

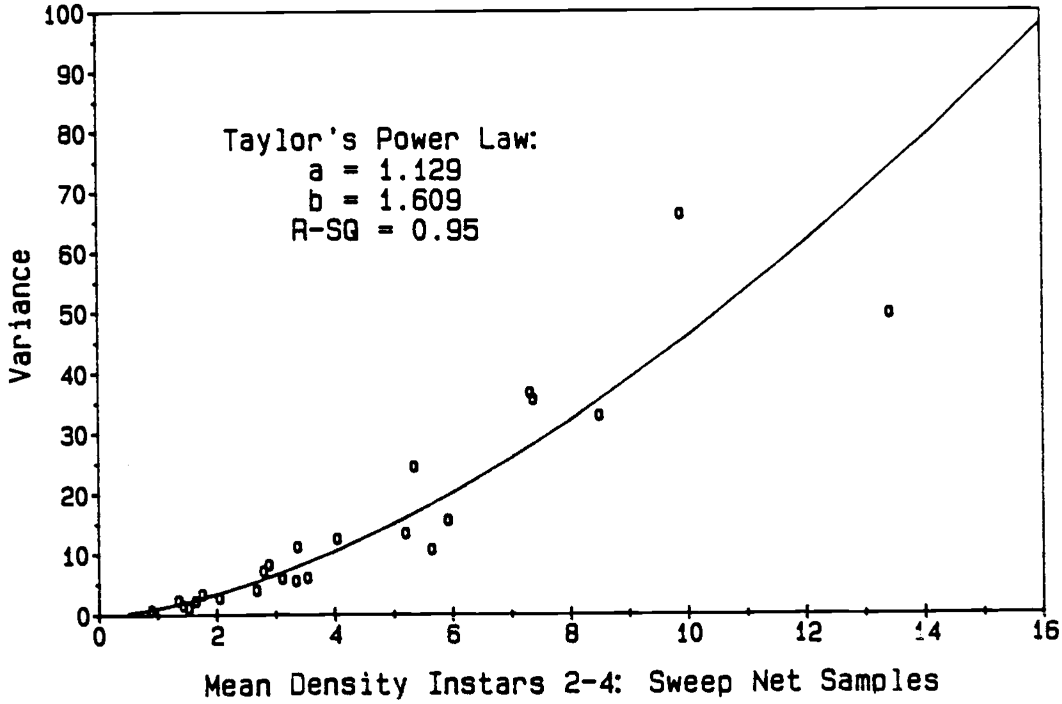

Fig. IV.1. Relationship between the mean and variance for variegated cutworm instars 2 to 4 collected in sweep-net samples in peppermint, western Oregon, 1983-85.

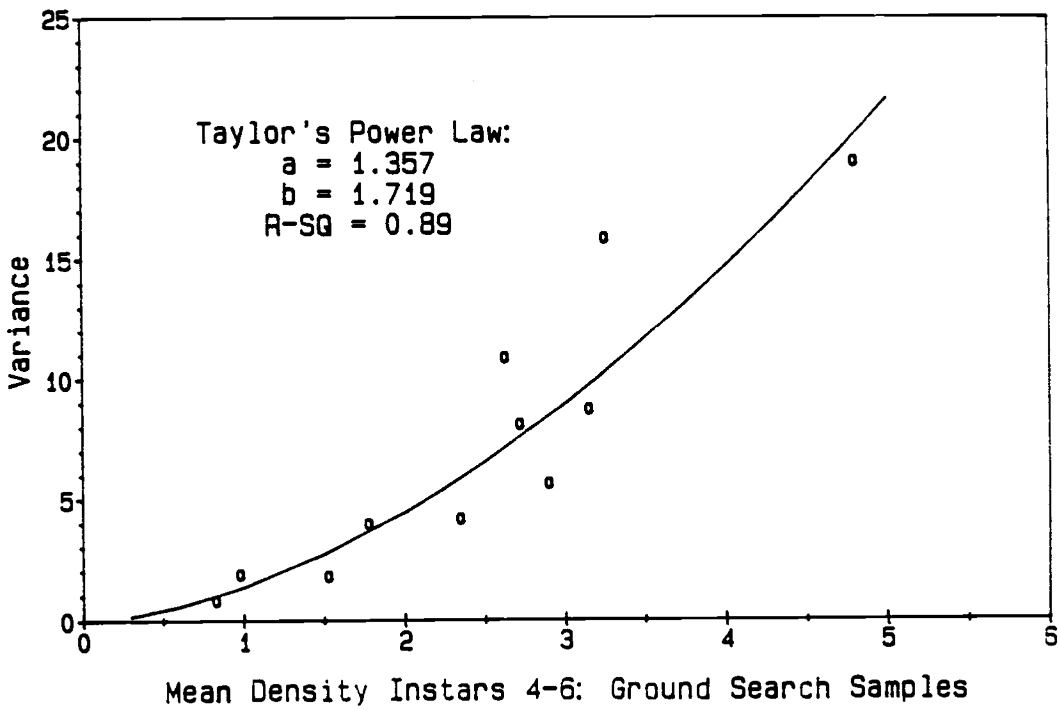

Fig. IV.2. Relationship between the mean and variance for variegated cutworm instars 4 to 6 collected during 10 minute ground searches in peppermint, western Oregon, 1983-85

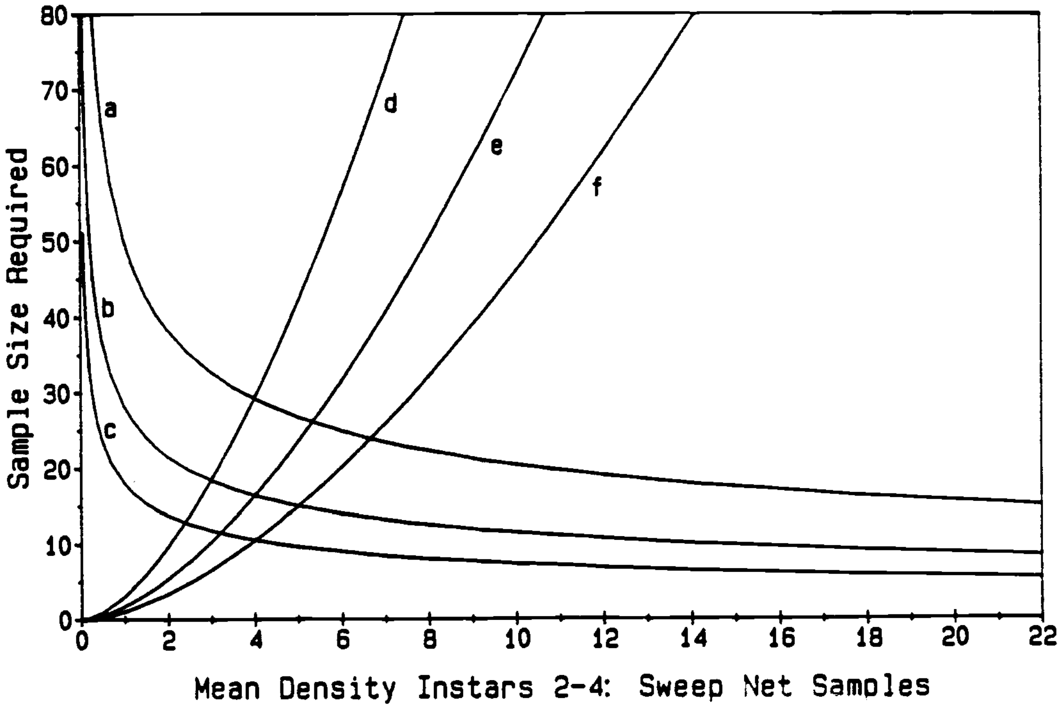

Fig. IV.3. Sample size requirements for variegated cutworm instars 2 to 4 using sweep-net samples taken in western Oregon, 1983-85, based on Taylor's power law to estimate variances. Curves a, b, and c using fixed standard error values of 0.60, 0.80, and 1.0. Curves d, e, and f using the standard error as a proportion of the mean, set at 0.15, 0.20, and 0.25.

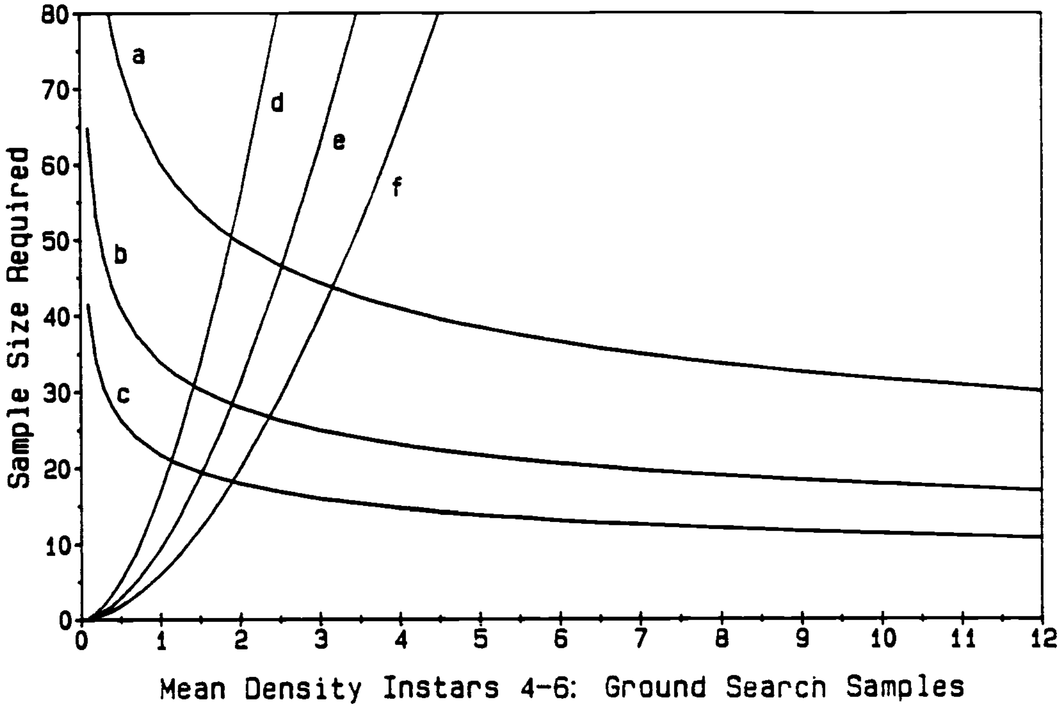

Fig. IV.4. Sample size requirements for variegated cutworm instars 4 to 6 for ground search samples taken in western Oregon, 1983-85, based on Taylor's power law to estimate variances. Curves a, b, and c using fixed standard error values of 0.29, 0.38, and 0.48. Curves d, e, and f using the standard error as a proportion of the mean, set at 0.15, 0.20, and 0.25.

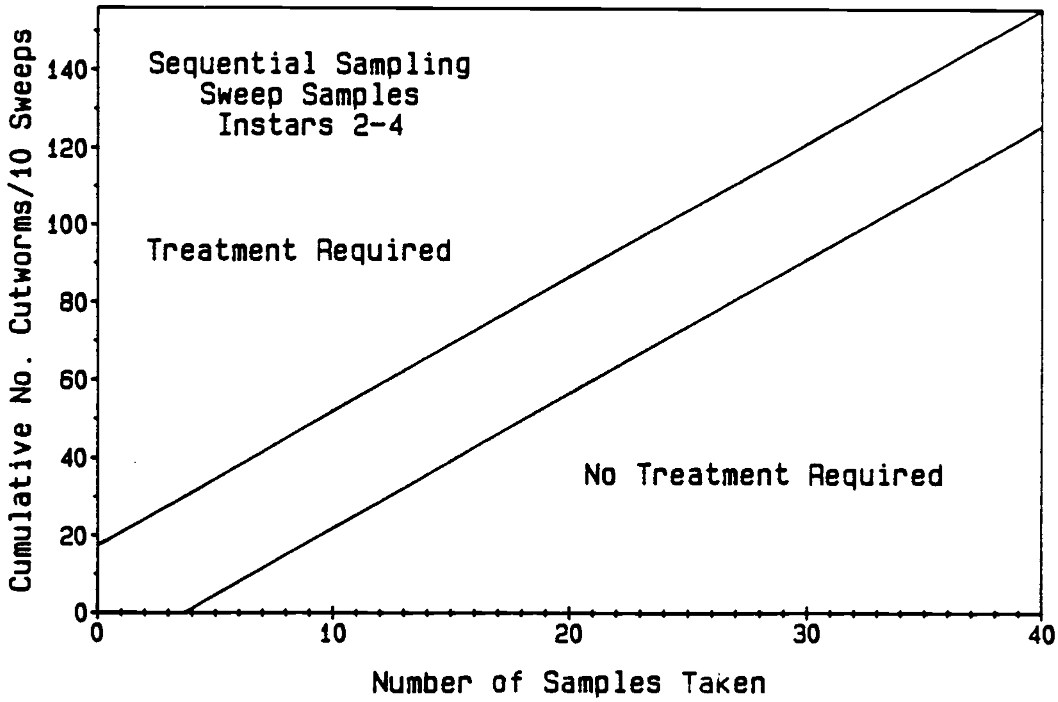

Fig. IV.5. Sequential sampling plan for sweep-net samples (10, 180° sweeps/sample, western Oregon peppermint fields) to estimate densities of variegated cutworm larval instars 2 to 4 equal to the economic threshold of 4.0 larvae and 75% of the threshold.

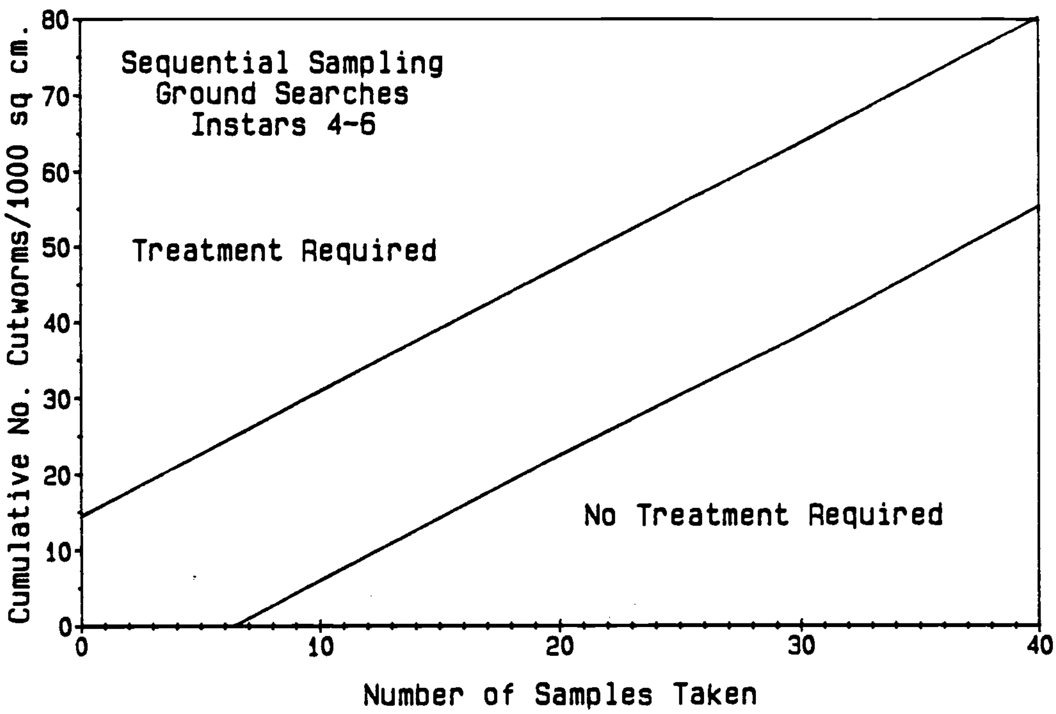

Fig. IV.6. Sequential sampling plan for use of ground search samples (1000 cm^2, 10 minute search/sample, western Oregon peppermint fields) to estimate densities of variegated cutworm larval instars 4 to 6 equal to the economic threshold of 1.9 larvae and 75% of the threshold.

Table IV.1. Summary of sweep-net (SW) and ground search (GS) sampling methods for variegated cutworm larvae in peppermint, western Oregon, 1983-85.

Instar	Sample Method	$\bar{x}$ Values			Taylor's Power Law	Regression: GS = β(SW)			
		$\bar{x}$	RV	RNP[1]	β	β	$\pm$ SE	r^2	$P(\beta=0)$
I	SW	1.7	27.2	26.3	1.09	0.02	0.01	0.66	0.005
	GS	0.0	79.8	5.3	0.95				
II	SW	2.1	19.2	37.2	1.37	0.30	0.05	0.81	0.0002
	GS	0.6	35.9	11.7	1.28				
III	SW	3.7	18.1	39.4	1.33	0.42	0.03	0.96	0.0000
	GS	1.7	25.9	16.2	1.44				
IV	SW	2.3	21.5	33.2	1.28	0.48	0.08	0.82	0.0001
	GS	1.5	20.6	20.4	1.59				
V	SW	0.3	45.0	15.9	1.02	2.00	0.34	0.80	0.0002
	GS	0.8	24.9	23.8	0.98				
VI	SW	0.1	90.9	7.9	-	2.37	2.15	0.15	0.31
	GS	0.3	41.2	10.2	1.43				

[1]RNP is Relative Net Precision = 100 ÷ (RV × Cs).

Table IV.2. Sampling statistics from individual sample fields for variegated cutworm larvae collected by sweep-net and ground search, western Oregon, 1983-85.

Site ID	Date	n	$\bar{x}$	SD	s^2	SE	RV	est k[1]	est k[2]
Sweep-net Method (10, 180° sweeps/sample)									
DG	7/10/83	20	32.1	17.7	314.0	4.0	12.4	3.6	3.9
IB	7/5/85	40	13.4	7.1	50.0	1.1	8.3	4.9	3.0
TB	7/3/84	30	9.9	8.2	66.4	1.5	15.0	1.7	2.8
HP	7/4/84	40	8.5	5.8	33.1	0.9	10.7	2.9	2.7
E2	7/16/84	24	7.4	6.0	35.8	1.2	16.5	1.9	2.6
HP	7/11/84	40	7.3	6.1	36.8	1.0	13.1	1.8	2.6
CH	7/13/84	40	5.9	4.0	15.8	0.6	10.6	3.6	2.5
KP	7/8/84	40	5.7	3.3	11.0	0.5	9.3	5.9	2.5
JO	7/9/85	40	5.4	5.0	24.7	0.8	14.7	1.5	2.5
EU3	6/30/84	22	5.2	3.7	13.6	0.8	15.1	3.2	2.5
RO	7/8/85	40	4.1	3.6	12.8	0.6	14.0	1.9	2.5
E2	7/10/84	24	3.6	2.5	6.4	0.5	14.5	4.5	2.5
CH	7/21/83	20	3.4	3.4	11.5	0.8	22.4	1.4	2.5
HP	7/17/84	35	3.4	2.4	5.8	0.4	12.2	4.6	2.5
H99	7/11/85	40	3.1	2.5	6.2	0.4	12.6	3.2	2.5
CH	7/14/83	20	2.9	2.9	8.5	0.7	22.5	1.5	2.5
CU	7/21/83	30	2.8	2.7	7.5	0.5	17.8	1.7	2.5
E2	7/22/84	40	2.7	2.1	4.3	0.3	12.2	4.5	2.5
GF	7/26/84	31	2.1	1.7	3.0	0.3	15.2	4.5	2.7
CK	7/29/83	27	1.8	1.9	3.7	0.4	20.9	1.6	3.0
CK	7/30/83	30	1.7	1.6	2.5	0.3	17.6	3.1	3.1
PR	7/22/83	20	1.5	1.2	1.4	0.3	17.3	-17.0	3.3
HP	7/17/83	25	1.4	1.3	1.8	0.3	18.6	5.8	3.5
HP	6/27/84	40	1.4	1.6	2.7	0.3	18.9	1.4	3.8
KP	6/29/84	40	0.9	1.0	1.0	0.2	17.9	5.8	15.3
Ground Search Method (1000 cm^2/sample)									
DG	7/10/83	20	4.8	4.4	19.1	1.0	20.4	1.6	1.5
HP	7/4/84	40	3.3	4.0	15.9	0.6	19.4	0.8	1.5
HP	7/11/84	40	3.2	3.0	8.8	0.5	14.9	1.8	1.5
CH	7/13/84	40	2.9	2.4	5.7	0.4	13.0	3.0	1.5
E2	7/22/84	40	2.7	2.9	8.2	0.5	16.6	1.4	1.5
TB	7/3/84	40	2.6	3.3	11.0	0.5	19.9	0.8	1.5
HP	7/23/83	20	2.3	2.1	4.2	0.5	19.6	2.9	1.6
IB	7/5/85	40	1.8	2.0	4.0	0.3	17.9	1.4	1.7
JO	7/9/85	40	1.5	1.4	1.9	0.2	14.1	7.3	1.8
H99	7/11/85	40	1.0	1.4	1.9	0.2	22.4	1.0	2.9
RO	7/8/85	40	0.8	0.9	0.9	0.2	17.7	19.7	4.4

[1] k estimated from equation $k = \bar{x}^2 \div (s^2 - \bar{x})$.
[2] k estimated from equation $k = \bar{x} \div (\alpha \times \bar{x}^{\beta-1} - 1)$; α and β from Taylor's power law.

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APPENDICES

Appendix I. MINTSIM peppermint defoliation model source code listing; files Mintsim.pas and Dayrpt.inc.

```
PROGRAM MINTSIM; { MINT defoliation SIMulator version 3-24-87 }
{ THIS PROGRAM MODELS PEPPERMINT MORPHOLOGICAL GROWTH, HARVEST
  CONDITIONS, VARIEGATED CUTWORM FEEDING BEHAVIOR, CONSUMPTION RATE,
  DEVELOPMENT, AND SURVIVAL.  TO BE USED FOR DETERMINATION OF CUTWORM
  ECONOMIC THRESHOLDS.

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}

{**********************************************************************
                  MAJOR CONSTANTS AND DECLARED TYPES
**********************************************************************}
  CONST
    MAXNODES = 11; { MAX NO. OF NODES WITH LEAVES AT ANY ONE TIME }
    { USED FOR FACTORIAL MAPPING PROC.              }
    MAXWIN = 3; { MAX NO. WINDOWS }

  TYPE
    MAINLEAF =
      RECORD { THE PEPPERMINT PLANT MAINSTEM LEAF RECORD }
        EMRGED: BOOLEAN; { BECOMES TRUE WHEN NODE IS ADDED }
        ABCISSED: BOOLEAN; { TRUE WHEN NODE LEAVES ABSCISS }
        DATEORIG: INTEGER; { JULIAN DATE LEAVES ARE ADDED }
        DATEABCS: INTEGER; { JULIAN DATE LEAVES ARE ABSCISSED }
        DRYCON: REAL; { LEAF DRY WT. CONSUMED AT THAT LEAF NODE CURR. DAY }
        DRYCUM: REAL; { CUMULATIVE LEAF DRY WT. CONSUMED AT THAT LF NODE }
      END;

    PLNTTYPE =
      RECORD
        LATLVS: REAL; { # LATERAL LEAVES }
        LATCON: REAL; { DRY WT. CONSUMED LATERALS/1000 SQ CM FOR CURR DAY }
        LATCUM: REAL; { CUMULATIVE AMT. DRY WT. CONSUMED }
        MLVS: ARRAY [0..20] OF MAINLEAF;
      END;

    SCREENTYPE = (REG, SUPPR, NEITHER, GRF); { CHOICE OF DAILY OUTPUTS }
    FIELDAGETYPE = (EARLY, MID, LATE); { THREE FIELD PHENOLOGY TYPES }

    FACTORIAL = ARRAY [0..MAXNODES] OF REAL; { USE TO STORE FACTORIALS }
    SNAME = STRING[12];
    STR3 = STRING[3];

  VAR
{**********************************************************************
                  PLANT & OTHER GLOBAL VARIABLES
**********************************************************************}
    Pl: PLNTTYPE;
```

```
{ STRING VARIABLES }
  ISTNM: STRING[8];                    { WEATHER STATION NAME }
  YEAR: STRING[4];                      { YEAR OF WEATHR DATA }
  COMSTRING: STRING[50];   { USE FOR COMMENTS OUTPUT TO PRN FILES AND
                                                             SCRN }

{ DD (DEGREE-DAY) VARIABLES }
SETDD, { DEGREE-DAYS AFTER 1 JUNE FOR INITIAL MODEL SETTING }
 CURDD, { THE DD'S CALCULATED FOR THE CURRENT DAY }
 CUMDD, { CUMULATIVE DD'S SINCE 1 JUNE }
 CUMDDLAST: REAL; { CUM DD'S FROM PREVIOUS DAY }
RCURDD: INTEGER; { ROUNDED CURDD AND CUMDD }
TRIM, { REMAINDER FROM ROUNDING DD TO EVEN NO. }
 TCURDD, { DD 'TRIMMED' OR ROUNDED TO EVEN NO. }
 HITEMP: REAL; { DAILY HI TEMP }

{ PLANT NODE & ABSCISSION RELATED VARIABLES }
LSTJDABSC, { LAST JUL DATE ON WHICH LEAF ABSCISSION OCCURED }
 LSTJDADD, { LAST JUL DATE A LEAF WAS ADDED }
 XNODEADD, { TOTAL # NODES ON PLANT }
 XNODEABSC: INTEGER; { # NODES WITH ABSCISSED LEAVES }
RNEXTNODE, { NEXT NODE ADDED }
 RNODELOST: REAL; { NEXT NODE LOST }
NEXTNODE, { THE NEXT NODE ADDED - ROUNDED }
 NODELOST, { THE NEXT NODE LOST - ROUNDED }
 PARTNODE, { NODE ONLY PARTLY ABSC AT HARVEST }
 NODESIZE: INTEGER; { # OF NODES WITH LEAVES }
NEXTNODEPART: BOOLEAN; { NOTE WHICH LF PAIR IS PARTIALLY ABSCISSED;
                         THE LAST NODE (NODESIZE) OR THE NEXT NODE
                         (NODESIZE+1)}

{ DATE AND BOOLEAN VARIABLES RELATED TO DATE }
FRSTDAY, { FIRST JUL DAY OF MODEL RUN }
 TODAY, { CURRENT JUL DATE AFTER 1 JUNE }
 JDATEHARV, { JUL DATE OF HARVEST REQUESTED FROM INPUT FILE }
 HARVESTDAY: INTEGER; { JUL DATE OF HARVEST ACTUALLY USED }

HDATEFLAG, { FLAG TO SHOW (NON-DEFAULT) REQUESTED HARVEST DATE }
 ADDPLOTFLG, ABSCPLOTFLG: BOOLEAN; {FLAGS USED IN GRAPHICS OUTPUT}
HFLAG: INTEGER; { CONVERTED TO HDATEFLAG }

{ FEEDING LOCATION & LATERAL PREFERENCE VARS. }
FAC: FACTORIAL; {FACTORIAL ARRAY}
LATPREF, { 0<LATPREF<1.0 FEEDING PREFERENCE FOR LATERALS }
 LATPORP, { PROPORTION OF CONSUMPTION TO LATERALS }
 PORP: REAL; { 0<PORP<1.0 p PARAMETER OF BINOMIAL MASS FUNCTION }
CURFEEDDIST: ARRAY [0..MAXNODES] OF REAL; { CURRENT DISTRIB. ARRAY }

{ CONSUMPTION VARIABLES }
CUMTOT: REAL; { CUM DRY WT. CONSUMED TOTAL PLANT }
LFOILCONMAIN: REAL; { TOTAL OIL CONSUMED MAINSTEM PER 1000 SQ CM }
TOTOILCON: REAL; { TOTAL OIL CONSUMED PER 1000 SQ CM }
TOTDRYCON: REAL; { TOTAL DRY WT CONSUMED PER 1000 SQ CM }
TOTOILCONPERACRE: REAL; { TOTAL OIL CONSUMED CONVERTED TO LB/ACRE }

{ VARIABLES RELATING TO I/O }
```

```
    SCRTYPE: SCREENTYPE;
    NSCRTYPE, { INTEGER READ FROM PARAM FILE CONVERTED TO SCRTYP }
     DDOPT: INTEGER; { DD OPTIONS: 1= CALC DD'S 2= JUST READ FROM FILE }
    CALCDDFLAG: BOOLEAN; { TRUE IF WE CALC DAY DEGREES FROM WEATHR }
    FIELDTYPE: FIELDAGETYPE;
    FT: INTEGER; { INDICATE FIELDTYPE 1=EARLY 2=MID 3=LATE }
    ESTYIELD,          { EST YIELD LB/ACRE }
    OILPRICE,          { EST OIL PRICE $/LB }
    CONTROLCOST,    { EST. CONTROL COST $/ACRE }
    DAMAGETOLERANCE : REAL;
    ONLINEOPTION: INTEGER; { OPTION TO INPUT SAMPLE DATA ON ANY DATE }
    ONLINE: BOOLEAN;        { FLAG SIGNALS THAT ONLINE OPTION TAKEN }
    STARTDATE: INTEGER; { DATE TO START SIMULATION FOR ON-LINE OPTION }

    SK,                 { FILE FOR STORING USER PARAMETERS }
    DDDAT,              { FILE  USED FOR STORING TEMP AND DD'S }
    COUT, POUT: TEXT[$800];  { FILES USED FOR CUTWORM AND PLANT OUTPUT }

    FILENM1, FILENM2: STRING[12]; { FILENAME VARS }
    QLOOP: INTEGER;     { USED TO COUNT PROGRAM LOOPS }
    L,M: INTEGER;       { MISC. LOOP COUNTERS }
    RUNUM: STRING[2];   { STRING CONVERSION OF Q }
    ANSW: CHAR;         { USED FOR KEYBOARD RESPONSE }
    BCOL: INTEGER;      { USE FOR BKGND COLOR - MED RESOLUTION GRAPH MODE }

{*******************************************************************
                    VCDEV SECTION VARIABLES
*******************************************************************}

  CONST
    DU1 = 48 {44} ; { NO. DEV UNITS (DD'S BASE 5 C) REQUIRED FOR DEV }
    DU2 = 32 {30} ; { EACH INSTAR - USED AS THE # SUBSTAGES IN THE MODEL }
    DU3 = 33 {31} ; { NOW USE 1 SUBSTAGE = 2 DEV UNITS TO SPEED UP PRGRM }
    DU4 = 34 {31} ;
    DU5 = 45 {42} ;
    DU6 = 70 {65} ;
    DU7 = 1; { ONE SUBSTAGE IN PUPAL STAGE }
    MAXDU = 70 {65} ; { SET EQUAL TO HIGHEST DU ABOVE }
  TYPE

    DEVUNITS = ARRAY [1..7] OF INTEGER; { ARRAY OF DU1, DU2, ETC }

    VCREC = ARRAY [1..6] OF
        RECORD
          QUANTCONS, { AMT CONS BY EACH INSTAR PER DD }
           SURVRATE: REAL; { SURVIVORSHIP RATE APPLIED ONLY DURING }
        END; { TRANSITION FROM ONE INSTAR TO NEXT }

  VAR
    EGGSPERSQ: REAL;  { # EGGS PER 1000 SQ CM DURING RUN }
    DDSTEP: INTEGER; { COUNTER IN DDLOOP }
    DENS: ARRAY [1..7, 1..MAXDU] OF REAL; { STORE DENS OF EACH SUBSTAGE }
    DUS: DEVUNITS;
    DENSTOT: ARRAY [1..6] OF REAL; { TOTAL DENSITY EACH INSTAR }
    STARTL : ARRAY [1..6] OF REAL; { INIT DENS 6 INSTARS - ONLINE OPT }
    STARTTOT: REAL; { TOTAL INIT DENS - ONLINE OPT }
```

```
DENSTOTLST: ARRAY [1..6] OF REAL; { TOTAL INST DENS FOR PREV DAY }
TDENS: REAL; { TOTAL DENSITY L1-6 }
AMTFEEDTODAY: ARRAY [1..6] OF REAL; { TOTAL DRY WT CONSUMP EACH INST }
AMTFEEDTOT: REAL;     { TOTAL DRY WT CONSUMPTION ALL INSTARS }
VC: VCREC;
MEANEGGDD, { NEXT 4 PARAMS USED IN CUM NORMAL CALC OF EGG HATCH }
 STARTEGGDD, ENDEGGDD, VARIANCEGGDD: REAL;
OFFSETDD,         { USED TO SHIFT EGGHATCH TRAJECT. FOR BEHAV. STUDIES }
TRUNCFAC: REAL; { CORRECT EGG HATCH FOR TRUNCATED NORMAL DIST. }
EGGHATCH, { THE PROPORTION OF TOTAL EGG HATCH FOR THE DAY }
 CUMEGGHATCH: REAL; { CUMULATIVE - SHOULD = 1.00 AT END OF HATCH }
POPHATCHTODAY: REAL; { ACTUAL # HATCHING FOR THE DAY }

{*******************************************************************}


{********************************************************************
               BEGINNING OF WEATHER INPUT SECTION
*******************************************************************}

{$I WCALC.INC}
  { OPTIONAL INCLUDE FILE - A SLIGHTLY MODIFIED
  VERSION OF PASHEAT.PAS.  CONTAINS THE ROUTINES TO CALCULATE DEGREE
  DAYS FROM THE FILE WEATHR.DAT AND STORES THEM IN FILE CALLED HEAT.PRN }
  {******************************************************************
                      END OF WEATHER INPUT SECTION
  ******************************************************************}
  { GLOBAL DAY AND DATE FUNCTIONS }

    FUNCTION CALCMNTH(DAY: INTEGER): STR3; { CONVERT FROM GROWING DAY TO
                                             DATE }

      BEGIN
        { GROWING DAY SHOULD BE BETWEEN 1 AND 93 }
        IF ((DAY > 0) AND (DAY < 31)) THEN
          CALCMNTH := 'JUN'
        ELSE IF ((DAY > 30) AND (DAY < 62)) THEN
          CALCMNTH := 'JUL'
        ELSE IF ((DAY > 61) AND (DAY < 94)) THEN
          CALCMNTH := 'AUG';
      END;


    FUNCTION CALCDATE(DAY: INTEGER): INTEGER;

      BEGIN
        { GROWING DAY SHOULD BE BETWEEN 1 AND 93 }
        IF ((DAY > 0) AND (DAY < 31)) THEN
          CALCDATE := DAY
        ELSE IF ((DAY > 30) AND (DAY < 62)) THEN
          CALCDATE := DAY - 30
        ELSE IF ((DAY > 61) AND (DAY < 94)) THEN
          CALCDATE := DAY - 61;
      END;
```

```
PROCEDURE INITPLNT; { INIT THE PLANT ARRAY }

 VAR
   X: INTEGER;


 PROCEDURE MAPFACTORIAL; { SET UP ARRAY FOR FACTORIAL LOOKUP }
  { FACTORIALS (X!) USED BY BINOMIAL FUNCTION }

   VAR
     I: INTEGER;
     F: REAL;


   BEGIN
     F := 1;
     FAC[0] := 1;
     FOR I := 1 TO MAXNODES DO
       BEGIN
       F := (F * I);
       FAC[I] := F;
       END;
   END;


 BEGIN { INITPLNT }
   MAPFACTORIAL;
   WITH P1 DO      { INIT PLANT REGISTERS TO 0 }
     BEGIN
     LATLVS := 0.0;
     LATCON := 0.0;
     LATCUM := 0.0;
     FOR X := 0 TO 20 DO
       WITH MLVS[X] DO
         BEGIN
         DATEORIG := 0;
         EMRGED := FALSE;
         ABCISSED := FALSE;
         DRYCON := 0.0;
         DRYCUM := 0.0;
         END;
     END; { WITH P1 }
 END; { INITPLNT }

 PROCEDURE INITVC; { INITIALIZE VC PARAMETERS }

 VAR
 I, J: INTEGER;


     BEGIN { PROCEDURE INITVC }
       TRIM := 0.0;
       BEGIN {INIT EGG HATCH PARAMETERS}
       CASE FIELDTYPE OF
         EARLY:
           BEGIN
```

```
    MEANEGGDD := 175; { 50% HATCH AT 175 DD AFTER 1 JUNE }
    STARTEGGDD := 0.0; { 0% HATCH AT 0 DD AFTER 1 JUNE }
    ENDEGGDD := 350.0; { 100% HATCH AT 350 DD AFTER 1 JUNE }
    TRUNCFAC := 1.043; { USE TO CORRECT FOR THE TAIL TRUNCATION }
    END; { IS APPLIED EVENLY DURING INTERVAL OF HATCH }
  MID:
    BEGIN
    MEANEGGDD := 255;
    STARTEGGDD :=80.0;
    ENDEGGDD := 430;
    TRUNCFAC := 1.0369;
    END;
  LATE:
    BEGIN
    MEANEGGDD := 335;
    STARTEGGDD :=160;
    ENDEGGDD := 510;
    TRUNCFAC := 1.037;
    END;
  END; { CASE }
MEANEGGDD := MEANEGGDD + OFFSETDD;  { ALLOW OFFSET FOR BEHAV. }
STARTEGGDD := STARTEGGDD + OFFSETDD;  { & SENS. STUDIES }
ENDEGGDD := ENDEGGDD + OFFSETDD;

VARIANCEGGDD := 6916; { VARIANCE IN EGG HATCH CURVE }
END; {INIT EGG HATCH PARAMETERS}

VC[1].QUANTCONS := 0.0359;
 { CONSUMPTION RATE = DRYWT CONS/ 2 DD'S INSTARS }
 { 1-2 ESTIMATED SINCE THEY COULD NOT BE MEASURED}
VC[2].QUANTCONS := 0.1114;
VC[3].QUANTCONS := 0.3363; { BY BERRY & SHIELDS }
VC[4].QUANTCONS := 1.0215;
VC[5].QUANTCONS := 3.356;
VC[6].QUANTCONS := 9.21;
FOR I := 1 TO 3 DO
  VC[I].SURVRATE := 1.0; {SET 1ST 3 INSTARS TO 100%}
FOR I := 5 TO 6 DO
  VC[I].SURVRATE := 1.0;
VC[4].SURVRATE := 0.73   ; { < 1.0 DUE TO PAR. BY PORIZONTINAE
                                  AND METEORUS}
DUS[1] := DU1; { INIT DEV ARRAY }
DUS[2] := DU2;
DUS[3] := DU3;
DUS[4] := DU4;
DUS[5] := DU5;
DUS[6] := DU6;
DUS[7] := DU7;
FOR I := 1 TO 6 DO { INIT VC DENS ARRAYS TO 0 }
  BEGIN
  DENSTOTLST[I] := 0.0;
  FOR J := 1 TO MAXDU DO
    DENS[I, J] := 0.0;
  END;
DENS[7, 1] := 0.0; { DENSITY OF PUPAE := 0 }
CUMEGGHATCH := 0.0;
```

```
      END; { PROCEDURE INITVC }

{******************** DAILY_ITER SECTION ****************************
  THE MODEL GOES THROUGH ITS DAILY ITERATIONS WITH PROCEDURES TO
  SET UP THE PLANT ON THE INITIATION DATE, GET THE TABLED DAILY
  DEGREE DAYS, CALCULATE FOR TIME TO ADD PLANT NODES AND
  ABSCISS PLANT NODES, CALCULATE LATERAL LEAF DEVELOPMENT, CALCULATE
  VC DEVELOPMENT, CALCULATE THE DAILY AMOUNT OF DEFOLIATION, AND
  OUTPUT THE DAILY REPORT.
*******************************************************************}


  PROCEDURE DAILY_ITER;

    VAR
      NXTJD: INTEGER;
      I: INTEGER;
      TOSSREAL: REAL;


    FUNCTION BINOM(X: INTEGER;
                   T: INTEGER;
                   PORP: REAL): REAL;
    {THIS FUNCTION CALCULATES THE PROPORTION OF TOTAL MAINSTEM LEAF CONSUMP
     WHICH WILL OCCUR AT EACH LEAFNODE EACH DAY. PORP IS THE p OF THE BINOM
     MASS FUNCTION. X IS THE CURRENT NODE BEING CALCULATED. T IS THE NO. OF
     CLASSES OF THE BINOMIAL MASS FUNCTION - CURRENT # OF NODES ON PLANT}

      VAR
        T2: INTEGER;
        PP: REAL;


      BEGIN { p(x) = t!/x!(t-x)*((p**x(1-p)**t-x)) BINOMIAL MASS FUNCTION }
        T2 := T - X;
        PP := FAC[T] / (FAC[X] * FAC[T2]);
        BINOM := PP * (EXP(X * LN(PORP)) * EXP((T2) * LN(1 - PORP)));
      END;


    PROCEDURE SETPLANT(JDT: INTEGER); { SET UP THE PLANT AT BEGINNING OF
                                        SEASON }


      BEGIN {SETPLANT}
        CASE FIELDTYPE OF
          EARLY:
            XNODEADD := 6; { PLANT BEGINS WITH 6, 4, OR 3 MAINSTEM NODES }
          MID:
            XNODEADD := 4;
          LATE:
            XNODEADD := 3;
          END; { CASE }
        NODESIZE := XNODEADD;
        WITH P1 DO
```

```
      BEGIN
      FOR I := 0 TO XNODEADD DO { INIT MAINSTEM LEAVES AS
                                             EMERGED, DATE }
        WITH MLVS[I] DO
          BEGIN
          DATEORIG := JDT - 1;
          EMRGED := TRUE;
          END;
      END;
    IF FIELDTYPE = EARLY THEN { EARLY FIELDS ALREADY LOST 1 NODE }
      BEGIN
      XNODEABSC := 1;
      NODESIZE := XNODEADD - 1;
      P1.MLVS[XNODEADD].ABCISSED := TRUE;
      P1.MLVS[XNODEADD].DATEABCS := JDT - 1;
      END
    ELSE
      XNODEABSC := 0; { NONE ABCSISSED }
  END; {SETPLANT}


PROCEDURE GETSETDD(JDT: INTEGER); { INIT THE CURRENT CUMDD
   AND DD FOR THE FIRSTDAY OF THE MODEL RUN FROM THE
   DD FILE CALLED HEAT.PRN WHICH SHOULD LOOK SOMETHING
   LIKE THIS:

"WEATHER" "DATA" "SOURCE :" "HLOP     " "  84"
"THRESHOLDS"" K1=" 5.0" K2="  0.0" K3="  0.0"DEGREES C."
"MONTH""DAY""MAX""MIN""DDAY""TOTAL"
  5  1  12.8  6.7  4.7    4.7
  5  2  15.6  7.8  6.7   11.4
  5  3  15.0  6.7  5.8   17.2

       ETC. (THROUGH 8 31)

 }

    VAR
      TOSSTRING10: STRING[10]; { TEXT SKIPPED OVER FROM DD FILE }
      TOSSTRING9: STRING[9];
      TOSSTRING3: STRING[3];

    BEGIN
      ASSIGN(DDDAT, 'HEAT.PRN');
      RESET(DDDAT);
      CUMDD := 0.0;
      READ(DDDAT, TOSSTRING10);
      READ(DDDAT, TOSSTRING10);
      READ(DDDAT, TOSSTRING9);
      READ(DDDAT, ISTNM, TOSSTRING3, YEAR);
      FOR I := 1 TO 2 DO
        READLN(DDDAT); {SKIP NEXT 2 LINES}
      FOR I := 1 TO JDT + 30 DO
        READLN(DDDAT); {SKIP DAYS BEFORE SETDATE}
      FOR I := 1 TO 2 DO
        READ(DDDAT, TOSSREAL);
```

```
    READ(DDDAT, HITEMP);
    READ(DDDAT, TOSSREAL);
    READ(DDDAT, SETDD);
    READLN(DDDAT);
    CUMDD := CUMDD + SETDD;
  END; {GETSETDD}


PROCEDURE GETCURDD; { GET THE CURRENT HITEMP  AND DD'S FOR THE DAY }

  BEGIN
    FOR I := 1 TO 2 DO
      READ(DDDAT, TOSSREAL);
    READ(DDDAT, HITEMP);
    READ(DDDAT, TOSSREAL);
    READ(DDDAT, CURDD);
    READLN(DDDAT);
    CUMDDLAST := CUMDD;
    CUMDD := CUMDD + CURDD;
  END;


FUNCTION ADDNODEFLG: BOOLEAN; {DETN IF TIME TO ADD NODE}


  BEGIN
    CASE FIELDTYPE OF
      EARLY:
        RNEXTNODE := 6.504 + 0.1612 * (TODAY); { NODES ADDED LINEARLY }
      MID:                                     { AS A FUNCTION OF GROWING DAY }
        RNEXTNODE := 4.704 + 0.1581 * (TODAY);
      LATE:
        RNEXTNODE := 3.425 + 0.1544 * (TODAY);
      END; { CASE }
    NEXTNODE := ROUND(RNEXTNODE); { ROUND TO NEAREST INTEGER }
    IF NEXTNODE > XNODEADD THEN { SET FLAGS FOR NODE ADDITION }
      BEGIN
      ADDNODEFLG := TRUE;
      ADDPLOTFLG := TRUE;
      END
    ELSE { NO NEW NODE TODAY }
      BEGIN
      ADDNODEFLG := FALSE;
      ADDPLOTFLG := FALSE;
      END;
  END; {ADDNODEFLG}


FUNCTION ABSCNODEFLG: BOOLEAN;
 {DETN IF TIME TO ABSCISS LOWEST LEAVES ON PLANT}


  BEGIN
    CASE FIELDTYPE OF
      EARLY:
        RNODELOST := 0.2964 + 0.1360 * (TODAY);
```

```
      MID:
        RNODELOST := - 0.7027 + 0.1207 * (TODAY);
      LATE:
        RNODELOST := - 2.279 + 0.1237 * (TODAY);
      END; { CASE }
    NODELOST := ROUND(RNODELOST);
    IF NODELOST > XNODEABSC THEN
      BEGIN
      ABSCPLOTFLG := TRUE;
      ABSCNODEFLG := TRUE;
      END
    ELSE
      BEGIN
      ABSCPLOTFLG := FALSE;
      ABSCNODEFLG := FALSE;
      END; {IF}
  END; { ABSCNODEFLG }


PROCEDURE ADDNODE; { TIME TO ADD A NODE TO PLANT }

  VAR
    I: INTEGER;

  BEGIN
    XNODEADD := XNODEADD + 1;
    NODESIZE := NODESIZE + 1;
    FOR I := XNODEADD DOWNTO 1 DO { SHIFT RECORDS ONE NODE DOWN THE
                                                                PLANT }
      BEGIN
      P1.MLVS[I].DRYCUM := P1.MLVS[I - 1].DRYCUM;
      P1.MLVS[I].DATEORIG := P1.MLVS[I - 1].DATEORIG;
      P1.MLVS[I].ABCISSED := P1.MLVS[I - 1].ABCISSED;
      P1.MLVS[I].DATEABCS := P1.MLVS[I - 1].DATEABCS;
      P1.MLVS[I].EMRGED := P1.MLVS[I - 1].EMRGED;
      END;
    P1.MLVS[0].EMRGED := TRUE; { SET UP NEW NODE #0 (NOT YET FULLY
                                 EXPANDED) }
    P1.MLVS[0].DATEORIG := TODAY;
    P1.MLVS[0].ABCISSED := FALSE;
    P1.MLVS[0].DATEABCS := 0;
    P1.MLVS[0].DRYCUM := 0.0;
    P1.MLVS[0].DRYCON := 0.0;
  END;


PROCEDURE ABSCNODE; { TIME TO ABSCISS LEAVES FROM BOTTOM }

  BEGIN
    XNODEABSC := XNODEABSC + 1;
    WITH P1 DO
      WITH MLVS[NODESIZE] DO { STRIP THE BOTTOM LEAF PAIR }
        BEGIN
        ABCISSED := TRUE;
        DATEABCS := TODAY;
        END;
```

```
      NODESIZE := NODESIZE - 1;
    END;


  PROCEDURE CALCLATS; { CALCULATE THE # OF LATERAL LEAVES FOR TODAY }

    VAR
      NLATS: REAL; { # OF LATERAL LEAVES }

    BEGIN
      CASE FIELDTYPE OF
        EARLY:
          NLATS := 0.5762 + 0.8213 * (EXP(0.06599 * TODAY));
        MID:
          NLATS := - 1.401 + 1.093 * (EXP(0.05115 * TODAY));
        LATE:
          NLATS := - 0.6667 + 0.5243 * (EXP(0.05516 * TODAY));
        END; { CASE }
      IF NLATS < 0.0 THEN
        NLATS := 0.0; { DON'T ALLOW NEG NLATS }
      P1.LATLVS := NLATS;
    END;

  PROCEDURE VCDEV;
{**********************************************************************
      VCDEV SECTION INCLUDES DEVELOPMENT, SURVIVORSHIP, AND
      CONSUMPTION. THESE PROCESSES ARE IMPLEMENTED AT A TIME
      RESOLUTION OF 2 DD.  THE OUTPUT WILL BE THE AMOUNT OF
      PEPPERMINT DRY LF. WT. CONSUMED FOR ONE DAY.
**********************************************************************}

    VAR
      I, J: INTEGER;
      POPHATCHPERDD: REAL; { # EGGS HATCHING PER DD }
      AMTFEED_DD: ARRAY [1..6] OF REAL; { AMT OF FEEDING PER 2 DD EACH
                                                                INSTAR }


    FUNCTION EGGHATCHTODAY(HCURDD, HCUMDD: REAL): REAL;
   {******************************************************************
     CALC THE EGG HATCH FOR THE CURRENT DD USING THE TRAPEZOID METHOD
     OF INTEGRATING THE TRUNCATED NORMAL DISTRIBUTION
     ADAPTED FROM: MERCHANT, M. J. 1981. FORTRAN 77 LANGUAGE AND STYLE.
     WADSWORTH PUBL. CO. BELMONT, CA p 394.
     INPUT: THE CUMDD, CURRDD AND FIELDTYPE.
     OUTPUT: THE PROPORTION OF TOTAL EGG HATCH OCCURING TODAY.
   ******************************************************************}

      VAR
        A, B: REAL; { BEGIN AND END POINTS OF INTEGRAL }
        TEMP1, TEMP2: REAL; { TEMPORARY VARS }
        I, N: INTEGER; { N IS THE # SUBINTERVALS USED BY THE TRAPEZOID
                                                                    RULE }


      FUNCTION NORM(X: REAL): REAL; { THE NORMAL DISTRIBUTION }
```

```
    BEGIN
      NORM := (1 / SQRT(2 * PI * VARIANCEEGGDD)) * EXP( - (SQR(X -
              MEANEGGDD) / (2 * VARIANCEEGGDD)));
    END;


  BEGIN { EGGHATCHTODAY }
    IF (HCUMDD > STARTEGGDD) AND (HCUMDD - HCURDD < ENDEGGDD) THEN
      BEGIN { SOME EGGHATCH TO CALC; SET A AND B INTEG. ENDPTS }
      IF HCUMDD > ENDEGGDD THEN { RIGHT TAIL }
        BEGIN
        A := HCUMDD - HCURDD;
        B := ENDEGGDD;
        END
      ELSE IF HCUMDD - HCURDD < STARTEGGDD THEN { LEFT TAIL }
        BEGIN
        A := STARTEGGDD;
        B := HCUMDD;
        END
      ELSE { NOT IN TAIL }
        BEGIN
        A := HCUMDD - HCURDD;
        B := HCUMDD;
        END;
      N := 50;
      TEMP2 := 0.0;

    {************  THE TRAPEZOID INTEGRATION RULE:  *************}
      TEMP1 := (NORM(A) + NORM(B)) / 2;
      FOR I := 1 TO N - 1 DO
        TEMP2 := TEMP2 + NORM(A + I * (B - A) / N);
      EGGHATCHTODAY := TRUNCFAC * ((TEMP1 + TEMP2) * (B - A) / N);
      END { IF }
    ELSE
      EGGHATCHTODAY := 0.0; {NO EGGHATCH TODAY}
  END; { FUNCTION EGGHATCHTODAY }
 {******************************************************************}


 PROCEDURE ADV_AND_MORT;
{*******************************************************************
         ADVANCE EACH CUTWORM SUBSTAGE AND APPLY
            MORTALITY DURING STAGE TRANSITION
*******************************************************************}

  VAR
    I, J: INTEGER;


  BEGIN { PROCEDURE ADV_AND_MORT }
    FOR I := 6 DOWNTO 1 DO { FROM 6TH INSTAR DOWNTO 1ST }
      BEGIN
      IF DENSTOT[I] > 1.0E-8 THEN { DENS IS HIGH ENOUGH TO ADVANCE
                                    DEVELOPMENT }
        BEGIN
```

```
          DENSTOT[I] := 0.0; { SET INSTAR ACCUM. TO ZERO }
          IF I + 1 = 7 THEN { PUPAL STAGE }
            DENS[I + 1, 1] := DENS[I + 1, 1] + DENS[6, DUS[6]]; { ADD
            DENS OF LAST SUBSTAGE OF 6TH INSTAR TO PUPAL ACCUM }
          FOR J := DUS[I] DOWNTO 2 DO { ADVANCE DENS EACH SUBSTAGE
                                                          IN INSTAR }
            BEGIN
            DENS[I, J] := DENS[I, J - 1];
            DENSTOT[I] := DENSTOT[I] + DENS[I, J]; { RE-ACCUM TOTAL
                                                         INSTAR DENS }
            END;
          END; { IF THEN }

        IF I > 1 THEN { APPLY MORT. TO LAST SUBSTAGE OF LAST STAGE }
          DENS[I, 1] := DENS[I - 1, DUS[I - 1]] * VC[I].SURVRATE
        ELSE { I = 1 LAST STAGE WAS EGGS }
          DENS[I, 1] := 2 * POPHATCHPERDD * VC[1].SURVRATE;

        DENSTOT[I] := DENSTOT[I] + DENS[I, 1] + DENS[I, DUS[I]];
                                                 { SUM UP TOTALS }
        IF DENSTOT[I] < 1.0E-7 THEN
          DENSTOT[I] := 0.0; { RESET TO 0 IF TOO SMALL }
        END; { INSTAR FOR LOOP }
    END; { PROCEDURE ADV_AND_MORT }
  {*****************************************************************}


  PROCEDURE FIGCONS;
{*******************************************************************
        CALC & SUM UP QUANTITY CONSUMED AT END OF EVERY DD
*******************************************************************}

    VAR
      I: INTEGER;

    BEGIN
      FOR I := 1 TO 6 DO
        BEGIN { FEEDING = DENSITY X CONSUMPTION RATE }
        AMTFEED_DD[I] := DENSTOT[I] * VC[I].QUANTCONS;
        AMTFEEDTODAY[I] := AMTFEEDTODAY[I] + AMTFEED_DD[I]; { SUM ALL
          INSTARS }
        END;
    END; { PROCEDURE FIGCONS }


  FUNCTION RNDTOEVEN(RNUM: REAL): INTEGER; {ROUND TO NEAREST EVEN #}

    BEGIN
      IF ODD(ROUND(RNUM)) THEN
        RNDTOEVEN := ROUND(RNUM) - 1
      ELSE
        RNDTOEVEN := ROUND(RNUM);
    END;


  BEGIN { VCDEV }
```

```
      TCURDD := CURDD + TRIM; { ADD YESTERDAYS REMAINDER TO DD'S TODAY }
      RCURDD := RNDTOEVEN(TCURDD); { ROUND TO AN EVEN # OF DD'S }
      TRIM := TCURDD - RCURDD; { GET TODAYS REMAINDER }

      EGGHATCH := EGGHATCHTODAY(CURDD, CUMDD); { USE ACTUAL DD'S FOR EGG
                                                 HATCH }
      CUMEGGHATCH := CUMEGGHATCH + EGGHATCH; { SUM CUMULATIVE EGG HATCH }
      POPHATCHTODAY := EGGHATCH * EGGSPERSQ; { DENS. HATCHING FOR TODAY }
      POPHATCHPERDD := POPHATCHTODAY / RCURDD; { CALC EGGHATCH PER
                                                              2 DD ITER }

      FOR I := 1 TO 6 DO
        AMTFEEDTODAY[I] := 0.0; { RESET DAY FEEDING ACCUM.S }

      FOR DDSTEP := 1 TO RCURDD DIV 2 DO { APPLY DEV, SURV, AND CONS.
                                          PROC EVERY 2 DD'S FOR DAY }
        BEGIN
        ADV_AND_MORT; { CUTWORM DEV AND MORTALITY }
        FOR I := 1 TO 6 DO
          AMTFEED_DD[I] := 0.0; { RESET DD FEEDING ACCUM }
        FIGCONS; { FIGURE CONSUMPTION }
        END; { FOR }
    END; { VCDEV }

  PROCEDURE VCDEFOL;
{*********************************************************************
 CALCULATE THE QUANTITY OF LEAF DRY WT CONSUMED FOR EACH LEAF
 STRATA AND FOR LATERAL LEAVES
*********************************************************************}

    FUNCTION PORPFEED: REAL;
  { DETERMINE WHAT THE MIDPOINT OF FEEDING SHOULD BE TODAY BASED ON
    THE DAILY TEMPERATURE  }

      BEGIN
        IF HITEMP < 21.6 THEN
          PORPFEED := 0.45 { LOWER LIMIT FOR COLD DAYS }
        ELSE IF HITEMP > 28.3 THEN
          PORPFEED := 0.58 { UPPER LIMIT FOR HOT DAYS }
        ELSE
          PORPFEED := 0.0286 + 0.0195 * HITEMP; { OTHERWISE A
                                                 FUNCTION OF TEMP }
      END; {PORPFEED}


    BEGIN { VCDEFOL }
      LATPREF := 0.6; { PREF. FOR LATERAL LVS IS ONLY 60% COMPARED TO
                        MAINSTEM }
      PORP := PORPFEED;

      { NEXT CALC PROPORTION OF FEEDING GOING TO LATERAL LEAVES }
      LATPORP := LATPREF * (P1.LATLVS * 12.1) / ((NODESIZE * 56.3 * 2) +
                 (P1.LATLVS * 12.1));

      { ACTUAL CALCULATION OF FEEDING DIST. }
      FOR I := 0 TO MAXNODES DO
```

```
        CURFEEDDIST[I] := 0.0;
      FOR I := 0 TO NODESIZE DO
        CURFEEDDIST[I] := (1 - LATPORP) * BINOM(I, NODESIZE, PORP);
      CURFEEDDIST[1] := CURFEEDDIST[1] + CURFEEDDIST[0];
                                                  { SUM FOR LVS 0 & 1 }
      CURFEEDDIST[0] := 0.0; { DONT ALLOW FEEDING ON LEAF PAIR ZERO }

      { SUM TODAY'S FEEDING FOR ALL 6 INSTARS }
      AMTFEEDTOT := 0.0; { RESET TO ZERO }
      FOR I := 1 TO 6 DO
        AMTFEEDTOT := AMTFEEDTOT + AMTFEEDTODAY[I];

      { PARTITION THE FEEDING OVER MAINSTEM NODES AND LATERALS }
      AMTFEEDTOT := AMTFEEDTOT * 0.9906; { CALIB. FACTOR TO CORRECT THE
                                           SWITCH TO 2 DD/SUBSTAGE }

      { RESET CONSUMPTION ARRAY AND RECALC TODAYS VALUES }
      FOR I := NODESIZE + 1 TO XNODEADD DO
        P1.MLVS[I].DRYCON := 0.0;
      FOR I := 1 TO NODESIZE DO
        BEGIN
        P1.MLVS[I].DRYCON := CURFEEDDIST[I] * AMTFEEDTOT;
        P1.MLVS[I].DRYCUM := P1.MLVS[I].DRYCUM + P1.MLVS[I].DRYCON;
        END;
      P1.LATCON := LATPORP * AMTFEEDTOT; { LATERAL CONSUMPTION TODAY }
      P1.LATCUM := P1.LATCUM + P1.LATCON;
    END; { PROC. VCDEFOL }
  {*****************************************************************}

PROCEDURE INITFOR_ONLINE;
{ INIT VC DEV ARRAYS BY SPREADING OVER SUBSTAGES EACH INSTAR }
VAR
  I, J: INTEGER;

BEGIN
 EGGSPERSQ := 0.0;  { WONT USE ANY EGG HATCH }
 FOR I := 1 TO 6 DO
   FOR J := 1 TO DUS[I] DO
   DENS[I,J] := STARTL[I] / DUS[I];
 FOR I := 1 TO MAXNODES DO
   CURFEEDDIST[I] := 0.0;
 FOR I := 1 TO 6 DO
   DENSTOT[I] := STARTL[I];
 LATPORP := 0.0;
END;

{$I DAYRPT.INC} { CODE USED FOR DAILY REPORT }

    BEGIN { PROC. DAILY_ITER }

      CASE FIELDTYPE OF
        EARLY:
          HARVESTDAY := 66; { AUG 5 }
        MID:
          HARVESTDAY := 76; { AUG 15 }
        LATE:
```

```
        HARVESTDAY := 86; { AUG 25 }
      END;
    IF HDATEFLAG THEN
      HARVESTDAY := JDATEHARV;
    { IF FLAG SET THEN OVERRIDE ABOVE HARVEST DATES }
    SETPLANT(FRSTDAY); { SETUP PLANT }
    GETSETDD(FRSTDAY); { GET INITIAL DD'S }
    INITVC;

    FOR TODAY := FRSTDAY TO HARVESTDAY DO
      BEGIN { DAILY ITERATION LOOP }
      GETCURDD; { GET DEGREE DAYS FOR TODAY }
      IF ADDNODEFLG THEN
        ADDNODE;
      IF ABSCNODEFLG THEN
        ABSCNODE;
      CALCLATS; { CALC # LATERAL LEAVES }
      IF NOT ONLINE THEN
        BEGIN
        VCDEV; { CUTWORM DEVELOPMENT }
        VCDEFOL; { CUTWORM DEFOLIATION }
        END
      ELSE { ONLINE OPTION CHOSEN }
        IF TODAY < STARTDATE THEN {} { DONT DO VCDEV OR VCDEFOL }
          ELSE
            IF TODAY = STARTDATE THEN
              BEGIN
              INITFOR_ONLINE; { INIT BUT SKIP VCDEV & VCDEFOL }
              END
            ELSE
              BEGIN
              VCDEV;
              VCDEFOL;
              END;

      IF NOT ((SCRTYPE = NEITHER) OR (SCRTYPE = GRF)) THEN
        DAYREPORT; { ONLY GIVE DAYREPORT IF NOT SUPPRESSED }
      IF SCRTYPE = GRF THEN
        GRFRPT(TODAY);
      END;
    CLOSE(DDDAT);
  END; {DAILY_ITER}
{********************** END DAILY_ITER SECTION **********************
*******************************************************************}

{********************** BEGIN HARVEST SECTION ***********************
THE PURPOSE OF THIS SECTION IS PRIMARILY TO CONVERT DAMAGE IN MG DRY
WEIGHT TO UG OIL WHICH IS COMPARED TO UG OIL EXPECTED FOR AN AVERAGE
FIELD.  FINAL RESULTS ARE ALSO REPORTED.
*******************************************************************}

  PROCEDURE HARVEST;

    CONST
      OILPERACRE = 76.096; { PREDICTED OIL YIELD IN LBS/ACRE }
      OILCONFACTOR = 8930; { CONVERT FROM LB/ACRE TO UG/1000 SQ CM }
```

```
VAR
  REMNODELOST: REAL;    { PROP OF LOWEST LEAF NOT LOST TO ABSC }
  I: INTEGER;
  LFOIL: ARRAY [1..20] OF INTEGER; { UG OIL/LEAF FROM GC STUDIES }
  LFZEROOIL, { UG OIL/LEAF FOR LEAF PAIR ZERO }
   LFPARTOIL, { " " FOR PART OF BOTTOM LEAF NOT ABSCISSED }
   FLROIL, { UG OIL/FLR BUD }

  OILPERLAT, { AVG OIL/LATERAL LEAF }
   LATOIL: REAL; { TOTAL OIL LATERALS }
  TOTOIL: REAL; { TOTAL OIL PER PLANT }
  TOTOILMAIN: REAL; { TOTAL OIL EXCEPT LATERALS PER PLANT }

  LFOILPORP: ARRAY [1..20] OF REAL; { PROPORTION OF OIL IN EACH }
  LFZEROPORP, { LEAF PAIR FROM GC STUDIES }
   FLROILPORP, { PROPORTION OIL IN FLOWER BLOSSOMS }
   LFPARTPORP, { PROP OIL IN BOTTOM LF NOT FULLY ABSCISSED }
   LATOILPORP: REAL; { PROPORTION OIL IN LATERAL LEAVES }

  TOTOILPOTENT: REAL; { PREDICTED YIELD IN UG OIL/1000 SQ CM }
  TOTPRCNTCON: REAL;       { YIELD LOSS PERCENTAGE }

  LFOILPOTENT: ARRAY [1..20] OF REAL; { POTENTIAL YIELD UG/1000 }
  LFZEROOILPOTENT, { SQ CM PER LEAF PAIR }
   FLROILPOTENT,
   LATOILPOTENT,
   LFPARTOILPOTENT, { PART OF BOTTOM LF }
   LFOILPOTENTMAIN: REAL;

  LFOILPERMG, { UG OIL PER MG DRY WT OF LEAF FROM GC STUDIES }
   LFOILCON: ARRAY [1..20] OF REAL; { = DRYCON * LFOILPERMG }
  LFOILCONPART,
   LATOILCON: REAL;
  LFZEROOILPERMG, { UG OIL PER LEAF ZERO (NOT FULLY EXPANDED) }
   FLROILPERMG, { UG OIL PER FLOWER BUD }
   OILPERLATPERMG: REAL; { UG OIL PER LATERAL LEAF }
  Z: REAL; { USE FOR DRYCON ADDED FOR ALL ABSC LEAVES }
  OILABSCPOTENT: REAL;
  OILABSCCON: REAL;

PROCEDURE INITHARV;

  BEGIN
     { CALC PROPORTION OF ABSCISSED LEAF NOT REALLY GONE YET }
    NODELOST := TRUNC(RNODELOST) + 1;
    NODESIZE := XNODEADD - NODELOST;
    REMNODELOST := 1 - (RNODELOST - TRUNC(RNODELOST));
    PARTNODE := NODESIZE + 1;

    FOR I := 1 TO XNODEADD DO
      LFOILPORP[I] := 0.0;
    LFZEROPORP := 0.0;
    FLROILPORP := 0.0;
    LATOILPORP := 0.0;
```

```
    LFOIL[1] := 2 * 610; { AVG OIL (UG) PER LEAF FROM GC STUDIES * 2
                          LEAVES }
    LFOIL[2] := 2 * 790;
    LFOIL[3] := 2 * 766;
    LFOIL[4] := 2 * 859;
    LFOIL[5] := 2 * 868;
    LFOIL[6] := 2 * 810;
    LFOIL[7] := 2 * 810;
    LFOIL[8] := 2 * 799;
    FOR I := 9 TO XNODEADD DO
      LFOIL[I] := 2 * 790;
    LFZEROOIL := 2 * 279;
    LFPARTOIL := ROUND(LFOIL[PARTNODE] * REMNODELOST);
    FLROIL := 1698; { SHOULD BE DETN BY % BUD DEV (IF ADDED LATER) }
    OILPERLAT := 313;
    LATOIL := 0; { LATERAL OIL TO BE DETN BY #LATS AND OILPERLAT }

    IF (SCRTYPE = NEITHER) OR (SCRTYPE = GRF) THEN
    { PLANT PRN FILE SHOULD BE INITIALIZED }
      BEGIN
      FILENM2 := 'C:PUT' + RUNUM + '.PRN';
      ASSIGN(POUT, FILENM2);
      REWRITE(POUT);
      WRITELN(POUT, ' "', COMSTRING, '" ');
      WRITE(POUT, '"WEATHR"," SOURCE:","', ISTNM, '","YEAR:",', YEAR,
           ',','"FIELDTYPE:",');
      CASE FIELDTYPE OF
        EARLY:
          WRITE(POUT, '"EARLY",');
        MID:
          WRITE(POUT, '"MID",');
        LATE:
          WRITE(POUT, '"LATE",');
        END;
      WRITELN(POUT, '"EGGSPERSQ","', EGGSPERSQ: 5: 3, '", "HARVDAY:",',
              HARVESTDAY: 5);
      END; { IF }
    WRITELN(POUT, '"NODE", "DRYCON", "OILCON", "POTENOIL", "%OILCON",',
            '"ABS", "DATEABSC", "DATEADD"');

  END; { PROCEDURE INITHARV; }

PROCEDURE PERCENTPROFILE;
{ CALCULATE THE PROPORTION OF TOTAL OIL FOUND IN EACH LEAF PAIR AND
FLOWER BUDS (PER STEM BASIS) }


  BEGIN
    TOTOIL := 0;
    TOTOILMAIN := 0;
    FOR I := 1 TO NODESIZE DO
      TOTOILMAIN := TOTOILMAIN + LFOIL[I];
    TOTOILMAIN := TOTOILMAIN + LFPARTOIL;
    TOTOILMAIN := TOTOILMAIN + LFZEROOIL + FLROIL; { OIL IN MAINSTEM }
    LATOIL := (ROUND)(P1.LATLVS * OILPERLAT); { OIL IN LATS }
    TOTOIL := TOTOILMAIN + LATOIL; { TOTAL OIL PER PLANT }
```

```
    FOR I := 1 TO XNODEADD DO
      LFOILPORP[I] := LFOIL[I] / TOTOIL; { INCL ABSC }
    LFZEROPORP := LFZEROOIL / TOTOIL;
    LFPARTPORP := LFPARTOIL / TOTOIL;
    FLROILPORP := FLROIL / TOTOIL;
    LATOILPORP := LATOIL / TOTOIL;
  END; { PROCEDURE PERCENTPROFILE }


PROCEDURE CALCOILSQCMBASIS;
 { CALCULATE THE AMT. OIL CONSUMED AND POTENTIAL ON A 1000
                                             SQ. CM BASIS }


  BEGIN
    LFOILPERMG[1] := 21.4; { FIRST INIT LEAF ARRAY WITH VALUES OF }
    LFOILPERMG[2] := 18.2; { AVG OIL (UG) PER MG LEAF FROM GC STUDIES }
    LFOILPERMG[3] := 15.3;
    LFOILPERMG[4] := 13.6;
    LFOILPERMG[5] := 15.7;
    LFOILPERMG[6] := 14.2;
    LFOILPERMG[7] := 13.7;
    LFOILPERMG[8] := 16.9;
    FOR I := 9 TO XNODEADD DO
      LFOILPERMG[I] := 15.8;
    LFZEROOILPERMG := 24.9;
    FLROILPERMG := 40.0;
    OILPERLATPERMG := 25.9;

    { NOW CALC AMT OIL CONSUMED PER LEAFPAIR (1000 SQ CM BASIS) }
    FOR I := 1 TO XNODEADD DO
      LFOILCON[I] := LFOILPERMG[I] * P1.MLVS[I].DRYCUM;
    LFOILCONPART := P1.MLVS[PARTNODE].DRYCUM * LFOILPERMG[PARTNODE]
                    * REMNODELOST;
    LATOILCON := OILPERLATPERMG * P1.LATCUM;

    { NEXT CALC AMT. OIL POTENTIAL EACH LEAF PAIR (1000 SQ CM BASIS) }
    TOTOILPOTENT := (OILPERACRE)ESTYIELD * OILCONFACTOR; { TOT OIL
                                                       1000 SQ CM }
    FOR I := 1 TO XNODEADD DO { CALC OIL PER LEAF STRATUM MAIN LVS }
      LFOILPOTENT[I] := LFOILPORP[I] * TOTOILPOTENT;
    LFZEROOILPOTENT := LFZEROPORP * TOTOILPOTENT; { OIL FOR LF PR 0 }
    LFPARTOILPOTENT := LFPARTPORP * TOTOILPOTENT; { OIL FOR ABSC LF }
    FLROILPOTENT := FLROILPORP * TOTOILPOTENT; { OIL FOR FLOWER BUD }
    LATOILPOTENT := LATOILPORP * TOTOILPOTENT; { OIL FOR LAT LVS }
  END; { PROCEDURE CALCOILSQCMBASIS }


PROCEDURE REPORTHARVEST;
{ CALCULATE THE AMOUNT OF OIL LOSS PER LEAF NODE BASED ON THE CURRENT
  CONSUMED DRY WT. ACCUMULATED AND THE LEAF OIL VALUES OF PROC
  PERCENTPROFILE AND REPORT TO THE SCREEN AND FILE }


  BEGIN
```

```
(******* PAGE 1 OF FINAL SCREEN REPORT - INDIV LEAF PAIRS *******)
WRITELN('FINAL MINTSIM REPORT PAGE 1: INDIVIDUAL LEAF PAIRS ');
WRITELN('NODE  DRY WT    OIL     POTENT. %OIL   ABSC-  DATE ',
        '  DATE  ');
WRITELN(' #   CONSUMED CONSUMED   OIL  CONSUMED ISSED  ABSC ',
        '  ADDED ');
WRITELN('-------------------------------------------------',
        '--------');

{ SET UP DISK FILE REPORT }
WRITE(POUT, 'NODE     DRYCON   OILCON  POTENOIL  %CON');
WRITELN(POUT, '  ABSC  DATE   DATEADD');

{ REPORT VALUES FOR FLOWER BUDS AND LEAF PAIR ZERO }
WRITELN(POUT, '"FLR",      " ",       " ",  ', FLROILPOTENT: 8: 0,
         ' ': 4);
WRITELN(POUT, 0: 4, ',      " ",       " ",  ', LFZEROOILPOTENT: 8: 0,
         ' ': 4);
{     WRITELN('FLR ', ' ': 18, FLROILPOTENT/8930: 8: 2, ' ': 4);
      WRITELN(0: 4, ' ': 18, LFZEROOILPOTENT/8930: 8: 2, ' ': 4);
}
LFOILPOTENTMAIN := LFZEROOILPOTENT + FLROILPOTENT;
LFOILPOTENTMAIN := LFOILPOTENTMAIN + LFPARTOILPOTENT;

{ BEGIN ADDING TOTAL OIL }
LFOILCONMAIN := 0.0; { POTENTIAL AND CONSUMPTION }
LFOILCONMAIN := LFOILCONMAIN + LFOILCONPART;

FOR I := 1 TO NODESIZE DO { CALC AMT OIL/1000 CM SQ CONSUMED AND
                             POTENT }
  BEGIN
  LFOILCONMAIN := LFOILCONMAIN + LFOILCON[I];
  LFOILPOTENTMAIN := LFOILPOTENTMAIN + LFOILPOTENT[I];
  END;

  { REPORT ON SCREEN }
  { 1. LEAVES PRESENT }
FOR I := 1 TO  NODESIZE DO
  BEGIN
  WRITE(I: 2,'  ', P1.MLVS[I].DRYCUM: 8: 0, LFOILCON[I]/8930: 8: 2,
        LFOILPOTENT[I]/8930: 10: 2, (LFOILCON[I] / LFOILPOTENT[I])
        * 100: 7: 2);
  WRITE('     P ', '       ', P1.MLVS[I].DATEORIG: 6);
  WRITELN;
  END;
  { 2. PARTIALLY ABSCISSED LEAVES }
WRITE(PARTNODE: 2,'  ', P1.MLVS[PARTNODE].DRYCUM * REMNODELOST: 8:
      0, LFOILCONPART/8930: 8: 2,
      LFPARTOILPOTENT/8930: 10: 2, (LFOILCONPART / LFPARTOILPOTENT)
      * 100: 7: 2);
WRITELN('     * ', P1.MLVS[PARTNODE].DATEABCS: 6,
       P1.MLVS[PARTNODE].DATEORIG: 6);
  { 3. ABSCISSED LEAVES }
FOR I := (PARTNODE + 1) TO XNODEADD DO
  BEGIN
```

```
  WRITE(I: 2,'  ', P1.MLVS[I].DRYCUM: 8: 0, LFOILCON[I]/8930: 8: 2,
        LFOILPOTENT[I]/8930: 10: 2, (LFOILCON[I] / LFOILPOTENT[I])
        * 100: 7: 2);
  WRITELN('      A ', P1.MLVS[I].DATEABCS: 6, P1.MLVS[I].DATEORIG: 6);
  END;

  { REPORT TO FILE }
  { 1. LEAVES PRESENT }
FOR I := 1 TO  NODESIZE DO
  BEGIN
  WRITE(POUT, I: 4,',', P1.MLVS[I].DRYCUM: 8: 0,
       ',', LFOILCON[I]: 8: 0,
       ',', LFOILPOTENT[I]: 10: 0, ',', (LFOILCON[I] /
       LFOILPOTENT[I]) * 100: 7: 2,',');
  WRITE(POUT,'   "P",','         ', P1.MLVS[I].DATEORIG: 6);
  WRITELN(POUT);
  END;
  { 2. PARTIALLY ABSCISSED LEAVES }
WRITE(POUT, PARTNODE: 4,
    ',', P1.MLVS[PARTNODE].DRYCUM * REMNODELOST: 8: 0,
    ',', LFOILCONPART: 8: 0,',', LFPARTOILPOTENT: 10: 0,
    ',', (LFOILCONPART / LFPARTOILPOTENT) * 100: 7: 2,',');
WRITELN(POUT, '    "*"',
    ',', P1.MLVS[PARTNODE].DATEABCS: 6,
    ',', P1.MLVS[PARTNODE].DATEORIG: 6);
  { 3. ABSCISSED LEAVES }
FOR I := (PARTNODE + 1) TO XNODEADD DO
  BEGIN
  WRITE(POUT, I: 4,',', P1.MLVS[I].DRYCUM: 8: 0,
       ',', LFOILCON[I]: 8: 0,',', LFOILPOTENT[I]: 10: 0,
       ',', (LFOILCON[I] / LFOILPOTENT[I]) * 100: 7: 2,',');
  WRITELN(POUT, '    "A"',
       ',', P1.MLVS[I].DATEABCS: 6,
       ',', P1.MLVS[I].DATEORIG: 6);
  END;

{ REPORT TOTALS FOR MAINSTEM LEAVES, LATERALS, AND ALL LEAVES }
CUMTOT := 0.0;
FOR I := 1 TO NODESIZE DO
  CUMTOT := CUMTOT + P1.MLVS[I].DRYCUM; { SUM CONSUMP FOR ALL
                                                    MAINSTEM }
  CUMTOT := CUMTOT + P1.MLVS[PARTNODE].DRYCUM * REMNODELOST;


WRITELN(#228, 'MN ', CUMTOT: 8: 0, LFOILCONMAIN/8930: 8: 2,
        LFOILPOTENTMAIN/8930: 10: 2,
        (LFOILCONMAIN / LFOILPOTENTMAIN) * 100: 7: 2);
WRITELN('LAT ', P1.LATCUM: 8: 0, LATOILCON/8930: 8: 2
       , LATOILPOTENT/8930: 10: 2,
        (LATOILCON / LATOILPOTENT) * 100: 7: 2,
        '    NLATS: ',P1.LATLVS:6:2);
WRITELN(POUT, '"  MN",', CUMTOT: 6: 0, ',', LFOILCONMAIN: 8: 0,
        ',', LFOILPOTENTMAIN: 10: 0,
        ',', (LFOILCONMAIN / LFOILPOTENTMAIN) * 100: 7: 2);
WRITELN(POUT, '" LAT",', P1.LATCUM: 6: 0, ',', LATOILCON: 8: 0,
        ',', LATOILPOTENT: 10: 0,
```

```
        ',', (LATOILCON / LATOILPOTENT) * 100: 7: 2,
        ',','" NLATS:",',P1.LATLVS:6:2);

TOTDRYCON := CUMTOT + P1.LATCUM;
TOTOILCON := LFOILCONMAIN + LATOILCON;

{ CALC. TOTAL OIL CONSUMED PER ACRE }
TOTOILCONPERACRE := TOTOILCON / OILCONFACTOR;

TOTPRCNTCON := (TOTOILCON / TOTOILPOTENT) * 100;
WRITELN(POUT, '" ALL",', TOTDRYCON: 6: 0, ',', TOTOILCON/8930: 8: 2,
        ',', TOTOILPOTENT/8930: 10: 2,
        ',', TOTPRCNTCON: 7: 2);
WRITELN(#228, 'ALL', TOTDRYCON: 8: 0, TOTOILCON/8930: 8: 2
       , TOTOILPOTENT/8930:
       10: 2, TOTPRCNTCON: 8: 3);

{ EST YIELD AND DAMAGE LOST TO SENESCENCE - HYPOTHETICAL }
Z := 0.0;
OILABSCPOTENT := 0.0;
OILABSCCON := 0.0;
FOR I := NODESIZE + 2 TO XNODEADD DO
  BEGIN
  Z := Z + P1.MLVS[I].DRYCUM;
  OILABSCPOTENT := OILABSCPOTENT + LFOILPOTENT[I];
  OILABSCCON := OILABSCCON + LFOILCON[I];
  END;

 { ADD PART OF PARTIALLY ABSC LEAF PAIR TO ABSC TOTALS }
 Z := Z + P1.MLVS[PARTNODE].DRYCUM * (1 - REMNODELOST);
 OILABSCPOTENT := OILABSCPOTENT +
        (LFOILPOTENT[PARTNODE] * (1-REMNODELOST));
 OILABSCCON := OILABSCCON + (P1.MLVS[PARTNODE].DRYCUM *
         LFOILPERMG[PARTNODE] * (1-REMNODELOST));

    { DISPLAY RESULTS ON SCREEN AND FILE }
 WRITE('ABSC', Z: 8: 0, OILABSCCON/8930: 8: 2
       , OILABSCPOTENT/8930: 10: 2,
       (OILABSCCON / TOTOILPOTENT) * 100: 7: 2, ' ');
 WRITE(POUT, '"ABSC",', Z: 6: 0, ',', OILABSCCON: 8: 0, ',',
       OILABSCPOTENT: 10: 0, ',', (OILABSCCON / TOTOILPOTENT)
       * 100: 7: 2, ',', ' ');
GOTOXY(1,25);
REPEAT { HOLD SCREEN UNTIL KEY IS PRESSED }
UNTIL KEYPRESSED;

 {******** PAGE 2 OF FINAL REPORT - THRESHOLD VALUES ETC. ******** }
CLRSCR;

WRITELN('               FINAL MINTSIM REPORT PAGE 2: THRESHOLD'
        ,' VALUES');
WRITELN('    ------------------------- INPUT VARIABLES'
       ,' ------------------------');
WRITELN('    COST OF CONTROL:                                      '
        , CONTROLCOST:5:2,' $ / ACRE');
WRITELN('    ESTIMATED YIELD:                                      '
```

```
        , ESTYIELD:5:2,' LB / ACRE');
WRITELN('    PRICE OF OIL:                                              '
        , OILPRICE:5:2,' $ / LB');
IF NOT ONLINE THEN
  BEGIN
  WRITELN('    INITIAL VC DENSITY (# EGGS / 1000 SQ CM):                  '
        , EGGSPERSQ: 5: 2,' EGGS');
  END
ELSE
  BEGIN
  WRITELN('    TOTAL INITIAL SAMPLE DENSITY (LARVAE / 1000 SQ CM):        '
        , STARTTOT: 5: 2,' CUTWORMS');
  WRITELN('    SAMPLE DATE:                                               '
        , CALCMNTH(STARTDATE),' ',CALCDATE(STARTDATE): 2);


 END;

WRITELN('    HARVEST DATE:                                              '
        , CALCMNTH(HARVESTDAY),' ',CALCDATE(HARVESTDAY):2);

WRITELN('    FIELDTYPE (1=EARLIEST 3=LATEST):                           '
        , FT: 2);
WRITELN('    WEATHER DATA SOURCE:                                       '
        ,ISTNM,YEAR);
WRITELN;
WRITELN('    -------------------------- MODEL RESULTS'
         ,' --------------------------');
WRITELN('    % DAMAGE TOLERANCE:                                   '
        , DAMAGETOLERANCE:8:2,' % ');
WRITELN('    % DAMAGE INFLICTED:                                   '
        , TOTPRCNTCON: 8: 2, ' % ');

WRITELN;
WRITELN('    DAMAGE TOLERANCE IN LB./ACRE:                         '
        , (DAMAGETOLERANCE/100)*OILPERACRE:8:2,' LB./ACRE');
WRITELN('    OIL CONSUMED IN LB./ACRE:                             '
        , TOTOILCONPERACRE: 8: 3, ' LB./ACRE');
WRITELN;

IF NOT ONLINE THEN
  BEGIN
  WRITELN('    THRESHOLD (# EARLY INSTAR LARVAE / 1000 CM SQ):       '
        , DAMAGETOLERANCE * (EGGSPERSQ /
          TOTPRCNTCON): 6: 2,' CUTWORMS');
  END
ELSE { ONLINE }
  BEGIN
  WRITELN('    # LARVAL INJURY UNIT''S (LB./ACRE):                   '
        , ( TOTOILCONPERACRE / STARTTOT * 1.00): 6: 2,' LIUs');
  END;
WRITELN(POUT, '% INJURY TO PRESENT PLUS ABSCISSED LEAVES:           '
        , (OILABSCCON + TOTOILCON) / (TOTOILPOTENT) * 100: 5: 2,' %');
{    WRITELN('    % INJURY TO PRESENT PLUS ABSCISSED LEAVES:            '
        , (OILABSCCON + TOTOILCON) / (TOTOILPOTENT) * 100: 4: 2,' %');
 }   WRITELN('    % OF TOTAL INJURY TO LEAVES PRESENT:                 '
```

```
          , (TOTOILCON / TOTOILPOTENT) /
            ((OILABSCCON + TOTOILCON) / (TOTOILPOTENT))*100: 4: 2,' %');

    WRITELN(POUT,#26); { ADD END OF FILE MARKER }
    CLOSE(POUT);
    END; { PROCEDURE REPORTHARVEST }


   BEGIN { HARVEST }
     INITHARV;
     PERCENTPROFILE;
     CALCOILSQCMBASIS;
     REPORTHARVEST;
   END; { HARVEST }
{************************** END HARVEST SECTION **********************
********************************************************************}

  BEGIN {************* MAIN PROGRAM ****************}
  ClrScr;

   QLOOP := 0;
   REPEAT; { PROGRAM LOOP }
     QLOOP := QLOOP + 1;
     STR(QLOOP, RUNUM); { CONVERT INTEGER TO TYPE STRING }
     CLRSCR;
     WRITELN(
            'THIS PROGRAM MODELS PEPPERMINT MORPHOLOGICAL GROWTH,'
            ,' VARIEGATED CUTWORM FEEDING BEHAVIOR, CONSUMPTION');
     WRITELN(' RATE, DEVELOPMENT, AND SURVIVAL.');
     WRITELN('TO BE USED FOR DETERMINATION OF CUTWORM ECONOMIC'
            ,' THRESHOLDS');
     WRITELN('  BY LEN COOP - OREGON STATE UNIVERSITY  VERSION 3-24-87');

     { SETUP STUFF }
     ASSIGN(SK, 'SK.PRN'); { SK.PRN IS A SHORT PARAM FILE }
     RESET(SK);
     READLN(SK);
     READLN(SK, COMSTRING); { JUST A LINE OF TEXT USED FOR COMMENTS }
     READLN(SK, NSCRTYPE); { CHOICE OF SUPPRESSED OUTPUT TO SPEED UP PROG
                                                                    50% }
     READLN(SK, EGGSPERSQ); { INITIAL CUTWORM DENSITY EGGS/1000 SQ CM }
     READLN(SK, DDOPT); { OPTION TO CALC. DD'S OR READ LAST VERSION }
     READLN(SK, FT); { FT IS FIELDTYPE }
      READLN(SK, HFLAG); { TRUE IF REQUESTED HARVEST DATE USED }
     IF HFLAG = 1 THEN
       HDATEFLAG := TRUE
     ELSE
       HDATEFLAG := FALSE;
     READLN(SK, JDATEHARV); { JUL DATE OF HARV MAY BE SPEC }
     READLN(SK, ESTYIELD);  { ESTIMATED YIELD }
     READLN(SK, CONTROLCOST); { EST. CONTROL COST }
     READLN(SK, OILPRICE);  { EST. OIL PRICE }
     READLN(SK, OFFSETDD);  { VALUE TO SHIFT EGGHATCH DIST. }
     READLN(SK, ONLINEOPTION);  { OPTION TO USE PROGRAM ON-LINE }
     CASE ONLINEOPTION OF
       1:
```

```
    ONLINE := FALSE; { START SIMULATION ON 1 JUNE, READ NEW PARAMS }

  2:
    BEGIN { THE USER SUBMITS INSTAR DENSITIES ON A GIVEN DATE }
    ONLINE := TRUE;
    READLN(SK, STARTDATE);
    STARTTOT := 0.0;
    FOR L := 1 TO 6 DO
      BEGIN
      READLN(SK, STARTL[L]);
      STARTTOT := STARTTOT + STARTL[L];
      END;
    END;
END; { CASE }

CLOSE(SK);

CASE NSCRTYPE OF
  1:
    SCRTYPE := REG; { REGULAR FULL DAILY OUTPUT TO SCREEN AND FILE }
  2:
    SCRTYPE := SUPPR; { SUPPRESS DAILY OUTPUT TO SCREEN }
  3:
    SCRTYPE := NEITHER; { SUPPRESS DAILY SCREEN AND FILE OUTPUT }
  4:
    SCRTYPE := GRF; { GRAPHICS SCREEN DISPLAY, NO DAILY FILE OUTPUT }
 END; { CASE }
CASE FT OF
  1:
    FIELDTYPE := EARLY;
  2:
    FIELDTYPE := MID;
  3:
    FIELDTYPE := LATE;
  END; { CASE }
CASE DDOPT OF
  1:
    CALCDDFLAG := TRUE; { RE-CALCULATE DD FILE }
  2:
    CALCDDFLAG := FALSE; { USE DD FILE ALREADY EXISTING }
  END; { CASE }
BCOL := 1; { BACKGROUND COLOR CHOICE: 1=BLUE 8=GREY 15=WHITE 7=LT.
                                                                GREY }

{ MAJOR EVENTS }
{ FIRST - EST % DAMAGE TOLERANCE FROM EST YIELD, CONTROL COST,
                                                       OIL PRICE }
DAMAGETOLERANCE := 100*(CONTROLCOST/(ESTYIELD*OILPRICE));
FRSTDAY := 1; { JULIAN DAYS BEGIN 1 JUNE }
INITPLNT; { INITIALIZE THE PLANT }
IF CALCDDFLAG THEN
  WCALC; { CALC DAY DEGREES AND PLACE IN FILE HEAT.PRN }
{ ELSE USE MOST RECENT HEAT.PRN }

DAILY_ITER; { DAILY ITERATION - MOST OF PROGRAM RUNS HERE }
HARVEST; { CALC FINAL HARVEST }
```

```
      { CLOSING STUFF }
      IF NOT ((SCRTYPE = NEITHER) OR (SCRTYPE = GRF)) THEN
        BEGIN
        WRITE(COUT,#26); { ADD END OF FILE MARKER }
        CLOSE(COUT);
        END;
      WRITELN;
      WRITE('    COMMENT:  ');
      WRITELN(COMSTRING); { WRITE A COMMENT STRING TO SCREEN }
      WRITE('                            ANOTHER RUN? (Y/N)');

     REPEAT
        READ(KBD, ANSW);
        ANSW := UPCASE(ANSW);
      UNTIL ANSW IN ['Y', 'N'];
      WRITELN;

    UNTIL ANSW = 'N'; { REPEAT PROGRAM UNTIL 'N' }
END. { PROGRAM MINTSIM }



(*************** DAILY REPORT - SEPARATE FILE DAYPRT.RPT ************)
PROCEDURE DAYREPORT;
{**********************************************************************
     DAILY OUTPUT - TEXT OR GRAPHICS USED IN MINTSIM MODEL
       REPORT DAILY CONSUMPTION, NUMBER OF MAINSTEM AND
     LATERAL LEAVES PRESENT, DD'S, ETC. TO SCREEN AND FILES.
**********************************************************************}

VAR
  TOTPORP: REAL;
  CONTOT: REAL; { DRY WT. CONSUMED TOTAL PLANT }


BEGIN
{*********************** DAILY FILE REPORTS ************************}
  IF TODAY = FRSTDAY THEN { CREATE OUTPUT FILES AND THEIR HEADINGS }
    BEGIN
    FILENM2 := 'C:PUT' + RUNUM + '.PRN';
    ASSIGN(POUT, FILENM2);
    REWRITE(POUT);
    FILENM1 := 'C:CUT' + RUNUM + '.PRN';
    ASSIGN(COUT, FILENM1);
    REWRITE(COUT);

    { SET UP TITLES FOR PRN FILES }
    WRITELN(COUT, ' "', COMSTRING, '" '); { PLACE COMMENT STRING IN FILE
                                            }
    WRITE(COUT, '"WEATHR"," SOURCE:","', ISTNM, '","YEAR:",', YEAR, ',',
          '"FIELD","TYPE:",');
    CASE FIELDTYPE OF
      EARLY:
        WRITE(COUT, '"EARLY",');
      MID:
```

```
      WRITE(COUT, '"MID",');
    LATE:
      WRITE(COUT, '"LATE",');
    END;
  WRITELN(COUT, '"EGGSPERSQ","', EGGSPERSQ: 5: 3, '"');
  WRITELN(POUT, ' "', COMSTRING, '" ');
  WRITE(POUT, '"WEATHR"," SOURCE:","', ISTNM, '","YEAR:",', YEAR, ',',
        '"FIELDTYPE:",');
  CASE FIELDTYPE OF
    EARLY:
      WRITE(POUT, '"EARLY",');
    MID:
      WRITE(POUT, '"MID",');
    LATE:
      WRITE(POUT, '"LATE",');
    END;
  WRITELN(POUT, '"EGGSPERSQ","', EGGSPERSQ: 5: 3, '"');
  WRITELN(COUT, '"DAY",', '"DD",', '"CUMDD",', '"HATCH",', '"CUMH",',
          '"DENS1",', '"DENS2",', '"DENS3",', '"DENS4",', '"DENS5",',
          '"DENS6",', '"PUP"');
  WRITE(POUT, '"DAY",', '"CUMDD",', '"#NODES",', '"#LATS",',
        '"LATPREF",', '"#ABSC",', '"CONTOT",', '"LATCON",', '"CON1",',
        '"CON2",', '"CON3",', '"CON4",', '"CON5",');
  WRITELN(POUT, '"CON6",', '"CON7",', '"CON8",');
  WRITE(POUT,
        'DAY  CUMDD #NODES #LATS LATPREF #ABSC CONTOT   LATCON    ');
  WRITE(POUT, 'CON1     CON2     CON3     CON4     CON5     CON6');
  WRITELN(POUT, '     CON7     CON8');
  END; { TODAY = FRSTDAY }

{ NOW DO EVERYDAY - FILES }
WRITE(COUT, TODAY: 3, ',', CURDD: 5: 1, ',', CUMDD / 10: 6: 1, ',',
      POPHATCHTODAY: 7: 2, ',', CUMEGGHATCH * EGGSPERSQ: 7: 2, ',');
FOR I := 1 TO 6 DO
  WRITE(COUT, DENSTOT[I]: 7: 2, ',');
WRITE(COUT, DENS[7, 1]: 7: 2);
WRITELN(COUT);
WRITE(POUT, TODAY: 3, ',', CUMDD: 7: 1, ',', NODESIZE: 3, ',',
      P1.LATLVS: 5: 1, ',', LATPORP: 6: 2, ',', XNODEABSC: 3, ',');
CUMTOT := 0.0;
FOR I := 1 TO NODESIZE DO
  CUMTOT := CUMTOT + P1.MLVS[I].DRYCUM; { SUM CONSUMP FOR ALL MAINSTEM
                                         }
CUMTOT := CUMTOT + P1.LATCUM; { ADD IN LAT CONS FOR TODAY }
WRITE(POUT, CUMTOT: 8: 1, ',', P1.LATCUM: 8: 1, ',');
FOR I := 1 TO 8 DO
  WRITE(POUT, P1.MLVS[I].DRYCUM: 8: 1, ',');
WRITELN(POUT);

{********************** DAILY SCREEN REPORT **********************}
IF (SCRTYPE = REG) AND (NOT ODD(TODAY)) THEN { UPDATE PLANT REPORT
                                               SCRN }
  BEGIN
  WRITELN;
  FOR I := 1 TO 25 DO
    WRITE(#205);
```

```
  WRITE(' PLANT SUMMARY FOR DAY: ', TODAY, ' ');
  FOR I := 1 TO 25 DO
    WRITE(#205);
  WRITELN;
  WRITE('    # LATS ', P1.LATLVS: 4: 2, '    # NODES ', NODESIZE,
        '    # ABSC''D ', XNODEABSC);
  WRITELN('    LATPORP ', LATPORP: 4: 4);
  CONTOT := 0.0;
  FOR I := 1 TO NODESIZE DO
    CONTOT := CONTOT + P1.MLVS[I].DRYCON; { SUM CONSUMP FOR MAINSTEM }
  CONTOT := CONTOT + P1.LATCON; { PLUS CUM LATERAL CONSUMPTION }

  WRITE('NODE:     ALL    LAT    N1     N2     N3     N4     N5');
  WRITELN('    N6     N7     N8');
  TOTPORP := 0.0;
  FOR I := 1 TO NODESIZE DO
    TOTPORP := TOTPORP + CURFEEDDIST[I];
  TOTPORP := TOTPORP + LATPORP;
  WRITE('FPORP: ', TOTPORP: 6: 3, LATPORP: 6: 3);
  FOR I := 1 TO 8 DO
    WRITE(' ', CURFEEDDIST[I]: 6: 3);
  WRITELN;
  WRITE('DRYCON:', CONTOT: 6: 1, P1.LATCON: 6: 1);
  FOR I := 1 TO 8 DO
    WRITE(' ', P1.MLVS[I].DRYCON: 6: 1);
  WRITELN;
  WRITE('DRYCUM:', CUMTOT: 6: 1, P1.LATCUM: 6: 1);
  FOR I := 1 TO 8 DO
    WRITE(' ', P1.MLVS[I].DRYCUM: 6: 1);
  WRITELN;
  FOR I := 1 TO 77 DO
    WRITE(#205);
  WRITELN;
  END;

IF (SCRTYPE = REG) AND (NOT ODD(TODAY)) THEN { UPDATE WORM SCRN REPORT
                                                 }
  BEGIN
  FOR I := 1 TO 27 DO
    WRITE(#196);
  WRITE(' VC SUMMARY FOR DAY: ', TODAY, ' ');
  FOR I := 1 TO 26 DO
    WRITE(#196);
  WRITELN;
  WRITE('  EGGHATCH ', POPHATCHTODAY: 7: 3, '  CUM ');
  WRITELN(CUMEGGHATCH * EGGSPERSQ: 8: 3, '  CURDD ', CURDD: 5: 1,
          '  CUMDD ', CUMDD: 7: 1);
  END;
IF (SCRTYPE = REG) AND (NOT ODD(TODAY)) THEN
  BEGIN
  FOR I := 1 TO 6 DO
    WRITE(' VC', I: 1, '=', DENSTOT[I]: 6: 3);
  WRITE(' PUP=', DENS[7, 1]: 6: 3);
  WRITELN;
  FOR I := 1 TO 77 DO
    WRITE(#196);
```

```
    END;
END; { DAYREPORT }

{******************** DAILY GRAPHICS REPORT ********************}

PROCEDURE GRFRPT(DAY: INTEGER); {DISPLAY DAILY GRAPHICS OUTPUT}

VAR
  I: INTEGER;
  SCALEFAC: REAL; { KEEPS GRAPHICS WITHIN SCREEN BOUNDS }
  CURFEED: REAL; { CURRENT FEEDING DIST }


PROCEDURE LINE(X0, X1, Y: INTEGER); {DRAW A LINE FROM X0 TO X1 AT Y}
  { EQUIV. TO DRAW(X1,Y1,X2,Y2,COLOR) BUT FASTER }
  BEGIN
    INLINE($8B / $BE / X1 / {MOV DI,X1}
           $8B / $8E / X0 / {MOV CX,X0}
           $39 / $CF / {CMP DI,CX}
           $7D / $02 / {JGE 2 BYTES}
           $87 / $F9 / {XCHG CX,DI}
           $8B / $96 / Y / {MOV DX,Y}
           $BB / $01 / $0C / {MOV BX,0C01}
           $89 / $D8 / {L1: MOV AX,BX}
           $CD / $10 / {INT 10H}
           $41 / {INC CX}
           $3B / $F9 / {CMP DI,CX}
           $7D / $F7); {JG L1}
  END;


PROCEDURE CLRLINE(X0, X1, Y: INTEGER); { DRAW A CLEAR LINE FOR ERASING }

  BEGIN
    INLINE($8B / $BE / X1 / $8B / $8E / X0 / $39 / $CF / $7D / $02 /
           $87 / $F9 / $8B / $96 / Y / $BB / $00 / $0C / {MOV BX,0C00}
           $89 / $D8 / $CD / $10 / $41 / $3B / $F9 / $7D / $F7);
  END;

PROCEDURE LFPLOT(LPOS, LCOL: INTEGER); { PLOT A LEAF }

  VAR
    I, J, SX, SY: INTEGER;

  BEGIN
    { FIRST SET UP BUDDING LEAF }
    SY := 5 + (8 * LPOS);
    SX := 15;
    FOR J := SY + 2 TO SY + 10 DO {DO STEM FIRST}
      LINE(SX - 1, SX + 1, J);
    LINE(SX - 7, SX - 4, SY + 3);
    LINE(SX - 7, SX - 3, SY + 4);
    LINE(SX - 6, SX - 2, SY + 5);
    LINE(SX - 5, SX - 2, SY + 6);
    LINE(SX + 4, SX + 7, SY + 3);
    LINE(SX + 3, SX + 7, SY + 4);
```

```
    LINE(SX + 2, SX + 6, SY + 5);
    LINE(SX + 2, SX + 5, SY + 6);

    { NOW MATURE LEAF BELOW }
    SY := 5 + (8 * (LPOS + 1));
    { BLACKEN OLD IMAGE }
    CLRLINE(SX - 7, SX - 4, SY + 3);
    CLRLINE(SX - 7, SX - 3, SY + 4);
    CLRLINE(SX - 6, SX - 2, SY + 5);
    CLRLINE(SX - 5, SX - 2, SY + 6);
    CLRLINE(SX + 4, SX + 7, SY + 3);
    CLRLINE(SX + 3, SX + 7, SY + 4);
    CLRLINE(SX + 2, SX + 6, SY + 5);
    CLRLINE(SX + 2, SX + 5, SY + 6);

    { PLOT REG LEAF }
    FOR J := SY TO SY + 10 DO
      LINE(SX - 1, SX + 1, J);
    LINE(SX - 15, SX + 15, SY + 5);
    LINE(SX - 13, SX - 3, SY + 4);
    LINE(SX - 13, SX - 3, SY + 6);
    LINE(SX - 10, SX - 6, SY + 3);
    LINE(SX - 10, SX - 6, SY + 7);
    LINE(SX + 3, SX + 13, SY + 4);
    LINE(SX + 3, SX + 13, SY + 6);
    LINE(SX + 6, SX + 10, SY + 3);
    LINE(SX + 6, SX + 10, SY + 7);
    GOTOXY(6, LPOS + 2);
    WRITE(DAY);
  END;

PROCEDURE LFABSCPLOT(LPOS, LCOL: INTEGER); { ABSCISS A LEAF }

  VAR
    I, J, SX, SY: INTEGER;

  BEGIN
    SY := 5 + (8 * LPOS);
    SX := 15;
    FOR J := SY TO SY + 10 DO
      CLRLINE(SX - 1, SX + 1, J);
    CLRLINE(SX - 13, SX + 13, SY + 5);
    GOTOXY(8, LPOS + 2);
    WRITE(DAY);
  END;


PROCEDURE FDISTBARPLOT(LPOS: INTEGER; AMT: REAL; COL: INTEGER);
{ FEEDING DIST BAR PLOT UPDATED ONLY AFTER CHANGE IN PLANT PROFILE
                                                            OCCURS }
  VAR { PLOT FEEDING DIST. BAR CHART VALUE }
    I, J, SX, SY: INTEGER;

  BEGIN
  IF ONLINE AND (TODAY < STARTDATE) THEN ELSE
    BEGIN
```

```
    SY := 10 + (8 * LPOS);
    SX := 84;
    FOR I := SY - 1 TO SY + 1 DO
      LINE(SX, SX + TRUNC(AMT * 120 + 0.01), I);
    END;
  END;


PROCEDURE FDISTBARCLEAR(LPOS: INTEGER; AMT: REAL; COL: INTEGER);

  VAR { CLEAR A FEEDING DIST. BAR CHART VALUE }
    I, J, SX, SY: INTEGER;

  BEGIN
    SY := 10 + (8 * LPOS);
    SX := 84;
    FOR I := SY - 1 TO SY + 1 DO
      CLRLINE(SX, SX + ROUND(AMT * 120), I);
  END;

PROCEDURE CONSUMPBARPLOT(LPOS: INTEGER; OLDAMT, NEWAMT: REAL;
                                                  COL: INTEGER);
 { PLOT CUMULATIVE CONSUMP. BAR CHART VALUE }

  CONST
    FAC = 0.26;

  VAR
    I, J, SX, SY: INTEGER;
    SCALE: REAL;

  BEGIN
    SCALE := FAC * SCALEFAC;
    SY := 10 + (8 * LPOS);
    SX := 131;
    IF OLDAMT + NEWAMT > 0.005 THEN
      FOR I := SY - 1 TO SY + 1 DO
        LINE(SX + ROUND(OLDAMT * SCALE),
             SX + ROUND(OLDAMT * SCALE) + ROUND(NEWAMT * SCALE), I);
  END;

PROCEDURE DENSPLOTAXIS; { PLOT AXIS FOR DENSITY PLOT }

  CONST
    FAC = 1;

  VAR
    I, J, SX, SY: INTEGER;
    SCALE: REAL;

  BEGIN
    SCALE := (FAC / 1.33) / SCALEFAC;
    SY := 141;
    SX := 290; {194}
    FOR I := 1 TO 130 DO { PLOT Y AXIS }
      LINE(SX + 1, SX + 2, (SY + 1) - I);
```

```
    LINE(SX - 93, SX + 2, SY); { PLOT X AXIS }
    GOTOXY(38, 18);
    WRITE('0.0');
    FOR I := 1 TO 16 DO
      BEGIN
      SY := 140 - (I * 8);
      FOR J := 1 TO 3 DO { Y AXIS TICK MARKS }
        LINE(SX - 1, SX, SY);
      GOTOXY(38, 18 - I);
      IF ((NOT ODD(I)) AND ((I * SCALE / 12) < 10)) THEN
        WRITE((I * SCALE / 12): 3: 1);
      IF ((NOT ODD(I)) AND ((I * SCALE / 12) >= 10)) THEN
        WRITE((I * SCALE / 12): 2: 0);
      END;

  END;

PROCEDURE DENSPLOT(INSTAR: INTEGER; SIZE, SIZELAST: REAL);
 {PLOT DENSITY EACH INSTAR VC}

  CONST
    FAC = 125; {60}

  VAR
    I, SX, SY: INTEGER;
    SCALE: REAL;

  BEGIN
    SCALE := FAC * SCALEFAC;
    SY := 140;
    SX := 183 + (INSTAR * 16);
    IF ((SIZE > 0.01) OR (SIZELAST > 0.000001)) THEN
      BEGIN
      IF SIZE >= SIZELAST THEN { NEED TO ADD TO BARPLOT }
        BEGIN
        FOR I := SY - ROUND(SIZE * SCALE) TO SY - ROUND(SIZELAST *
         SCALE) DO

          IF NOT ODD(INSTAR) THEN
            LINE(SX + 1, SX + 7, I {+1} )
          ELSE
            LINE(SX + 1, SX + 7, I);

        END
      ELSE { NEED TO TAKE AWAY FROM BARPLOT }
        FOR I := SY - ROUND(SIZELAST * SCALE) TO SY - ROUND(SIZE *
         SCALE) DO
          CLRLINE(SX + 1, SX + 7, I);
      END; {IF}
  END;

 BEGIN {GRFRPT}
  { SCALE FACTORING }
  IF NOT ONLINE THEN
    IF EGGSPERSQ < 2.5 THEN
      SCALEFAC := 1.0 {4.5}
```

```
    ELSE IF EGGSPERSQ < 5.5 THEN
      SCALEFAC := 0.5 {8.5}
    ELSE
      SCALEFAC := 0.25
  ELSE { ONLINE OPTION }
    IF STARTTOT < 1.5 THEN
      SCALEFAC := 1.0 {4.5}
    ELSE IF STARTTOT < 2.5 THEN
      SCALEFAC := 0.5 {8.5}
    ELSE
      SCALEFAC := 0.25;

  IF DAY = FRSTDAY THEN {INIT THE SCREEN}
    BEGIN
    {SETUP 2 COLOR 640x200 MED RES:}
       HIRES;
     HIRESCOLOR(2);

    {SETUP 4 COLOR 320x200 LOW RES:}
    GRAPHCOLORMODE;
    GRAPHBACKGROUND(BCOL);
    PALETTE(2); { GREEN=1 LEAVES, OTHER COLORS YELLOW=3, RED=2}
    {  PALETTE(1); } { LT BLUE=1 LEAVES, OTHER COLORS WHITE=3, PURPLE=2}
    TEXTCOLOR(3);
    GOTOXY(1, 20);

    { PUT INITIAL TEXT UP ON SCREEN }
    WRITE('                              1 2 3 4 5 6');
    GOTOXY(1, 22);
    WRITE('MINT GROW FEED  CUMULAT   VC DENSITY');
    GOTOXY(1, 23);
    WRITE('STEM DAYS DIST  CONSUMP   PER .1 SQ M');
    GOTOXY(1, 25);
    WRITE('DAY:', DAY: 2, ' DATE:', CALCMNTH(DAY), ' ', CALCDATE(DAY):
          2, ' HARV:', CALCMNTH(HARVESTDAY), ' ', CALCDATE(HARVESTDAY):
          2, ' #VC:0.000');

    { DRAW INITIAL PLANT }
    FOR I := 18 DOWNTO 18 - XNODEADD DO
      LFPLOT(I, 1);
    FOR I := 19 DOWNTO 18 - XNODEADD + NODESIZE + 1 DO
      LFABSCPLOT(I, 1);

    { DRAW INITIAL FEEDING DISTRIBUTION }
    IF NOT ONLINE THEN { OK TO DO INIT FEEDING DIST }
      FOR I := 18 - XNODEADD TO 18 - XNODEABSC DO
        BEGIN
        CURFEED := CURFEEDDIST[(I + XNODEADD) - 18];
        CURFEED := 0.0;     (* DEBUG *)
        FDISTBARPLOT(I, CURFEED, 1);
        END;
    DENSPLOTAXIS;
    GOTOXY(2, 1);
    WRITE('#LATS:0');
    END; { TODAY = FRSTDAY }
```

```
{ NOW DO EVERYDAY:}
IF ADDPLOTFLG THEN
  LFPLOT(18 - XNODEADD, 1); { UPDATE PLANT }
IF ABSCPLOTFLG THEN
  BEGIN
  LFABSCPLOT(18 - XNODEADD + NODESIZE + 1, 1);
  END;

IF (ADDPLOTFLG OR ABSCPLOTFLG)
     AND (NOT ONLINE OR (ONLINE AND (TODAY > STARTDATE)))
  THEN { UPDATE FDIST BARGRAPH ON SCREEN }
  BEGIN
  FOR I := 18 - XNODEADD TO (18 - XNODEABSC) + 1 DO
    FDISTBARCLEAR(I, 0.38, 0);
  FOR I := 18 - XNODEADD TO 18 - XNODEABSC DO
    FDISTBARPLOT(I, CURFEEDDIST[(I + XNODEADD) - 18], 1);
  GOTOXY(8, 1);
  WRITE(P1.LATLVS: 2: 0);
  FDISTBARCLEAR( - 1, 0.38, 0);
  FDISTBARPLOT( - 1, LATPORP, 1);
  END;
IF NOT ONLINE OR ONLINE AND (TODAY > STARTDATE) THEN
  BEGIN
  FOR I := 18 - XNODEADD TO 18 - XNODEABSC DO { SHOW CUM. CONSUMPTION }
  CONSUMPBARPLOT(I,
               (P1.MLVS[(I + XNODEADD) - 18].DRYCUM) -
               (P1.MLVS[(I + XNODEADD) - 18].DRYCON),
               P1.MLVS[(I + XNODEADD) - 18].DRYCON, 1);
  CONSUMPBARPLOT( - 1, P1.LATCUM - P1.LATCON, P1.LATCON, 1);
  END;

{ UPDATE GRAPHICS TEXT STUFF; DAY, DAYS TO HARV, VC DENS: }
GOTOXY(5, 25);
WRITE(TODAY: 2);
GOTOXY(13, 25);
WRITE(CALCMNTH(DAY), ' ', CALCDATE(DAY): 2);
TDENS := 0.0;
IF NOT ONLINE OR ONLINE AND (TODAY > STARTDATE) THEN
  FOR I := 1 TO 6 DO
    BEGIN
    DENSPLOT(I, DENSTOT[I], DENSTOTLST[I]);
    TDENS := TDENS + DENSTOT[I];
    DENSTOTLST[I] := DENSTOT[I];
    END;

GOTOXY(36, 25);
WRITE(TDENS: 5: 2);

IF TODAY = HARVESTDAY THEN {HOLD IMAGE UNTIL KEYBOARD USED}
  BEGIN
   REPEAT
  UNTIL KEYPRESSED;     TEXTMODE;
  END;
END; {GRFRPT}
{******************************************************************}
```

APPENDIX II. Accessory files MINTSIM.DOC and SK.PRN used with MINTSIM peppermint defoliation model.

BRIEF DOCUMENTATION ON HOW TO USE/RUN THE MINTSIM PROGRAM. APRIL 1987

Written by:
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BRIEF DESCRIPTION OF PROGRAM:

MINTSIM is a simulation model for determination of variegated cutworm economic threshold values in Oregon peppermint. Peppermint morphological growth, cutworm development, feeding behavior, and injury are simulated. MINTSIM was written in TURBO Pascal for IBM PC's and compatibles and requires a color graphics adaptor for the optional graphics output. A more detailed description of MINTSIM and its uses are available from the program author.

STEPS REQUIRED TO RUN MINTSIM:
1. Edit model parameters in file SK.PRN using any text editor.
2. Save the changes.
3. Type MINTSIM from the DOS prompt.
4. View output, examine result files PUT.PRN and CUT.PRN with text editor or spreadsheet.

DESCRIPTION OF FILES NEEDED:

```
MINTSIM.COM    <--- Compiled version of MINTSIM
MINTSIM.PAS    <--- Most of the source code written in Turbo Pascal
WCALC.INC      <--- Degree day calculation routines used in MINTSIM
DAYRPT.INC     <--- Daily output routines used in MINTSIM
SK.PRN         <--- The parameter file
WEATHR.DAT     <--- Weather (MAX-MIN) data file
HEAT.PRN       <--- Degree day file in Lotus .PRN (ASCII) format
```

RUNNING AND COMPILING NOTES
1. All files must be in the default directory.
2. The file MINTSIM.PAS is the one compiled, it contains compiler options to include the two include files WCALC.INC and DAYRPT.INC.
3. Turbo Pascal (Borland International, 4113 Scotts Valley Drive, Scotts Valley, California 95066) version 3.0 is the only compiler which this program should compiler under. Other Pascal compilers may be used after some minor source code modifications.
4. MINTSIM.COM is already compiled and is ready to run.

MINTSIM OUTPUT
1. Text screen report every other day of the simulation, choice #1 for screen display type in parameter file SK.PRN.
2. Continually updated graphics screen output, choice 4 for screen display type in parameter file SK.PRN.
3. File output to CUTxx.PRN (xx from run counter), reports daily the

status of cutworm variables. CUTxx.PRN is spreadsheet compatible.
4. File output to PUTxx.PRN, reports daily the status of peppermint plant variables. PUTxx.PRN is spreadsheet compatible.
5. Final harvest summary reported to the screen and appended to PUTxx.PRN.

PARAMETER OPTIONS (set in SK.PRN file)
1. Display of output (see above).
2. Initial variegated cutworm egg density per 1000 sq. cm. Default = 0.909.
3. Option to recalculate degree days from a different weather station site.
4. Field type; Early, Average, or Late. Chosen according to a table listing the range of acceptable harvest dates at the bottom of SK.PRN.
5. Option to use the default harvest dates or input another.
6. Harvest date other than default.
7. Estimated yield. Default = 76.10 lb/acre.
8. Estimated treatment cost. Default = 18.22/acre Default #2 = 20.00/acre.

```
{PARAMETER FILE SK.PRN READ BY MINTSIM MODEL- NEXT LINE FOR COMMENTS}
RUN FOR BEHAVIORAL STUDIES
4        { SCREEN DISP TYPE: 1=REG 2=SUPPRESS 3= FILE ALSO 4=GRAPHICS}
0.909    {0.909}{ EGGSPERSQ (VAR CUTWORM EGGS PER 1000 SQ CM }
2        { DDOPT: 1 = CALC DD'S 2 = SKIP CALC JUST READ DD'S FROM FILE}
2        { FT: FIELDTYPE 1 = EARLY, 2 = AVERAGE, 3 = LATE }
2        { HDATEFLAG: 1 TO USE HARVEST DATE ON NEXT LINE, 2 - DEFAULT}
66       { REQUESTED JULIAN DATE OF HARVEST AFTER 1 JUNE - TABLE BELOW}
76.10    { ESTIMATED YIELD - DEFAULT = 76.10 LB/ACRE }
20.00    { EST. TREATMENT COST - Nom1 = 18.22 $/ACRE, Nom2=20 }
12.0     { EST. OIL VALUE - Nom1 = 10.0/LB, Nom2=12 }
0.0      { OFFSETDD: #DD'S TO OFFSET EGGHATCH CURVE  ex 100 = 6-7 DAYS}
1        { ONLINE OPT. 1=NO 2=YES - INPUT SAMPLE DATE & DENS }
40       { DATE OF SAMPLE FOR ONLINE OPTION ex. 40 = 10 JUL }
0        { INIT DENS. FIRST INSTAR/1000 CM SQ FOR ONLINE OPTION }
2.0      { INIT DENS. SECOND INSTAR/1000 CM SQ FOR ONLINE OPTION }
1.5      { INIT DENS. THIRD INSTAR/1000 CM SQ FOR ONLINE OPTION }
0        { INIT DENS. FORTH INSTAR/1000 CM SQ FOR ONLINE OPTION }
0        { INIT DENS. FIFTH INSTAR/1000 CM SQ FOR ONLINE OPTION }
0        { INIT DENS. SIXTH INSTAR/1000 CM SQ FOR ONLINE OPTION }

     FOR ALLOWABLE HARVEST DATES USE THE FOLLOWING TABLE:

          FIELDTYPE  ALLOWABLE RANGE         DEFAULT
          EARLY      59-73 (28JUL-12AUG)    66 (5AUG)
          AVERAGE    69-83 (8AUG-22AUG)     76 (15AUG)
          LATE       79-93 (18AUG-1SEPT)    86 (25AUG)
```

Appendix III. Example output from the MINTSIM peppermint defoliation model.

FINAL MINTSIM REPORT PAGE 1: INDIVIDUAL LEAF PAIRS

NODE #	DRY WT CONSUMED	OIL CONSUMED	POTENT. OIL	%OIL CONSUMED	ABSC-ISSED	DATE ABSC	DATE ADDED
1	0	0.00	2.90	0.00	P		69
2	0	0.00	3.76	0.01	P		62
3	2	0.00	3.65	0.09	P		56
4	10	0.01	4.09	0.36	P		50
5	30	0.05	4.13	1.28	P		43
6	66	0.10	3.86	2.70	P		37
7	103	0.16	3.86	4.08	P		31
8	116	0.22	3.80	5.79	P		25
9	50	0.09	1.99	4.45	*	0	18
10	53	0.09	3.76	2.51	A	68	12
11	20	0.04	3.76	0.94	A	60	6
12	5	0.01	3.76	0.22	A	52	1
13	1	0.00	3.76	0.04	A	44	0
14	0	0.00	3.76	0.01	A	35	0
15	0	0.00	3.76	0.00	A	27	0
16	0	0.00	3.76	0.00	A	19	0
17	0	0.00	3.76	0.00	A	10	0
ΣMN	376	0.64	37.41	1.71			
LAT	70	0.20	38.68	0.53	NLATS:	51.92	
ΣALL	447	0.85	76.10	1.111			
ABSC	124	0.22	31.86	0.29			

FINAL MINTSIM REPORT PAGE 2: THRESHOLD VALUES

INPUT VARIABLES	
COST OF CONTROL:	20.00 $ / ACRE
ESTIMATED YIELD:	76.10 LB / ACRE
PRICE OF OIL:	12.00 $ / LB
INITIAL VC DENSITY (# EGGS / 1000 SQ CM):	0.91 EGGS
HARVEST DATE:	AUG 15
FIELDTYPE (1=EARLIEST 3=LATEST):	2
WEATHER DATA SOURCE:	HAVG 50
MODEL RESULTS	
% DAMAGE TOLERANCE:	2.19 %
% DAMAGE INFLICTED:	1.11 %
DAMAGE TOLERANCE IN LB./ACRE:	1.67 LB./ACRE
OIL CONSUMED IN LB./ACRE:	0.845 LB./ACRE
THRESHOLD (# EARLY INSTAR LARVAE / 1000 CM SQ):	1.79 CUTWORMS
% OF TOTAL INJURY TO LEAVES PRESENT:	79.45 %

COMMENT: RUN FOR BEHAVIORAL STUDIES

ANOTHER RUN? (Y/N)