United States
Department of
Agriculture

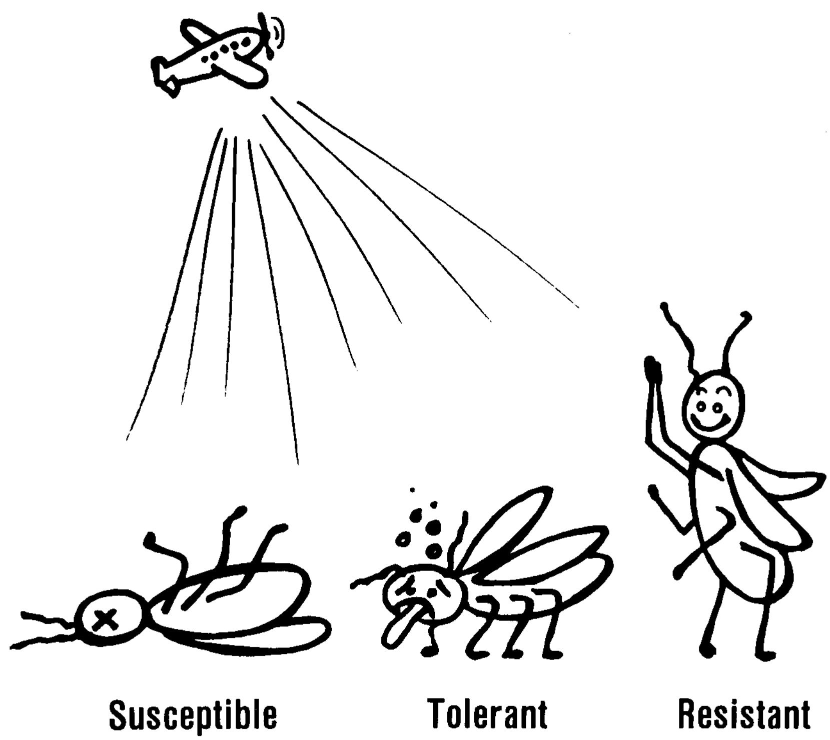
Forest Service

**Pacific Southwest
Forest and Range
Experiment Station**

General Technical
Report PSW-89

# Computer Prediction of Insecticide Efficacy for Western Spruce Budworm and Douglas-fir Tussock Moth

**Jacqueline L. Robertson** **Molly W. Stock**



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## Acknowledgments:

We thank Jo Ellen Force, University of Idaho, Moscow; Robert W. Campbell, Forest Service, Corvallis, Oregon; Carroll B. Williams, Forest Service, Berkeley, California; and Michael Saunders, Texas A&M University, College Station, for their helpful reviews of this manuscript. Michael Shook, Washington State University, Pullman, provided valuable assistance with the graphics of the computer program developed in the study reported herein.

## Publisher:

**Pacific Southwest Forest and Range Experiment Station**
**PO. Box 245, Berkeley, California 94701**

**April 1986**

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# INTRODUCTION

Because laboratory experiments are relatively inexpensive compared to field trials, many attempts have been made to use laboratory data to estimate the results of applying insecticides to populations of a target forest defoliator. Predictions based on well-designed laboratory tests and validated by field tests can help ensure that the desired insect mortality is attained with minimum cost.

Early laboratory studies emphasized screening of candidate insecticides by topical application (e.g., Robertson and Lyon 1973; Robertson and others 1975, 1976). By comparing the relative contact toxicities of new candidates to the toxicities of insecticides already field-tested, crude extrapolations were made to suggest field application rates for each new insecticide. This procedure is inherently inaccurate: measurement units in topical application bear little relationship to those units actually reaching the insect in a field application. Laboratory spray chambers (e.g., Potter 1952, Nigam 1975, Robertson and others 1979) were also used to determine contact effectiveness. Since sprays in these chambers were usually applied to fully exposed insects, even the fact that application rates were calculated in units equivalent to those applied in the field did not improve the accuracy of extrapolations. Field application rates were consistently underestimated because factors such as evaporation and shielding of the insects by foliage were not taken into account. In order to compensate for underestimation of the dose actually reaching the insect in the field, a laboratory-based spray dose estimate was routinely multiplied by an arbitrarily chosen factor of 3 to obtain a field application rate (Williams 1973).

Besides contact effectiveness, toxicity by ingestion was also recognized as an important component of overall efficacy. Bioassays were developed to test toxicity by feeding (e.g., Granett and Retnakaran 1977, Gillette and others 1978) but data were useful only for determination of relative toxicities and were subject to the same limitations as topical and spray application data.

The first deliberate attempt to integrate data on contact and feeding effectiveness in order to predict field effectiveness was a series of bioassays and ranking criteria developed for western spruce budworm (*Choristoneura occidentalis* Freeman) (Robertson and Haverty 1981). Although an improvement over previous attempts such as that of Robertson and Boelter (1979a,b), this method still provided no satisfactorily accurate means to predict field application rates. Subsequently, multiplication factors for suggesting field application rates for western spruce budworm were derived (Haverty and Robertson 1982). These factors were based on a new type of bioassay in which larvae were sprayed while foraging on host plant foliage.

Definition of the relationship between laboratory and field data provided a rational basis for a computer model, based on laboratory data, to predict the efficacy of insecticides applied to the Douglas-fir tussock moth (*Orgyia pseudotsugata* [McDunnough]) and the western spruce budworm (Force and others 1982). The model was used to simulate the effects of applying a given rate of either acephate (Orthene 75S formulation) or carbaryl (Sevin-4-oil formulation) at any time during larval development of either species in the field. The original computer program was not interactive; it calculated single time-point predictions based on fixed instar distributions and separate estimates of contact and feeding mortalities.

This report describes a generalized, interactive version of the computer model that has been expanded to simulate efficacy, over seasonal development of western spruce budworm and Douglas-fir tussock moth, of any insecticide for which the user has laboratory-based concentration-response data. In addition, the model can be used to predict the effect of an insecticide for a particular instar distribution specified by the user. The program has four options, is written in BASIC, and can be operated on a microcomputer. The program listing is found in the *appendix.* Users can obtain a printout of program output by linking the program output to a graphics terminal.

# 1. MATHEMATICAL PROCEDURES

As in the original model (Force and others 1982), logic of the general model is based on probability theory. The model uses the multiplication law for independent events and the definition of conditional probability for two events. According to the multiplication law, if events A and B are statistically independent, the probability of their joint occurrence equals the product of their individual probabilities. For example, the probability of mortality (M) of an insect in instar i ($I_i$) when the population is sprayed on day y is the conditional probability $P(M|I_i)$. Once the user has specified the insect species, the genetic response category, the insecticide, and the amount (dose or concentration) reaching the insects, the probability of mortality is equal to the probability of mortality in instar i times the probability of the insect being in instar i, summed

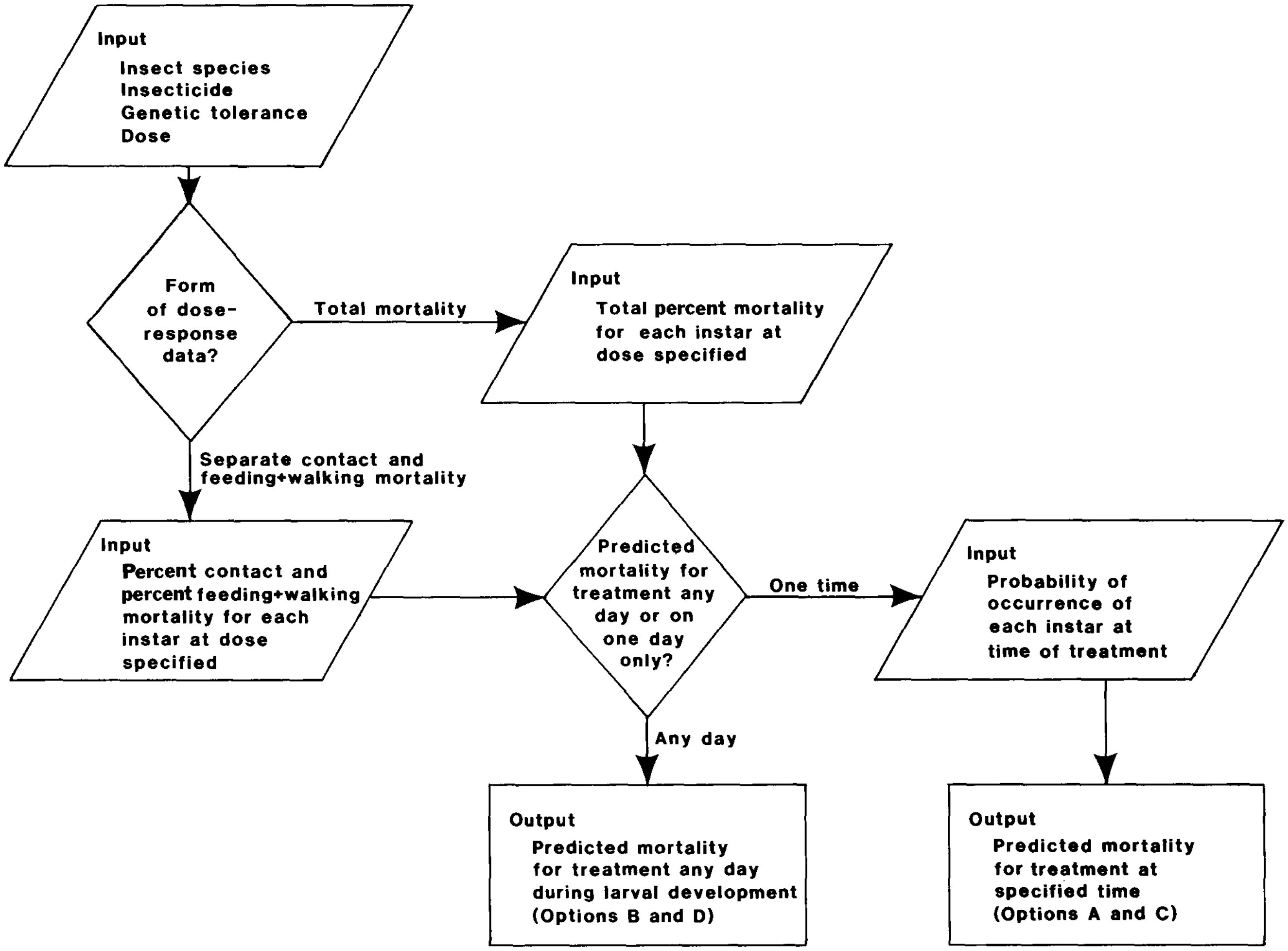


**Figure 1**--Model logic showing input required and resulting output.

over all instars. Program options (*fig. 1*) are designed to provide (1) a simulation of mortality when the chemical is applied at the specified rate on any day during population development, or (2) a prediction of mortality at a specified time during population development. Two general types of laboratory data can serve as input: (1) separate estimates of mortality by feeding and by contact or (2) estimated total mortality resulting from both feeding and contact. The resultant four options provide the flexibility needed for efficient use of the results of contemporary bioassays.

## 2. PROGRAM

### 2.1 Insect

The user first specifies the target species, either Douglas-fir tussock moth (DFTM) or western spruce budworm (WSBW).

### 2.2 Genetic Predisposition of Population

Responses of populations of both western spruce budworm and Douglas-fir tussock moth to a given chemical may vary widely (Robertson and others 1978; Stock and Robertson 1979, 1980). These differences should be considered in developing realistic models of chemical efficacy. A genetic basis has been documented for differential population responses to acephate and carbaryl (Stock and Robertson 1979, 1980).

A particular population can be designated as relatively tolerant, susceptible, or resistant by comparing its response to that of a standard reference population. One way to separate groups is by comparison of $LC_{50}$'s and their 95 percent confidence limits (e.g., Roush and Wolfenbarger 1985). A more precise way to separate groups is to use the likelihood ratio test for equality of response (Savin and others 1977). Although the relationships between genetic characteristics and response to other chemicals are at present unknown, the terminology for responses to acephate and carbaryl has been retained in the general model.

### 2.3 Insecticide

The user must specify the name of the chemical for which a prediction is desired.

### 2.4 Application Rate Per Unit Area

The user must specify the application rate of each chemical in terms of weight of the active ingredient per unit area. The units specified must match the units of the data base. For example, the application rate is called "dose in unit area" in the program.

In simulation operations (options A and C in the program), the user may compare the predicted effects of applying a given rate on all days over the entire course of population development. Because relative efficacy is of interest in this type of situation, the choice of rate may be entirely arbitrary. To predict efficacy at one point in time (options B and D), the rate may be considered either desirable or likely to reach the insects.

## 3. PROGRAM OPTIONS

### 3.1 Option A

This option simulates mortality (over time) based on percent mortality of each instar for a given chemical and rate (user specifies mortality by contact and by feeding) (*fi*gs. *2, 3*).

The input data required are (1) percent mortalities for each instar sprayed with a given rate when larvae are fully exposed, and (2) percent mortalities for each instar feeding and walking on foliage sprayed at this rate. These data may be read directly from dose-mortality regression lines for full exposure and feeding plus walking. In the example (*fig. 2*), calculations are made with the Douglas-fir tussock moth population instar distribution stored in the program in order to estimate percent mortality by contact, by feeding plus walking, and total mortality.

We assume that an insect may die from either direct contact with the spray or from feeding and walking on sprayed foliage. The probability of death by direct contact is assumed to depend on the insect's body size (e.g., Busvine 1971); body size is assumed to be a function of the instar at the time of spray. Therefore, mortality by direct contact (MDC) of an insect in instar i is multiplied by the probability of contact (C) for the instar on day y when the toxicant is applied. This probability is summed over all instars (n) to determine expected mortality from direct contact if the treatment were applied on day y:

$$P(MDC_y) = \sum_{i=1}^{n} P(MDC|I_i, C)P(C|I_i) \cdot P(I_i)$$

Results of these calculations are shown in the second column of output (CONTACT) (*fig. 2*).

Death from feeding plus walking may occur in insects that survive direct contact effects or that were not hit directly by spray droplets. Therefore, expected mortality from direct contact (MDC) must be subtracted from the total proportion of the population in instar i on day y; the remaining insects in instar i are assumed to be exposed to the chemical by feeding plus walking. The probability of feeding plus walking exposure is then multiplied by the probability of death from feeding plus walking when the insect is in instar i[P(MFW $I_i$)]. Total probability of mortality from feeding plus walking beginning on day y is the sum of MFW over all instars (n):

$$P(MFW_y) = \sum_{i=1}^{n} P(MFW|I_i) \cdot P(I_i) \cdot [1 - P(C|I_i)P(MDC|I_i, C)]$$

Results of these calculations are shown in the third column of output (FEEDING) in (*fig. 2*). Total mortality of the population, if the treatment is applied on day y, is the sum of mortality from both types of exposure:

$$P(TM_y) = \sum_{i=1}^{n} P(MDC|I_i, C)\,P(C|I_i)P(I_i) + \sum_{i=1}^{n} P(MFW|I_i) \cdot P(I_i) \cdot [1 - P(C|I_i)P(MDC|I_i, C)]$$

Results of these calculations are shown in the fourth column of output (TOTAL) in *figure 2.* The results are displayed in *figure 3.*

### 3.2 Option B

This option predicts mortality (at one time) based on percent mortalities of each instar for a given chemical and application rate (user specifies mortality by contact and by feeding plus an estimate of the relative proportions of the instars at the time of treatment).

Calculations are performed as described for option A after the user has entered percent mortality for each instar by contact at the application rate, percent mortality by feeding plus walking at the application rate, and the probability of occurrence of each instar.

In the example (*fig. 4*), the user wanted to estimate total mortality when a susceptible western spruce budworm population is sprayed with 53 g/ha of acephate and the population consists of 5 percent second instars, 14 percent third instars, 13 percent fourth instars, 43 percent fifth instars, and 25 percent sixth instars. Data on instar distribution are usually collected by sampling the target population immediately before spray application.

### 3.3 Option C

This option simulates mortality (over time) based on total percent mortality of each instar for the given chemical and application rate (overall effects of contact and feeding determined from laboratory bioassays).

```
SPECIFY INSECT -- DFTM OR WSBW? DFTM

SPECIFY GENETIC PREDISPOSITION OF POPULATION --
   SUSCEPTIBLE, TOLERANT, OR RESISTANT? TOLERANT

CHEMICAL NAME? ACEPHATE

DOSE IN UNIT/AREA (FOR EXAMPLE, 2.0 G/HA)? 17.7 G/HA

DO YOU WANT A DESCRIPTION OF PROGRAM OPTIONS? YES

PROGRAM OPTIONS ARE:

  A. SIMULATION OF MORTALITY (OVER TIME) BASED ON
     PERCENT MORTALITY OF EACH INSTAR FOR THE GIVEN CHEMICAL
     AND DOSE BY CONTACT AND BY FEEDING DETERMINED FROM
     LABORATORY BIOASSAYS.

  B. PREDICTION OF MORTALITY (FOR ONE TIME) BASED ON
     PERCENT MORTALITY OF EACH INSTAR FOR THE GIVEN CHEMICAL
     AND DOSE BY CONTACT AND BY FEEDING DETERMINED FROM
     LABORATORY BIOASSAYS AND AN ESTIMATE OF THE RELATIVE
     PROPORTIONS OF THE INSTARS AT THE TIME OF TREATMENT.

  C. SIMULATION OF MORTALITY (OVER TIME) BASED ON TOTAL
     PERCENT MORTALITY OF EACH INSTAR FROM THE GIVEN
     CHEMICAL AND DOSE DETERMINED FROM LABORATORY BIOASSAYS.

  D. PREDICTION OF MORTALITY (FOR ONE TIME) BASED ON
     PERCENT MORTALITY OF EACH INSTAR FROM THE GIVEN
     CHEMICAL AND DOSE DETERMINED FROM LABORATORY BIOASSAYS
     AND AN ESTIMATE OF THE RELATIVE PROPORTIONS OF
     INSTARS AT THE TIME OF TREATMENT.

SPECIFY OPTION -- A, B, C, OR D? A

INPUT PERCENT MORTALITY BY CONTACT
    FOR EACH INSTAR AT THIS DOSE.
CONTACT MORTALITY FOR INSTAR 1 ? 60
CONTACT MORTALITY FOR INSTAR 2 ? .5
CONTACT MORTALITY FOR INSTAR 3 ? 6.5
CONTACT MORTALITY FOR INSTAR 4 ? .2
CONTACT MORTALITY FOR INSTAR 5 ? 1.4
CONTACT MORTALITY FOR INSTAR 6 ? 2
VALUES ENTERED WERE: 60  .5  6.5  .2  1.4  2 -- IS THIS CORRECT? YES

INPUT PERCENT MORTALITY BY FEEDING + WALKING
   FOR EACH INSTAR AT THIS DOSE.
FEEDING + WALKING MORTALITY FOR INSTAR 1 ? 20
FEEDING + WALKING MORTALITY FOR INSTAR 2 ? 1
FEEDING + WALKING MORTALITY FOR INSTAR 3 ? .01
FEEDING + WALKING MORTALITY FOR INSTAR 4 ? 13
FEEDING + WALKING MORTALITY FOR INSTAR 5 ? 1.6
FEEDING + WALKING MORTALITY FOR INSTAR 6 ? 11
VALUES ENTERED WERE: 20  1  .01  13  1.6  11 -- IS THIS CORRECT? YES
```

---

DRY CONDITIONS -- MORTALITY

DFTM    ACEPHATE    TOLERANT

DOSE 17.7 G/HA

| DAY | CONTACT | FEEDING | TOTAL |
|---|---|---|---|
| 1 | 0.08 | 19.98 | 20.07 |
| 2 | 0.08 | 19.98 | 20.07 |
| 3 | 0.08 | 19.98 | 20.07 |
| 4 | 0.08 | 19.98 | 20.07 |
| 5 | 0.08 | 19.98 | 20.07 |
| 6 | 0.08 | 19.98 | 20.07 |
| 7 | 0.07 | 17.52 | 17.59 |
| 8 | 0.07 | 15.62 | 15.68 |
| 9 | 0.06 | 13.91 | 13.97 |
| 10 | 0.05 | 12.57 | 12.62 |
| 11 | 0.06 | 11.58 | 11.65 |
| 12 | 0.07 | 10.59 | 10.67 |
| 13 | 0.08 | 9.79 | 9.88 |
| 14 | 0.09 | 9.18 | 9.28 |
| 15 | 0.10 | 8.58 | 8.68 |
| 16 | 0.11 | 8.09 | 8.20 |
| 17 | 0.11 | 8.06 | 8.17 |
| 18 | 0.11 | 8.29 | 8.40 |
| 19 | 0.11 | 8.39 | 8.50 |
| 20 | 0.10 | 8.70 | 8.80 |
| 21 | 0.10 | 8.81 | 8.92 |
| 22 | 0.10 | 8.53 | 8.63 |
| 23 | 0.10 | 7.96 | 8.06 |
| 24 | 0.11 | 7.38 | 7.49 |
| 25 | 0.11 | 6.69 | 6.80 |
| 26 | 0.13 | 5.95 | 6.08 |
| 27 | 0.14 | 5.03 | 5.17 |
| 28 | 0.15 | 4.99 | 5.14 |
| 29 | 0.17 | 5.01 | 5.18 |
| 30 | 0.20 | 5.14 | 5.34 |
| 31 | 0.22 | 5.25 | 5.48 |
| 32 | 0.26 | 5.49 | 5.75 |
| 33 | 0.28 | 5.64 | 5.92 |
| 34 | 0.31 | 5.99 | 6.30 |
| 35 | 0.35 | 6.31 | 6.66 |
| 36 | 0.40 | 6.75 | 7.15 |
| 37 | 0.45 | 7.05 | 7.50 |
| 38 | 0.51 | 7.33 | 7.84 |
| 39 | 0.53 | 7.10 | 7.63 |
| 40 | 0.56 | 6.83 | 7.39 |
| 41 | 0.59 | 6.47 | 7.05 |
| 42 | 0.62 | 6.19 | 6.81 |
| 43 | 0.66 | 5.81 | 6.47 |
| 44 | 0.69 | 5.65 | 6.34 |
| 45 | 0.72 | 5.38 | 6.10 |
| 46 | 0.76 | 5.43 | 6.19 |
| 47 | 0.81 | 5.69 | 6.49 |
| 48 | 0.84 | 5.96 | 6.80 |
| 49 | 0.89 | 6.31 | 7.20 |
| 50 | 0.94 | 6.78 | 7.72 |
| 51 | 1.00 | 7.24 | 8.23 |
| 52 | 1.05 | 7.70 | 8.75 |
| 53 | 1.11 | 8.26 | 9.37 |
| 54 | 1.20 | 9.09 | 10.29 |
| 55 | 1.27 | 9.64 | 10.91 |
| 56 | 1.30 | 9.92 | 11.22 |
| 57 | 1.34 | 10.29 | 11.63 |
| 58 | 1.40 | 10.85 | 12.25 |
| 59 | 1.40 | 10.85 | 12.25 |
| 60 | 1.40 | 10.85 | 12.25 |

---

DO YOU WANT TO TRY ANOTHER OPTION?

**Figure 2**--Program option A simulates mortality (overtime) based on information on percent mortality of each instar for a given chemical and rate. User specifies mortality by contact and by feeding.

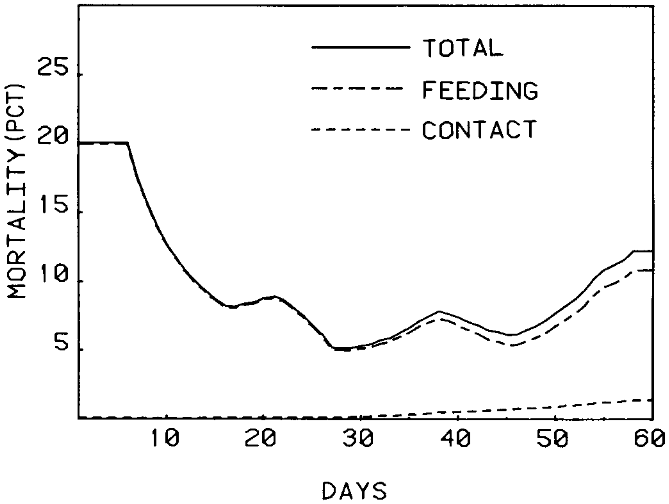


**Figure 3**--Results of using program option A shows simulation of mortality (contact, feeding, and total) overpopulation development of the Douglas-fir tussock moth.

```
SPECIFY INSECT -- DFTM OR WSBW? WSBW

SPECIFY GENETIC PREDISPOSITION OF POPULATION --
   SUSCEPTIBLE, TOLERANT, OR RESISTANT? SUSCEPTIBLE

CHEMICAL NAME? ACEPHATE

DOSE IN UNIT/AREA (FOR EXAMPLE, 2.0 G/HA)? 53 G/HA

DO YOU WANT A DESCRIPTION OF PROGRAM OPTIONS? NO

SPECIFY OPTION -- A, B, C, OR D? B

INPUT PERCENT MORTALITY BY CONTACT
    FOR EACH INSTAR AT THIS DOSE.
CONTACT MORTALITY FOR INSTAR 1 ? 87
CONTACT MORTALITY FOR INSTAR 2 ? 80
CONTACT MORTALITY FOR INSTAR 3 ? 76
CONTACT MORTALITY FOR INSTAR 4 ? 78
CONTACT MORTALITY FOR INSTAR 5 ? 58
VALUES ENTERED WERE: 87  80  76  78  58 -- IS THIS CORRECT? YES

INPUT PERCENT MORTALITY BY FEEDING + WALKING
   FOR EACH INSTAR AT THIS DOSE.
FEEDING + WALKING MORTALITY FOR INSTAR 1 ? 98
FEEDING + WALKING MORTALITY FOR INSTAR 2 ? 98
FEEDING + WALKING MORTALITY FOR INSTAR 3 ? 98
FEEDING + WALKING MORTALITY FOR INSTAR 4 ? 98
FEEDING + WALKING MORTALITY FOR INSTAR 5 ? 98
VALUES ENTERED WERE: 98  98  98  98  98 -- IS THIS CORRECT? YES


INPUT PROBABILITY (AS DECIMAL -- E.G., .25) OF OCCURRENCE OF
      EACH INSTAR AT TIME OF TREATMENT
PROBABILITY OF INSTAR 1 ? .05
PROBABILITY OF INSTAR 2 ? .14
PROBABILITY OF INSTAR 3 ? .13
PROBABILITY OF INSTAR 4 ? .43
PROBABILITY OF INSTAR 5 ? .25


VALUES ENTERED WERE: .05  .14  .13  .43  .25 -- IS THIS CORRECT? YES
--------------------------------------------
DRY CONDITIONS -- MORTALITY

WSBW          ACEPHATE      SUSCEPTIBLE

          DOSE 53 G/HA

    CONTACT      FEEDING       TOTAL
     16.32        82.01        98.33
--------------------------------------------
DO YOU WANT TO TRY ANOTHER OPTION?
```

**Figure 4**--Program option B predicts mortality (at one time) based on percent mortality of each instar for a given chemical application rate. User specifies mortality by contact and by feeding plus an estimate of the relative proportions of the instars at the time of treatment.

```
SPECIFY INSECT -- DFTM OR WSBW? WSBW

SPECIFY GENETIC PREDISPOSITION OF POPULATION --
   SUSCEPTIBLE, TOLERANT, OR RESISTANT? TOLERANT

CHEMICAL NAME? UC62644

DOSE IN UNIT/AREA (FOR EXAMPLE, 2.0 G/HA)? 0.71 G/HA

DO YOU WANT A DESCRIPTION OF PROGRAM OPTIONS? NO

SPECIFY OPTION -- A, B, C, OR D? C

INPUT TOTAL PERCENT MORTALITY FOR EACH INSTAR AT THIS DOSE
TOTAL MORTALITY FOR INSTAR 1 ? 65
TOTAL MORTALITY FOR INSTAR 2 ? 65
TOTAL MORTALITY FOR INSTAR 3 ? 57
TOTAL MORTALITY FOR INSTAR 4 ? 89
TOTAL MORTALITY FOR INSTAR 5 ? 90
VALUES ENTERED WERE: 65  65  57  89  90 -- IS THIS CORRECT? YES
--------------------------------------------
DRY CONDITIONS -- MORTALITY

WSBW          UC62644       TOLERANT

          DOSE 0.71 G/HA

DAY   MORTALITY
 1        65.00
 2        65.00
 3        65.00
 4        65.00
 5        65.00
 6        64.84
 7        64.52
 8        64.36
 9        64.60
10        65.40
11        66.28
12        67.16
13        68.12
14        69.32
15        70.60
16        72.22
17        72.37
18        73.43
19        74.16
20        74.98
21        75.56
22        76.79
23        77.79
24        79.28
25        80.53
26        81.53
27        82.78
28        83.94
29        85.35
30        86.52
31        87.10
32        87.69
33        88.28
34        88.96
35        88.99
36        89.35
37        89.39
38        89.76
39        89.80
40        89.85
41        89.89
42        89.93
43        89.97
44        89.99
45        90.00
46        90.00
47        90.00
--------------------------------------------
DO YOU WANT TO TRY ANOTHER OPTION?
```

**Figure 5**--Program option C simulates mortality (over time) based on total percent mortality of each instar for the given chemical and application rate. User specifies overall effects of contact and feeding as determined from laboratory bioassays.

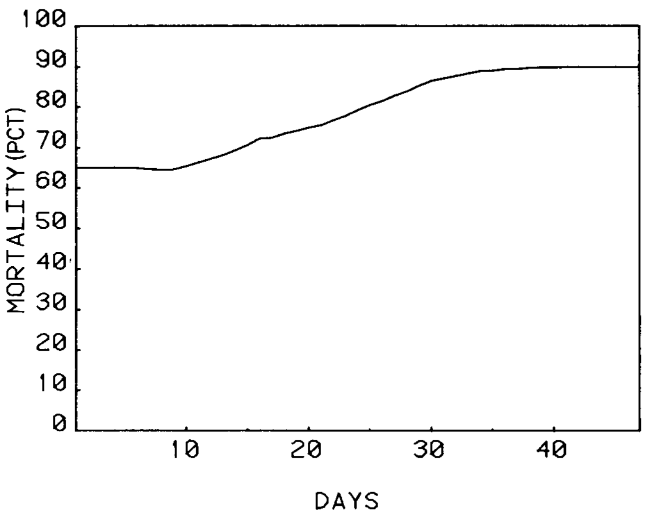


**Figure 6**--Results using program option C shows total mortality over population development of the western spruce budworm treated with the insecticide UC 62644.

Simulation over the course of population development is done with option C after the user has input total percent mortality read from dose-mortality regressions for insects sprayed while on host plant foliage. This input, P(MCFW)--the probability of mortality by contact, feeding, and walking-is multiplied by the values of $P(I_y)$ contained in the program to simulate $P(TM_y)$ over the course of population development.

In the example (*fig. 5*), the user has specified that a tolerant western spruce budworm population has been sprayed with 0.71 g/ha of the insecticide UC62644. Mortality data for other instars exposed to this application rate are second (65 pct), third (65), fourth (57), fifth (89), and sixth (90). The results of this simulation are graphically illustrated in *figure 6.*

## 3.4 Option D

This option predicts mortality (at one time) based on percent mortalities of each instar for the given chemical and application rate as determined from laboratory bioassays, and an estimate of the relative proportions of instars present at the time of treatment.

With option D, total mortality is predicted for one time during population development after the user has provided percent mortality for each instar at a given dose and instar distribution (*fig. 7*).

# 4. DISCUSSION

Both as a research tool and as an aid for forest managers, this program will be useful to those specifically concerned with western spruce budworm or Douglas-fir tussock moth population management. For example, the predicted efficacy of several insecticides can be compared to select the one that will be the most effective. If a field application does not achieve the desired impact, reasons for the failure can be traced with the aid of model logic.

```
SPECIFY INSECT -- DFTM OR WSBW? WSBW

SPECIFY GENETIC PREDISPOSITION OF POPULATION --
   SUSCEPTIBLE, TOLERANT, OR RESISTANT? TOLERANT

CHEMICAL NAME? UC62644

DOSE IN UNIT/AREA (FOR EXAMPLE, 2.0 G/HA)? 0.71 G/HA

DO YOU WANT A DESCRIPTION OF PROGRAM OPTIONS? NO

SPECIFY OPTION -- A, B, C, OR D? D

INPUT TOTAL PERCENT MORTALITY FOR EACH INSTAR AT THIS DOSE
TOTAL MORTALITY FOR INSTAR 1 ? 65
TOTAL MORTALITY FOR INSTAR 2 ? 65
TOTAL MORTALITY FOR INSTAR 3 ? 57
TOTAL MORTALITY FOR INSTAR 4 ? 89
TOTAL MORTALITY FOR INSTAR 5 ? 90
VALUES ENTERED WERE: 65  65  57  89  90 -- IS THIS CORRECT? YES

INPUT PROBABILITY (AS DECIMAL -- E.G., .25) OF OCCURRENCE OF
     EACH INSTAR AT TIME OF TREATMENT
PROBABILITY OF INSTAR 1 ? .05
PROBABILITY OF INSTAR 2 ? .14
PROBABILITY OF INSTAR 3 ? .13
PROBABILITY OF INSTAR 4 ? .43
PROBABILITY OF INSTAR 5 ? .25
VALUES ENTERED WERE: .05  .14  .13  .43  .25 -- IS THIS CORRECT? YES
---------------------------------------------
DRY CONDITIONS -- MORTALITY

WSBW          UC62644       TOLERANT

         DOSE 0.71 G/HA

PERCENT MORTALITY IS 80.53
---------------------------------------------
DO YOU WANT TO TRY ANOTHER OPTION?
```

**Figure 7**--Program option D predicts mortality (at one time) based on percent mortalities of each instar for the given chemical and application rate as determined from laboratory bioassays, and on estimate of the relative proportions of instars present at the time of treatment.

The logic of this model should be applicable to other forest defoliators, although such adaptations must await the development of comprehensive data bases. Additional laboratory research is required to determine the roles of environmental variables such as temperature, radiation intensity, and host-plant foliage type or quality in responses of western spruce budworm and Douglas-fir tussock moth to chemicals. Once the requisite data are available, the model can be modified to include these factors.

The present database for the model includes results of bioassays of toxicological response of Douglas-fir tussock moth and western spruce budworm that range from very simple to highly elaborate. These bioassays, done over a 15-year period, provide the most comprehensive database available for any forest defoliator and serve as a guide to the sorts of information needed to begin to realistically predict insecticide efficacy on other forest defoliators. The present model predicts the results of actual field applications done under dry conditions with 73 to 95 percent accuracy (Williams and Robertson 1983).

## 5. APPENDIX: PROGRAM LISTING

```
LIST
10 REM **************** GENERAL MODEL *******************************************
20 DIM D(60),A$(3),B$(4),C$(11),D$(10),E$(15),F$(1),P(60,6),T(6),R(6),Q(6),M(6),S(60),A(60),F(60),V(60),G(60)
30 REM
40 PRINT 'SPECIFY INSECT -- DFTM OR WSBW';
50    INPUT B$
60    PRINT
70 PRINT 'SPECIFY GENETIC PREDISPOSITION OF POPULATION --'
80 PRINT '    SUSCEPTIBLE, TOLERANT, OR RESISTANT';
90     INPUT C$
100    PRINT
110 PRINT 'CHEMICAL NAME';
120    INPUT D$
130    PRINT
140 PRINT 'DOSE IN UNIT/AREA (FOR EXAMPLE, 2.0 G/HA)';
150    INPUT E$
160    PRINT
170 PRINT 'DO YOU WANT A DESCRIPTION OF PROGRAM OPTIONS';
180    INPUT A$
190    IF A$='NO' THEN 430
200    PRINT
210 PRINT 'PROGRAM OPTIONS ARE:'
220    PRINT
230    PRINT '  A. SIMULATION OF MORTALITY (OVER TIME) BASED ON'
240    PRINT '     PERCENT MORTALITY OF EACH INSTAR FOR THE GIVEN CHEMICAL'
250    PRINT '     AND DOSE BY CONTACT AND BY FEEDING DETERMINED FROM'
260    PRINT '     LABORATORY BIOASSAYS.'
270    PRINT
280    PRINT '  B. PREDICTION OF MORTALITY (FOR ONE TIME) BASED ON'
290    PRINT '     PERCENT MORTALITY OF EACH INSTAR FOR THE GIVEN CHEMICAL'
300    PRINT '     AND DOSE BY CONTACT AND BY FEEDING DETERMINED FROM'
310    PRINT '     LABORATORY BIOASSAYS AND AN ESTIMATE OF THE RELATIVE'
320    PRINT '     PROPORTIONS OF THE INSTARS AT THE TIME OF TREATMENT.'
330    PRINT
340    PRINT '  C. SIMULATION OF MORTALITY (OVER TIME) BASED ON TOTAL'
350    PRINT '     PERCENT MORTALITY OF EACH INSTAR FROM THE GIVEN'
360    PRINT '     CHEMICAL AND DOSE DETERMINED FROM LABORATORY BIOASSAYS.'
370    PRINT
380    PRINT '  D. PREDICTION OF MORTALITY (FOR ONE TIME) BASED ON'
390    PRINT '     PERCENT MORTALITY OF EACH INSTAR FROM THE GIVEN'
400    PRINT '     CHEMICAL AND DOSE DETERMINED FROM LABORATORY BIOASSAYS'
410    PRINT '     AND AN ESTIMATE OF THE RELATIVE PROPORTIONS OF'
420    PRINT '     INSTARS AT THE TIME OF TREATMENT.'
430    PRINT
440 PRINT 'SPECIFY OPTION -- A, B, C, OR D';
450    INPUT F$
460    PRINT
470 REM  **************************************************************************
480 REM READ DATA (BODY SIZE ADJUSTMENT FACTOR AND POPULATION STRUCTURE)
490 FOR Z=1 TO 2
500 IF Z=2 THEN 550
510 REM DFTM (N=INSTARS, Y=DAYS)
520    N=6
530    Y=60
540 GOTO 580
550 REM WSBW (N=INSTARS, Y=DAYS)
560    N=5
570    Y=47
580 REM READ BODY SIZE ADJUSTMENT FACTOR
590    FOR K=1 TO N
600    READ T(K)
610    NEXT K
620 REM READ POPULATION STRUCTURE
630    FOR I=1 TO Y
640    READ D(I)
650    FOR J=1 TO N
660    READ P(I,J)
670    NEXT J
680    NEXT I
```

```
690 IF B$='DFTM' THEN 710
700 NEXT Z
710 REM  ***********************************************************************
720 REM OPTIONS -- DATA INPUT
730 IF F$='C' THEN 1410
740 IF F$='D' THEN 1410
750 REM OPTIONS A AND B
760 PRINT 'INPUT PERCENT MORTALITY BY CONTACT'
770 PRINT '     FOR EACH INSTAR AT THIS DOSE.'
780     FOR I=1 TO N
790     PRINT 'CONTACT MORTALITY FOR INSTAR';I;
800     INPUT R(I)
810     NEXT I
820     PRINT 'VALUES ENTERED WERE:';
830     FOR I=1 TO N
840     PRINT R(I);
850     NEXT I
860     PRINT '-- IS THIS CORRECT';
870     INPUT A$
880     IF A$='NO' THEN 780
890     PRINT
900 PRINT 'INPUT PERCENT MORTALITY BY FEEDING + WALKING'
910 PRINT '    FOR EACH INSTAR AT THIS DOSE.'
920     FOR I=1 TO N
930     PRINT 'FEEDING + WALKING MORTALITY FOR INSTAR';I;
940     INPUT Q(I)
950     NEXT I
960     PRINT 'VALUES ENTERED WERE:';
970     FOR I=1 TO N
980     PRINT Q(I);
990     NEXT I
1000    PRINT '-- IS THIS CORRECT';
1010    INPUT A$
1020    IF A$='NO' THEN 920
1030    PRINT
1040    IF F$='A' THEN 1250
1050 REM OPTIONS B AND D
1060 PRINT
1070 PRINT 'INPUT PROBABILITY (AS DECIMAL -- E.G., .25) OF OCCURRENCE OF'
1080 PRINT '       EACH INSTAR AT TIME OF TREATMENT'
1090    I=1
1100    FOR J=1 TO N
1110    PRINT 'PROBABILITY OF INSTAR';J;
1120    INPUT P(I,J)
1130    NEXT J
1140    PRINT 'VALUES ENTERED WERE:';
1150    FOR J=1 TO N
1160    PRINT P(I,J);
1170    NEXT J
1180    PRINT '-- IS THIS CORRECT';
1190    INPUT A$
1200    IF A$='NO' THEN 1090
1210    IF F$='D' THEN 1560
1220 REM OPTION B
1230    J=1
1240    GOTO 1320
1250 REM OPTIONS A AND B
1260 REM CALCULATE ADJUSTED CONTACT MORTALITY (A), ADJUSTED FEEDING
1270 REM       MORTALITY (V), AND TOTAL MORTALITY (G)
1280    FOR J=1 TO Y
1290    A(J)=0
1300    V(J)=0
1310    G(J)=0
1320    FOR K=1 TO N
1330    A(J)=A(J)+(R(K)*T(K)*P(J,K))
1340    V(J)=V(J)+(Q(K)*(P(J,K)-(R(K)*T(K)*P(J,K)/100)))
1350    NEXT K
1360    G(J)=A(J)+V(J)
1370    IF F$='B' THEN 1630
1380    NEXT J
1390    GOTO 1630
1400 REM OPTIONS C AND D
1410 PRINT 'INPUT TOTAL PERCENT MORTALITY FOR EACH INSTAR AT THIS DOSE'
1420    FOR I=1 TO N
1430    PRINT 'TOTAL MORTALITY FOR INSTAR';I;
```

```
1440    INPUT N(I)
1450    NEXT I
1460    PRINT 'VALUES ENTERED WERE:';
1470    FOR I=1 TO N
1480    PRINT N(I);
1490    NEXT I
1500    PRINT '-- IS THIS CORRECT';
1510    INPUT A$
1520    IF A$='NO' THEN 1420
1530 IF F$='D' THEN 1050
1540 REM OPTION C
1550    FOR I=1 TO Y
1560 REM OPTIONS C AND D
1570    G(I)=0
1580    FOR J=1 TO N
1590    G(I)=G(I)+(N(J)*P(I,J))
1600    NEXT J
1610    IF F$='D' THEN 1630
1620    NEXT I
1630 REM  ****************************************************************
1640 REM PRINTOUT
1650 REM ALL OPTIONS
1660    REM PRINT MORTALILTY FOR SINGLE DOSE LEVEL
1670    PRINT '------------------------------------------'
1680    PRINT 'DRY CONDITIONS -- MORTALITY'
1690    PRINT
1700    PRINT B$,D$,C$
1710    PRINT
1720    PRINT '          DOSE ';E$
1730    PRINT
1740 IF F$='A' THEN 1780
1750 IF F$='B' THEN 1840
1760 IF F$='C' THEN 1880
1770 IF F$='D' THEN 1940
1780 REM OPTION A
1790    PRINT 'DAY     CONTACT      FEEDING      TOTAL'
1800    FOR J=1 TO Y
1810    PRINT USING ' ##      ###.##       ###.##       ###.##';D(J),A(J),V(J)
1820    NEXT J
1830    GOTO 1960
1840 REM OPTION B
1850    PRINT '    CONTACT      FEEDING       TOTAL'
1860    PRINT USING '    ###.##       ###.##       ###.##';A(J),V(J),G(J)
1870    GOTO 1960
1880 REM OPTION C
1890    PRINT 'DAY   MORTALITY'
1900    FOR J=1 TO Y
1910    PRINT USING '##       ###.##';D(J),G(J)
1920    NEXT J
1930    GOTO 1960
1940 REM OPTION D
1950    PRINT 'PERCENT MORTALITY IS';G(I)
1960 PRINT '--------------------------------------------'
1970 PRINT 'DO YOU WANT TO TRY ANOTHER OPTION';
1980 INPUT A$
1990 IF A$='YES' THEN RUN
2000 END
2010 REM  ****************************************************************
2020 REM DFTM BODY SIZE ADJUSTMENT FACTOR
2030 DATA 0.0014,0.011,0.048,0.10,0.26,0.70
2040 REM
2050 REM DFTM POPULATION STRUCTURE, ASYNCHRONOUS
2060 DATA  1,1,0,0,0,0,0
2070 DATA  2,1,0,0,0,0,0
2080 DATA  3,1,0,0,0,0,0
2090 DATA  4,1,0,0,0,0,0
2100 DATA  5,1,0,0,0,0,0
2110 DATA  6,1,0,0,0,0,0
2120 DATA  7,.87,.13,0,0,0,0
2130 DATA  8,.77,.23,0,0,0,0
2140 DATA  9,.68,.32,0,0,0,0
2150 DATA 10,.61,.38,0,0,0,0
2160 DATA 11,.56,.39,.05,0,0,0
2170 DATA 12,.51,.40,.09,0,0,0
2180 DATA 13,.47,.40,.13,0,0,0
2190 DATA 14,.44,.39,.17,0,0,0
```

```
2200 DATA 15,.41,.38,.21,0,0,0
2210 DATA 16,.38,.36,.25,.01,0,0
2220 DATA 17,.36,.34,.26,.04,0,0
2230 DATA 18,.34,.32,.25,.09,0,0
2240 DATA 19,.32,.30,.25,.13,0,0
2250 DATA 20,.31,.29,.23,.17,0,0
2260 DATA 21,.29,.27,.22,.21,.01,0
2270 DATA 22,.25,.27,.22,.25,.01,0
2280 DATA 23,.20,.27,.22,.28,.03,0
2290 DATA 24,.15,.27,.22,.31,.05,0
2300 DATA 25,.10,.27,.22,.33,.08,0
2310 DATA 26,.06,.27,.22,.33,.12,0
2320 DATA 27,.01,.27,.22,.33,.17,0
2330 DATA 28,0,.23,.22,.34,.21,0
2340 DATA 29,0,.19,.22,.34,.25,0
2350 DATA 30,0,.13,.22,.34,.30,.01
2360 DATA 31,0,.09,.22,.34,.33,.02
2370 DATA 32,0,.06,.20,.34,.36,.04
2380 DATA 33,0,.04,.17,.34,.40,.05
2390 DATA 34,0,.03,.13,.34,.42,.08
2400 DATA 35,0,.01,.11,.34,.43,.11
2410 DATA 36,0,0,.07,.34,.44,.15
2420 DATA 37,0,0,.04,.33,.44,.19
2430 DATA 38,0,0,.01,.31,.44,.24
2440 DATA 39,0,0,0,.28,.47,.25
2450 DATA 40,0,0,0,.24,.49,.27
2460 DATA 41,0,0,0,.20,.52,.28
2470 DATA 42,0,0,0,.16,.54,.30
2480 DATA 43,0,0,0,.11,.57,.32
2490 DATA 44,0,0,0,.08,.58,.34
2500 DATA 45,0,0,0,.04,.60,.36
2510 DATA 46,0,0,0,.02,.59,.39
2520 DATA 47,0,0,0,.01,.56,.43
2530 DATA 48,0,0,0,.01,.53,.46
2540 DATA 49,0,0,0,0,.49,.51
2550 DATA 50,0,0,0,0,.44,.56
2560 DATA 51,0,0,0,0,.39,.61
2570 DATA 52,0,0,0,0,.34,.66
2580 DATA 53,0,0,0,0,.28,.72
2590 DATA 54,0,0,0,0,.19,.81
2600 DATA 55,0,0,0,0,.13,.87
2610 DATA 56,0,0,0,0,.10,.90
2620 DATA 57,0,0,0,0,.06,.94
2630 DATA 58,0,0,0,0,0,1
2640 DATA 59,0,0,0,0,0,1
2650 DATA 60,0,0,0,0,0,1
2660 REM
2670 REM WSBW BODY SIZE ADJUSTMENT FACTOR
2680 DATA 0.0033,0.013,0.05,0.16,0.71
2690 REM
2700 REM WSBW POPULATION STRUCTURE, ASYNCHRONOUS
2710 DATA  1,1,0,0,0,0
2720 DATA  2,.99,.01,0,0,0
2730 DATA  3,.97,.03,0,0,0
2740 DATA  4,.88,.12,0,0,0
2750 DATA  5,.79,.21,0,0,0
2760 DATA  6,.72,.26,.02,0,0
2770 DATA  7,.65,.29,.06,0,0
2780 DATA  8,.57,.31,.11,.01,0
2790 DATA  9,.51,.32,.14,.03,0
2800 DATA 10,.46,.31,.16,.07,0
2810 DATA 11,.42,.30,.17,.11,0
2820 DATA 12,.39,.28,.18,.15,0
2830 DATA 13,.36,.27,.18,.19,0
2840 DATA 14,.33,.25,.18,.24,0
2850 DATA 15,.31,.23,.17,.29,0
2860 DATA 16,.29,.22,.17,.32,.01
2870 DATA 17,.28,.20,.16,.35,.01
2880 DATA 18,.26,.19,.15,.37,.03
2890 DATA 19,.24,.18,.15,.39,.04
2900 DATA 20,.23,.17,.14,.40,.06
2910 DATA 21,.22,.17,.13,.40,.08
2920 DATA 22,.17,.17,.13,.42,.11
2930 DATA 23,.13,.17,.13,.42,.15
2940 DATA 24,.08,.16,.13,.43,.20
```

```
2950 DATA 25,.05,.14,.13,.43,.25
2960 DATA 26,.03,.12,.13,.43,.29
2970 DATA 27,.01,.09,.13,.43,.34
2980 DATA 28,.01,.07,.11,.43,.38
2990 DATA 29,0,.05,.09,.43,.43
3000 DATA 30,0,.03,.07,.42,.48
3010 DATA 31,0,.02,.06,.42,.50
3020 DATA 32,0,.01,.05,.41,.53
3030 DATA 33,0,0,.04,.40,.56
3040 DATA 34,0,0,.02,.38,.60
3050 DATA 35,0,0,.02,.35,.63
3060 DATA 36,0,0,.01,.32,.67
3070 DATA 37,0,0,.01,.28,.71
3080 DATA 38,0,0,0,.24,.76
3090 DATA 39,0,0,0,.20,.80
3100 DATA 40,0,0,0,.15,.85
3110 DATA 41,0,0,0,.11,.89
3120 DATA 42,0,0,0,.07,.93
3130 DATA 43,0,0,0,.03,.97
3140 DATA 44,0,0,0,.01,.99
3150 DATA 45,0,0,0,0,1
3160 DATA 46,0,0,0,0,1
3170 DATA 47,0,0,0,0,1
3180 REM  ******************************************************************
Ok
```

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A generalized interactive computer model that simulates and predicts insecticide efficacy, over seasonal development of western spruce budworm and Douglas-fir tussock moth, is described. This model can be used for any insecticide for which the user has laboratory-based concentration-response data. The program has four options, is written in BASIC, and can be operated on a microcomputer.

*Retrieval Terms:* insecticides, models, western spruce budworm, Douglas-fir tussock moth