Phenology of the European corn borer, *Ostrinia nubilalis* (Hubner) (Lepidoptera: Pyralidae) in Virginia

by

Joseph L. Despins

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APPROVED:

J. E. Roberts, Sr., Chairman

W. A. Allen

R. L. Pienkowski

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Chapter I

INTRODUCTION

The European corn borer, *Ostrinia nubilalis* (Hubner) (Lepidoptera: Pyralidae) is a serious pest of field corn and many vegetable crops. In 1975, Virginia corn growers realized an estimated loss in yield amounting to $3,610,878 from the European corn borer - armyworm - cutworm complex. Including the cost of control, a loss of $5,733,630 was experienced by corn growers in this state (USDA Coop. Pl. Pest Rept. 1976).

In Virginia, the European corn borer has 2 to 3 generations per year (Jones et al. 1939). First generation European corn borer is present from early May through late June; the second generation occurs from the last of June to the first week of August; and the third generation starts in early August and continues until environmental conditions induce diapause in the fifth instar larvae. The larvae and pupae of the first generation infest the stems of Irish potatoes and early planted corn. Successive generations develop in late planted corn, bell peppers, snap beans and other truck crops (Jones et al. 1939).

Many tactics have been investigated for control of the European corn borer, with the most successful being cultural and chemical in nature. Methods of cultural control have been explored by several researchers in the past (Caffrey and Worthley 1927, Worthley and Caffrey 1927, Ficht 1936). It has been determined that European corn borer populations could be satisfactorily reduced through sound agronomic practices. Such practices included low cutting and ensiling of the corn crop, and deep clean plowing of the residues. This latter practice was especially important as it removed the ground cover which protected those larvae which successfully burrowed to the soil surface. With the concepts of no tillage and minimum tillage cropping becoming a more accepted practice in Virginia, such sanitation practices have become passe in many areas.

Properly timed application of insecticides will reduce European corn borer populations. However, the key to satisfactory control is the timing of applications to coincide with field populations at the economic threshold. Extension personnel frequently recieve questions related to the seasonal occurrence of the European corn borer. Information leading to a control decision currently can be obtained through scouting reports. Scheduling of scouting activities is often based on records of corn borer adult emergence taken from black light trap equipment operated at appropriate locations. Black light trap studies at the Virginia

Truck and Ornamentals Research Station at Painter have indicated that peak moth emergence of the overwintering generation might be expected to occur on 10 May, the first generation on 1 July and the second generation on 10 August (Hofmaster et al. 1960). However, Hofmaster et al. (1960) report that much divergence in these dates has been observed due to seasonal variation, with peak emergence occurring within 7 days of these expected calendar dates.

The goal of the present research was to develop an accurate method to predict the seasonal activity of the European corn borer in Virginia. Objectives of the study were to:

1) record the seasonal flight periods of adult European corn borer and first generation oviposition in field corn;

2) investigate the relationship between European corn borer phenology and cumulative degree days, and evaluate a method of predicting cumulative percentages of overwintering and first generation moth flight;

3) evaluate the practicality of using flowering plant phenology as indicators of adult European corn borer seasonal occurrence.

Chapter II

LITERATURE REVIEW

DIAPAUSE IN THE EUROPEAN CORN BORER

Insect phenology deals with the timing of recurring biological events in relation to key environmental factors. Insects are physiologically and behaviorally adapted to their environment, and these adaptations serve to allow insects to survive unfavorable periods and to synchronize activity with favorable periods during the season (Tauber and Tauber 1976). Environmental cues such as critical daylength and temperature induce periods of diapause, in which the insects endure unfavorable seasonal periods.

Induction and termination of diapause in the European corn borer has been well studied. Diapause is facultative, and is induced by short day photoperiods of 12 hours of dark per 24 hour day (Beck 1963). A chilling period is not needed for termination of diapause. Under field conditions diapause is completed by early winter (Beck 1963). Spring pupation occurs in response to rising temperatures, moisture contact and intake of water (Babcock 1927, Mellanby 1958, Beck 1963, 1967).

The diapause inducing effect of photoperiod is temperature sensitive, and incidence of diapause in fifth instar larvae under short day conditions was reduced at high temperatures (Beck and Apple 1961). Beck and Apple (1961) observed that incidence of diapause in European corn borer populations from various geographical regions was positively correlated with the latitudes from which the populations were obtained. Following studies performed on populations from Minnesota, Iowa and Missouri, Sparks et al. (1966) concluded that diapause is governed by a multigenetic makeup that responds to photoperiod and temperature. Chiang et al. (1968) revealed differences in ecological responses of the above mentioned populations; the Missouri population was more responsive to photoperiod and temperature than the Minnesota population. Based on diapause response (ie. voltinism) Showers et al. (1975) concluded that 3 ecotypes exist in North America.

EFFECT OF TEMPERATURE ON EUROPEAN CORN BORER DEVELOPMENT

Physiological development is resumed once diapause has been terminated and environmental conditions are favorable. Insects are poikilotherms, and rate of growth during the post diapause period is primarily a function of temperature (Tauber and Tauber 1976). The effect of temperature on the development of the immature stages of the European corn borer was first studied by Caffrey and Worthley (1927). They determined the thresholds of developement as: 14.8°C for eggs, 9.8°C for larvae and 13.0°C for pupae. Matteson and Decker (1964) later observed European corn borer development under constant and variable temperature regimes. They found the normal range for borer development as: 18.3 - 26.7°C for eggs; 15.6 - 35.0°C for larvae and 15.6 - 29.4°C for pupae. Temperature thresholds for eggs, larvae and pupae were 14.1°C, 11.1°C and 12.5°C, respectively. Controlled variable temperatures had little effect on the durations of the corn borer immature stages when temperatures were within the normal range of development (Matteson and Decker 1964).

THE EFFECTS OF TEMPERATURE AND RAINFALL ON EUROPEAN CORN BORER BIOLOGY

Atmospheric temperature and the occurrence and abundance of rainfall have a great impact on European corn borer biology, as has been observed by many researchers (Barber 1925, Huber et al. 1928, Jones et al. 1939, Arbuthnot 1949, Everett et al. 1958, Barlow et al. 1963, Sparks et al. 1967, Frye 1971, 1972, and Wressell 1972). In general, conditions suitable for good corn growth favored infestations. Their conclusions were that cool, wet or hot, dry conditions during the critical periods during the season lowered populations. High temperatures accompanied by low soil moisture content increased the rolling of the corn leaves which tends to dislodge egg masses. Excessively high temperature and low humidity also increased larval mortality through reduced successful eclosion (Huber et al. 1928). Frequent precipitation during moth flight periods was beneficial to moth survival, and resulted in increased fecundity (Huber et al. 1928, Barlow and Mutchmor 1963, Schurr and Holdaway 1966, Kira et al. 1969). Stirrett (1938) observed that optimum temperatures for flight occurred between 18.0° and 21.1°C and indicated that a positive relationship existed between temperature and flight. Optimum temperature for oviposition in the laboratory was 29.4°C (Huber et al. 1928, Vance 1949).

RELATIONSHIP BETWEEN EUROPEAN CORN BORER MOTH FLIGHT AND OVIPOSITION

The number of egg masses on any given day was a function of the number of moths in flight (Stirrett 1938, Showers et al. 1974). They reported that the dates of flight and of egg laying do not coincide, but peak ovipositon lags behind peak moth flight by a varying number of days.

WITHIN-PLANT DISTRIBUTION OF EUROPEAN CORN BORER EGG MASSES

The relative position of egg masses on the plant has been well reported in the literature. Huber et al. (1928) observed the within-plant ovipositional pattern of European corn borer egg masses in field corn. They found (counting from the base of the corn plant) the sixth leaf received 17.9% of the total number of egg masses, the seventh received 16.9%, and 90% were deposited on the third through ninth leaves. Eighty six percent of the egg masses were laid on the undersurface of the leaf. Stirrett (1938) found egg masses to be deposited on the undersurface of leaves, on the upper surface of leaves and on the stalk (94.4%, 5.01% and 0.55% of the total number of egg masses, respectively) over a 10 year period. Windels and Chiang (1975) reported the distribution of second generation corn borer egg masses on field and sweet corn plants. They found the leaves immediately above and below the ear region were preferred for oviposition, with limited oviposition occurring on the ear structures. They suggested that checking the leaves in the ear region on several plants would provide a quick sampling technique without examining the entire plant.

WITHIN-FIELD EUROPEAN CORN BORER EGG MASS DISTRIBUTION

The within-field distribution pattern of first generation European corn borer egg masses was found to fit the Poisson distribution (Chiang and Hodson 1959).

LIGHT TRAPS AS MONITORING TOOLS FOR EUROPEAN CORN BORER MOTH EMERGENCE

The fluorescent black light trap has been a valuable aid for monitoring the time of appearance and seasonal abundance of European corn borer moths (Brindley and Dicke 1963, Frye 1972, Wressell 1972, Showers et al. 1974, McClanahan and Elliott 1976, McLeod 1981). It is a relative method of sampling insect populations, which has been shown to be influenced by actual species population size, the number of insects in a particular phase (ie. behavioral responses to the trap as influenced by age), levels of activity, differential responsiveness between sexes, atmospheric temperature, wind velocity and the phase of the moon (Broersma et al. 1976, Southwood 1978). Barlow (1963) and Barlow et al. (1963) reported that the number of European corn borer females captured in light traps during the spring flight indicated the size of the first generation. Wressell (1972), however, found that a large flight did not necessarily mean a high infestation but that a relationship existed between a small flight and a low infestation. Showers et al. (1974) observed that peak occurrence of mated, gravid European corn borer females coincided with peak capture of females at other stages of reproductive development, and that the peak flight period signalled that corn fields should be checked for egg masses and early instar larvae.

DEGREE DAY METHOD OF ESTIMATING INSECT SEASONALITY

The determination of the temperature thresholds is a requisite for calculation of heat requirements (degree days) for growth and development. The heat units required to complete development from the egg through adult emergence was 518 degree days, above a temperature threshold of 10°C (Apple 1952, Mattson and Decker 1964).

Calculation of degree days is a common method to predict the seasonal activity and population maturity of insects in the field. Apple (1952) first explored this relationship with the European corn borer. Using a temperature threshold of 10°C, a value used by many Midwestern sweet corn canners to schedule planting and harvesting operations, the first appearance of each life stage was accurately predicted. This method of estimating population maturity facilitated the scheduling of scouting and control operations in Wisconsin. Similar studies were conducted by Frye (1971) in North Dakota to predict European corn borer seasonality. Jarvis and Brindley (1965) followed the emergence of adult European corn borer and subsequent oviposition in Iowa over a 12 year period. Cumulative percentages of moth flight and oviposition were predicted using accumulated degree days. Effective timing of field scouting activities resulted from a similar study conducted in Ohio by Clement et al. (1981).

The relationship between heat unit accumulation and insect development has been investigated with many other insects. These include: The southwestern corn borer, *Diatraea grandiosella* (Dyar) (Lepidoptera: Pyralidae) (Whitworth and Poston 1979), black cutworm, *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae) (Luckmann et al. 1976), cabbage maggot, *Hylemya brassicae* (Weidemann) (Diptera: Anthomyiidae) (Eckenrode and Chapman 1972, Libby 1974), onion maggot, *Hylemya antiqua* (Meigen) (Diptera: Anthomyiidae) (Eckenrode et al. 1975), diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Yponomeutidae) (Butts and McEwen 1981), pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae) (Sevacherian et al. 1977, Toscano et al. 1979), and tufted apple budmoth, *Platynota idaeusalis* (Walker) (Lepidoptera: Tortricidae) (Hogmire et al. 1979). Physiological time relationships have been incorporated into models for management of western cherry fruit fly, *Rhagoletis indifferens* Curran (Diptera: Tephritidae) (AliNiazee 1976), and codling moth, *Laspeyresia pomonella* (L.) (Lepidoptera: Tortricidae) (Riedl 1976).

USE OF PLANT PHENOLOGY TO PREDICT INSECT SEASONALITY

Insect seasonality as a function of cumulative degree days has been a reliable predictive method, however, weather elements other than ambient air temperature also have an effect on insect seasonal occurence (Kapler 1967). Many researchers have studied the seasonal occurrence of insects in relation to the phenological growth characteristics of plants. Straub and Huth (1976) observed that the seasonal development of the European corn borer in New York was positively correlated with the selected phenological events of 10 plant species. Lathrop and Dirks (1944, 1945) predicted the emergence of the apple maggot, Rhagoletis pomonella (Walsh) in relation to petal fall in apple orchards. Tashiro and Gambrell (1963) predicted the development of the European chafer, Rhizotrogus majalis (Razoumowsky) (Coleoptera: Scarabaeidae) in relation to the flowering common plants in New York. Similarly, Kapler (1967) was able to predict spring emergence of the smaller European elm bark beetle, Scolytus multistriatus (Marsham) (Coleoptera: Scolytidae) through observations of flowering plant phenology in Iowa. Morris et al. (1965) published methods of surveys for insects based upon phenological growth characteristics (shoot elongation) in Balsam fir. Larval emergence and development of the Red pine sawfly, Neodiprion nanulus nanulus Schedl (Hymenoptera: Diprionidae) have been correlated with leaf and flower development of selected plants in Wisconsin (Kapler and Benjamin 1960). Wegner and Niemczyk

(1981) developed a prediction system for the life stages of the black turfgrass ataenius, *Ataenius spretulus* (Haldeman) (Coleoptera: Scarabaeidae) using flowering plant phenology. Hewitt (1980) developed grasshopper control recommendations based upon observations of the flowering periods of 28 forb species on the rangeland of Montana. As Kapler (1967) and Straub and Huth (1976) purport, the underlying hypothesis to these studies is that insect development is influenced by many of the environmental factors that affect the flowering of plants.

Chapter III

METHODS AND MATERIALS

MOTH SURVEILLANCE

Studies were conducted during 1980 and 1981 in cooperation with the dairy operations of N. A. Boone and D. E. Gaither in Bedford, County, Virginia. An Ellisco general purpose black light trap was used to monitor adult European corn borer abundance at the two sites. The lamp was a General Electric F15T8/BL, replaced at the beginning of each season. Another black light trap was operated at the Virginia Truck and Ornamentals Research Station, at Painter, Virginia, during the 1958 through 1980 seasons by Dr. R. N. Hofmaster. Flight data recorded at Blacksburg by Dr. W. A. Allen and at Warsaw, Virginia by Dr. R. McPherson were also available for analysis. The light traps were located in the immediate vicinity of planted corn fields. A dichlorvos-impregnated resin strip was placed in the collection cannister to kill the attracted insects. The traps were emptied, and European corn borer moths counted every 24 hours. Moth activity was expressed in terms of average number moths per week.

EGG MASS SAMPLING

Field History

In 1980, two fields were chosen for study at the Gaither and Boone dairies. Field 1 at the Gaither site was planted on 24 April with Pioneer 3368-A field corn, with a 36 inch row width and a seed population of 22,000/A. This 55 acre field was a no-till system, planted after corn, into a rye stubble cover crop. The rye cover crop had previously been killed with an application of paraquat at a rate of 0.28 kg ai/ha. Other herbicides applied with the paraquat were atrazine (1.12 kg ai/ha) and simazine (1.12 kg ai/ha). Furadan 10G (1.3 kg ai/ha) was applied as a soil insecticide at the time of planting. All fields in this study had the same row width, seed population and received the same herbicide-insecticide treatment during 1980 and 1981. Field 2 at the Gaither site, a 12 acre field, was in conventional tillage, planted after corn with Pioneer 3147 se ed on 9 May. On 24 April, field 1 at the Boone site was planted with DeKalb 72-B field corn. Boone field 1, an 11 acre field was in conventional tillage. Boone field 2 also was in conventional tillage; this field (47 acres) was planted on 30 April with Pioneer 3147 seed. In 1981, this latter field was planted on 29 April with Pioneer 3147 seed and was in conventional tillage. The 12 acre field at the Gaither site was planted on

24 April with Pioneer 3147A field corn and was a no-tillage system.

Egg mass sampling procedure

Sampling for first generation European corn borer egg masses was begun when adults were taken in the black light traps. Each field was sampled 2 to 3 times per week until the apparent end of the oviposition period had occurred. The corn plant was considered as the sampling unit, and 100 plants per field were selected at random on each survey date. Each field was entered at the most accessible point and the first plant was selected using a random numbers table. Every plant thereafter was selected by walking down the row and examining every 20th plant. Recorded data included the number of masses per leaf, and the total number of leaves per plant.

MEASUREMENT OF AMBIENT AIR TEMPERATURE AND DEGREE DAY CALCULATION

Daily fluctuations in air temperature were measured using a Cole-Parmer recording hygrothermograph (model no. 8368-00), housed in an instrument shelter at each site in Bedford County. Temperature data for Painter, Blacksburg and Warsaw were obtained from Climatological Data, published by the National Oceanic and Atmospheric Administration.

Temperature was checked against standard sling psychrometer readings on a weekly basis to verify the recording precision of the hygrothermograph units. The sine wave method (Baskerville and Emin 1969) for estimation of degree days from daily maximum and minimum temperatures was used in this study, with a lower threshold of 10°C.

Degree day accumulation was begun on 1 January of each year. Average weekly moth catches and egg mass sampling data were plotted as a function of cumulative degree days.

MOTH FLIGHT DATA ANALYSIS TECHNIQUE

In order to develop a prediction system, the cumulative percentage of light trap catch of adult European corn borer for the overwintering and first generation were plotted against degree days. The sigmoid relationship between these variables was made linear through transformation of the cumulative percentage of catch values to probits (probability units). Simple linear regression was performed on the transformed data, yielding the equation: $y = a + b(x)$, where y is the probit of cumulative percentage of catch and x is cumulative degree days (Jarvis and Brindley 1965, Riedl et al. 1976, McLeod 1981 and Clement et al. 1981).

PLANT PHENOLOGY OBSERVATIONS

Observations of the flowering of several species of trees, wild flowers and weeds were made twice weekly during the spring and early summer of 1980 and 1981. Potential indicator plants in the vicinity of buildings or in urban situations were not observed, as plant development often occurs earlier than in rural habitats (Leopold and Jones 1947). Observations were made on plants growing near the sites and field borders. Plant species which had easily visible flowering characteristics (eg. large blooms, vivid flower color) were selected for study. The beginning and end of plant bloom were related to the seasonal occurrence of the overwintering generation adult European corn borer.

Chapter IV

RESULTS AND DISCUSSION

ADULT EUROPEAN CORN BORER SEASONAL ABUNDANCE

The seasonal abundance of adult European corn borer in relation to calendar date showed considerable variation from year to year (Fig. 1) at the sites in Bedford County. Average peak adult emergence occurred on 28 May, 25 July and 27 August for the respective generations. Hofmaster et al. (1960) noted peak adult emergence could be expected on 1 May, 1 July and 10 August on the Eastern Shore of Virginia, and considerable divergence existed about the calendar dates. Seasonal variations as high as 21 days from the average date of occurrence existed for the overwintering generation, and maximum deviations of 16 days for the first and second generations (Fig. 2). The main feature of the phenological diagrams presented in Figs. 1 and 2 is that little reliance can be placed on the average calendar date to predict adult European corn borer seasonal abundance. These "phenograms" can also be used to determine the "earliness" or "lateness" of a season, albeit under an after-the-fact situation. With respect to the average dates, 1980 was a late year and 1981 could considered an early year for the overwintering generation corn borer in Bedford County. At Painter, 1959, 1973, 1974 and 1976 (in part) could be classified as early years, as peak adult emergence took place from 7 to 21 days before the average date of occurrence for the overwintering generation, and from between 4 and 16 days for the first generation. Late seasons would include the years 1958, 1965 and 1976 while some years might be classified in an intermediate category. The rate of insect development is largely affected by temperature, and much of the seasonal variation shown in Figs. 1 and 2 may be explained if the rate of degree day accumulation during the spring and summer is considered. There was an increased rate of degree day accumulation in January, February and April in 1981 over that which occurred in 1980 in Bedford County (Fig. 3). This phenomenon had an apparent influence on the rate of development of prepupal larvae. Similar trends may be seen at Painter (Fig. 4). Early seasons for peak overwintering and first generation emergence were observed after the effects of the warm months of January through April. Conversely, late years occurred with a relatively low degree day accumulation rate through this same time period.

The graph of adult European corn borer seasonal abundance as a function of cumulative degree days reveals 3 well defined peaks in Bedford Co. and Painter, Va. (Fig. 5). Overwintering generation moth activity occurred over a relatively short period of time, lasting ca. 317 ± 62 degree

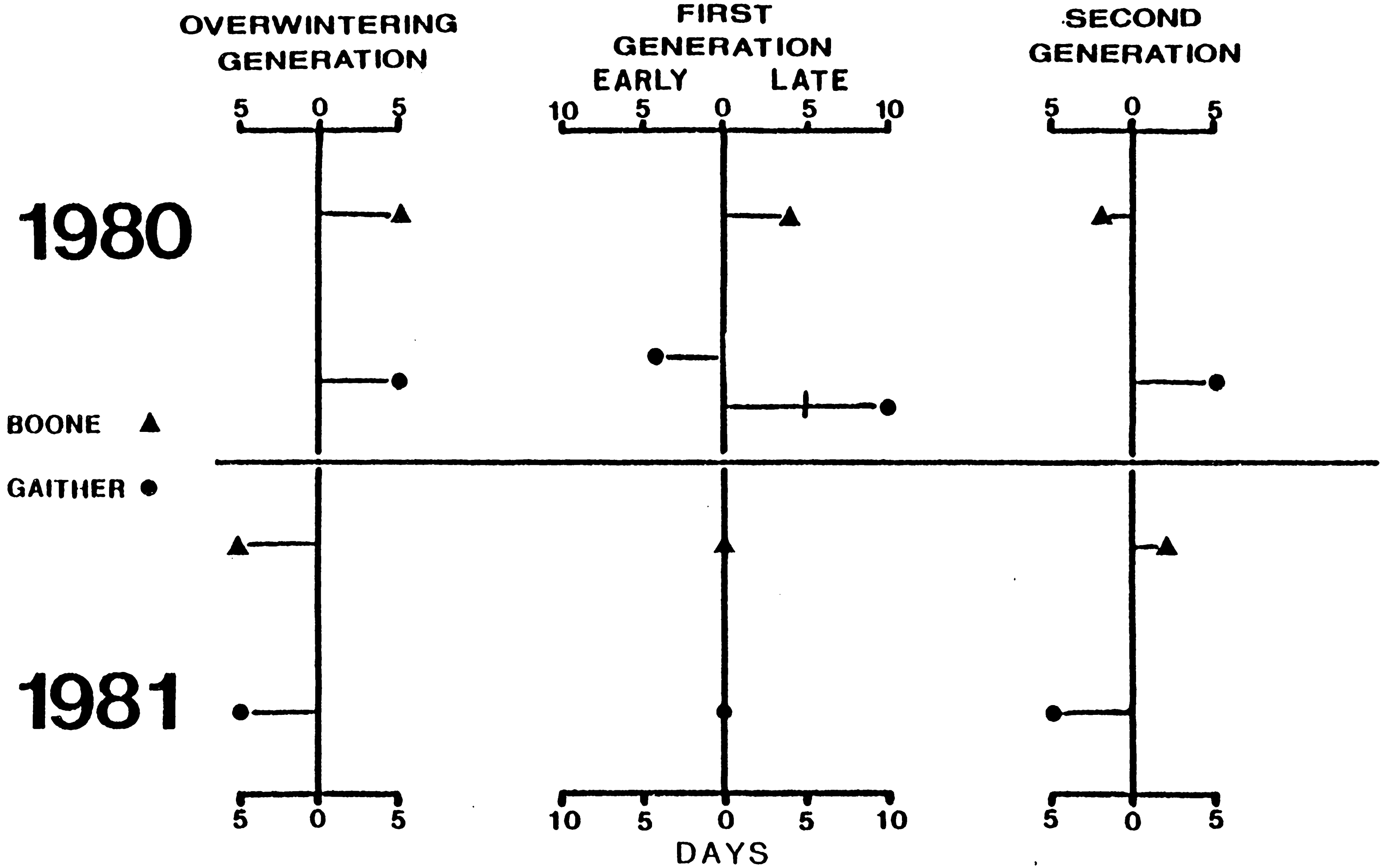

Fig. 1. Seasonal variation of peak adult European corn borer activity in relation to average calendar date, Bedford County, Virginia.

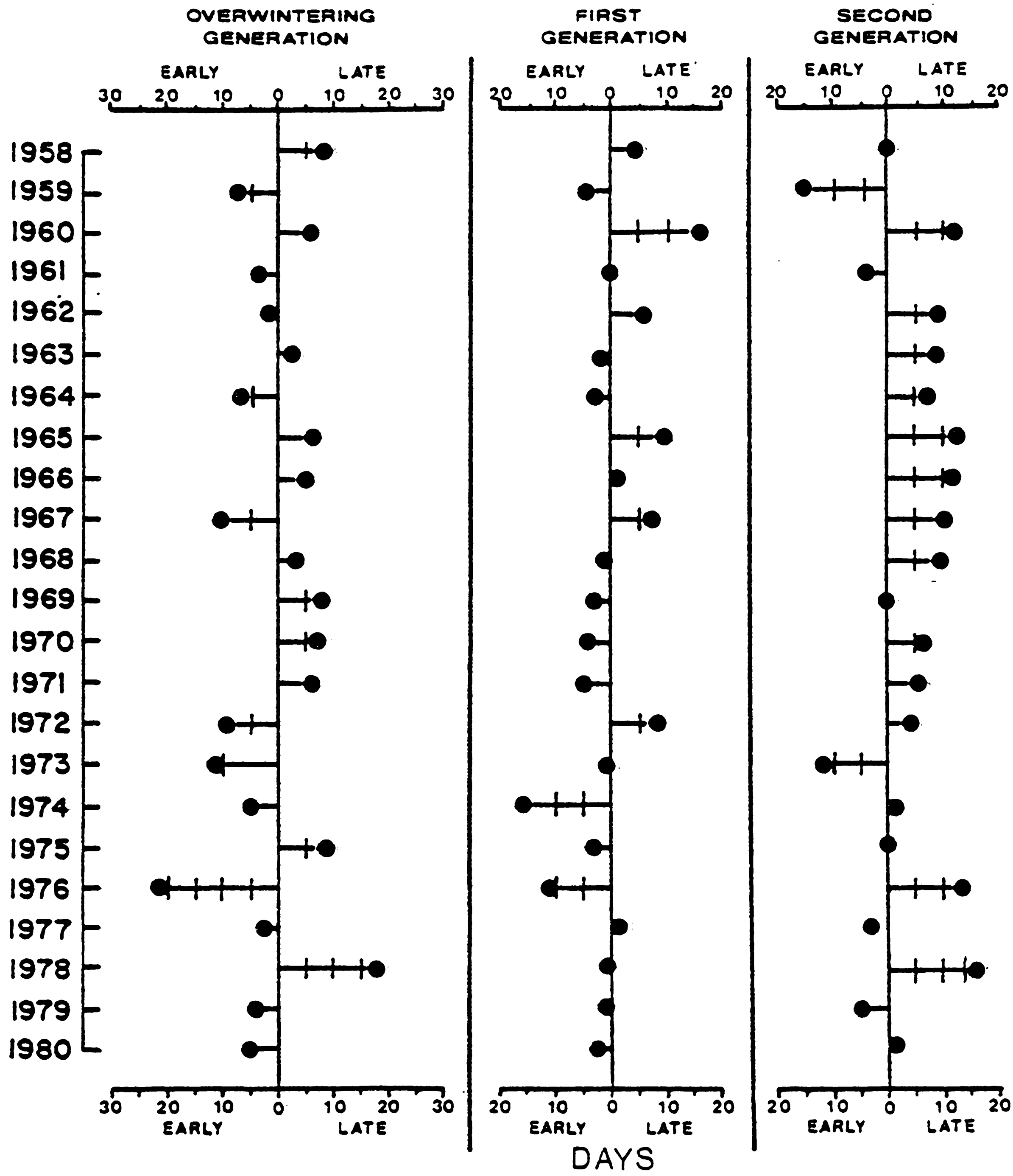

Fig. 2. Seasonal variation of peak adult European corn borer activity in relation to average calendar date, Painter, Virginia, 1958-1980.

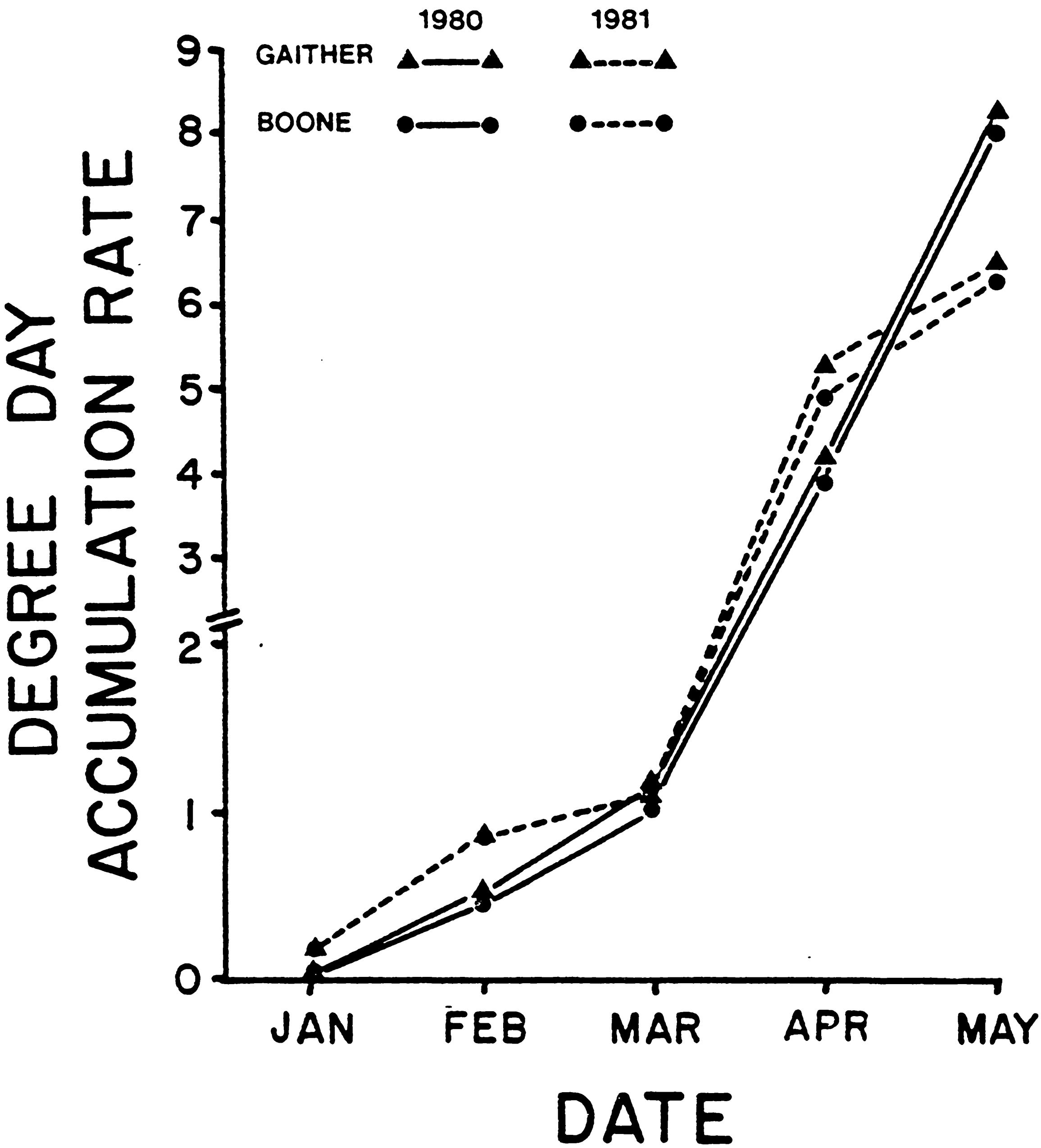

Fig. 3. Monthly rate of degree day accumulation, January through May, Bedford County, Virginia.

days ($\bar{X} \pm SD$). Adult activity periods of first and second generation showed some overlap and were greatly extended in comparison with that of the overwintering generation flight period.

The average number of degree days for peak emergence of overwintering and first generation borer moths was significantly less (P=0.05) at Painter that at the sites in Bedford County (Table 1); the average values at the peak of second generation moth activity were not significantly different from each other. The heat unit accumulation between peak flight periods was 606 ± 96 DD at the Bedford Co. sites, and 612 ± 111 DD at Painter, which is comparable to the 518 DD necessary to complete development from egg to adult under laboratory conditions (Matteson and Decker 1965). The observed disparity in early season borer occurrence is thought to be an expression of the different weather conditions between the sites. The Eastern Shore has a longer growing season (based on frost-free days) than Bedford Co. (Hoffman 1969) which can be attributed to the moderating effects of the Atlantic Ocean and Chesapeake Bay, which surround the DELMARVA Peninsula. It is conceivable that post-diapause development of fifth instar borer larvae could begin earlier in the season under these moderate conditions, resulting in the different emergence patterns between sites.

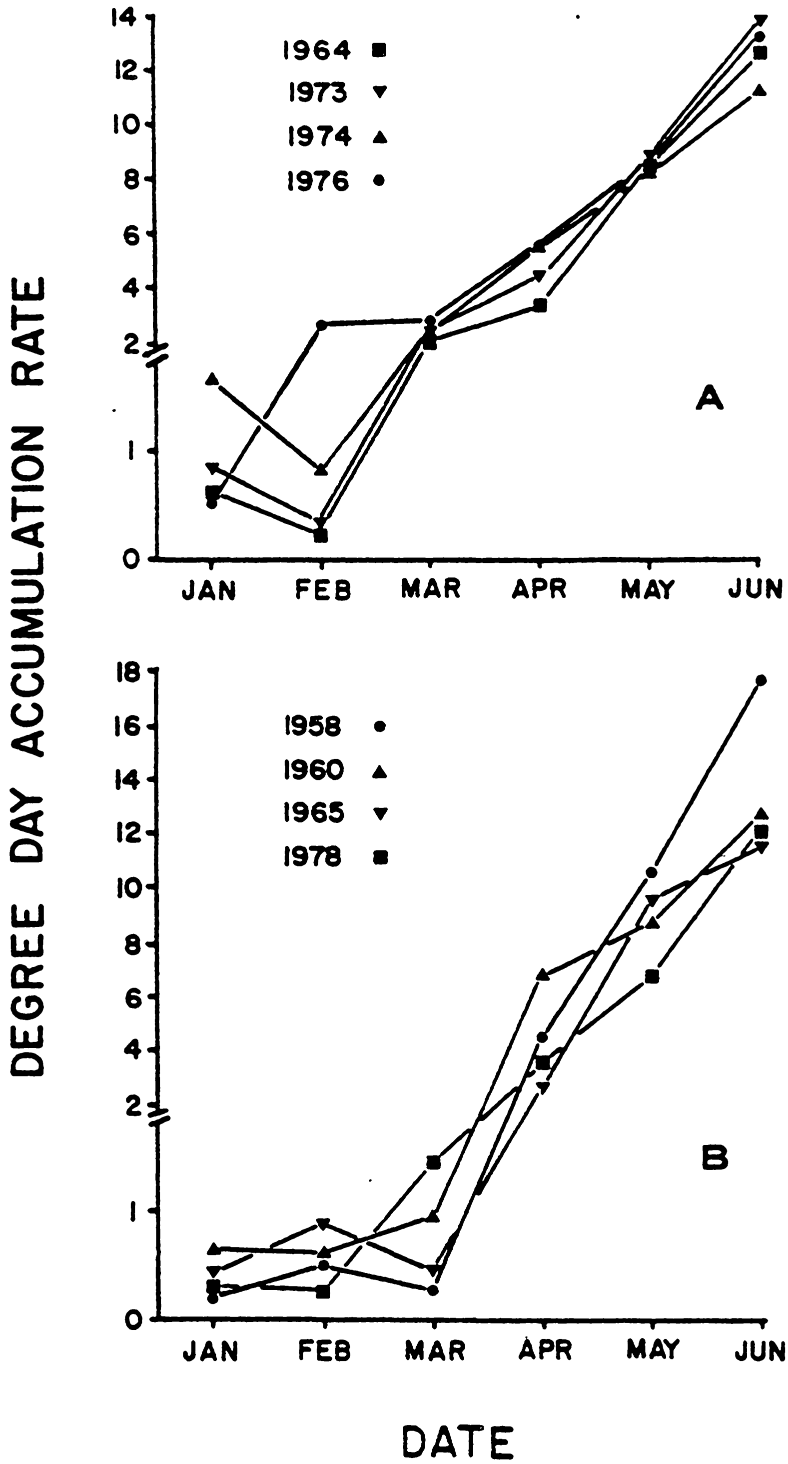

Fig. 4. Monthly rate of degree day accumulation, Painter, Va. A) Early arrival of overwintering generation European corn borer moths; B) late arrival of overwintering generation European corn borer moths.

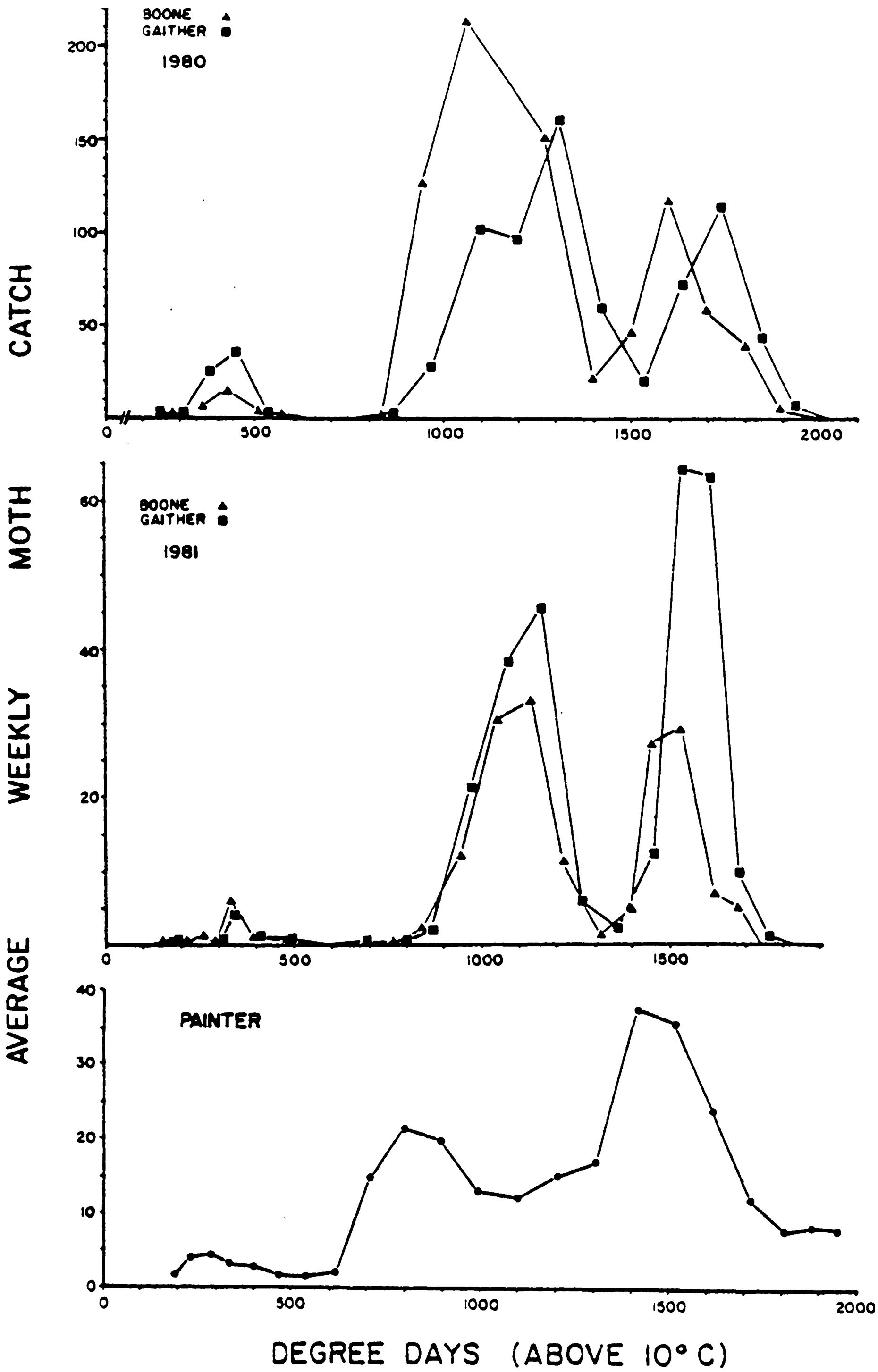

Fig. 5. Average weekly blacklight trap catches of adult European corn borer, plotted as a function of cumulative degree days, Bedford County (1980-1981) and Painter (an average figure, 1958-1980).

Table 1. Peak adult European corn borer activity in relation to cumulative degree days at various locations in Virginia.

	Degree days [1]			
Peak flight activity	Bedford County	Blacksburg	Warsaw	Painter
Overwintering Generation	384 (60) a [2]	NA	NA	287 (46) b
First Generation	1161 (104) a	1002 (28) b	1171 (117) a	865 (87) c
Second Generation	1595 (96) a	--	1577 (90) a	1507 (114) a

1/ from 1 January.

2/ $\bar{x}$ (SD); means between sites followed by the same letter are not significantly different at the 5% level of significance, Student's t-test.

PROBIT-DEGREE DAY REGRESSION ANALYSES

Based upon the cumulative percent of adult European corn borer emergence for the 2 year study in Bedford Co., and upon the extensive data base collected at the Virginia Truck and Ornamentals Research Station over the past 23 years, various cumulative percentages of moth flight may be estimated for the overwintering and first generation European corn borer (Figs. 6, 7, 8 and 9). Regression analyses were also conducted on the moth flight data taken from black light traps operated in Blacksburg, Va. (1971-1973, 1975) and at the Eastern Virginia Research Station, Warsaw, Va. (1971-1972, 1981) (Figs. 10 and 11). Analysis of only the first generation corn borer flight data could be conducted because of the incomplete trapping records at these sites. The emergence patterns were very similar between the Bedford Co. sites and at Warsaw, as the degree day estimates for 50% of flight resulted in a difference of 20 DD. First generation corn borer moths appeared earlier in the season in the Blacksburg, Va. area than at the Bedford Co. sites. In Bedford Co., 1800 DD usually accumulate by 1 September, while in Blacksburg, only 1200 DD have been accumulated by this date. Since ca. 520 DD are required for completion of the borer life cycle, it appears that only 2 generations can occur during the season in the Blacksburg area. While additional data are needed to explain this phenomenon, it would appear that immature development of the European corn borer proceeds at an increased rate in the Blacksburg area over that which occurs in the Bedford Co. region, which might account for the earlier appearance of the moths in the season at the former site. The probit value of 3.9, 5.0 and 6.0 (ie. 15%, 50% and 85% of moth flight, respectively) can be used as reference points to denote the onset, peak and approach of the end of each flight period. The estimate of 50% of the population flight corresponds well with the observed degree day values of peak corn borer activity presented in Table 1. This type of analysis did not lend itself well for the second generation because it was not possible to delineate the beginning of the emergence period due to population overlap.

The degree day method for estimating the seasonal abundance of adult European corn borer is more accurate than prediction based upon calendar days. For example, in 1976 at Painter, peak flight of adult overwintering generation corn borer was 21 days earlier than the average date of occurrence (Fig. 2). When peak adult seasonal occurrence was placed on a physiological-time scale, the difference was 40 degree days, or about the degree day accumulation over 3 days during that time of the year. Consequently, adult Euro-

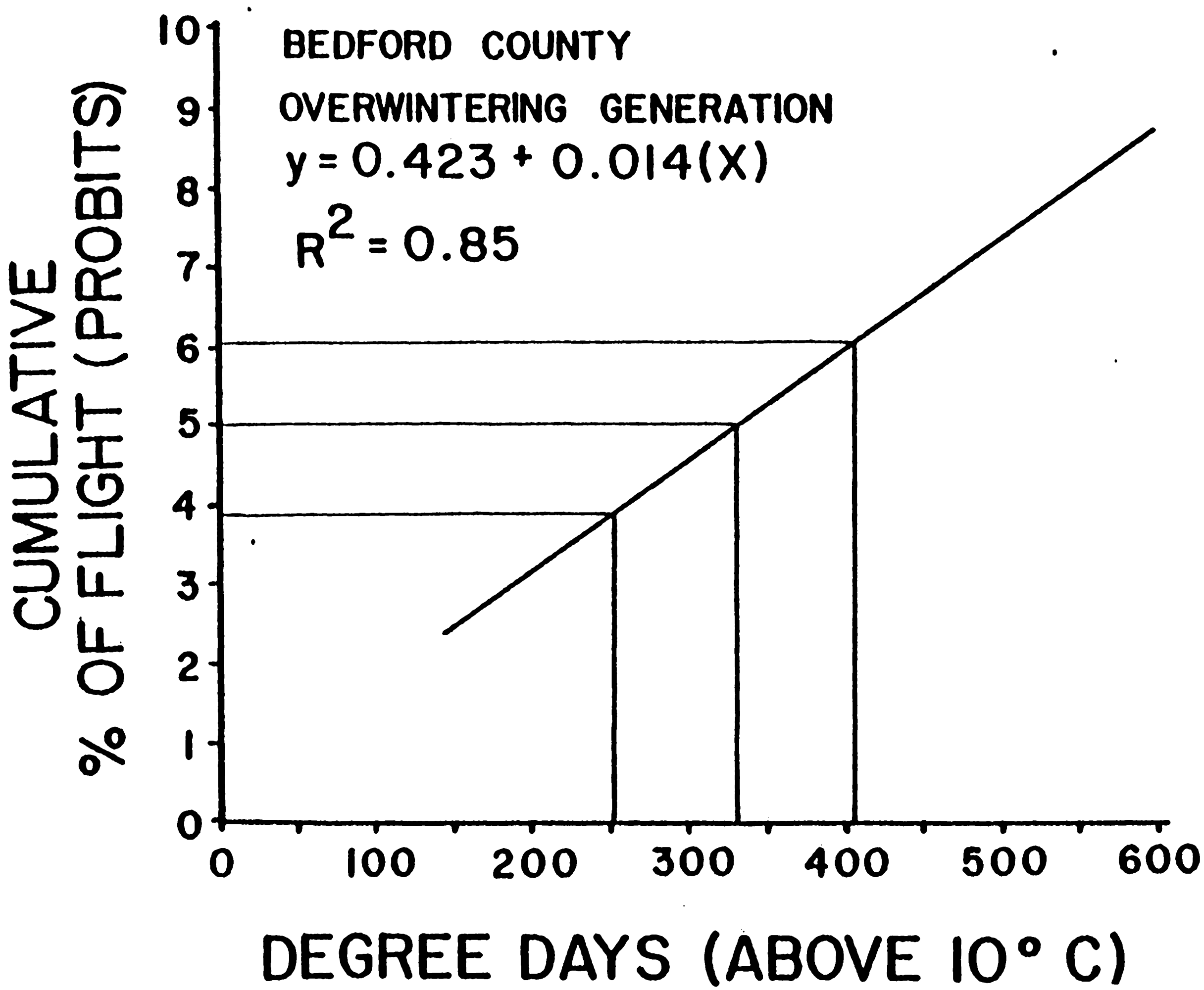

Fig. 6. Probit of cumulative percent of overwintering generation European corn borer flight in relation to cumulative degree days, Bedford County, Virginia, 1980-1981.

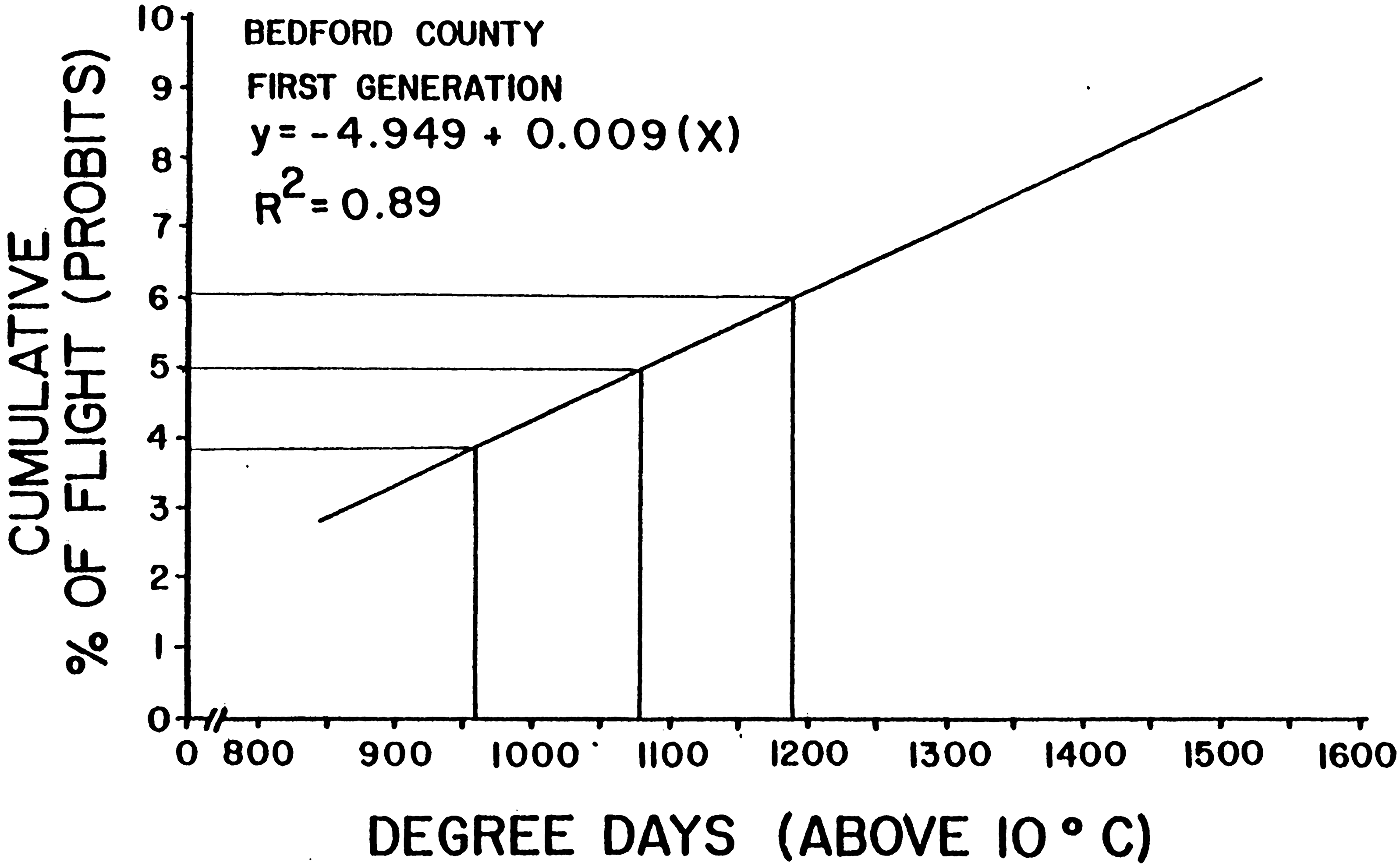

Fig. 7. Probit of cumulative percent of first generation adult European corn borer flight in relation to cumulative degree days, Bedford County, Virginia, 1980-1981.

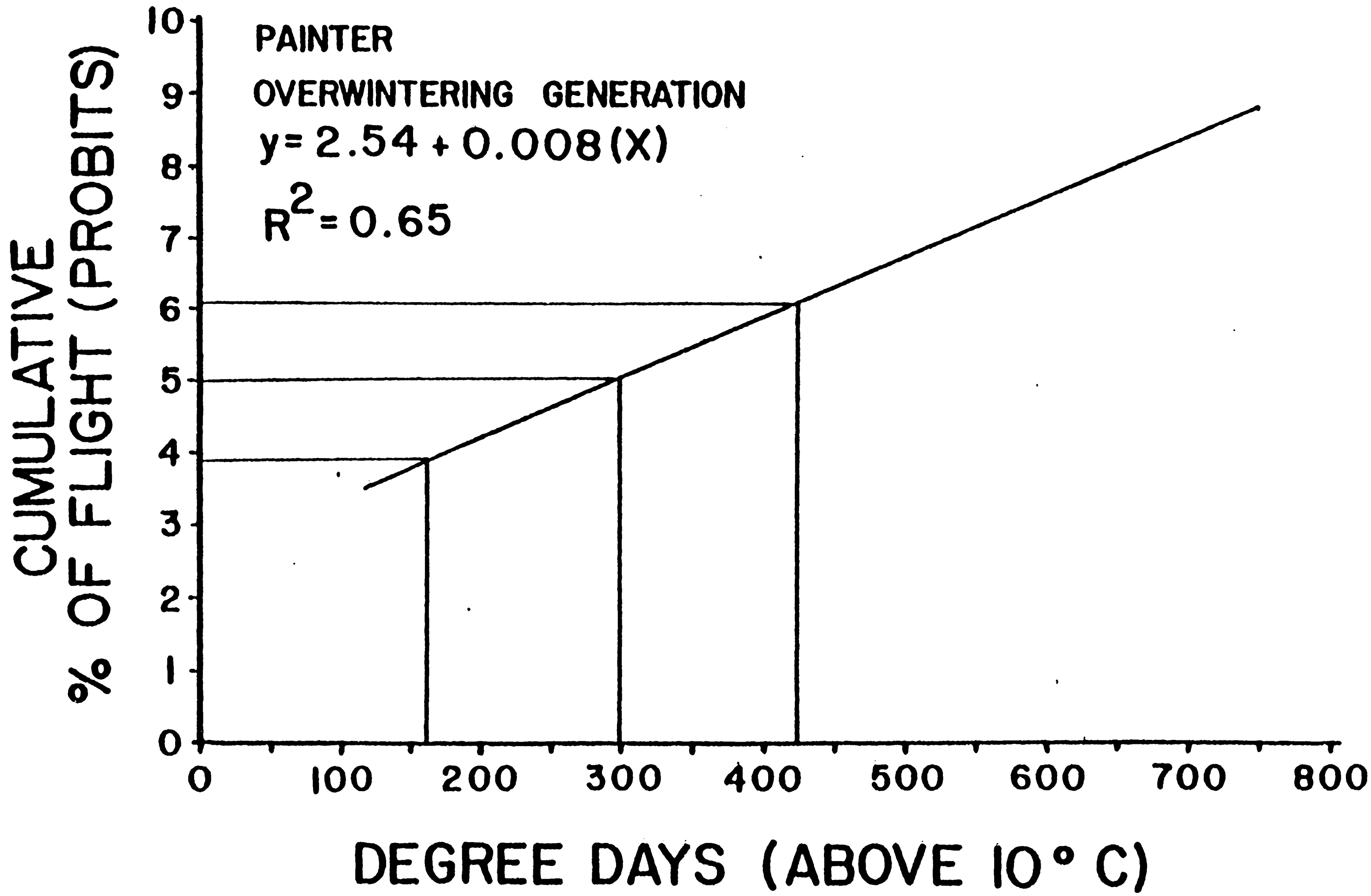

Fig. 8. Probit of cumulative percent of overwintering generation adult European corn borer flight in relation to cumulative degree days, Painter, Virginia, 1958-1980.

pean corn borer seasonal arrival and emergence can be estimated by monitoring the accumulation of degree days.

FIRST GENERATION EUROPEAN CORN BORER EGG MASS SEASONAL ABUNDANCE

A single peak in first generation corn borer oviposition was observed in each field in 1980 and 1981 (Fig. 12). The oviposition curves followed that of moth flight (cf. Figs. 5 and 12), and peaks of oviposition were well synchronized between fields each year. Average peak oviposition occurred at 428 $\pm$ 43 DD, lagging ca. 44 DD behind peak moth flight. Riedl et al. (1976) suggested that forecasting methods based entirely on climatic data without reference to the population lacked accuracy and that definable biological reference points could be used to show a relationship between phenological events. Using the date of first moth catch as an initiation point for degree day accumulation, peak first generation oviposition occurred at 197 $\pm$ 21 DD. By monitoring European corn borer moth emergence in the spring and the progression of the season in terms of degree day accumulation, a more accurate estimate can be made of when peak oviposition may occur.

First generation corn borer egg mass density was the highest in Boone Field 1 and Gaither Field 1 during 1980, with the former field receiving 48 egg masses per 100 plants

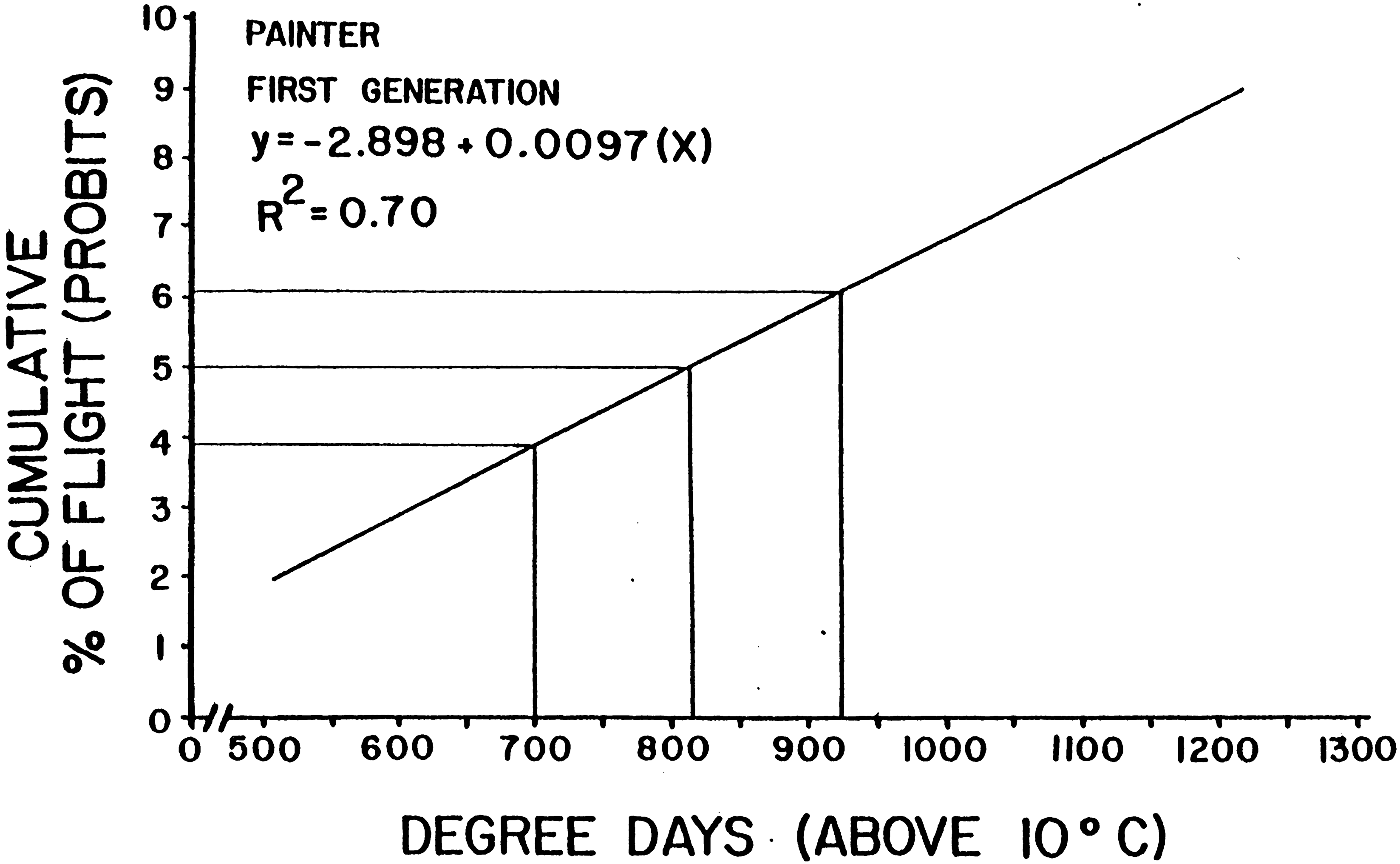

Fig. 9. Probit of cumulative percent of first generation adult European corn borer flight in relation to cumulative degree days, Painter, Virginia, 1958-1980.

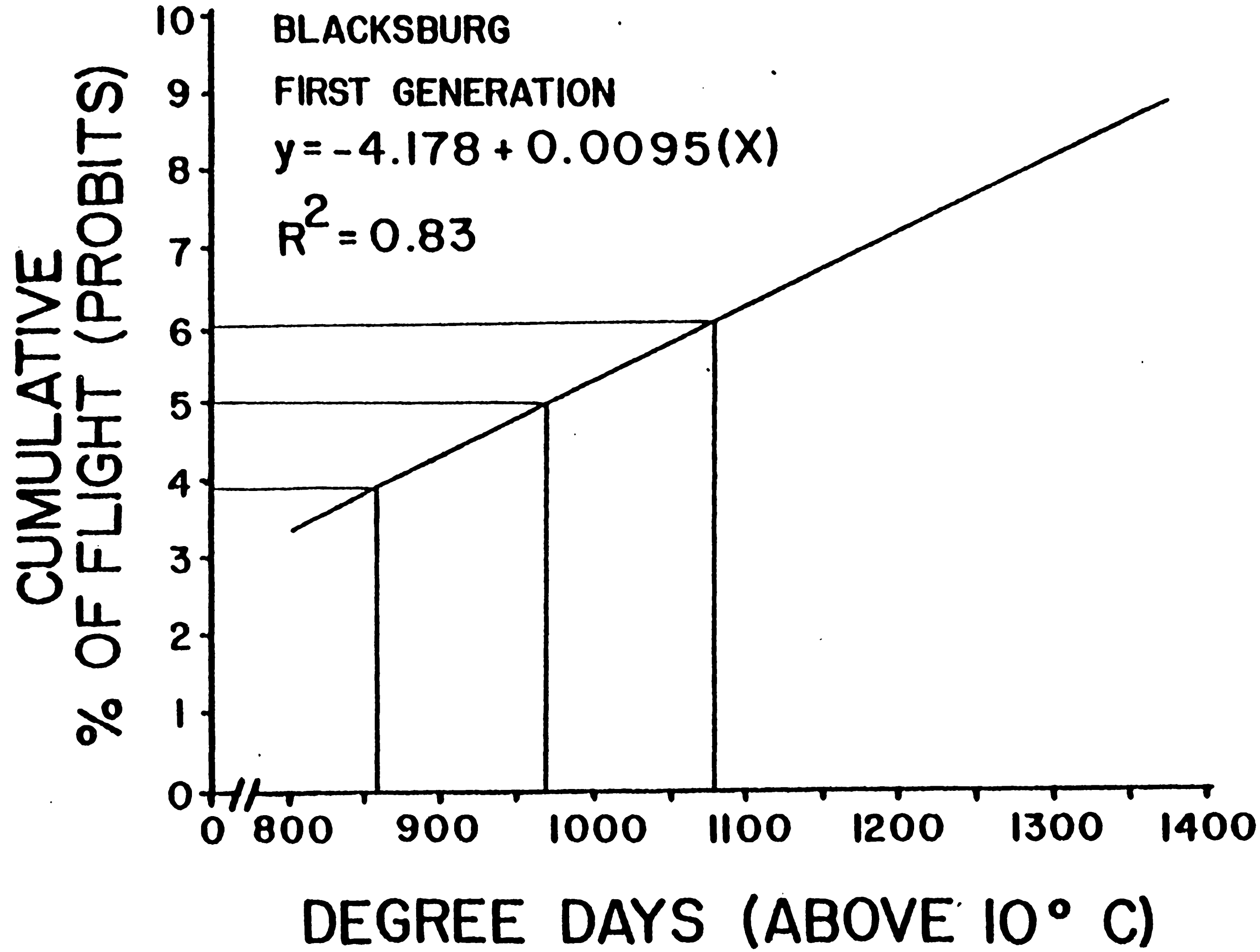

Fig. 10. Probit of cumulative percent of first generation adult European corn borer flight, Blacksburg, Virginia, 1971-1973, 1975.

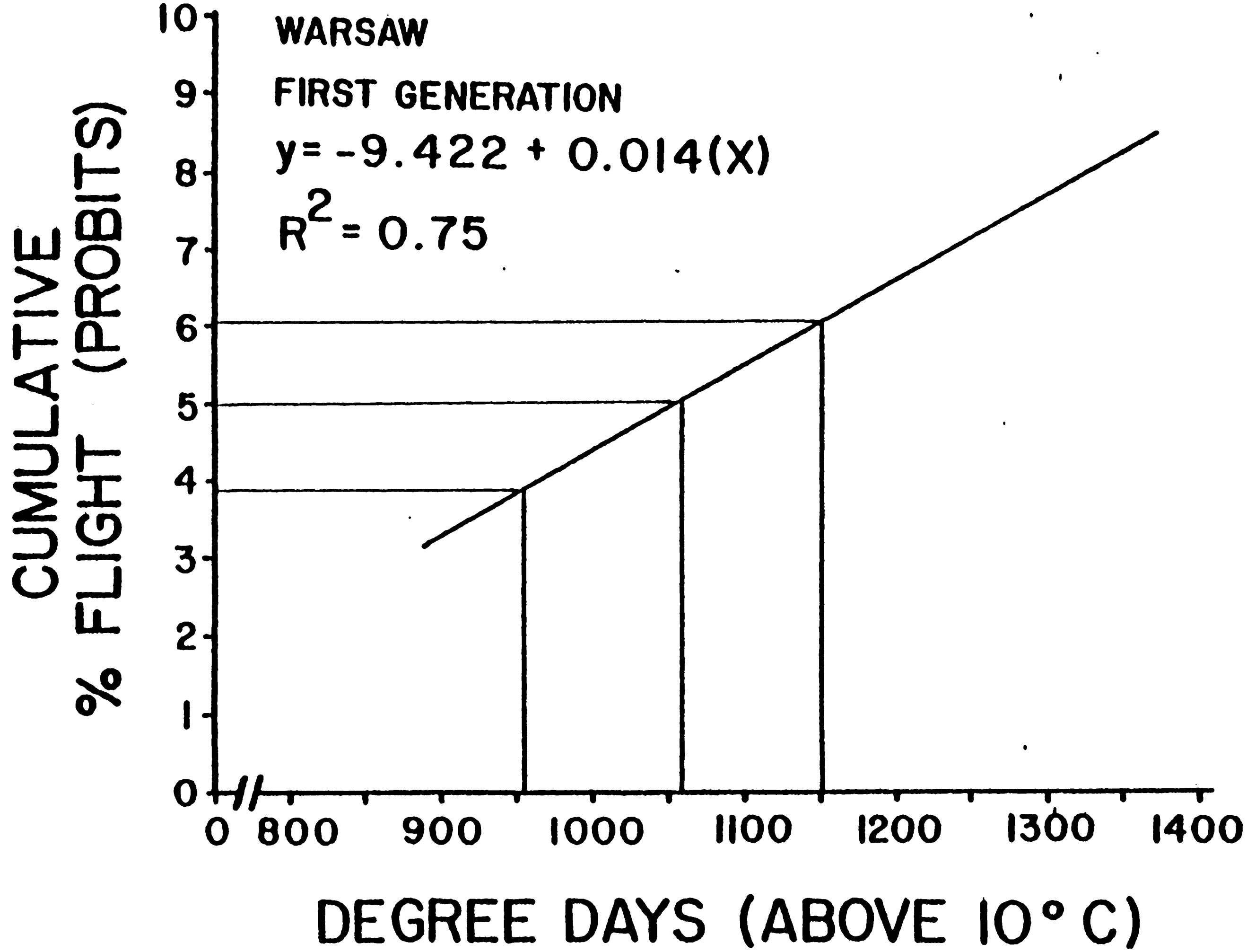

Fig. 11. Probit of cumulative percent of first generation adult European corn borer flight, Warsaw, Virginia, 1971-1972 1981.

and the latter field having a maximum density of 43 per 100 plants (Fig. 12). Relatively few egg masses were sampled in 1981. This was probably a result of the cool, wet weather encountered during the period of overwintering generation corn borer moth flight, (Fig. 13), which reduced nightly moth activity.

WITHIN-PLANT DISTRIBUTION OF FIRST GENERATION EUROPEAN CORN BORER EGG MASSES

The vertical distribution of first generation borer egg masses was skewed towards the lower regions of the plant (Fig. 14). Of the 368 egg masses sampled, 92% were found on leaves 1 through 5. Egg masses were consistently found on the lower leaves, even when 10 or more leaves were available to females for oviposition later in the season (Figs. 15, 16, 17) Nearly all of the egg masses (98.6%) were found on the leaf undersurface and the remaining 1.4% were located on the stalk. Knowledge of the within-plant distribution of corn borer egg masses is important when developing sampling schemes for this insect. When infestations of first generation European corn borer occur, the corn crop usually is in the early to mid whorl stage, having between 4 and 10 leaves on a plant. Much sampling time could be saved if examination for egg masses were confined to the undersurfaces of the leaves found in the lower regions of the plant.

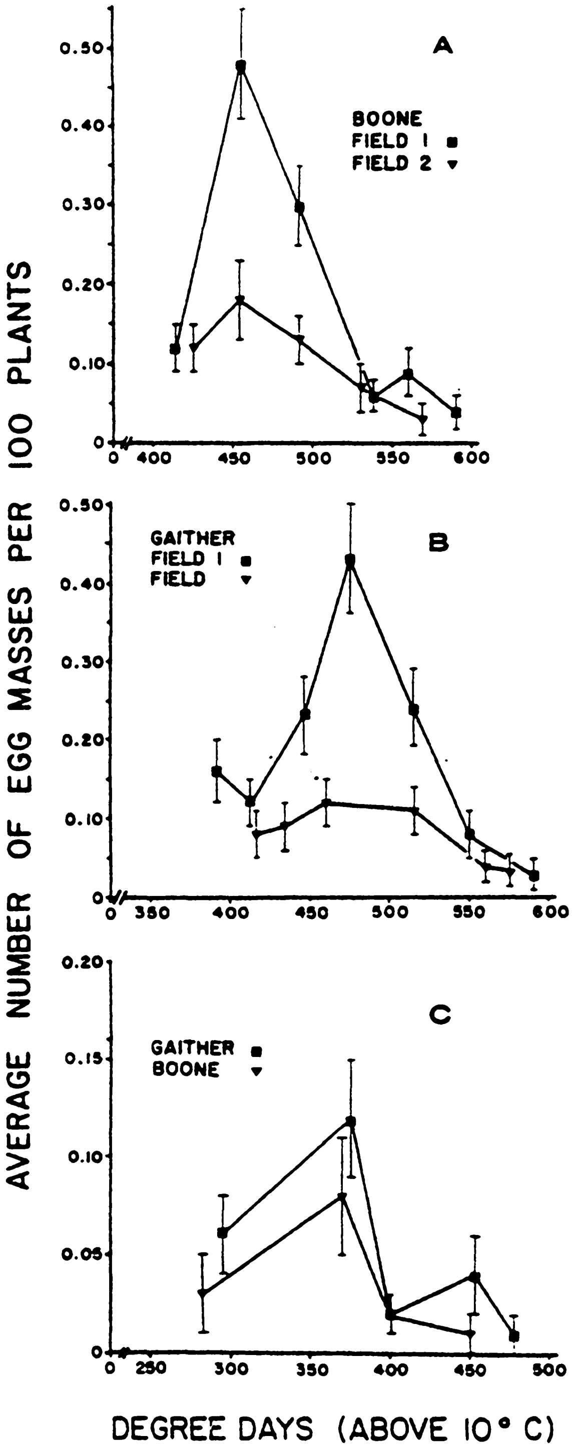

Fig. 12. Abundance of first generation European corn borer egg masses in relation to cumulative degree days, Bedford County; A,B) 1980; C) 1981.

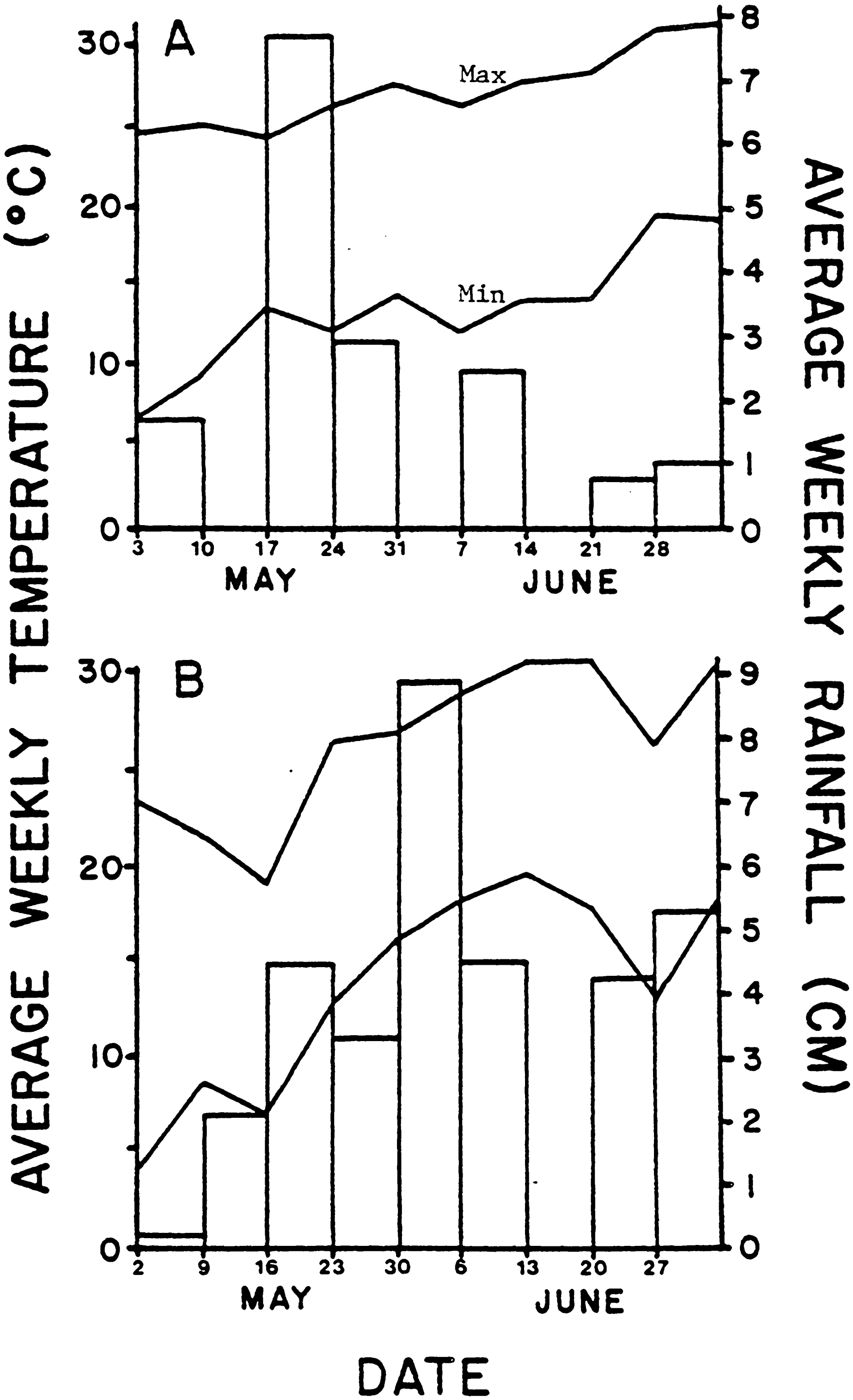

Fig. 13. Average weekly rainfall and temperature during overwintering generation adult European corn borer flight period; A) 1980, flight occurred between 11 May and 15 June; B) 1981, flight occurred between 25 April and 6 June.

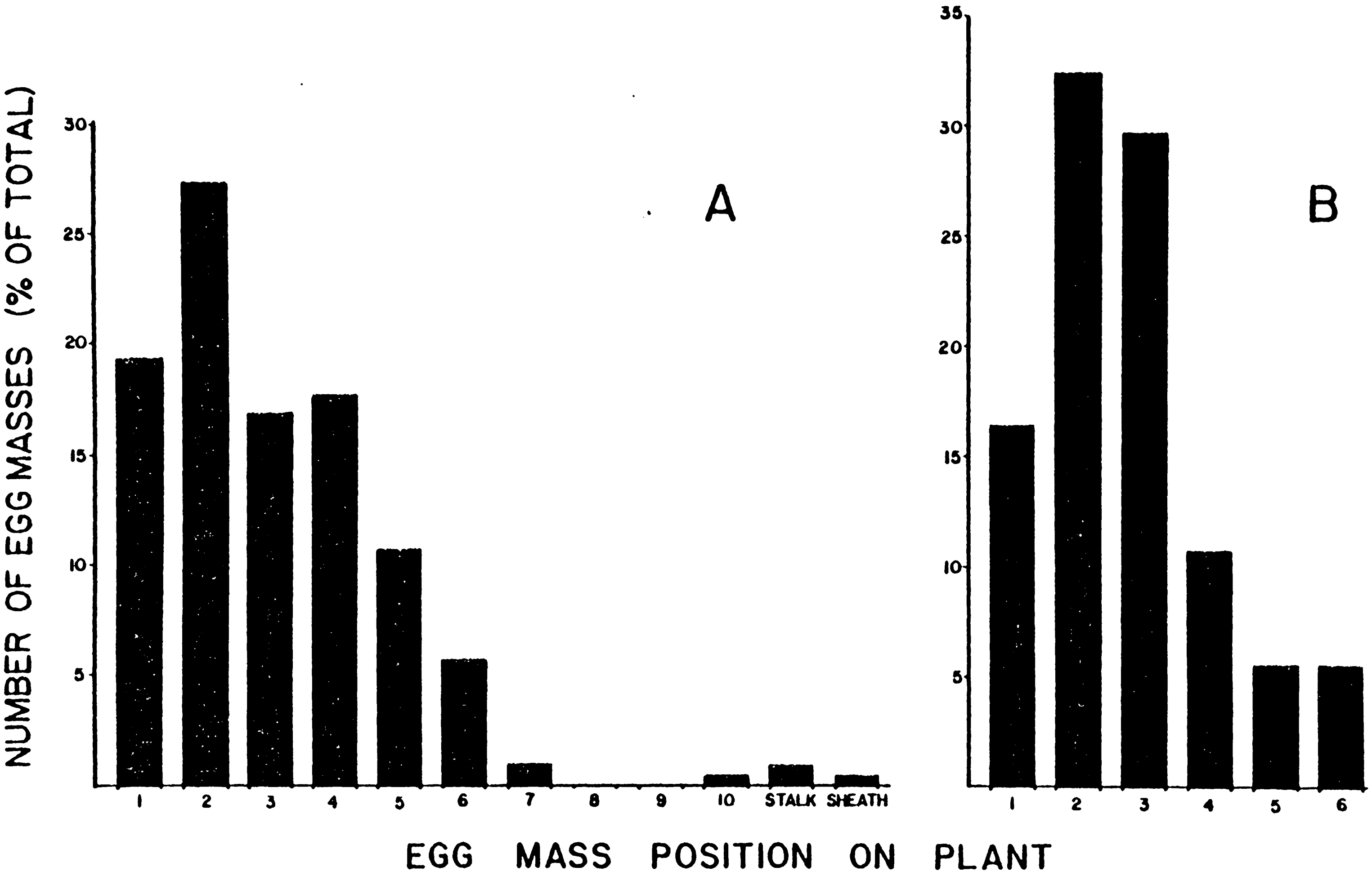

Fig. 14. Within-plant distribution of first generation European corn borer egg masses; A) 1980; B) 1981.

WITHIN-FIELD DISTRIBUTION OF FIRST GENERATION EUROPEAN CORN BORER EGG MASSES

The average number of egg masses per plant and the variance were computed for each field, and the variance:mean relationship was analyzed by calculating the parameters a and b of Taylor's Power Law. Data from the 1981 season were pooled for analysis due to low egg mass densities. Finally, all data were combined to show the overall pattern of egg mass dispersion. The parameters a and b were estimated through simple linear regression of log s^2 on log $\bar{x}$ (Taylor 1961). In all cases the parameter b was close to 1 (Fig. 18), which indicates a near random, or Poisson spatial distribution (where the variance:mean ratio equals unity). The spatial distribution pattern did not change with increased egg mass density. However, deviations from this relationship occurred when egg mass densities were relatively high. These observations were not significantly different from randomness when tested against the X^2 distribution (Index of dispersion, P=0.05) (Southwood 1978). Chiang and Hodson (1959) observed a similar trend towards a contagious distribution at higher densities, which was attributed to differential oviposition on plants of an advanced stage of growth within a field.

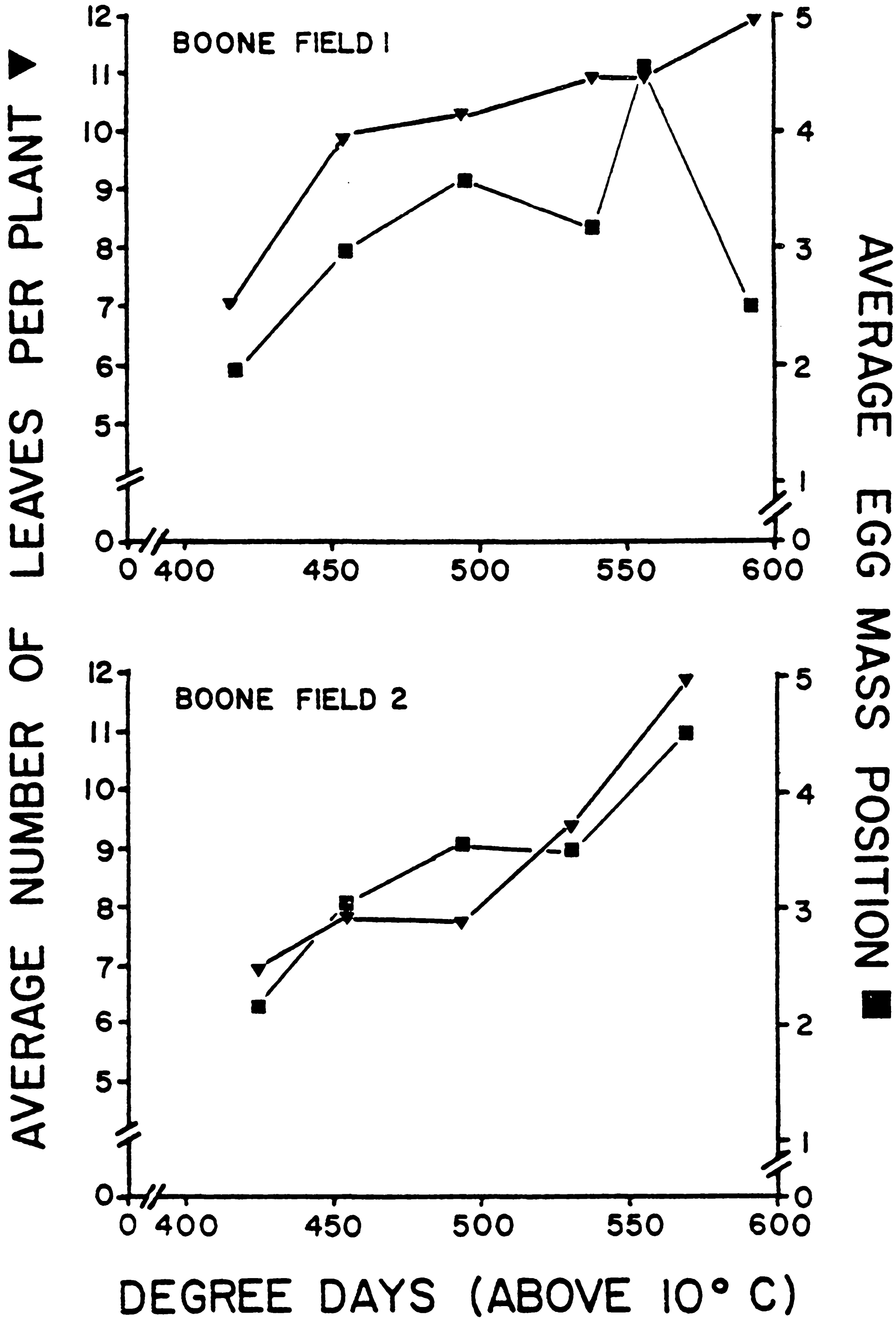

Fig. 15. Relationship between crop development and average first generation European corn borer egg mass position, Boone sites, Bedford County, 1980.

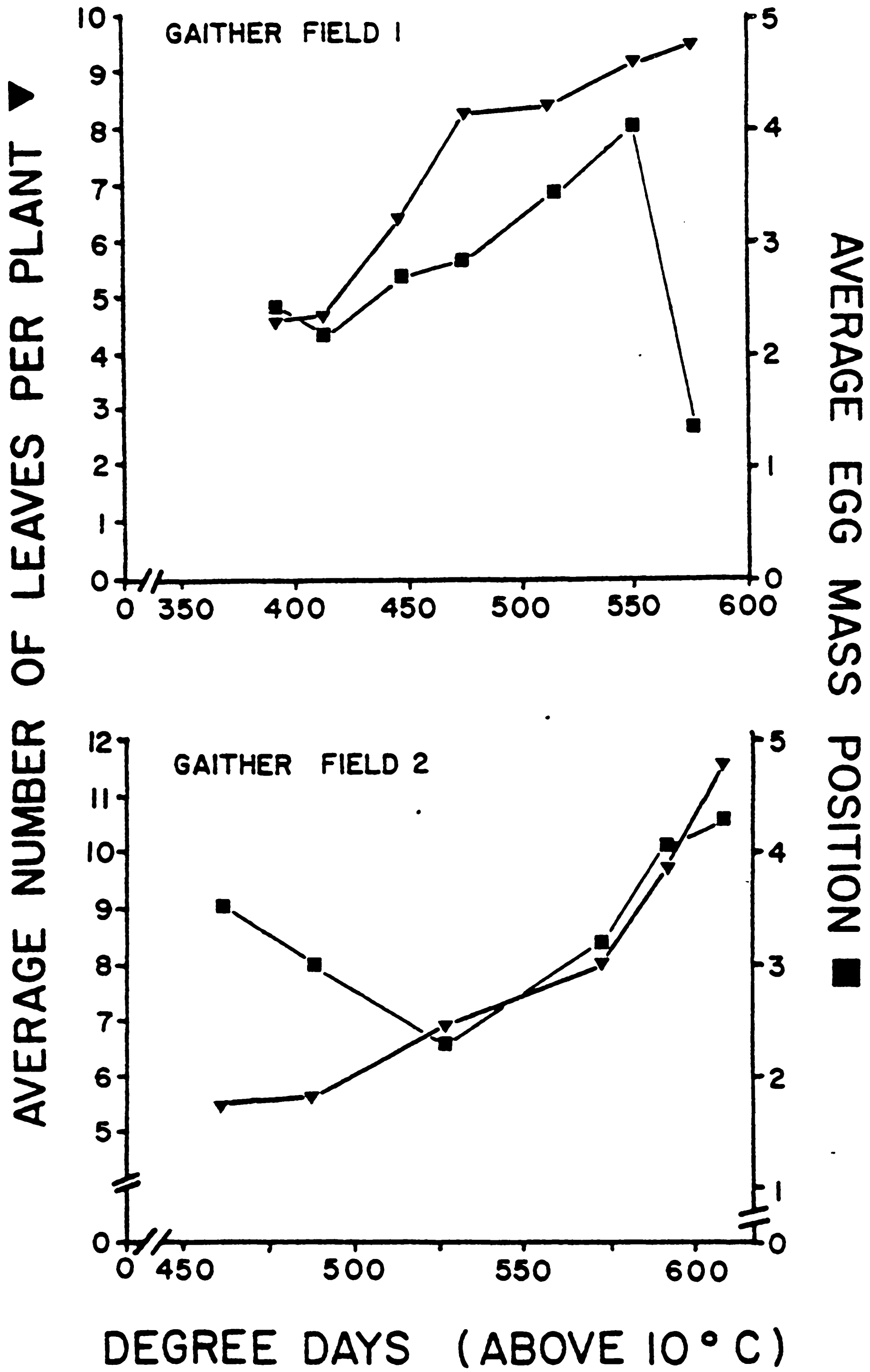

Fig. 16. Relationship between crop development and average first generation European corn borer egg mass position, Gaither sites, 1980.

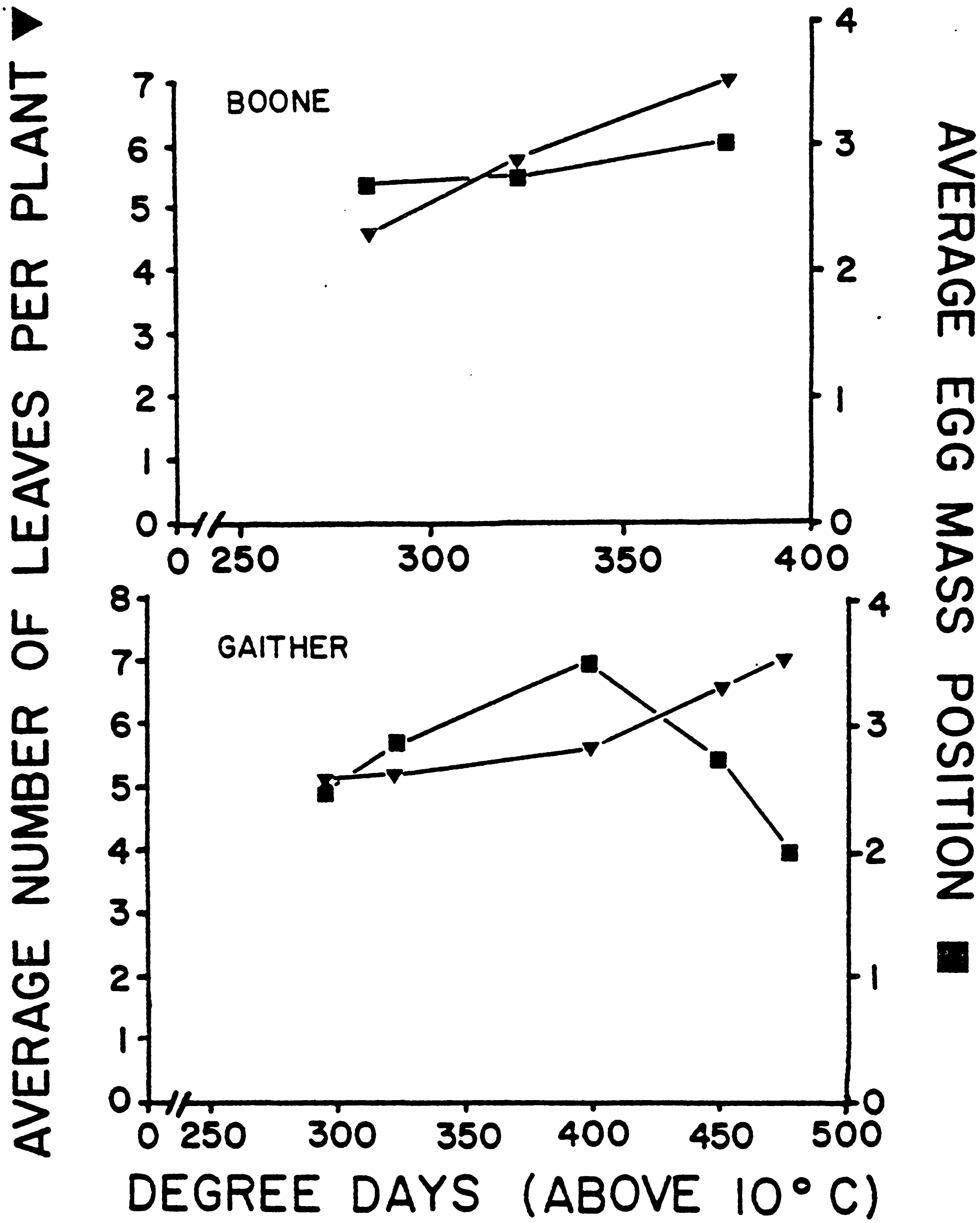

Fig. 17. Relationship between crop development and average first generation European corn borer egg mass position, Bedford County, 1981.

ESTIMATION OF OPTIMUM SAMPLE SIZE FOR FIRST GENERATION EUROPEAN CORN BORER EGG MASSES

Karandinos (1976) discussed the estimation of optimum sample size based in terms of 3 definitions of reliability for 3 parent distributions. In this study, the coefficient of variability of Karandinos (1976), or the measure of relative variability (standard error/mean), as the definition of the estimate's reliability for the Poisson parent distribution. The formula used was: $n = 1/[(\bar{x})(C^2)]$, were n is the optimum sample size, $\bar{x}$ is the sample mean and C is a predetermined standard error expressed as a decimal of the mean. For extensive sampling programs (eg. for damage assessment and control studies), a relative variability estimate of 25%, which is an estimate of population density with a standard error of 25% of the mean, is an acceptable level of precision. A higher relative variability estimate of 10% is a frequently used precision level for intensive sampling programs (eg. for life table studies on natural populations) (Southwood 1981). Optimum sample size for a relative variability estimate of 10% and 25% was inversely proportional to egg mass density (Fig. 19). As can be seen, at the lower level of precision, a sample size of 100 plants per field would provide an estimate of the population mean with a relative variability of 25%, if egg mass densities of ca. 0.15/plant were present in a field. Fewer plant samples could likely be taken at greater egg mass densities with the same degree of sampling error. This would save a considerable amount of time per field, as it required ca. 3 to 4 hours to examine the leaves and stalks of 100 plants. As with any sampling program, a decision must be made about the cost of sampling, in terms of time available and the amount of monetary resources available for the operation. A decision of sampling relatively fewer plants per field would mean that more fields could be assessed for infestation at the critical time of peak first generation European corn borer oviposition.

PLANT PHENOLOGY STUDY

With the progression of the spring season, a succession of plants came into bloom in Bedford County. Moreover, distinct groupings of plant species produced flowers at approximately the same time in each season. The plant species and respective phenological event (or phenophase), and points of first occurrence are plotted in Fig. 20 in relation to phenophases of a segments of European corn borer biology (note that the lines between two points of a phenophase should not be interpreted as periods of duration, rather they are to aid in the illustration of seasonal variation between years). The plant phenophase "first bloom" was selected

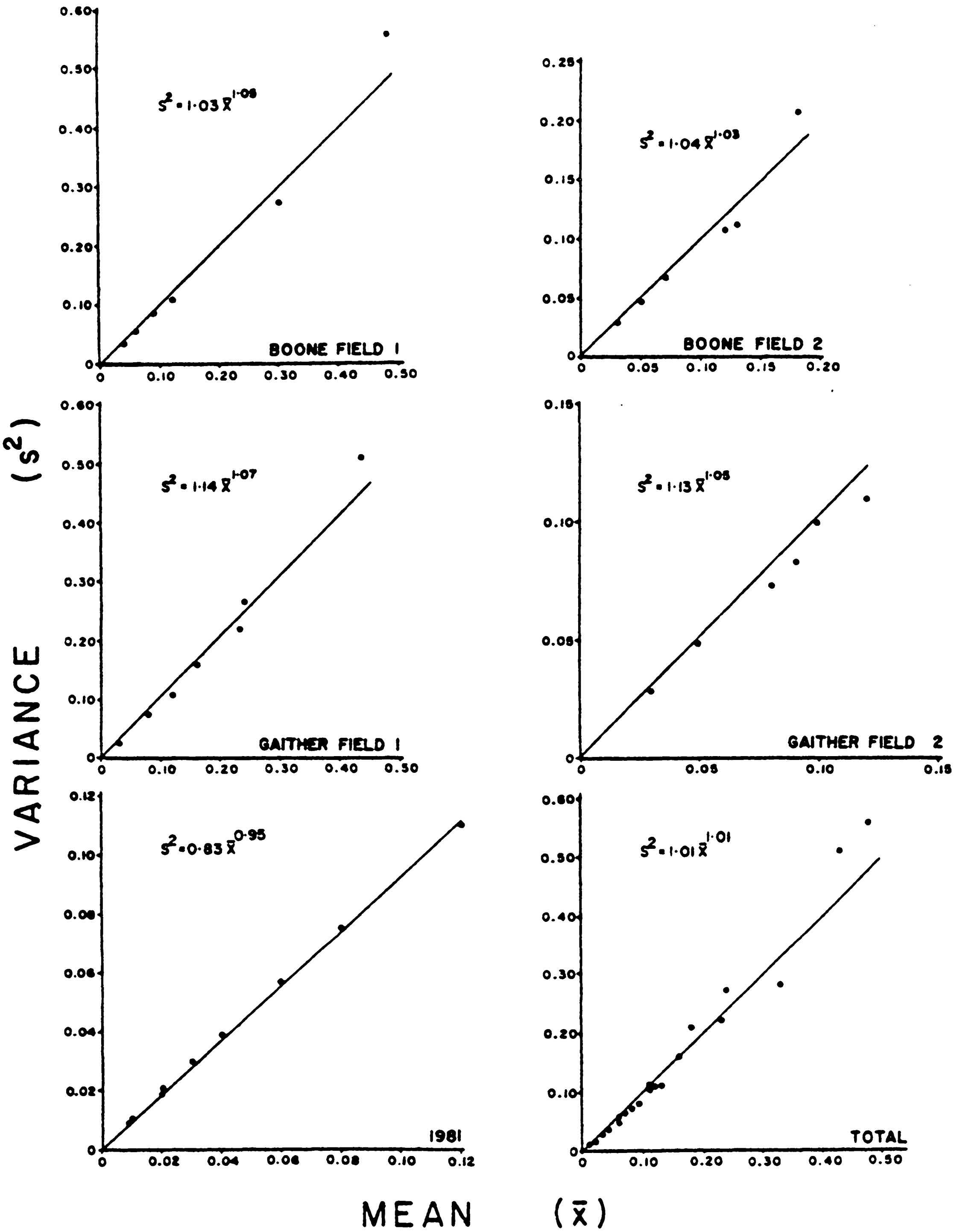

Fig. 18. Relationship between the sample mean and variance for each field and combined total, 1980 and 1981 first generation European corn borer egg mass sampling study, Bedford County, Va.

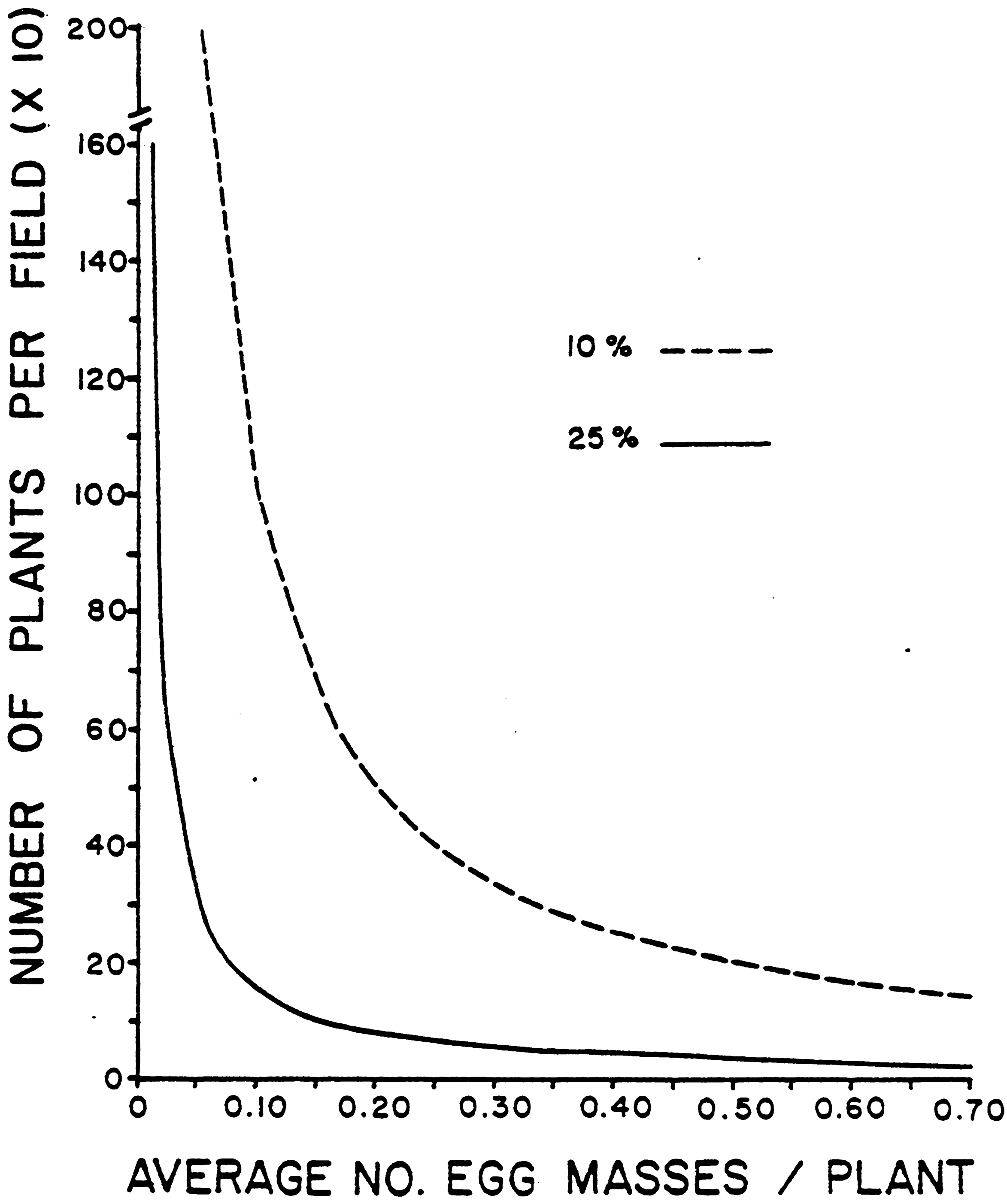

Fig. 19. Relationship between first generation European corn borer egg mass density and numbers of samples required for 2 levels of sampling precision in field corn.

because the flowers of the observed plants were strikingly noticeable. This characteristic is requisite for phenological studies, as an observable phenophase should be <u>distinct</u>, in the sense that 2 observers looking for it will recognize and date it alike (Leopold and Jones 1947). The approach and onset of the overwintering generation adult corn borer flight was indicated by the first bloom phenophase of the group of plant species in the no. 1 series of Fig. 20. The no. 2 series of plant species produced respective phenophases which occurred near the peak overwintering generation adult flight and peak oviposition. The adult borer flight period was on the decline with the occurrence of the phenophases of the plant species in the no. 3 series, Fig. 20. The plant species observed in this study could be easily identified by any Extension agent or grower. These plants are commonly found growing along fencerows, roadsides, and field borders (Table 2) and the blooming periods agree with those reported by Justice and Bell (1979).

Development of plants and insects is regulated by the environment. Flowering is thought to be controlled by temperature in most tree species (Flint 1974), while in other plant species, interactions of photoperiod and temperature serve to mediate in the flowering process (Zeevart 1962). Tashiro and Gambrell (1963) observed a consistent positive

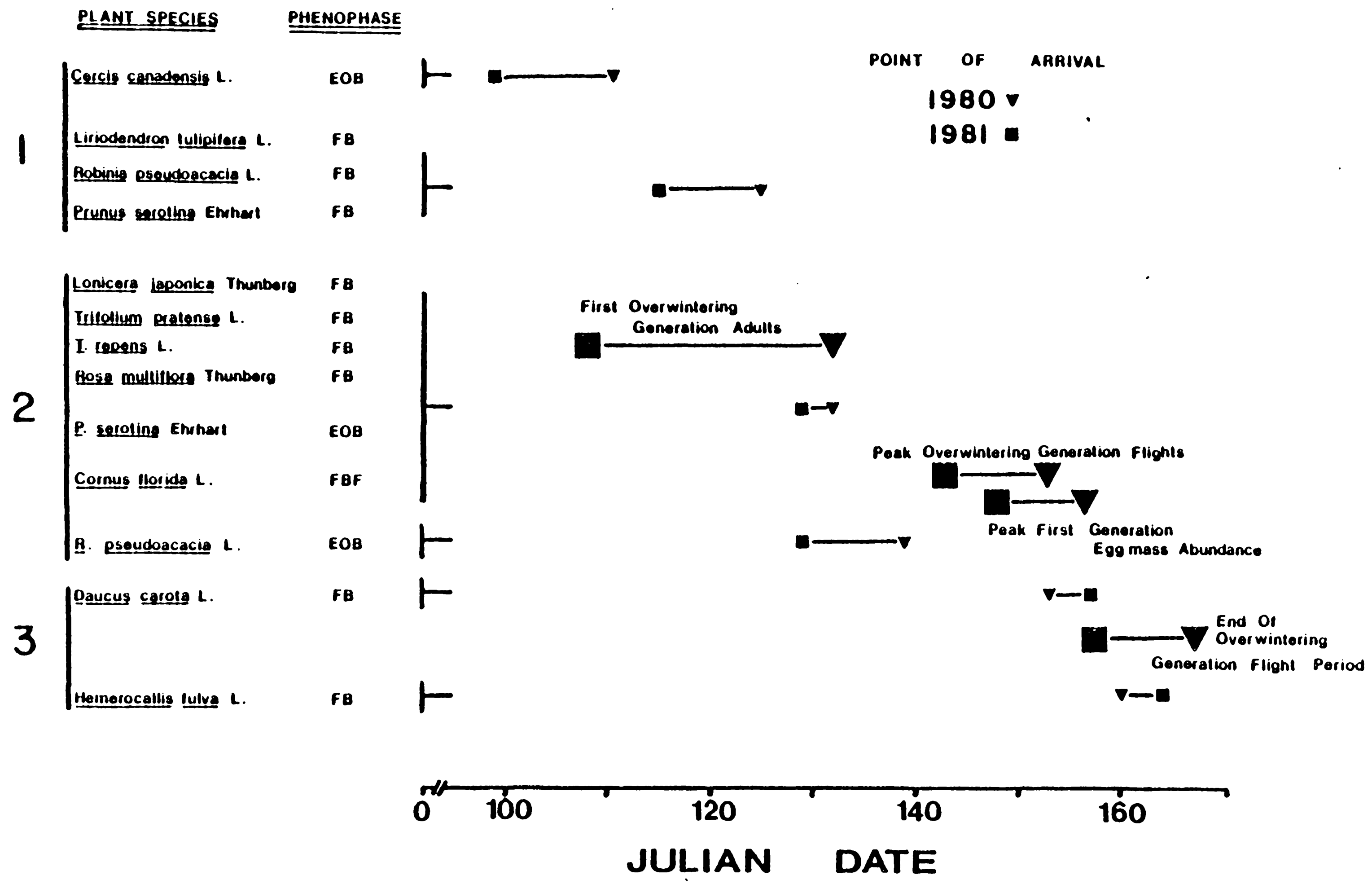

Fig. 20. Relationship of phenological events (FB-first bloom; EOB-end of bloom; FBF-full bract fall) in 3 series of plant species to segments of European corn borer biology.

Table 2. Periods of blooming and habitats of nine potential plant indicator species of European corn borer seasonality.

Plant species	Months in bloom [1/]	Habitat [1/]
Liriodendron tulipifera L.	April - June	Found in coves or low, often recently cleared woodlands.
Robinia pseudoacacia L.	April - June	Grows in old fields or along woodsides, fencerows and woodlands margins.
Prunus serotina Ehrhart	April - May	Found in low woodlands and along fencerows.
Rosa multiflora Thunberg	May - June	Clearings, roadsides and field borders.
Trifolium pratense L.	May - September	Roadsides, clearings and turf.
Trifolium repens L.	May - October	Grasslands, roadsides and open pastured woods.
Cornus florida L.	March - April	Acid woods and open woodlands.
Hemerocallis fulva L.	May - June	Roadsides, borders of fields and Thickets.
Daucus carota L.	May - September	Fallow fields, waste places and along roadsides.

[1/] from Justice, W. S. and C. R. Bell. 1979. Wildflowers of North Carolina. University of North Carolina Press, 217 pp.

correlation between plant and European chafer development, and demonstrated that ambient atmospheric temperature was responsible for the relationship. Similarly, much of the seasonal variation in peak arrival of adult overwintering generation European corn borer could be explained if this particular phenophase was placed on a scale based upon physiological time.

Observations from this study indicate the potential for a phenology system which could be used as an aid in developing grower-awareness of the seasonality of adult overwintering generation corn borer flight and first generation oviposition. However, before any program can be undertaken, additional observations should be made with populations in other geographic localities at which time the error due to intraspecific genetic variation can be evaluated (Flint 1974). This study was conducted in one geographic location, with only one observer in an attempt to reduce the inherent error present when any phenological study is performed (Leopold and Jones 1947). In future studies, error due to observer should also be evaluated in order to create a viable prediction system.

SUMMARY

Research during 1980 and 1981 was concerned with defining the seasonal activity of adult European corn borer, and first generation borer egg mass seasonal abundance and distribution in field corn in Virginia. Blacklight trap observations and the egg mass sampling study were conducted in Bedford County, Virginia. Additional blacklight trap data were also used from the extensive data base accumulated at the Virginia Truck and Ornamentals Research Station at Painter, as well as from trap records taken at Blacksburg and Warsaw, Virginia.

Results of the flight data analyses indicated that adult European corn borer seasonality could be accurately predicted if placed on a physiological-time scale. Seasonal peak first generation egg mass abundance lagged behind peak overwintering generation moth activity, and could also be predicted in the same fashion. Estimates of temporal egg mass abundance were accurately made if accumulation of degree days was begun with the first arrival of overwintering generation moths.

Results from the observations of plant flowering phenology indicated a positive relationship between certain segments of European corn borer biology and the flowering char-

acteristics of several species of wildflowers and trees in Bedford County, thus yielding another viable alternative in the prediction of European corn borer seasonality.

Within-field spatial distribution of first generation European corn borer egg masses closely aproximated the Poisson distribution for the range of egg mass densities sampled. However trends towards a slightly clumped distribution occurred at relatively high egg mass densities. Nearly all sampled egg masses were found on the leaf undersurfaces, and the within-plant distribution was skewed towards the lower leaves of the plant. Such information is important when sampling for decision making purposes. Much time and effort could be saved if plant examinations were restricted to the lower regions of the plants.

Accurate prediction of adult European corn borer seasonality and subsequent oviposition is important in the management of this insect pest. More precise scheduling of scouting operations can be beneficial, in the form of savings in the time spent in sampling, and in moneys realized from the use of less insecticide materials.

REFERENCES CITED

AliNiazee, M. T. 1976. Thermal unit requirements for determining adult emergence of the western cherry fruit fly (Diptera: Tephritidae) in the Willamette Valley of Oregon. Environ. Entomol. 5: 397-402.

Apple, J. W. 1952. Corn borer development on canning corn in relation to temperature accumulations. J. Econ. Entomol. 45: 877-879.

Arbuthnot, K. D. 1949. Temperature and precipitation in relation to the number of generations of the European corn borer in the United States. U. S. Dept. of Agric. Tech. Bull. 987. 22 pp.

Babcock, K. W. 1927. The European corn borer Pyrausta nubilalis Hubn. I. A discussion of its dormant period. Ecology. 8: 45-59.

Barber, G. W. 1925. A study of the cause of the decrease in the infestation of the European corn borer, Pyrausta nubilalis (Hbn.), in the New England area during 1923. Ecology. 6: 39-47.

Barlow, C. A. 1963. Predicting the size of European corn borer infestations (Ostrinia nubilalis Hbn.). Can. Entomol. 95: 1285-1292.

Barlow, C. A. and J. A. Mutchmor. 1963. Some effects of rainfall on the population dynamics of the European corn borer, Ostrinia nubilalis (Hbn.) (Pyraustidae: Lepidoptera). Entomol. Exp. Appl. 6: 21-36.

Barlow, C. A., H. B. Wressell and G. R. Driscoll. 1963. Some factors determining the size of infestations of the European corn borer, Ostrinia nubilalis (Hbn.) (Pyralidae: Lepidoptera). Can. J. Zool. 41: 963-970.

Baskerville, G. L. and P. Emin. 1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology. 50: 514-517.

Beck, S. D. 1963. Physiology and ecology of photoperiodism. Bull. Entomol. Soc. Amer. 9: 8-16.

Beck, S. D. 1967. Water intake and the termination of diapause in the European corn borer, Ostrinia nubilalis. J. Insect Physiol. 13: 739-750.

Beck, S. D. and J. W. Apple. 1961. Effects of temperature and photoperiod on voltinism of geographical populations of the European corn borer, Pyrausta nubilalis. J. Econ. Entomol. 54: 550-558.

Brindley, T. A. and F. F. Dicke. 1963. Significant developments in European corn borer research. Ann. Rev. Entomol. 8: 155-176.

Broersma, D. B., J. R. Barrett, Jr. and J. O. Sillings. 1976. Activity and blacklight induced flight of black cutworm and European corn borer as related to temperature and relative humidity. Environ. Entomol. 5: 1191-1194.

Butts, R. A. and F. F. McEwen. 1981. Seasonal populations of the diamondback moth, Plutella xylostella (Lepidoptera: Plutellidae), in relation to day-degree accumulations. Can. Entomol. 113: 127-131.

Caffrey, D. J. and L. H. Worthley. 1927. A progress report on the investigations of the European corn borer. U. S. Dept. Agr. Tech. Bull. 1476. 154 pp.

Chiang, H. C. and A. C. Hodson. 1959. Distribution of the first-generation egg masses of the European corn borer in corn fields. J. Econ. Entomol. 52: 295-299.

Chiang, H. C., A. J. Keaster and G. L. Reed. 1968. Differences in ecological responses of Ostrinia nubilalis from the north central United States. Ann. Entomol. Soc. Amer. 61: 140-146.

Clement, S. L., W. L. Rubink, R. W. Rings and M. A. Casey. 1981. Predicting flight activities of the European corn borer. Ohio Report. 66: 3-4.

Eckenrode, C. J. and R. K. Chapman. 1972. Seasonal adult cabbage maggot populations in the field in relation to thermal-unit accumulation. Ann. Entomol. Soc. Amer. 65: 151-156.

Eckenrode, C. L., E. V. Vea and K. W. Stone. 1975. Population trends of onion maggots correlated with air thermal unit accumulations. Environ. Entomol. 4: 785-789.

Everett, T. R., H. C. Chiang and E. T. Hibbs. 1958. Some factors influencing populations of European corn borer (Pyrausta nubilalis (Hbn.)) in the north central states. Minn. Agric. Exp. Stn. Publ. 87. 63 pp.

Ficht, G. A. 1936. The European corn borer in Indiana. Purdue Univ. Agr. Exp. Sta. Bull. 406. 8 pp.

Flint, H. L. 1974. Phenology and genecology of woody plants. in Phenology and Seasonality Modeling, Lieth, H., ed. Heidlberg, Berlin: Springer-Verlag New York Inc. pp. 83-97.

Frye, R. C. 1971. European corn borer populations in North Dakota. N. D. Res. Rept. No. 27. 16 pp.

Frye, R. D. 1972. Factors influencing corn borer populations in North Dakota. N. D. Res. Rept. No. 37. 28 pp.

Hewitt, G. B. 1980. Plant phenology as a guide in timing grasshopper control efforts on Montana rangeland. J. Range Mgt. 33: 297-299.

Hoffman, R. L. 1969. The biotic regions of Virginia. VPI&SU Res. Div. Bull. 48: 23-62.

Hofmaster, R. N., D. F. Bray and L. P. Ditman. 1960. Effectiveness of insecticides against the European corn borer and green peach aphid on peppers. J. Econ. Entomol. 53: 624-626.

Hogmire, H. W., Jr. and A. J. Howitt. 1979. The bionomics of the tufted apple budmoth, Platynota idaeusalis in Michigan. Ann. Entomol. Soc. Amer. 72: 121-126.

Huber, L. L., C. R. Neiswander and R. M. Salter. 1928. The European corn borer and its environment. Ohio Agr. Exp. Sta. Bull. 429. 196 pp.

Jarvis, L. and A. Brindley. 1965. Predicting moth flight and oviposition of European corn borer by use of temperature accumulations. J. Econ. Entomol. 58: 300-302.

Jones, D. W., H. G. Walker and L. D. Anderson. 1939. The European corn borer on the Eastern shore of Virginia. Va. Truck Exp. Sta. Bull. 102: 1621-1648.

Justice, W. S. and C. R. Bell. 1979. Wildflowers of North Carolina. University of North Carolina Press. 217 pp.

Kapler, J. E. 1967. Phenological events associated with the spring emergence of the smaller European elm bark beetle in Dubuque, Iowa. J. Econ. Entomol. 60: 50-52.

Kapler, J. E. and D. M. Benjamin. 1960. The biology and ecology of the red-pine sawfly in Wisconsin. Forest Sci. 6: 253-268.

Karandinos, M. G. 1976. Optimum sample size and comments on some published formulae. Bull. Entomol. Soc. Amer. 22: 417-421.

Kira, M. T., W. D. Guthrie and J. L. Huggans. 1968. Effect of drinking water on production of eggs by the European corn borer. J. Econ. Entomol. 62: 1366-1368.

Lathrop, F. H. and C. O. Dirks. 1944. Timing the seasonal cycles of insects. J. Econ. Entomol. 37: 199-204.

Lathrop, F. H. and C. O. Dirks. 1945. Timing the seasonal cycles of insects: the emergence of Rhagoletis pomonella. J. Econ. Entomol. 38: 330-334.

Leopold, A. and S. E. Jones. 1947. A phenological record for Sauk and Dane Counties, Wisconsin, 1935-1945. Ecol. Monogr. 17: 81-122.

Libby, J. L. 1974. Predicting cabbage maggot appearance. Proc. N. Centr. Br. Entomol. Soc. Amer. 29: 35-36.

Luckmannm, W. H., J. T. Shaw, D. W. Sherrod and W. G. Ruesink. 1976. Developmental rate of the black cutworm. J. Econ. Entomol. 69: 386-388.

McClanahan, R. J. and W. M. Elliott. 1976. Light trap collections of certain economically important lepidoptera at Harrow, Ontario. Proc. Entomol. Soc. Ont. 107: 57-63.

McCleod, D. G. R. 1981. Factors affecting the temporal distribution of the spring flight of the European corn borer, Ostrinia nubilalis (Lepidoptera: Pyralidae). Can. Entomol. 113: 433-439.

Matteson, J. W. and G. C. Decker. 1965. Development of the European corn borer at controlled constant and variable temperatures. J. Econ. Entomol. 58: 344-349.

Mellanby, K. 1958. Water drinking by the larvae of the European corn borer. J. Econ. Entomol. 51: 744-745.

Morris, R. F., F. E. Webb and C. W. Bennett. 1956. A method of phenological survey for use in forest insect studies. Can. J. Zool. 34: 533-540.

Riedl, H., B. A. Croft and A. J. Howitt. 1976. Forecasting codling moth phenology based on pheromone trap catches and physiological-time models. Can. Entomol. 108: 499-560.

Schurr, K. M. and F. G. Holdaway. 1966. Periodicity in oviposition of Ostrinia nubilalis. Ohio J. Sci. 66: 76-80.

Showers, W. B., H. C. Chiang, A. J. Keaster, R. E. Hill, G. L. Reed, A. N. Sparks and G. J. Musick. 1975. Ecotypes of the European corn borer in North America. Environ. Entomol. 4: 753-760.

Showers, W. B., G. L. Reed and H. Oloumi-Sadeghi. 1974. Mating studies of female European corn borer: relationships between deposition of egg masses on corn and captures in light traps. J. Econ. Entomol. 67: 616-619.

Sevacherian, V., N. C. Toscano, R. A. Van Steenwyk, R. K. Sharma and R. R. Sanders. 1977. Forecasting pink bollworm emergence by thermal summation. Environ. Entomol. 6: 545-549.

Southwood, T. R. E. 1978. Ecological methods with particular reference to the study of insect populations. Chapman and Hill Ltd., London. 524 pp.

Sparks, A. N., H. C. Chiang, A. J. Keaster, M. L. Fairchild and T. A. Brindley. 1966. Field studies of European corn borer biotypes in the midwest. J. Econ. Entomol. 59: 922-928.

Sparks, A. N., H. C. Chiang, C. A. Triplehorn, W. D. Guthrie and T. A. Brindley. 1967. Some factors influencing populations of the European corn borer, Ostrinia nubilalis (Hubner) in the north central states. Iowa Agr. Home Econ. Exp. Sta. Res. Bull. 559 (N. C. Reg. Res. Publ. 180). 103 pp.

Stirrett, G. M. 1938. A field study of the flight, oviposition and establishment periods in the life cycle of the corn borer, Pyrausta nubilalis Hbn., and the physical factors affecting them. Sci. Agric. 18: 355-369, 462-484, 536-557, 568-585, 656-683.

Straub, R. W. and P. C. Huth. 1976. Correlations between phenological events and European corn borer activity. Environ. Entomol. 5: 1079-1082.

Tashiro, H. and F. L. Gambrell. 1963. Correlation of European chafer development with the flowering period of common plants. Ann. Entomol. Soc. Amer. 56: 239-243.

Tauber, M. J. and C. A. Tauber. 1976. Insect seasonality: diapause maintenance, termination and postdiapause development. Ann. Rev. Entomol. 21: 81-107.

Taylor, L. R. 1961. Aggregation, variance and the mean. Nature. 189: 732-735.

Toscano, N. C., R. A. Van Steenwyk, V. Sevacherian and H. T. Reynolds. 1979. Predicting population cycles of the pink bollworm by thermal summation. J. Econ. Entomol. 72: 144-147.

U. S. Department of Agriculture. 1976. Estimates of damage by the European corn borer to grain corn in the United States in 1975. Coop. Pl. Pest Rept. 1: 873-874, 877.

Vance, A. M. 1949. Some physiological relationships of the female European corn borer in controlled environments. J. Econ. Entomol. 42: 474-484.

Wegner, G. S. and H. D. Niemczyk. 1981. Bionomics and phenology of Ataenia spretulus. Ann. Entomol. Soc. Amer. 74: 374-384.

Whitworth, R. J. and F. L. Poston. 1979. A thermal-unit accumulation system for the southwestern corn borer. Ann. Entomol. Soc. Amer. 72: 253-255.

Windels, M. B. and H. C. Chiang. 1975. Distribution of second-brood European corn borer egg masses on field corn and sweet corn plants. J. Econ. Entomol. 68: 133.

Worthley, L. H. and D. J. Caffrey. 1927. Scouting, quarantine and control for the European corn borer, 1917-1926. U. S. Dept. Agric. Tech. Bull. 53. 143 pp.

Wressell, H. B. 1972. A study of infestation by the European corn borer, Ostrinia nubilalis Hbn. (Lepidoptera: Pyralidae), in southwestern Ontario, 1946 to 1964. Proc. Entomol. Soc. Ont. 103: 17-26.

Zeevart, J. A. D. 1962. Physiology of flowering. Science. 137: 723-731.

APPENDIX I

Monthly Maximum and Minimum Temperatures (Fahrenheit), Boone Site, Bedford County, 1980.

Day	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept	
1	41	25	21	14	26	13	55	38	68	45	84	58	86	53	93	68	93	63
2	42	27	23	12	20	13	71	34	72	43	86	61	92	60	97	62	93	66
3	37	29	26	12	35	13	70	44	76	43	84	70	84	71	95	67	88	65
4	34	31	25	19	46	21	74	54	82	47	82	58	92	72	95	76	87	65
5	27	27	33	18	47	33	60	38	85	42	82	46	95	67	95	67	91	66
6	33	22	31	27	46	33	61	32	84	46	74	52	93	66	95	67	93	64
7	32	15	37	24	56	28	60	37	84	47	89	60	87	56	97	65	89	66
8	39	33	37	22	70	48	54	47	65	42	84	65	85	60	100	65	87	56
9	35	32	34	28	64	41	69	47	65	32	76	49	87	66	101	70	87	56
10	31	20	33	21	59	27	69	46	71	32	78	53	89	66	96	68	86	68
11	36	28	39	16	55	31	73	37	80	44	76	50	91	63	95	68	83	51
12	36	31	37	26	40	28	71	43	87	52	75	54	91	69	90	68	86	53
13	34	28	34	14	34	25	54	47	84	60	78	45	88	66	90	59	90	58
14	43	30	51	22	37	31	69	45	76	52	89	48	87	67	96	60	95	59
15	56	38	49	33	56	27	65	37	72	38	93	59	92	68	93	67	90	63
16	51	33	45	31	64	28	54	39	74	46	86	64	100	68	89	70	81	62
17	49	38	25	18	62	46	58	29	67	53	79	53	99	65	72	60	80	63
18	40	40	37	20	55	38	67	34	79	51	67	53	92	66	73	60	82	65
19	51	33	46	18	54	26	73	36	82	52	78	53	93	66	88	64	82	62
20	46	35	55	27	58	41	75	40	68	61	81	56	96	68	92	63	79	60
21	45	28	65	42	58	46	76	44	77	58	81	44	98	68	83	68	89	66
22	42	31	71	44	52	34	82	36	79	52	87	50	91	66	72	65	89	64
23	36	32	68	47	58	26	92	60	83	63	89	60	83	67	85	66	84	68
24	36	19	56	40	55	41	82	52	79	64	74	61	87	60	88	65	80	62
25	52	33	53	36	51	40	76	49	75	56	67	62	88	61	92	58	70	59
26	51	35	34	24	47	29	53	48	76	49	80	63	89	65	94	63	72	60
27	43	31	44	23	54	28	59	48	78	43	91	59	88	66	95	56	67	45
28	45	32	40	31	53	37	65	48	83	49	100	67	80	70	96	57	64	44
29	43	33	43	33	71	41	61	37	88	53	96	67	87	65	96	61	68	50
30	28	23			67	47	60	40	84	59	83	64	89	59	93	62	68	57
31	24	21			55	44			82	60			91	63	92	61		

APPENDIX I, Continued

Monthly Maximum and Minimum Temperatures (Fahrenheit), Gaither Site, Bedford County, Virginia, 1980.

Day	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept	
1	43	26	23	15	29	14	56	39	68	41	84	61	84	54	93	70	96	65
2	44	27	26	13	22	14	71	35	73	44	86	64	89	73	97	64	92	67
3	39	29	29	13	37	14	70	45	76	45	85	68	83	73	94	73	90	65
4	36	31	28	19	48	22	74	55	83	48	81	57	92	72	91	66	85	67
5	30	27	35	18	49	34	61	39	84	43	81	48	92	71	93	67	94	67
6	35	23	33	27	48	28	62	33	82	49	74	53	92	72	94	67	91	62
7	34	15	39	25	57	49	61	38	83	49	86	64	87	57	96	66	88	66
8	40	34	39	23	70	41	55	48	65	41	84	61	88	64	100	68	87	58
9	37	33	36	28	65	27	69	48	64	32	76	48	86	65	98	71	97	55
10	33	20	35	21	60	31	69	47	72	33	78	53	87	65	96	69	87	68
11	38	28	40	16	56	28	73	38	81	54	75	51	89	67	95	69	84	50
12	38	32	39	27	42	26	71	44	88	58	75	55	92	67	90	68	90	54
13	36	28	36	14	36	32	55	48	80	65	78	46	86	66	94	59	90	56
14	45	30	52	23	39	27	69	46	78	59	87	50	85	66	98	61	92	48
15	57	39	50	34	57	28	66	38	73	41	92	63	93	68	93	73	86	64
16	52	34	47	31	65	47	55	39	73	42	84	70	100	73	88	74	72	63
17	50	39	28	18	63	39	58	30	66	54	78	55	99	68	74	60	78	64
18	42	40	39	20	56	27	67	35	78	53	66	58	90	68	76	61	84	66
19	52	34	48	18	55	41	73	37	80	56	77	54	92	67	90	66	79	63
20	48	36	56	27	58	47	75	40	68	59	80	63	94	72	94	61	78	63
21	47	28	66	43	58	35	79	44	78	56	83	56	95	70	84	68	91	69
22	44	32	71	45	53	27	75	45	78	53	89	49	86	70	75	65	91	68
23	38	33	68	48	58	41	81	38	81	64	92	57	81	68	87	66	84	68
24	38	19	57	40	56	40	91	60	76	64	76	59	86	61	89	64	70	60
25	53	34	54	37	52	29	80	50	75	57	71	63	86	61	93	56	67	58
26	52	36	36	25	49	28	78	51	76	58	82	65	88	66	96	58	73	57
27	45	32	46	24	55	38	53	48	78	45	94	54	88	64	92	56	65	46
28	47	33	42	31	54	41	59	46	81	49	95	65	82	68	95	60	63	45
29	45	34	45	34	71	48	65	45	87	54	92	69	86	66	95	60	66	51
30	31	24			67	45	60	39	80	58	80	62	89	63	90	62	66	58
31	27	22			56	45			82	59			91	64	92	62		

APPENDIX I, Continued

Monthly Maximum and Minimum Temperatures (Fahrenheit), Boone Site, Bedford County, 1981.

Day	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept	
1	42	25	34	10	58	41	70	44	70	44	65	57	75	56	83	55	81	66
2	41	26	46	24	51	31	76	40	64	41	77	57	74	62	83	57	79	67
3	47	25	25	14	48	31	80	35	72	30	79	64	76	61	86	64	75	67
4	40	9	31	14	46	21	72	45	83	36	83	65	82	61	91	63	69	63
5	36	7	34	12	45	35	61	51	82	43	88	61	80	60	92	65	74	63
6	41	16	47	16	46	32	54	36	78	54	77	67	80	66	77	67	81	65
7	40	24	48	20	44	28	62	25	69	42	85	61	88	65	87	66	77	61
8	29	13	47	26	53	21	73	30	69	33	85	58	90	61	83	67	77	64
9	29	16	44	21	49	21	67	50	66	47	89	70	92	67	84	60	74	49
10	28	11	47	24	48	20	67	40	60	55	90	70	92	71	85	61	77	44
11	29	9	56	20	50	26	83	47	74	58	84	61	87	67	86	64	85	48
12	25	12	31	10	56	34	82	58	65	43	84	64	86	66	87	63	87	54
13	31	21	39	11	67	37	60	42	75	33	90	72	86	64	81	52	84	52
14	48	23	55	24	48	23	67	43	82	44	92	70	90	70	82	52	85	53
15	44	25	56	21	64	33	66	38	74	55	95	67	82	60	85	62	75	60
16	41	17	58	23	51	30	68	29	67	46	93	66	82	60	87	66	75	60
17	28	22	59	40	60	30	60	49	74	42	84	70	84	60	90	54	68	48
18	47	20	67	38	44	32	80	52	56	45	80	60	85	63	77	49	69	48
19	59	24	54	47	40	23	74	44	48	44	87	64	85	63	77	58	64	46
20	50	29	55	49	42	22	63	44	57	44	87	64	89	70	66	56	78	47
21	44	30	63	45	49	26	59	30	76	40	92	62	87	67	76	48	77	46
22	52	29	59	48	40	23	71	31	84	45	90	66	85	63	75	54	80	45
23	44	34	56	36	47	31	77	51	83	46	88	66	81	63	85	48	69	49
24	51	26	47	33	58	23	68	46	87	48	86	60	67	63	87	53	72	38
25	56	22	57	30	58	25	60	37	89	51	92	64	78	62	82	55	74	37
26	62	23	60	28	63	25	73	30	86	54	79	59	87	62	79	52	80	44
27	56	34	65	23	62	36	85	48	68	60	79	50	92	68	84	51	83	46
28	50	24	74	30	64	27	90	49	68	56	82	50	90	67	87	56	74	49
29	50	23			74	30	76	51	80	60	85	50	82	60	80	55	70	36
30	38	21			65	52	67	52	84	52	80	62	77	52	78	64	77	46
31	45	14			79	47			82	62			80	52	85	66		

APPENDIX I, Continued

Monthly Maximum and Minimum Temperatures (Fahrenheit), Gaither Site, Bedford County, 1981.

Day	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept	
1	42	28	33	13	56	44	70	42	68	49	66	56	78	55	88	54	83	65
2	41	29	42	25	50	32	76	40	64	41	77	56	73	60	85	56	81	68
3	47	28	26	17	49	31	80	35	72	30	81	65	70	60	89	65	82	67
4	40	15	32	12	42	23	72	45	83	36	83	68	83	60	91	63	65	63
5	35	13	36	11	46	34	61	51	82	43	82	63	83	62	93	68	73	63
6	41	21	47	20	45	30	54	37	76	54	76	64	81	67	83	66	80	65
7	39	27	49	23	43	29	62	25	66	40	82	62	88	65	88	66	80	62
8	29	18	46	26	50	26	73	30	68	31	84	58	90	63	84	67	76	63
9	29	21	44	18	50	26	66	50	68	44	88	69	93	70	86	62	74	50
10	28	18	36	25	49	27	70	40	59	53	88	73	94	70	90	64	81	47
11	29	17	58	20	52	29	82	50	74	58	85	63	88	67	87	66	86	57
12	24	15	30	10	57	32	82	60	64	48	88	63	87	67	84	63	88	57
13	31	17	38	12	66	37	58	42	76	36	89	69	86	69	85	55	87	53
14	48	25	54	23	48	33	77	42	80	45	94	73	89	72	87	56	87	57
15	44	26	56	22	63	31	69	35	70	54	94	70	86	60	88	63	76	67
16	41	28	59	25	50	30	70	32	66	44	94	66	75	63	91	67	77	60
17	32	20	61	40	58	29	62	51	74	44	84	68	88	66	88	58	66	52
18	46	17	66	43	44	31	79	57	60	46	78	61	90	64	81	48	69	50
19	59	31	54	48	39	23	76	44	58	44	86	64	86	64	67	57	64	46
20	53	32	54	46	42	22	66	38	56	44	88	65	90	70	83	57	75	50
21	42	31	60	47	49	27	61	34	76	41	95	63	89	67	80	46	76	47
22	52	31	57	47	40	25	72	32	82	46	94	68	90	66	80	58	80	48
23	44	28	56	40	46	31	76	57	82	47	88	66	85	65	86	51	74	46
24	54	32	48	38	56	26	62	46	86	50	88	62	69	64	86	56	74	42
25	57	34	58	31	59	27	62	38	86	52	94	67	82	63	87	56	76	38
26	62	30	59	30	62	26	72	33	82	60	84	58	88	67	80	52	79	45
27	54	37	66	27	64	47	86	50	69	60	78	50	91	73	84	53	82	48
28	49	33	74	33	64	29	88	51	69	58	83	49	90	68	89	57	74	54
29	49	28			71	40	78	56	78	66	85	50	84	65	79	54	70	37
30	37	28			68	53	69	50	84	55	83	61	82	52	77	56	76	45
31	43	22			80	46			82	66			80	50	85	56		

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PHENOLOGY OF THE EUROPEAN CORN BORER,

OSTRINIA NUBILALIS

(HUBNER) (LEPIDOPTERA: PYRALIDAE) IN VIRGINIA

by

Joseph Leo Despins

(ABSTRACT)

Flight activity of adult European corn borer field populations was monitored in Bedford County (1980 - 1981), Painter (1958 - 1980), Blacksburg (1971 - 1973, 1975) and Warsaw, Virginia (1971 - 1972, 1981). Peak occurrence of flight activity was accurately estimated by measuring the accumulation of degree days above 10^{o} C. The appearance of cumulative percentages of adult European corn borer flight at predicted degree day accumulations is reported.

The seasonal abundance, within - field and within - plant distribution of first gneeration European corn borer egg masses were observed in field corn in Bedford County, Virginia. Peak egg mass abundance occurred ca. 200 degree days after the first borer moths were taken in the light traps. The spatial pattern of first generation corn borer egg masses closely approximated the Poisson distribution. The within - plant distribution of egg masses was skewed towards the lower leaves of the plant throughout the oviposition period, and nearly all egg masses were deposited on the leaf undersurfaces. Optimum sample sizes for two levels of sampling

precision were developed from the sampling data.

The seasonal development of the European corn borer in the spring was studied in relation to the flowering phenology of several groups of trees and wildflowers. The potential indicator plants signalled the onset of overwintering generation adult emergence, peak overwintering generation peak flight activity - first generation egg mass abundance, and the end of overwintering generation adult European corn borer flight.