A MANAGEMENT MODEL FOR SECOND GENERATION SOUTHWESTERN CORN BORER IN KANSAS

by

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Part I

Literature Review

LITERATURE REVIEW

Since its migration into Kansas in 1931, the southwestern corn borer (SWCB), Diatraea grandiosella (Dyar), has become a severe pest of corn in the southwest and southcentral regions of the state (Knutson 1975). A combination of cultural practices and timely insecticide applications is used to economically manage second generation SWCB infestations (Higgins et al. 1988). Factors to consider include phenology and population dynamics of the insect, the relationship between pest density and yield loss experienced by the host plant, and a cost/benefit analysis of management options.

SWCB completes two generations each year in Kansas. On occasion, a partial, insignificant third generation has been reported (Wilbur et al. 1943). Overwintering SWCB larvae pupate and develop into moths in May and June. The adult emergence period in the spring and summer differs each year because of varying weather conditions (Hensley et al. 1955). Adults mate and eggs of the first generation are oviposited on whorl stage corn plants. Egg masses average between two and three eggs per mass (Schenck 1978). Larvae are dull white with dark brown or black spots and pass through five to six larval stages. Although five larval stages is most common, up to eight instars have been documented in the laboratory (Chippendale, 1979). First and second instars feed in the whorl and may destroy the terminal bud. First generation borer damage is referred to as deadheart and results in a stunted bushy plant (Wilbur et al. 1943).

Larger larvae enter the plant at internodes, feed within the stalk, then remain inside the plant during pupation.

Eggs of second generation SWCB are oviposited and hatch from mid-July to early August. Eggs are deposited in masses of 1 to 9, primarily on upper and lower corn leaf surfaces, and occasionally on stalks and leaf sheaths. Hensley and co-workers (1955) noted that 98.1% of eggs were deposited on leaves positioned at node seven or lower. New egg masses are translucent white and become opaque within a few hours of deposition. Within 24 hours after the eggs are laid, three red transverse bars develop.

Hensley and et al. (1955) determined the fate of eggs of second generation SWCB in Oklahoma. They reported 4.6% of the eggs were infertile, 7.3% had been lost or had fallen from the plant, 2.0% were eaten by predators, 67.8% had hatched, and 18.3% were parasitized by Trichogramma minutum (Riley). The authors believed parasitism was of minor importance in reducing the infestation. Calvin (1981) found 12.3% of the second generation SWCB egg population in southcentral Kansas parasitized by Trichogramma pretiosum (Riley). Davis and co-workers (1972) observed coccinellid beetles eating SWCB eggs.

Because the SWCB moth lays eggs in masses, the presence of one larva within an experimental plot increases the chance of more being found. After the eggs hatch, larvae travel in search of food. Corn plants form a continuous canopy within a row, permitting small second generation larvae to infest adjacent plants. Wilbur and co-workers (1943) observed SWCB larvae migrating across the ground to infest other plants. Neyman (1939) proposed a mathematical model for contagious distributions of insect larvae. His model assumes that the adult lays eggs in a random manner, that the fate of one egg is the same for all eggs in the mass, that larvae travel a limited distance from the mass and move independently of one another. Under these conditions, the probable number of infested plants can be deduced from the number of egg masses per plant (Poston, Welch and Safford, unpublished data).

Small larvae, feeding in the whorls and leaf sheaths, are vulnerable to insecticides and natural enemies. Third instars bore into and feed within the stalk (Hensley and Arbuthnot 1957). Large larvae also may be found tunneling in the shanks and ears (Wilbur et al. 1943). Second generation SWCB indirectly cause a reduction in grain yield by removing vascular tissue and disrupting translocation of nutrients to the ears (Chippendale 1979). Scott and Davis (1974) noted that kernels from plants infested with SWCB larvae weighed less than kernels from uninfested plants. Whitworth (1980) quantified second generation SWCB feeding on corn and defined the relationship between damage and yield. He found that the time of initial infestation in relation to the physiological age of the plant was more critical in reducing yield than the number of borers infesting the plant. Whitworth reported no differences in yields associated with varyious borer densities. As the corn plant approaches physiological maturity, feeding has less of an impact on yield.

In preparation for diapause, fifth instars tunnel downward in the stalk. Cannibalism is common in pre-diapause larvae and often reduces populations to one borer per plant (Bailey 1952). Larvae girdle the base of the stalk and construct an overwintering cell in the crown of the plant. Girdling causes the stalks to lodge and can result in heavy losses at harvest (Wilbur et al. 1950).

SWCB populations are greatly reduced during the winter months. Low temperatures and high soil moisture are fatal to the overwintering larvae (Wilbur et al. 1950; Roberts 1957) and primarily limit the insect's geographic distribution to regions where the temperature does not fall below -7 degrees Celsius (Chippendale and Reddy 1974). Although SWCB infestations may occur as far north as Nebraska, northern limits for overwintering on the Great Plains are the sandy regions in southwest and southcentral Kansas (Knutson 1975).

In post-harvest surveys conducted in corn fields in southcentral Kansas, Poston and co-workers (1983) found differences in SWCB larval densities. They noted that the variations in larval densities within a field and their corresponding cardinal points were not consistent from field to field. Larvae were regularly dispersed at high densities and randomly dispersed at low densities. Where population densities were low, larval density was greater near the exterior part of the field than in the interior.

Harvest losses due to girdled stalks may be partially reduced by planting short-season varieties of corn. Early planting and early harvesting at a high moisture content also may reduce losses (TenEyck and Lundquist 1975). Fall tillage reduces SWCB populations by destroying their overwintering cells and exposing them to harsh temperatures (Daniels and Chedester 1974). However, fall tillage is not practical on deep sandy soils or where wind erosion is a problem.

A phenological approach to managing insect populations can be valuable by predicting critical time periods for sampling and pesticide applications but it is important to determine a relationship between phenology and abundance. Presently, there is no standard method for determining the abundance of second generation SWCB. Whitworth and Poston (1979) developed a phenology model to predict the emergence period of first generation SWCB adults. Oviposition of second generation eggs by first generation moths coincides with emergence of those adults (Walton and Bieberdorf 1948). The phenology model uses a growing degree day accumulation system to advance SWCB development. Insecticide applications are timed to the anticipated period of adult emergence and duration of oviposition (Poston et al. 1978). The first of two treatments is applied at 50% emergence, and the second is applied two weeks later. If the flight is expected to be lighter than normal or if a short oviposition period is anticipated, a single treatment is applied when

75% of the adults have emerged (Higgins et al. 1988).

Another phenology model for second generation SWCB is presently under development at Texas A&M University. The Texas model allows the user to designate the percentage of larvae entering a sixth instar. The model is based on different temperature-based developmental studies than the Kansas model and predicts first generation adult emergence on a daily basis (Knutson, Texas A&M Univ., pers. comm.).

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Part II

Natural Mortality of Eggs and Larvae of Second Generation Southwestern Corn Borer

INTRODUCTION

The naturally occurring mortality of eggs and larvae of SWCB may impact on the damage level associated with an infestation. SWCB eggs and small larvae are susceptible to mortality from exposure to insecticides and naturally occurring enemies before the third instars enter corn stalks. The magnitude of third instar infestations representing second generation SWCB can be predicted from the size of the egg population if the natural mortality for egg and small larval stages has been documented.

The SWCB phenology model is used to determine percentage oviposition complete on the sample date. The egg mass population is determined by sampling plants in the field. This information is critical in preventing a yield loss since a management decision must be made after eggs begin to hatch, but before larvae invade the stalk. Insecticides, which also are toxic to humans, are usually applied when 50% of oviposition is complete, making it unsafe for unprotected persons to reenter the field for a specified time interval.

There are no estimates of naturally occurring mortality of eggs and larvae of SWCB in irrigated Kansas corn. Oklahoma researchers reported 67.8% of SWCB eggs laid in dryland corn successfully hatched, 18.3% of the eggs were parasitized by <u>Trichogramma</u> <u>minutum</u>, 7.3% were lost, 4.6% were infertile, and 2.0% were eaten by predators (Hensley et al. 1955). Mortality in the small larval stages (through third instar) was reported as 58%, however this figure probably does not reflect the true mortality since the original larval population was not determined and only dead or live larvae still present on the plant were counted. Exposed larvae may have fallen from the plant or have been eaten by predators. The study was conducted during a drought year, thus a portion of the mortality may have been caused by unfavorable microenvironments associated with water-stressed plants.

MATERIALS AND METHODS

During 1983 and 1984, plots were established in flood irrigated corn at the Sandyland Experiment Field, St. John, Kansas, for the purpose of studying the natural mortality of eggs and larvae of second generation SWCB. The field had been planted to corn in previous years, and was planted with Pioneer corn variety 3183 during this study. No insecticides were applied in or near the stand. Four plots were established approximately twenty feet into the field, away from the edge of the stand. Each plot consisted of 30 consecutive plants. To prevent larvae from migrating in or out of the row across the canopy, three plants were removed from the beginning and end of each row. Every plant was labeled for identification.

The SWCB phenology model developed by Poston (1978) was used to predict the oviposition period of second generation eggs by first generation adults. A standard light trap located adjacent to the experimental plots was monitored for adult flight and the plots were checked daily for initiation of oviposition. Plant surfaces were examined for SWCB egg masses at three day intervals during the oviposition period. SWCB egg masses were circled and labeled with indelible ink for later identification. The date of the initial observation of the egg mass, the plant and egg mass identification numbers, the number of eggs in the mass, and egg mass condition were recorded. Egg mass condition fell into the following categories: unhatched, hatched, parasitized, eaten (by predators), or desiccated. Previously circled egg masses were examined and their condition noted on all subsequent sampling dates.

When the phenology model indicated that most of the borers were third instars, the plants in two of the plots were dissected and examined for SWCB larvae. The number and stage of living larvae in each plant were recorded.

The plants in the remaining two plots were dissected and examined for large larvae (fifth instars) when the plants had reached physiological maturity. The number and stage of the living larvae were recorded for each plant.

RESULTS AND DISCUSSION

During 1983, the second generation SWCB infestation in Stafford County was severe. Corn plants in the study plots averaged 36.0 eggs per plant. The average number of third stage larvae infesting each plant was 5.0. Total mortality occurring in the egg stage was 33.1%, 53.1% occurred in the exposed small larval stages, and 10.6% occurred in the large larval stages (Table 1).

Table 1. The natural mortality of eggs and larvae of second generation southwestern corn borer at Sandyland Experiment Field, St. John, Kansas.

	% Mortality		Cumulative % Mortality	
Stage	1983	1984	1983	1984
Egg	33.1	32.0	33.1	32.0
Desiccation	6.5	2.0		
Parasitism	21.9	28.0		
Predation	4.7	2.0		
Small larvae	53.1	55.0	86.2	87.0
Large larvae	10.6	0	96.8	87.0

In contrast to the previous year, the level of infestation of second generation SWCB was not remarkably high in 1984. Corn plants in the study plots averaged 6.1 eggs per plant and .8 third stage larvae per plant. Egg mortality was 32%, 55% mortality occurred in the small larval stages, and no mortality was detected in the large larval stages (Table 1).

Mortality levels for all stages were similiar in both studies except in the large larval stages. Most of the mortality (10.6%) that occurred in the large larval stages in 1983 can be attributed to the high level of infestation in the study plots. Pre-diapause larvae are cannibalistic, usually reducing their own populations to one larva per infested plant by harvest (Bailey 1962). Mortality caused by cannibalism is not relevant to the SWCB management model because the deaths occur after these larvae have damaged the plant.

Although surviving larvae represented a small portion of the total egg complement during both years of the study, the resulting infestations were severe enough to have warranted control in a management situation. _Trichogramma pretiosum_ was the greatest factor contributing to egg mortality. However, crop yield losses may not have been greatly influenced by _T. pretiosum_ because the parasitoid appeared late in the oviposition period. The earlier in a corn plant's life cycle that borer damage is inflicted, the greater the effect on yield loss (Whitworth 1980). During 1983, first generation moths had a 24-day oviposition period. Parasitization was first noted on the sixth day and 50% parasitization was not reached until the final seven days of the oviposition period. During 1984, first generation moths had a 21-day oviposition period. Parasitization was detected on the seventh day, and 50% parasitization was reached during the final five days of oviposition. Therefore, early in the SWCB oviposition cycle, little to no parasitoid-induced mortality occurred.

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Part III

A Sampling Program for Eggs of Second Generation Southwestern Corn Borer

INTRODUCTION

Economic management of second generation SWCB depends on an adequate and timely estimate of the larval infestation. Quantification of the potential effects on crop grain yield is equally important. A computerized management model has been constructed that uses field collected samples to predict the amount of damage associated with a second generation SWCB infestation.

The SWCB phenology model provides calendar dates for the percentage completion of oviposition (Whitworth and Poston 1979). Since pesticides are ineffective in controlling larvae that have entered plants, timing treatments to coincide with the ovipostion and early larval periods is critical for economical management of SWCB. To accomplish this, the population magnitude must be estimated during the egg stage, before oviposition is 50% complete. Experience has shown that if the second generation SWCB infestation is severe, growers should apply the first of two insecticide applications when 50% of oviposition has been completed. The egg complement on the sample day is determined by counting hatched and unhatched egg masses on a specified number of plants. The phenology model is used to determine the percentage oviposition completed through the sample day. The potential magnitude of the SWCB population then can be predicted by multiplying the cumulative number of egg masses per plant by the average number of eggs in a mass and dividing the product by the percentage oviposition completed on the sample day. Deriving actual, rather than potential, population estimates requires mortality estimates reported in Part II of this thesis.

An effective egg mass sampling plan for second generation SWCB must account for egg dispersal patterns. In sampling SWCB populations in post-harvest corn, Poston and co-workers (1983) found that SWCB was underdispersed or clumped at high densities, and randomly dispersed at low densities. They also found differences in population density from one location to another in the same field. In fields with low borer populations, the density was highest near the edge of the field.

A practical sampling plan for second generation SWCB should be thorough enough to provide a realistic estimate of the population size, yet not be overly time consuming. During low level infestations, eggs may be difficult to detect early in the oviposition period unless a very large sample is taken. The fields most often considered for second generation SWCB management are approximately 130 acres (52.6 hectares) under center pivot irrigation. Because of the large size and remote location, access to entire fields is often unrealistic. Sampling is most often conducted by technicians for agricultural consulting firms, extension personnel, and growers who have a fixed amount of time to spend visiting each field.

MATERIALS AND METHODS

Fields were selected during 1983 and 1984 in Stafford County, Kansas for sampling second generation SWCB egg masses to estimate potential larval populations. Field selection was based on accessibility, history of infestation, and grower management practices. All fields consisted of approximately 130 acres of dent corn under a center pivot irrigation system. Rows were planted on 30 inch (76.2 cm) centers. During 1983, six fields were selected for sampling. Corn plant populations in these fields ranged from 25,000 to 27,000 plants per acre (61,787 to 66,690 plants per hectare). Fields were planted with either Pioneer variety 3183 or 3186. In 1984, five fields were selected for sampling. Plant populations ranged from 27,000 to 27,500 plants per acre (66,690 to 67,925 plants per hectare). Fields were planted with Pioneer 3183, Pioneer 3186, Garst 3183, and Cargill 967.

Schenk's (1978) records of second generation egg mass abundance were examined to determine an adequate sample size. His data indicate that a precision level of ten percent could be achieved by employing a sampling program before the peak of oviposition, if 30 sets of five consecutive plants were sampled. The following formula was used to determine the precision level for Schenk's data:

$$D = (1 / \bar{x}) \sqrt{s^2 / n}$$

where D is the index of precision, s^2 is the variance, n is the number of sampling units, and $\bar{x}$ is the sample mean (Elliot 1977).

Since SWCB density can vary across a large field, a two- stage sampling plan was employed. The sampling universe consisted of one acre evenly divided into six subplots. Two subplots were located in the interior of the field, 50 feet from the irrigation system's access road. The remaining four subplots were located 50 feet (15.2m) from the periphery of the field at cardinal points.

The SWCB phenology model (Poston 1978) was used to determine the oviposition period of second generation eggs by first generation adults. Fields were sampled daily and a standard black light trap was monitored to verify the initiation of oviposition. A sampling unit consisted of five consecutive plants. Five samples were selected at random from each subplot. A table of randomly generated numbers was used to select the row and number of steps down the row for each sample. The entire plant surface was examined for hatched and unhatched SWCB egg masses. The amount of time spent traveling to and sampling each subplot was measured with a stopwatch. Fields were sampled twice each week until pesticide applications prevented entry into the field.

A corn field at the Sandyland Experiment Field in St. John, Kansas was sampled at four-day intervals during the entire oviposition period of second generation SWCB. The field was not treated with insecticides for the duration of this study. Daily cumulative percentage oviposition was calculated by regressing cumulative egg mass counts against time.

Egg mass populations were calculated for individual fields on each sample date. The potential larval population

(PLP) was calculated through the following formula:

$$PLP = (EGMASS * LSURV * EPMASS)/(PCOVIP)$$

where EGMASS is the upper 95% confidence interval for the mean density of egg masses per five plant sample in a field, LSURV is the combined egg and larval survivorship, EPMASS is the average number of eggs per mass, and PCOVIP is the percentage oviposition completed on the sample day. The upper 95% confidence interval for the mean density of egg masses in a field is used in this formula because it is better to overpredict than underpredict in this type of management situation. Thus, a conservative management strategy is followed. LSURV is a constant determined by studies described in Part II, and equals .14. EPMASS is a constant and equals 2.52. The average potential number of larvae per plant may be derived by dividing the product of this equation by five.

RESULTS AND DISCUSSION

During 1983, the oviposition period for second generation eggs lasted approximately 24 days. Egg masses were detected in the field after 22 July. The initial capture of first generation adults in the light trap was on 25 July. Female SWCB moths are attracted to the light trap after mating and depositing their eggs, usually two days after eclosion (Schenk 1978). By 5 August, 50% of ovipostion was completed. These data are represented by the regression curve in Figure 1.

The oviposition period for second generation eggs lasted approximately 21 days in 1984. Egg masses were detected in the field after 20 July. The first SWCB moths were caught in the light trap on 23 July. By 6 August, 50% oviposition was completed. These data are represented by the regression curve in Figure 2.

Estimates of the potential number of larvae per plant are presented in Table 1. The larval estimates for 1983 tended to decrease as the oviposition period progressed. The most useful

Figure 1. Percentage completion of oviposition of second generation southwestern corn borer in Stafford County, Kansas, during 1983. The solid line represents the regression model: % completion of oviposition= $100/(1+e^{(9.776829-0.632921 day)})$. The dashed lines represent the 95% confidence interval. Day 1 corresponds to 22 July. $R^2 = .96$.

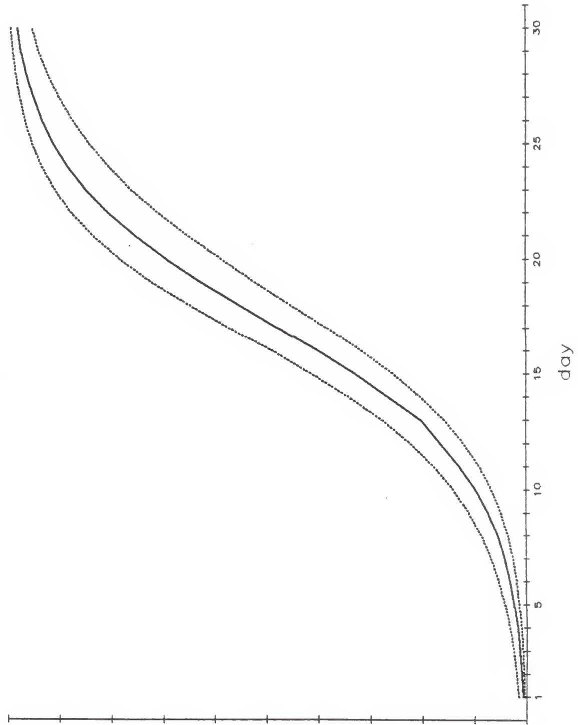
% completion of oviposition
0
10
20
30
40
50
60
70
80
90
100
day
1
5
10
15
20
25
30

Figure 2. Percentage completion of oviposition of second generation southwestern corn borer in Stafford County, Kansas, during 1984. The solid line represents the regression model: % completion of oviposition= $100/(1+e^{(5.259336-0.302509\text{day})})$. The dashed lines represent the 95% confidence interval. Day 1 corresponds to 21 July. $R^2 = .98$.

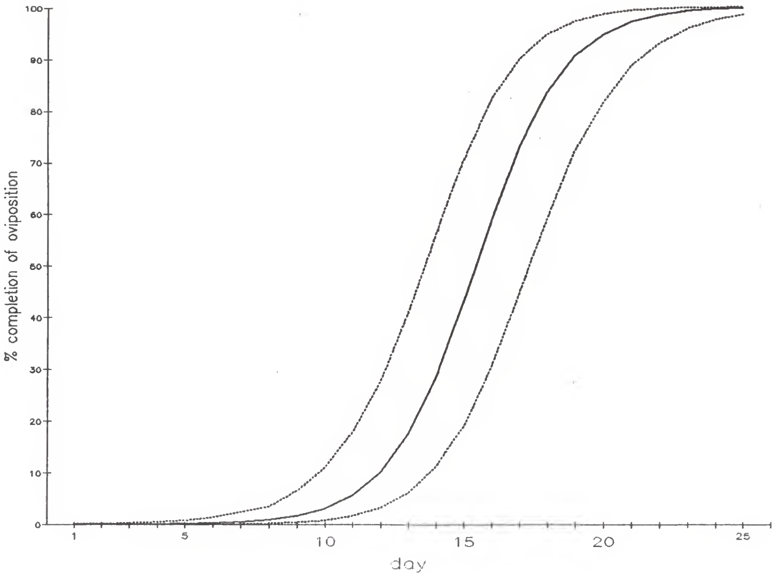
100
90
80
70
60
50
40
30
20
10
0
% completion of oviposition
1
5
10
15
20
25
day

Table 1. Estimates of potential second generation SWCB larval populations in field corn in Stafford County, Kansas during 1983 and 1984.

1983

Field	Sample Date	$\bar{x}^a$	U95CI[b]	% Oviposition Completed[c]	Potential Larvae/ Plant
Dunn	27 July	.03	.003	4.5	1.26
	30 July	.27	.55	1.7	2.32
	3 Aug.	1.87	2.45	17.5	.98
Fisher	26 July	.07	.16	.1	8.32
	29 July	.10	.21	.9	1.66
Mawhirter	30 July	.03	.05	1.7	.20
	4 Aug.	1.67	2.31	28.6	.58
Chadd	29 July	.17	.38	.9	3.00
Chris. I	28 July	.27	.57	.5	8.44
	3 Aug.	1.93	2.68	17.5	1.08
Chris. II	28 July	.07	.16	.5	2.34
	2 Aug.	1.70	2.29	10.1	1.59
	4 Aug.	2.77	3.63	28.6	.91

1984

Field	Sample Date	$\bar{x}$	U95CI	% Oviposition Completed	Potential Larvae/ Plant
Dunn	24 July	.57	3.50	1.7	14.41
Chris. I	24 July	.23	1.36	1.7	5.59
Chris. II	21 July	.07	.63	.7	6.38
Spare I	26 July	.07	.63	3.1	1.44
Spare II	23 July	.70	4.01	1.3	22.25
	26 July	2.77	9.08	3.1	20.71

[a] Mean number of egg masses per five plant sample.

[b] The upper 95% confidence interval for the mean number of egg masses per plant.

[c] The percentage oviposition completed by first generation females on the sample date.

estimates are probably from data collected closest to peak oviposition, in part because egg masses were more abundant. Larval estimates for 1984 are extremely high. The actual infestation at the Sandyland Experiment field was not as severe in 1984 as in 1983. Growers applied insecticides earlier than recommended, before 5% oviposition was completed, permitting only a short sampling period. Therefore, 1984 results are more limited in value. The management model for second generation SWCB should recommend egg mass sampling just before 50% oviposition is completed for the most accurate estimates of larval populations.

Workers averaged 41 minutes in traveling to and sampling subplots. Thus it would take approximately 4 hours for an experienced person to sample a similiar field using the same recommended sampling program.

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Part IV

Southwestern Corn Borer
Egg Mass Detrition

INTRODUCTION

A computer model for management of second generation SWCB has been constructed that calculates crop yield reduction based on anticipated larval density. Since insecticides often are applied before oviposition of second generation is complete, the model must predict larval density from an egg mass sample. Larval density is calculated by multiplying the cumulative number of eggs by the percentage survivorship and dividing by the percentage oviposition completed on the sample day. The cumulative number of egg masses is the sum of the hatched and unhatched egg masses on the sample date. Egg masses of SWCB may fall or be washed off the plant at any time. If significant losses occur, then correcting sample counts for detrition may be necessary. Based on field studies, Calvin's (1985) European corn borer model estimates 1.14 to 1.46 percent of egg masses missing when oviposition is 50% complete. He found that the management decision was not affected by correcting for egg mass detrition.

MATERIALS AND METHODS

During 1983 and 1984, plots were established in flood irrigated corn for the purpose of studying egg mass detrition. The field was planted to corn in previous years and was planted with Pioneer corn variety 3183 for this study. No insecticides were used in or near the crop. Four plots of 30 consecutive labeled plants were established.

The SWCB phenology model (Poston 1978) was used to predict oviposition of second generation eggs by first generation adults. Plots were checked daily for eggs to determine the initiation of oviposition. The entire plant surface was examined for SWCB egg masses which were circled and labeled with indelible ink for later identification. Plants were rechecked for new or lost egg masses at three and four day intervals for the duration of the oviposition period. Frequency of oviposition was noted and the daily percentage of oviposition completed was estimated with a regression model.

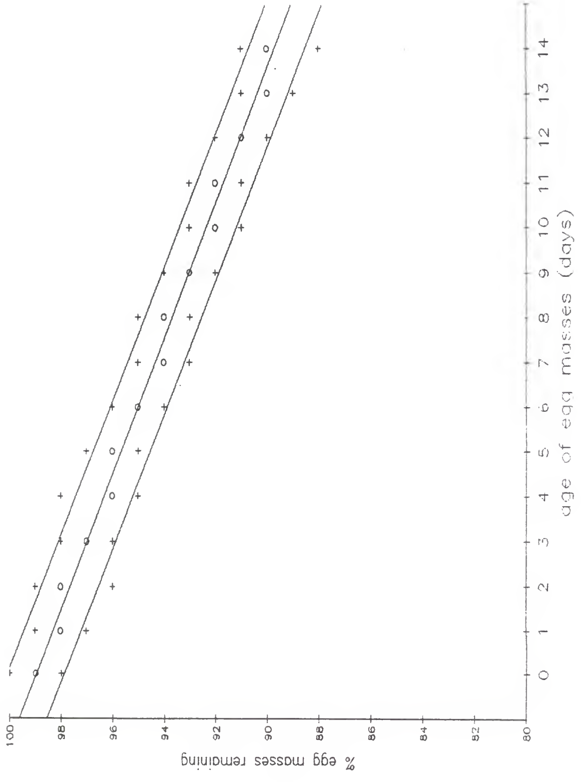
RESULTS AND DISCUSSION

The percentage of egg mass cohorts remaining on plants during a sixteen day period was fit to a regression model (Figure 1). Four sets of egg cohorts were used to build the model. The chance of an egg mass falling from the oviposition site increases with egg mass age. The model estimates that a set of sixteen day old egg masses represents 90% of the actual egg mass population.

The estimated percentage oviposition occurring daily in 1983 and 1984 was multiplied by the percentage egg mass detrition associated with each age class. These daily estimates of missing egg mass percentages were calculated until 50% oviposition was completed. In 1983, .71% of egg masses are estimated as having fallen from the plant when 50% of oviposition was completed. In 1984, 1.08% of egg masses are estimated as having fallen from the plant when 50% of oviposition was completed.

Egg mass sample data from Part III were corrected for detrition and the results used as inputs for the SWCB management model. The corrected data did not change the treatment decisions. Thus, a correction factor for egg mass detrition was not incorporated into the model.

Figure 1. Percentage of second generation southwestern corn borer egg mass age classes remaining on corn plants. The symbol (o) represents the regression model: % egg masses remaining = 99.1171-0.6857day. The symbol (+) represents the 95% confidence interval. R^2 =.92.


% egg masses remaining
100
98
96
94
92
90
88
86
84
82
80
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
age of egg masses (days)

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Part V

A Management Model for Second Generation Southwestern Corn Borer

INTRODUCTION

Second generation SWCB may be effectively managed with insecticides. Insecticide applications are expensive and should be used only when economically justifiable. In addition, the overuse of insecticides promotes resistance in pest populations and diminishes environmental quality by killing non-target organisms. Economical management of agroecosystems may be improved through the use of computer models. For example, the European Corn Borer Management Model developed by Calvin (1985) integrates European corn borer population dynamics, corn plant phenology, insect-induced damage and grain yield loss estimates, and an economic analysis. The model is used by corn growers and university extension personnel for management of European corn borer in field corn.

A management model for second generation SWCB has been constructed that recommends needed insecticide treatments and predicts treatment dates for achieving economical suppression. The actual treatment decision must be made before larvae begin entering the plant so that insecticide applications coincide with the insect's period of vulnerability. Since crop yield potential and the intensity of a SWCB infestation vary from one locale to another, management recommendations should be based on information obtained from individual fields. These recommendations are based on the phenology of the insect and the host plant, estimated proportional yield reduction, and an economic analysis of treatment costs versus the benefits derived from that treatment. As a management tool, the model has several advantages over traditional pest control strategies. It uses local temperature data and SWCB population trends to make projections, and enables the user to compare several management strategies in a short period of time.

MATERIALS AND METHODS

The SWCB management model has been programmed in Microsoft GW^{TM} -Basic on a Zenith-150 computer with 320K memory. The model has three major components initially identified by construction of a conceptual model (Figure 1). The first component describes SWCB phenology and population dynamics. The insect-induced damage and grain loss relationship, and the cost/benefit analyses are described by the second and third components, respectively. The programming code for the model is listed in Appendix I. Instructions for loading and using the model are included in Appendix II.

ALGORITHM DESCRIPTION

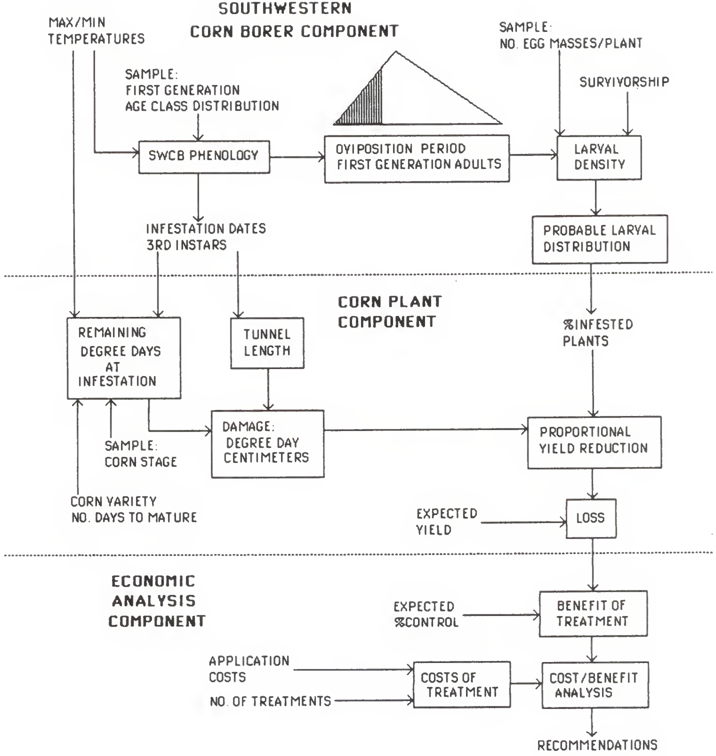
Phenology of second generation SWCB can be described by using a degree-day accumulation system (Whitworth and Poston 1979). The phenology model uses maximum and minimum daily temperatures from the county where the field is located to calculate the thermal units or growing degree-days on a daily basis. Daily maximum and minimum temperatures for the months of interest are stored on diskette for every Kansas county. Collecting a sample of first generation larvae from whorl stage corn provides information on the proportion of cohorts in each age class. Larvae are separated by instar, which can be determined by head capsule width. The model predicts the distribution of development through time for each set of cohorts. The dates for adult flight and proportional oviposition of second generation eggs are predicted by adding the percentages estimated to have completed their development on a daily basis. The infestation dates for second generation third instars and the proportion of larvae boring into plants on each day are determined in the same manner.

The magnitude of the second generation infestation is projected from a sample of second generation egg masses using the following formula:

$$LPP = (EGMASS * LSURV) / (PCTOVIP)$$

where LPP is the number of third stage larvae per plant, EGMASS is the cumulative number of egg masses per plant, LSURV is the survivorship through the third instar, and PCTOVIP is the percentage oviposition complete on the sample day. The cumulative number of egg masses per plant is determined by sampling hatched and unhatched egg masses of second generation SWCB. The sampling period is defined by the SWCB phenology

Figure 1. A conceptual model for management of second generation southwestern corn borer.


SOUTHWESTERN CORN BORER COMPONENT
MAX/MIN TEMPERATURES
SAMPLE: FIRST GENERATION AGE CLASS DISTRIBUTION
SWCB PHENOLOGY
OVIPOSITION PERIOD FIRST GENERATION ADULTS
SAMPLE: NO. EGG MASSES/PLANT
SURVIVORSHIP
LARVAL DENSITY
PROBABLE LARVAL DISTRIBUTION
INFESTATION DATES 3RD INSTARS
CORN PLANT COMPONENT
REMAINING DEGREE DAYS AT INFESTATION
TUNNEL LENGTH
%INFESTED PLANTS
SAMPLE: CORN STAGE
DAMAGE: DEGREE DAY CENTIMETERS
PROPORTIONAL YIELD REDUCTION
CORN VARIETY NO. DAYS TO MATURE
EXPECTED YIELD
LOSS
ECONOMIC ANALYSIS COMPONENT
EXPECTED %CONTROL
BENEFIT OF TREATMENT
APPLICATION COSTS
NO. OF TREATMENTS
COSTS OF TREATMENT
COST/BENEFIT ANALYSIS
RECOMMENDATIONS

component and occurs before fifty percent of oviposition is complete. Survivorship is a constant that describes the proportion of the second generation egg population surviving to infest the corn as third instars if there is no intervention with insecticides. Survivorship equals .14 and was determined by studies described in Part II. The percentage oviposition completed by the sample day is calculated through the model's SWCB phenology component.

Because the assumptions for a contagious distribution of larvae proposed by Neyman (1939) hold true for second generation SWCB larvae, it was possible to develop a mathematical model of their movement based on field observations (Poston, Welch and Safford, unpublished data). This model produces a table of values for the percentage larval infested plants as a function of the number of egg masses per plant was generated with the model (Table 1). The SWCB management model finds the values for the number of egg masses per plant and uses linear interpolation to determine the percentage of larval infested plants (PIP). If there are two or more egg masses per plant, 100 percent larval infestation is assumed.

The proportional yield reduction from second generation SWCB tunneling damage is estimated by using a method described by Whitworth (1980). Proportional yield reduction is estimated by placing anticipated borer damage and corn plant phenology on the same scale of degree-days. Proportional yield reduction is calculated for each set of cohorts entering the third larval stage during each day of infestation. Since the fraction of cohorts emerging on one day also represents the proportional yield reduction to the same fraction of infested plants, the total yield reduction is calculated by adding together all proportional yield reductions for all sets of cohorts.

SWCB tunnel length is calculated by the following equation:

$$TL = K / (1 + e^{-r(DD - D)})$$

where TL is tunnel length in centimeters, K is the mean tunnel length per larva in centimeters, r is the rate of tunneling in centimeters per degree-day, DD are SWCB degree-days, and D is the number of degree-days where fifty percent of tunneling occurs. K is a constant and is equal to 20.37 centimeters. The rate of tunneling is 0.026437 centimeters per degree-day. SWCB degree-days are calculated in the phenology component of the model. D is a constant and equals 397.5 degree-days.

Physiological events in a corn plant vary in seasonal occurrence from one field to another because of planting date, corn variety and local growing conditions. For many widely planted varieties of corn, the silking stage occurs when fifty percent of the total number of degree days necessary for completion of development (emergence to physiological maturity) have accumulated. Blister, dough, beginning dent, and

Table 1. The percentage of corn plants infested with second generation southwestern corn borer as a function of the mean number of egg masses per plant.

Mean number of egg masses per plant	Percentage infested plants
.05	.068
.1	.132
.15	.191
.2	.246
.25	.297
.3	.345
.35	.399
.4	.43
.45	.469
.5	.505
.55	.539
.6	.571
.65	.601
.7	.629
.75	.655
.8	.679
.85	.701
.9	.721
.95	.741
1.0	.758
1.05	.775
1.15	.79
1.2	.805
1.25	.818
1.3	.831
1.35	.842
1.4	.853
1.45	.864
1.5	.874
1.55	.883
1.6	.892
1.65	.9
1.7	.908
1.75	.916
1.8	.923
1.85	.93
1.9	.937
1.95	.943
2.0	.954

physiological maturity occur at equal intervals thereafter (Hanway 1971).

Corn degree days are calculated so plant physiological development can be placed on an equivalent time scale with insect damage (Whitworth 1980). The number of degree-days remaining until the corn plant reaches physiological maturity are calculated for each day of projected infestation. The model calculates degree-days for each day with the following equation:

$$\mathrm{DDAY} = (\mathrm{MAX} + \mathrm{MIN} \,/\, 2) - 50$$

where DDAY is the degree-days for a given day, and MAX and MIN are thirty year maximum and minimum temperature averages for a specific day and locale. The base temperature for SWCB and corn development is 50 degrees Fahrenheit. A maximum threshhold temperature is not used for either species. Degree-days are accumulated by adding the degree-days calculated each day to the previous day's cumulative total. The degree-days remaining at the time of infestation are calculated by subtracting the accumulated number of degree-days from the total number of degree-days necessary for the plant to complete development. Degree-days are calculated with the same equation for SWCB. The total number of degree days accumulated by the crop at the time of sampling (ACDD) is determined by the following formula:

$$\mathrm{ACDD} = \mathrm{DDPM} * \mathrm{MATURITY}$$

where DDPM is the percentage of degree days already accumulated by the predetermined corn stage and MATURITY is the total number of degree days necessary for the corn plant to reach physiological maturity. The corn stage is determined by examining plants when the egg mass sample is taken. The total number of degree days needed for the corn plant to reach physiological maturity is available on the seed package or may be obtained from the seed company.

The average loss per infested plant (LPIP) for each set of cohorts is estimated by the following regression equation:

$$\text{LPIP} = .0795 + .000016\ \text{DDCMS}$$

where DDCMS are degree-day centimeters. DDCMS (TUCMS in Whitworth, 1980) are derived by plotting SWCB tunneling against corn degree days and integrating the area under the curve. This equation is a modified version of Whitworth's regression model (Whitworth 1980). Validation data indicate that the intercept in the original regression model was too small (Parsons 1983). The proportional yield reduction is calculated by the following:

$$\text{PYR} = \text{LPIP} * \text{PIP}$$

where PYR is proportional yield reduction. The total crop loss caused by second generation SWCB infestation is projected by multiplying the expected yield in the absence of borers by the proportional yield reduction that the infestation is expected to cause.

A cost/benefit ratio is calculated to determine whether treating the second generation SWCB infestation is economically justifiable. The situations of one and two insecticide applications are analyzed. The model assumes proper timing of treatments if insecticides are applied to the crop. One treatment is applied when 75 percent of oviposition is complete. If two treatments are recommended by the model, the first is applied when 50 percent of oviposition is complete and the second is applied 14 days later (Higgins et al. 1988).

Cost is derived by adding together all costs associated with application of an insecticide of the crop manager's choice. Multiplying this figure by the number of applications (1 or 2) gives the total cost of treatment. Benefit is calculated by multiplying the expected crop loss attributed to second generation SWCB infestation by the current or expected market value. The loss value then is multiplied by the expected percentage control resulting from intervention with insecticide. A cost to benefit ratio is calculated by dividing the cost by the benefit.

Once the cost/benefit ratios are calculated, different treatment strategies can be analyzed. Treatment recommendations are based on the following situations:

COST/BENEFIT > 1, treatment not recommended
COST/BENEFIT <= 1, treatment recommended

RESULTS AND DISCUSSION

Several projections were made with the completed SWCB management model. The sampling data from Part III were used as inputs for the number of egg masses per plant. First generation SWCB larvae were collected from corn fields in Stafford County in 1983 and 1984. Larvae were separated by instar and the age class distribution was used as an input for the phenology component of the model (Table 2). The same inputs were used both years for the remaining variables in the model (Table 3).

For data collected on 27 July 1983 in Dunn's field, the management model does not recommend insecticide treatment. Subsequent egg mass sample data collected from this field and evaluated by the model resulted in a recommendation of one insecticide treatment. One insecticide treatment is recommended in the remaining situations (Table 4). Model recommendations are in contrast to actual practices in observed in 1983 and 1984 since all growers applied two insecticide treatments. Yield loss was not validated in these fields, thus accuracy of the model recommendations cannot be evaluated.

Outputs from the phenology model are compared to the actual oviposition of second generation SWCB in Table 5. In 1983, actual percentages of oviposition completed were close to the model's predictions: 5% oviposition was predicted two days earlier, 50% oviposition was predicted two days

Table 2. The age class distribution of first generation southwestern corn borer larval samples collected in Stafford County, Kansas in 1983 and 1984.

	6 July 1983	10 July 1984
Stage	no. of larvae	no. of larvae
first instar	8	0
second instar	15	0
third instar	23	0
fourth instar	6	2
fifth instar	0	20
pupa	0	3

Table 3. A list of inputs for southwestern corn borer management model estimates used in combination with egg mass sample data durin 1983 and 1984 for Stafford County, Kansas.

Cost of pesticide and application = $13.00

Price of corn per bushel = $1.50

Corn growing degree days = 2200

Expected yield = 200

Corn stage = blister

Percent control, 1 application = 50

Percent control, 2 applications = 75

County = Stafford

Table 4. Southwestern corn borer management model recommendations for egg mass sample data collected in fields in Stafford County, Kansas in 1983 and 1984.

1983

Field	Sample Date	Average No. Egg Masses Per Plant	Model Recs.	Cost Benefit Ratio
Dunn	27 July	.0006	no trt.	42.30
	30 July	.11	no trt.	1.59
	3 Aug	.49	1 trt.	.45
Fisher	26 July	.03	1 trt.	.89
	29 July	.04	1 trt.	.56
Mawhirter	30 July	.01	no trt.	2.15
	4 Aug	.46	1 trt.	.73
Chadd	29 July	.08	1 trt.	.73
Chris. I	28 July	.11	no trt.	1.29
	3 Aug	.54	1 trt.	.45
Chris. II	28 July	.03	1 trt.	.80
	2 Aug	.46	1 trt.	.81
	4 Aug	.73	1 trt.	.48

1984

Field	Sample Date	Average No. Egg Masses Per Plant	Model Recs.	Cost Benefit Ratio
Chris. I	24 July	.27	1 trt.	.61
Chris. II	21 July	.13	1 trt.	.58
Dunn	24 July	.70	1 trt.	.36
Spare I	26 July	.13	1 trt.	.45
Spare II	20 July	.16	no trt.	1.25
	23 July	.80	1 trt.	.38
	26 July	1.82	1 trt.	.38

Table 5. Dates for actual and predicted percentage oviposition of second generation southwestern corn borer in Stafford County, Kansas during 1983 and 1984.

1983

% Oviposition Completed	Actual Date	Predicted Date
5	24 July	22 July
50	5 Aug	2 Aug
90	9 Aug	11 Aug

1984

% Oviposition Completed	Actual Date	Predicted Date
5	28 July	12 July
50	6 Aug	19 July
90	13 Aug	26 July

earlier, and 90% oviposition was predicted two days later than the actual occurrence. For 1984 data, the model predicted 5% oviposition 16 days earlier, 50% oviposition 18 days earlier, and 90% oviposition 18 days earlier than the actual occurrence. These poor predictions of oviposition probably explain the eventual need for two insecticide applications in 1984. Unnecessarily early applications of insecticides occurred that year when growers based their management decisions on the phenology model's outputs. Preliminary investigation has shown that SWCB development rate was slower when temperatures were in excess of 100 degrees Fahrenheit (Poston, Welch and Knapp, unpublished data). Extended periods of high temperatures have been common in southwest and southcentral Kansas in recent years. The results of the model evaluations indicate that the rate of development of SWCB at high temperatures needs to be investigated further. When these data become available, further evaluation of the model's accuracy will be possible.

The sample data were corrected for egg mass detrition and the results used as inputs in the model. Because the corrected data did not change the treatment decisions, a correction for egg mass detrition was not incorporated into the model.

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Appendix I

```
100 DIM O(6,6),TT(6,6),N(6)
110 DIM C(50),BP(4)
120 DIM ST(6)
130 DIM DA(10)
180 OFLAG=1
190 TFLAG=0
195 A3=LOG(1+EXP(.026437*397.5))/.026437
196 TUCMS=0
197 LTUCMS=0
200 BP(0)=.05
210 BP(1)=.5
220 BP(2)=.75
221 BP(3)=.9
225 BK=0
230 ST(0)=.5
240 ST(1)=.1
250 ST(2)=.1
260 ST(3)=.1
270 ST(4)=.1
280 ST(5)=.1
300 FOR I=0 TO 5
301 FOR J=0 TO 5
302 READ O(I,J)
303 NEXT J
304 NEXT I
310 DATA 725,-.02867,7.10,158.59,-.014167,4.80
320 DATA 567,-.02667,7.10,185.04,-.01143,4.28
330 DATA 432,-.03448,7.10,142.09,-.01379,4.16
340 DATA 286,-.04412,7.05,99.14,-.01739,4.40
350 DATA 142,-.05172,5.00,67.42,-.01575,2.57
360 DATA 025,-.043206,1.74,000,-.043206,1.74
400 FOR I=0 TO 5
401 FOR J=0 TO 5
402 READ TT(I,J)
403 NEXT J
404 NEXT I
410 DATA 1225,-.028968,7.51,125,-.015793,5.86
420 DATA 1050,-.031819,8.41,150,-.016511,6.12
430 DATA 0900,-.032435,7.06,100,-.017100,5.52
440 DATA 0725,-.035289,7.34,100,-.017949,5.61
450 DATA 0525,-.044563,8.16,100,-.018603,5.57
460 DATA 0375,-.054547,8.08,075,-.025492,5.90
470 DIM E(41), IP(41)
475 EMPP=0
480 FOR I=0 TO 40
485 E(I)=EMPP
490 EMPP=EMPP+.05
495 NEXT I
529 IP(0)=0
530 IP(1)=6.800001E-02
531 IP(2)=.132
532 IP(3)=.191
533 IP(4)=.246
534 IP(5)=.297
535 IP(6)=.345
```

```
536 IP(7)=.389
537 IP(8)=.43
538 IP(9)=.469
539 IP(10)=.505
540 IP(11)=.539
541 IP(12)=.571
542 IP(13)=.601
543 IP(14)=.629
544 IP(15)=.655
545 IP(16)=.679
546 IP(17)=.701
547 IP(18)=.721
548 IP(19)=.741
549 IP(20)=.758
550 IP(21)=.775
551 IP(22)=.79
552 IP(23)=.805
553 IP(24)=.818
554 IP(25)=.831
555 IP(26)=.842
556 IP(27)=.853
557 IP(28)=.864
558 IP(29)=.874
559 IP(30)=.883
560 IP(31)=.892
561 IP(32)=.9
563 IP(33)=.908
564 IP(34)=.916
565 IP(35)=.923
566 IP(36)=.93
567 IP(37)=.937
568 IP(38)=.943
569 IP(40)=.954
575 N=41
1000 REM first generation larval sample
1010 INPUT "enter larval sample date - day of year";LSDATE
1019 NTOT=0
1020 FOR I=0 TO 5
1021 IF I=5 THEN GOTO 1024
1022 PRINT "enter instar";I+1;" count"
1023 GOTO 1025
1024 PRINT "enter pupal count"
1025 INPUT N(I)
1026 NTOT=NTOT+N(I)
1027 NEXT I
1028 FOR I=0 TO 5
1029 N(I)=N(I)/NTOT
1030 NEXT I
1039 REM egg sample
1040 INPUT "egg sample date - day of year";ESDATE
1045 INPUT "egg density - masses/plant";EGMASS
1060 LSURV=.138
1070 REM remaining corn thermal units
1080 PRINT "enter corn stage"
1081 PRINT "  vegatative=1"
```

```
1082 PRINT "  silk      =2"
1083 PRINT "  blister   =3"
1084 PRINT "  dough     =4"
1085 PRINT "  beg. dent =5"
1086 PRINT "  dent      =6"
1087 INPUT STAGE
1088 STAGE=STAGE-1
1090 INPUT "enter degree-days required for corn
physiological maturity";MATURITY
1100 REM expected yield
1110 INPUT "enter expected yield - bu/acre";YIELD
1120 REM economic analysis
1125 INPUT "enter market value $/bu";PRICE
1130 INPUT"enter expected % control for 1 treatment";PCTCTRL1
1140 PCTCTRL1=PCTCTRL1/100
1150 INPUT"enter expected % control for 2 treatments";PCTCTRL2
1160 PCTCTRL2=PCTCTRL2/100
1170 INPUT"enter costs of insecticide plus 1 application";COST1
1180 COST2=COST1*2
1300 GOSUB 10000
1310 INPUT "county name";C$
2000 REM calculate ddays from esdate to PM
2010 DDPM=ST(STAGE)/2
2020 FOR I=STAGE+1 TO 5
2030 DDPM=DDPM+ST(I)
2040 NEXT I
2050 DDPM=DDPM*MATURITY
2100 TDAY=LSDATE
2101 JD=TDAY
2102  GOSUB 11000
2103 DDAY=((MAX+MIN)/2)-50
2104 IF (RET) THEN PRINT "there was an error!"
2105 DDTOT=DDAY
2106 TTOT=0
2110 GOSUB 5000
2125 DAY=LSDATE
2130 LOVIP=OVIP
2150 TDAY=DAY+1
2154 TSUM=0
2160 TJ=0
2169 JD=TDAY
2170  GOSUB 11000
2171 DDAY=((MAX+MIN)/2)-50
2172 IF (RET) THEN PRINT "there was an error!"
2180 TSUM=TSUM+DDAY
2185 PRINT TDAY
2187 GOSUB 3000
2190 DA(TJ)=TSUM
2200 IF TDAY=ESDATE THEN GOTO 2500
2210 IF TSUM>=100 THEN GOTO 2260
2220 IF TDAY>LSDATE+90 THEN STOP
2230 TDAY=TDAY+1
2240 TJ=TJ+1
2250 GOTO 2170
2260 IF TFLAG=0 THEN GOSUB 6000
```

```
2261 IF THIRD>.01 THEN TFLAG=1
2263 IF OFLAG=0 THEN GOTO 2282
2265 DDTOT=DDTOT+TSUM
2270 GOSUB 5000
2280 IF OVIP>=BP(BK) THEN GOTO 2290
2282 DAY=TDAY
2286 GOTO 2130
2290 X=(BP(BK)-LOVIP)/(OVIP-LOVIP)*TSUM
2300 TJ=0
2310 IF DA(TJ)>=X THEN GOTO 2340
2320 TJ=TJ+1
2330 GOTO 2310
2340 PRINT 100*BP(BK);"emergence is"
2350 BP(BK)=DAY+TJ+1
2360 PRINT " on day of year";BP(BK)
2370 BK=BK+1
2380 DAY=TDAY
2390 IF BK=4 THEN OFLAG=0
2392 GOTO 2130
2400 STOP
2500 REM calculate pct ovip complete
2510 DDTOT=DDTOT+TSUM
2515 PMDD=DDTOT+DDPM
2516 PRINT "ddate of PM";PMDD
2517 PRINT "ddtot,ddpm";DDTOT,DDPM
2520 GOSUB 5000
2530 PCTOVIP=OVIP
2535 DDTOT=DDTOT-TSUM
2540 PRINT "ovip";100*PCTOVIP;"pct complete"
2550 PRINT "on egg sample date";TDAY
2560 GOTO 2210
3000 REM third analysis
3005 TTOT=TTOT+DDAY
3007 IF TFLAG=0 THEN RETURN
3010 GOSUB 6000
3011 GOSUB 8000
3012 TUCMS=TUCMS+DTUCMS*(THIRD-LTHIRD)
3013 PRINT "this cohorts tucms = "DTUCMS*(THIRD-LTHIRD)
3018 LTHIRD=THIRD
3020 IF TTOT<PMDD THEN RETURN
3030 PRINT "tucms = "TUCMS
3040 LPIP=.0795+.000016*TUCMS
3050 PRINT "loss per infested plant "LPIP
3060 LPP=(EGMASS*LSURV)/PCTOVIP
3061 PRINT "larvae per plant";LPP
4000 GOSUB 6500
4010 PYR=LPIP*PIP
4020 LOSS=PYR*YIELD
4021 PRINT "loss=";LOSS
4030 GOSUB 7000
4040 END
5000 REM ovip subroutine
5010 OVIP=0
5020 FOR I=0 TO 5
5030 XX=DDTOT-O(I,0)
```

```
5040 IF XX>O(I,3) THEN GOTO 5070
5050 UU=O(I,1)*XX+O(I,2)
5060 GOTO 5080
5070 UU=O(I,4)*XX+O(I,5)
5080 OVIP=OVIP+N(I)/(1+EXP(UU))
5090 NEXT I
5096 INPUT GO
5100 RETURN
6000 REM third subroutine
6010 THIRD=0
6020 FOR I=0 TO 5
6030 XX=TTOT-TT(I,0)
6040 IF XX>TT(I,3) THEN GOTO 6070
6050 UU=TT(I,1)*XX+TT(I,2)
6060 GOTO 6080
6070 UU=TT(I,4)*XX+TT(I,5)
6080 THIRD=THIRD+N(I)/(1+EXP(UU))
6090 NEXT I
6100 RETURN
6500 REM percentage infested plants
6510 IF EGMASS>2 GOTO 6520 ELSE 6540
6520 PIP=1!
6530 RETURN
6540 NM1=N-1
6550 FOR I=0 TO NM1
6560 J=I
6570 IF EGMASS>E(I) THEN 6580 ELSE 6590
6580 NEXT
6590 J=J-1
6600 DYDX=(IP(J+1)-IP(J))/(E(J+1)-E(J))
6610 DELTAX=(EGMASS-E(J))/(E(J+1)-E(J))
6620 PIP=IP(J)+DYDX*DELTAX
6630 RETURN
7000 REM cost/benefit analysis
7005 BENEFIT1=LOSS*PRICE*PCTCTRL1
7006 BENEFIT2=LOSS*PRICE*PCTCTRL2
7010 CB1=COST1/BENEFIT1
7020 CB2=COST2/BENEFIT2
7021 PRINT"cb1= ";CB1
7022 PRINT "cb2= ";CB2
7030 IF CB1<=CB2 THEN 7040 ELSE 7050
7040 IF CB1<=1 THEN 7100 ELSE 7300
7050 IF CB2<=1 THEN 7200 ELSE 7300
7100 PRINT"1 treatment recommended"
7101 PRINT"apply at 75% emergence"
7110 RETURN
7200 PRINT"2 treatments recommended"
7201 PRINT"apply two treatments at 50% emergence and 14 days
later"
7210 RETURN
7300 PRINT"no treatment recommended"
7310 RETURN
8000 A1=.026437*(PMDD-397.5)
8010 A2=.026437*(TTOT-397.5)
8020 IF A1>=-6.91 THEN 8050
```

```
8030 DTUCMS=0
8040 GOTO 8090
8050 IF A1<=6.91 THEN 8080
8060 DTUCMS=A1
8070 GOTO 8090
8080 DTUCMS=LOG(1+EXP(A1))
8090 IF A2 >= -6.91 THEN 8110
8100 GOTO 8150
8110 IF A2 <= 6.91 THEN 8140
8120 DTUCMS=DTUCMS-A2
8130 GOTO 8150
8140 DTUCMS=DTUCMS-LOG(1+EXP(A2))
8150 DTUCMS=(20.37/.026437)*DTUCMS
8160 RETURN
10000 DIM C$(30),T(30,5,1)
10010 OPEN "SPECIAL.WDB" FOR INPUT AS 1
10020 FOR T=0 TO 30
10030    C$(T)=""
10050       C$(T)=C$(T)+INPUT$(5,1)
10070    INPUT
#1,T(T,0,0),T(T,0,1),T(T,1,0),T(T,1,1),T(T,2,0),T(T,2,1),
T(T,3,0),T(T,3,1),T(T,4,0),T(T,4,1),T(T,5,0),T(T,5,1)
10080 NEXT
10090 RETURN
11000 H=0:L=31
11002 FOR T=1 TO 5
11004    IF MID$(C$,T,1) > "Z" THEN
MID$(C$,T,1)=CHR$(ASC(MID$(C$,T,1))-32)
11006    IF MID$(C$,T,1) = "" THEN C$=C$+" "
11008 NEXT T
11009 IF LEN(C$)>5 THEN C$=LEFT$(C$,5)
11010 T=INT((H+L)/2)
11020 IF C$=C$(T) THEN 11050
11030 IF C$<C$(T) THEN IF L=T THEN 11500 ELSE L=T ELSE IF
H=T THEN 11500 ELSE H=T
11040 GOTO 11010
11050 IF JD<135 THEN 11510
11058 IF JD<135 THEN 11510
11060 IF JD<166 THEN MIN=(T(T,1,0)*(JD-135)+T(T,0,0)*(166-
JD))/31 :
MAX=(T(T,1,1)*(JD-135)+T(T,0,1)*(166-JD))/31 : GOTO 11100
11070 IF JD<196 THEN MIN=(T(T,2,0)*(JD-166)+T(T,1,0)*(196-
JD))/30 :
MAX=(T(T,2,1)*(JD-166)+T(T,1,1)*(196-JD))/30 : GOTO 11100
11080 IF JD<227 THEN MIN=(T(T,3,0)*(JD-196)+T(T,2,0)*(227-
JD))/31 :
MAX=(T(T,3,1)*(JD-196)+T(T,2,1)*(227-JD))/31 : GOTO 11100
11090 IF JD<258 THEN MIN=(T(T,4,0)*(JD-227)+T(T,3,0)*(258-
JD))/31 :
MAX=(T(T,4,1)*(JD-227)+T(T,3,1)*(258-JD))/31 : GOTO 11100
11095 IF JD<288 THEN MIN=(T(T,5,0)*(JD-258)+T(T,4,0)*(288-
JD))/30 :
MAX=(T(T,5,1)*(JD-258)+T(T,4,1)*(288-JD))/30 : GOTO 11100
11100 RET=0:RETURN 'Successful return
11500 RET=1:RETURN 'County not found
```

```
11510 RET=2:RETURN 'Julian date out of range (135-258)
12000 '------------------------------------------------------------
12010 '-
12020 '-    GETWDATA - The BASIC version
12030 '-        Input parameters:
12040 '-          C$ = County name
12050 '-          JD = Julian Date
12060 '-        Output comes back in:
12070 '-          MIN = Minimum Temperature 30 year average
for county       -
12080 '-          MAX = Maximum Temperature 30 year average
for county       -
12090 '-          RET = Return value
12100 '-              RETurn values can be:
12110 '-              0 : Successful Return
12120 '-              1 : County not found
12130 '-              2 : Julian date out of range (135-258)
12140 '-
12150 '-     When starting to use these subroutines, always
make sure to     -
12160 '-     call the initilizing routine first (gosub
10000), then each     -
12170 '-     call to getwdata should look like this:
12180 '-
12190 '-     C$="Barton" : JD=160 : GOSUB 11000
12200 '-
12210 '-     After a call to getwdata, the return code
should be inspected   -
12220 '-     at least minimally to determine if an error
occurred.          -
12230 '-
12240 '-     IF (RET) THEN PRINT"There was an error!"
12250 '-
12260 '-     should suffice.  Error codes are explained
above.               -
12270 '-
12280 '-     Remember these tips:
12290 '-     1.  Only GOSUB 10000 ONCE during a program.
12300 '-     2.  Set C$ and JD before GOSUBing 11000
12310 '-     3.  Call me if there are any problems...
12320 '-
12330 '------------------------------------------------------------
```

Weather data base for Kansas counties:

```
BARBE 53.6 80.3 63.2 90.2 67.6 95.4 65.9 94.3 57.5 85.1 45.1 75.0
BARTO 53.4 78.2 63.3 88.8 68.6 94.0 66.6 92.4 57.3 83.2 45.9 72.8
BUTLE 54.2 78.2 63.3 86.7 68.4 92.4 66.5 91.3 58.1 82.6 46.8 72.3
CLARK 51.1 79.4 61.0 89.7 66.2 95.3 64.3 94.0 55.2 84.8 41.7 74.9
COMAN 53.5 80.1 62.9 88.9 67.5 95.4 65.5 94.0 57.2 84.8 45.7 74.1
COWLE 55.2 79.4 64.6 88.5 69.0 93.9 67.3 93.0 59.6 84.7 47.5 74.4
EDWAR 51.8 77.3 61.8 88.1 67.2 93.6 65.0 92.2 55.8 82.9 43.5 72.6
FINNE 50.3 76.8 60.6 88.2 66.2 93.8 64.2 94.5 54.6 82.2 41.5 71.5
FORD  52.0 76.2 62.0 87.2 67.4 92.5 65.7 90.8 56.6 81.5 44.4 71.0
GRANT 48.3 79.4 58.7 90.4 63.9 94.8 61.6 92.1 53.6 84.3 39.4 74.3
```

GRAY	49.9	78.5	59.5	89.3	64.3	94.0	62.1	92.2	53.5	84.2	41.0	74.1
HAMIL	47.8	78.9	58.1	89.7	63.6	94.8	61.3	92.1	51.7	84.1	37.9	73.5
HARPE	54.7	80.1	64.4	90.6	69.4	95.7	67.3	94.6	59.4	85.1	47.3	74.7
HARVE	53.7	77.8	63.3	88.1	68.4	93.9	66.7	92.5	58.2	83.2	46.8	72.3
HASKE	50.2	79.0	60.2	89.6	65.2	94.0	63.2	91.9	54.3	84.3	42.1	74.3
KEARN	49.0	77.6	59.1	88.9	64.5	94.1	62.1	91.5	52.8	82.6	40.1	72.4
KINGM	54.0	79.1	63.6	89.2	68.5	94.7	66.6	93.4	58.0	84.2	46.2	73.7
KIOWA	52.1	78.1	62.2	88.6	67.2	94.0	65.2	92.6	56.3	83.2	44.5	71.5
MARIO	53.3	78.1	62.9	87.3	67.8	93.3	65.9	92.2	57.1	83.2	45.5	72.7
MCPHE	52.9	77.5	62.8	88.4	68.1	94.1	66.3	92.6	57.6	82.9	46.1	72.3
MEADE	51.8	80.0	61.7	90.2	66.3	95.1	64.5	93.6	55.7	85.3	43.4	75.6
MORTO	50.0	79.4	59.8	89.4	65.0	93.2	63.4	91.3	54.7	83.5	42.7	73.5
PRATT	53.1	79.0	62.7	89.0	67.5	94.1	65.5	92.7	57.1	83.9	45.4	73.7
RENO	53.3	78.0	62.8	88.6	67.9	93.6	66.0	91.9	57.4	82.7	45.9	72.2
RICE	53.4	78.2	63.3	88.8	68.6	94.0	66.6	92.4	57.3	83.2	45.9	72.8
SEDGW	54.6	77.1	64.7	87.4	69.8	92.9	67.9	91.5	59.2	82.0	46.9	71.2
SEWAR	52.0	80.6	62.2	91.3	67.3	95.6	65.1	93.8	56.4	85.6	44.4	75.5
STAFF	53.3	78.0	62.8	88.6	67.9	93.6	66.0	91.9	57.4	82.7	45.9	72.2
STANT	48.3	79.4	58.7	90.4	63.9	94.8	61.6	92.1	53.6	84.3	39.4	74.3
STEVE	50.6	78.5	60.9	89.2	66.1	93.5	63.9	91.2	54.7	82.9	42.3	73.2
SUMNE	54.5	78.9	64.3	88.7	69.1	94.1	67.5	93.3	59.1	84.1	46.7	73.5

Appendix II

A User's Guide for the Management Model for Second Generation Southwestern Corn Borer in Kansas

The southwestern corn borer management model has been programmend in Microsoft GW^{TM}-Basic on a Zenith-150 computer with 320K memory. To use the program, you must have an appropriate computer, and a diskette with Basic and the management model saved on it.

1. Turn the computer on and boot the system.
2. Place the diskette with Basic and the SWCB management model on it in the disk drive.
3. Type BASICA and hit the return key.
4. Type LOAD"SWCB" and hit the return key.
5. Type RUN"SWCB". The management model is now working and will prompt you for inputs.
6. Type in the sample date for the first generation larval age class distribution as day of year. Hit the return key.
7. Enter the number of first generation larvae in each stage. Hit the return key.
8. Type in the sample date for the second generation egg mass sample as day of year. Hit the return key.
9. Enter the number of egg masses per plant. Hit the return key.
10. Select the stage the corn was in when you sampled for egg masses and enter the appropriate number. Hit the return key.
11. Enter the number of growing degree days necessary for the corn plant to reach physiological maturity. Hit the return key.

12. Enter the number of bushels per acre you would expect the crop to produce in the absence of second generation SWCB larvae. Hit the return key.

13. Enter the expected value of one bushel of corn. Hit the return key.

14. Enter the expected percentage control for one insecticide application. Hit the return key.

15. Enter the expected percentage control for two insecticide applications. Hit the return key.

16. Enter the cost per acre of one application of insectide. Hit the return key.

17. Type in the name of the county where the field is located. Hit the return key. When the program comes back with another question mark hit the return key again. Hit the return key after every question mark. The model produces dates for 5%, 50%, and 90% completion of oviposition of second generation SWCB, the number of recommended insecticide treatments, and the correct time for insecticide application.

18. When the program is finished, OK will appear on the screen. You may run the program again by typing RUN"SWCB". When you are through using the model type SYSTEM to exit basic and return to the system.

Appendix III

1983 Mortality Data

Plot:	A	B	C	D
Total number of eggs:	747	1180	1242	1077
Dessicated eggs:	40	85	90	63
Parasitized eggs:	137	315	224	253
Eaten eggs:	25	43	75	59
Number of living larvae:				
Third instars:	88	-	159	-
Fifth instars:	-	35	-	37

1984 Mortality Data

Plot:	A	B	C	D
Total number of eggs:	251	141	200	136
Dessicated eggs:	11	2	-	-
Parasitized eggs:	72	50	2	38
Eaten eggs:	4	-	6	7
Number of living larvae:				
Third instars:	43	7	-	-
Fifth instars:	-	-	26	18

1983 Sampling Data

Field	Date	Total Egg Masses Per Field
Dunn	7/23	0
	7/27	1
	7/30	8
	8/03	56
Fisher	7/22	0
	7/27	2
	7/29	3
Mawhirter	7/27	0
	7/30	1
	8/04	50
Chadd	7/26	0
	7/29	5
Christiansen I	7/25	0
	7/28	8
	8/03	58
Christiansen II	7/25	0
	7/28	2
	8/02	51
	8/04	83
	8/09	148

1984 Sampling Data

Field	Date	Total Egg Masses Per Field
Christiansen I	7/21	0
	7/24	7
Christiansen II	7/21	2
Dunn	7/20	0
	7/24	17
Spare I	7/23	0
	7/26	2
Spare II	7/20	3
	7/23	21
	7/26	83

Egg Mass Detrition

1983

No. Egg Masses	Egg Mass Age (days)
446	1
439	4
412	8
403	12
402	16

1984

No. Egg Masses	Egg Mass Age (days)
80	1
76	7
74	10
73	14
71	17

Oviposition

1983

Date	No. New Egg Masses
7/22	0
7/25	2
7/28	11
7/31	42
8/04	398
8/09	919
8/13	412
8/17	56

1984

Date	No. New Egg Masses
7/24	10
7/27	39
7/31	103
8/03	116
8/07	170
8/10	102
8/14	131
8/17	63

A MANAGEMENT MODEL FOR SECOND GENERATION SOUTHWESTERN CORN BORER IN KANSAS

by

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B.S., University of Rhode Island, 1981

AN ABSTRACT OF A THESIS

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ABSTRACT

Studies were conducted to determine the survivorship of eggs and small larvae of second generation southwestern corn borer (SWCB), Diatraea grandiosella (Dyar), as a correction factor for egg mass-based estimates of tunneling larvae. Approximately 14% of the total egg mass population survived in 1983 to infest the plants as third instars, and 13% survivorship was observed in 1984.

A sampling program was devised for estimating the second generation SWCB egg mass density. Five samples, consisting of 5 consecutive plants, were taken from each of 6 subplots in a 130 acre corn field, every four days. Egg mass data were used to calculate the potential number of third stage larvae per plant. Larval estimates for 1983 tended to decrease as the oviposition period progressed. As a result of sampling too early in the oviposition period, larval estimates for 1984 are extremely high.

Studies were conducted to estimate egg mass detrition as a possible correction factor for egg mass sampling. In 1983, 0.71% of egg masses had fallen from plants when oviposition was 50% complete. In 1984, 1.08% of egg masses fallen from plants when 50% oviposition was reached. Model recommendations remained unchanged as a result of correcting egg mass sample data for detrition.

A management model for second generation SWCB in Kansas field corn has been constructed that evaluates the need for insecticides and predicts treatment dates for economical suppression. The model has three major

components: second generation SWCB phenology and population dynamics, insect damage/grain loss, and cost/benefit analysis. The model projects the magnitude second generation larval infestations from an estimate of cumulative egg masses per plant.