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The European Corn Borer and Its Environment

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FOREWORD

Prior to its discovery in Ohio in 1921, the European corn borer had been known in the New England area since 1917 and in Europe, its native home, for several hundred years. During the interim between its appearance in America and its advent in Ohio, much had been learned of its life history and its ability to cause damage under New England conditions. However, it did not seem safe to assume that in Ohio the behavior of the pest would parallel that in New England or even in the newer infestations in New York and Canada, hence it appeared logical at the outset to initiate the investigational program with a thoro scrutiny of the insect in its new home.

Not only did this involve a detailed inquiry into the life history, habits, etc., of the insect itself, but at the same time a start was made in launching a broader biological investigation of the interrelationships of the pest and its hosts and its behavior under the climatic conditions as they obtain in Ohio. The fact that the insect is single brooded in Ohio should be kept clearly in mind while considering the subject matter of this bulletin.

The ultimate goal sought in any investigation of this character is the discovery of a practical, effective control; but the experience of others working with this insect as well as our own early efforts forced us to conclude that the attainment of the final objective would be no simple matter. It seemed evident that no short cut was likely to be found and that the most rapid progress was to be made by seeking the fundamental truths underlying the whole problem. Further, that such truths, if discovered, undoubtedly could be utilized in the formulation of a practical control program. Extreme care, however, must be exercised if generalization is attempted. For example, the relationship between stage of corn development and borer population constitutes a biological principle, but in applying this truth one must always bear in mind that all factors may vary in importance or alignment from season to season or from one region to another.

Our conception of the problem, therefore, is that of a broad biological complex which centers, first, around the insect itself; second, its environment (of which the corn plant, the chief host of the insect, temperature, moisture, and light are some of the principal components); and, third, the economic application to farming practices of the principles involved.

The fundamental studies as outlined have ramified into many fields of agricultural research and have resulted at the present time in there being linked together in an intensive, intimate, yet comprehensive manner, a greater number of the sciences bearing upon agriculture than probably has occurred at any time previous in the history of entomological research in America. Entomologists agronomists, plant breeders, plant and animal morphologists and physiologists, chemists, physicists, specialists in farm mechanics, economists, pedologists, ecologists, and meteorologists, as well as others, all have had a definite part in the research program. The progress that has attended our efforts thus far has been due in no small measure, to the fact that many agencies have contributed and that the closest cooperation has existed.

The agencies that have cooperated specifically with the Ohio Agricultural Experiment Station in accumulating the data upon which this bulletin is based are as follows: The State Department of Agriculture, the Departments of Entomology and Agricultural Engineering of the Ohio State University, and the Federal Bureau of Entomology in the development of low cutting attachments for corn binders during 1924 and 1926; the Department of Botany of the Ohio State University in the vegetation survey since 1926, having been aided by the Entomological Branch, Dominion Department of Agriculture, Canada; the Bureaus of Plant Industry and Entomology of the United States Department of Agriculture and the Department of Farm Crops of the Ohio State University since 1927 in the agronomic aspects of the investigation; the Bureau of Chemistry and Soils of the United States Department of Agriculture since 1927 in the study of the correlation of soil types with corn borer abundance; and the Howard Farms Company, Toledo, Ohio, in placing at the disposal of the Experiment Station for a nominal sum the land upon which the plot work at Bono is located. Finally, many individuals whose names do not appear in the authorship of the bulletin or any of its sections have contributed much to the work. A list of these will be found in a note on the first page of the discussion.

J. S. Houser

THE EUROPEAN CORN BORER AND ITS ENVIRONMENT

L. L. HUBER, C. R. NEISWANDER, AND R. M. SALTER[1]

I. INTRODUCTION

Any discussion of the control of the European corn borer involves a consideration of the environmental and hereditary factors which determine its behavior. The corn borer, like other insects, has the inherent or potential power to increase in numbers; but whether it increases rapidly or slowly, simply maintains status quo, or actually decreases in numbers, depends on how well it fits into the environment. Increase may be expected up to the time biotic potential and environmental resistance reach an equilibrium, after which the population will remain relatively constant. On the contrary, decrease in numbers or actual extinction will result only when the physical and biotic resistances are together greater than the potential of the insect. It must be obvious, therefore, that if the behavior of the insect is to be properly interpreted, three major conceptions must be kept clearly in mind, namely: (1) the actual abundance; (2) the biotic potential; and (3) the environmental resistance (3). The immediate discussion is a consideration of the actual abundance and the biotic potential of the insect.

Accordingly the subject matter of this bulletin deals with the normal behavior and activity of the insect under environmental conditions as they exist. When definite changes in the environment occur the attendant effect on the abundance of the insect is discussed and the factor evaluated as far as possible. In the laboratory partially controlled experiments have been conducted in which environmental changes were induced in order to aid in the interpretation of the factors responsible for the increase or decrease in environmental resistance as evidenced by an increase or decrease in the rate of accumulation or the abundance of the insect in the field.

The different factors influencing the accumulation and the abundance of the insect are considered in two groups, namely: (1) physical factors, consisting of temperature, humidity, nutrition,

[1]The accumulation and the interpretation of the data reported in this bulletin have been made possible only thru the untiring and patient endeavor of many trained investigators. A number of these who have given all or a part of their time to the work are authors of various sections. The following, however, are those who have been employed for the most part thru the summer months and consequently have contributed greatly to the execution of the numerous details: C. E. Dike, V. H Morris, F. C. Bukey, F. H. Moore, P. B. Sears, R. W. Gerdel, Agronomy; and C. O. Esselbaugh, E. A. Herr, J. P. Sleesman, H. G. Walker, G. Sleesman, R. B. Neiswander, A. A. Bowers and H. R. Watts, Entomology.

light, etc.; and (2) biotic factors, such as parasites, predators, and mechanics. The influence of some of the different agents is discussed independently for all four stages of the insect, namely: the adult, the egg, the larva, and pupa. The efficiency of farm methods of crop disposal is given in considerable detail. Following this is a discussion of the corn borer in relation to the host plant. In the latter part of the bulletin more attention is given to the general ecological phases. Figure 1 graphically represents the writers' conception of the European corn borer problem. The ecological point of view is maintained thruout. It is held that until each environmental factor has been measured both individually and in combination its effect on the behavior of the insect can not be definitely and accurately stated.

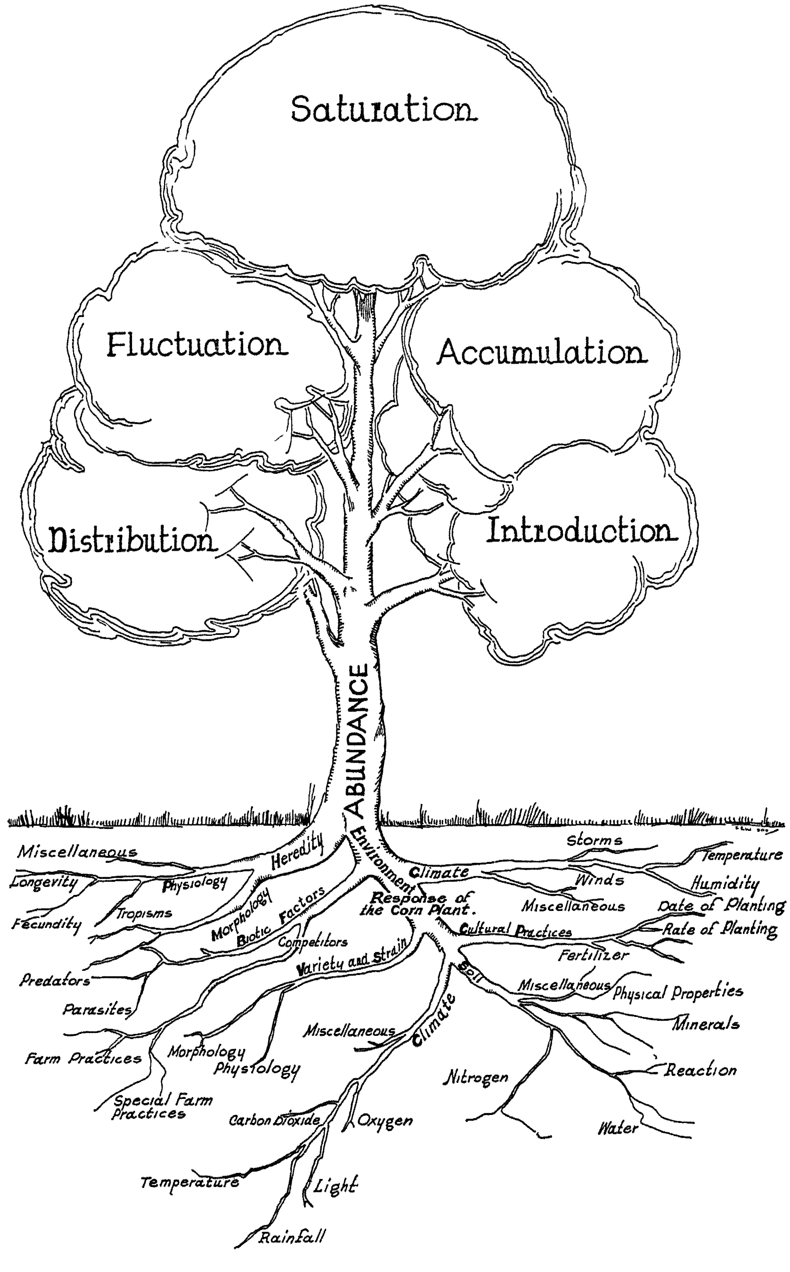

Fig. 1.—A graphic representation of the factors that influence the responses of the European corn borer

II. A QUANTITATIVE STUDY OF THE ACCUMULATION AND ABUNDANCE OF THE EUROPEAN CORN BORER

ACCUMULATION AND ABUNDANCE IN RELATION TO HABITAT

C. R. NEISWANDER AND L. L. HUBER

For every stage of the European corn borer there is a fixed range of activities, determined by heredity, beyond which there can be no changes, regardless of the type of environment. Within this fixed range the insect becomes adjusted to many changes in the environment so long as the changes are not critical. Since environment is so complex and variable and since the borer has a fixed, or inherited, range of activities, it is to be expected that in certain regions or areas more or less synchrony will be established between the range of activities of the insect and the environment which determines its expression. The more harmonious the relationship, the more rapid will be the rate of accumulation and the higher will be the level of population.

It is of interest therefore to consider briefly the insect from a quantitative point of view in an attempt to ascertain how successful it has been in fitting into the environment, or to what extent its potential possibilties have been inhibited by climate (9) and soil (11), the essential constituents of environmental resistance.

Investigations have indicated that a female moth under insectary conditions deposits about 400 eggs. If it be assumed that these eggs are all fertile, and that environmental conditions are such that the young larvae all reach maturity and finally develop into adults themselves, then a pair of moths could in one year produce 400 adults, or 200 pairs. If it be assumed further that the corn borer came to Ohio in 1921, or 7 years ago, then the progeny of one pair since 1921 would amount to 25.600,000,000,000,000 corn borer larvae, or an average of more than 800,000 larvae for every stalk of corn grown in Ohio in 1927. As a matter of fact, the progeny of one pair of moths in 1921 would have completely destroyed the entire corn crop of Ohio as early as 1925, had the insect been equally distributed over the entire State. When it is remembered that the Ohio infestation likely resulted not from the migration of one pair of moths but probably from hundreds it can be concluded that had the insect met no resistance, the corn crop of the State would have been totally destroyed within a few years.

The fact that the insect has not increased in accordance with its potential possibilities is not only fortunate but it signifies that there are natural factors either physical or biotic which impede and inhibit its progress. The estimates above indicate the potential of the insect; it is now of interest to examine the records of its actual behavior.

The mere determination of borer abundance is of little consequence. If it is to be of value its purpose must be the evaluation of those factors which influence or control abundance. If such be the purpose then it is imperative that the methods employed be in accord with the known biological facts. It follows therefore that with the establishment of new facts the methods of determination must be changed. While the methods of study herein reported are similar in many ways to those employed by others, they also differ in some important respects. Moreover, the point of view in some instances has been so different from that held by many investigators that the conclusions differ still more widely than the methods of study.

In the first place, definite habitats were selected as locations in which to conduct population studies. The first two years (11) (1923 and 1924) of investigations indicated that the corn borer showed a preference for certain restricted habitats, soil fertility being used as an index. In 1925 these habitats were mapped by Transeau and Sampson (27) on a vegetation type basis, as will be discussed later. In 1927 additional restrictions were made by pedologists on the basis of soil types. The conclusions herein reported are, therefore, the results of investigations in habitats of known size.

In the second place, it has been recognized that habitats of the same size may be very different in composition. Since there are differences in the composition of habitats, it is to be expected that these differences will be reflected in the responses of the plants and insects that live therein. For example, corn grows more vigorously in some areas than in others; condition of plant growth, as has been demonstrated, influences corn borer population or abundance. It follows, therefore, that an explanation of corn borer abundance must include a consideration of the factors which influence corn development, namely, soil and climate.

Moreover, the condition of corn growth must also be considered. The best corn in an area might be classified as good in one year but in another year due to weather conditions it might be less than average. For example, the average corn in the Bono area in

1927 was about equivalent to the late corn of 1926. In a given year, other factors being equal, all stages of development may be found, due to different planting dates. Chapman (4), in his experiments with the confused flour beetle *(Tribolium confusum* Duv.), wisely chose a food of uniform character. Under field conditions corn, the host of the corn borer, is not uniform; its character is known to change with its growth. It is logical to expect that, as far as the borer is concerned, the nutritional value of corn will vary thruout the season. These variations in food conditions impose certain limitations on the behavior of the insect, hence must be recognized. In view of the variation in condition of the food, the writers have felt that this factor can be most safely handled in the field by always giving first, but not exclusive, consideration to the population of the corn which is known to be most favorable to the propagation of the insect.

For example, on the experimental plots at Bono it has been shown that the first two plantings, May 10 and May 20, which are early for the area, carried 72 percent of the total population of the whole series; whereas the average planting, May 30, carried 17 percent, and the late, June 5-10, only 11 percent. It is not held, of course, that this experimental series is an exact replica of the area as a whole, but, since corn planting in the Bono area is spread over nearly a month, it follows that the acreage of corn represents many stages of growth. Population in the various field habitats, therefore, should and does have a similar relation to corn development.

With reference to the interpretation of data, it is of considerable importance to mention that the methods employed during the past five years permitted the study not only of the population of different habitats but also of the fluctuating population of single habitats. It is felt that the determination of the population from year to year must be made from data collected in the same habitats. Yearly population studies based on non-comparable areas, whether they be restricted by natural or political boundary lines, are likely to be misleading and unjustified.

In 1923 the average number of stalks examined per field was well over 500, but the infestation was so light that it was necessary in some fields to examine great numbers of stalks in order to find any that were infested. The average borers per infested stalk, as shown by miscellaneous stalk dissections, was less than one. In 1924 the average number of stalks examined was about 200 per field; in 1925, 1926, and 1927, 500 stalks—100 in each of the four corners and 100 in the center of the field. A total of 10 stalks was taken at random in each of these areas and dissected to determine the borer population. Other data, such as number of broken stalks, broken tassels, and ears on the ground, were also secured, but they are not included in the table.

TABLE 1.—Showing the Actual and Relative Population of Nine Habitats in Ohio

Habitat	1923 No.	1924 No.	1925 No.	1926 No.	1927 No.
Actual population per 100 stalks					
West Lucas	....	... .	0.2	0.6	3.6
Wood	....	....	.001	1.43	5.8
Oregon (Lucas County)	....	....	10.3	74.2	150.0
Lake	2.52	19.7	17.1	52.9	68.3
Ottawa	....	....	10.0	48.0	52.8
Lorain	....	....	2.4	....	22.3
Ashtabula	1.59	19.2	10.0	55.8	48.0
Erie	.005	....	.46	15.6	11.3
Jerusalem (Lucas County)	4.1	20.8	22.9	190.0	129.1
Relative population					
West Lucas	....	0	5	18	100
Wood	....	....	0.1	24	100
Oregon (Lucas County)	....	....	7	49	100
Lake	4	28	25	77	100
Ottawa	....	....	11	90	100
Lorain	....	....	10	....	100
Ashtabula	3	34	18	100	86
Erie	0.3	....	3	100	72
Jerusalem (Lucas County)	2	11	12	100	67

Table 1 is a summary of the examination of 484 fields, most of which were dent varieties. The records given for 1925, 1926, and 1927 are all from dent, or field varieties, while a part of those of 1923 and 1924 are from sweet corn varieties. Furthermore, since borer population is more significant than stalk infestation, the table indicates only the borer population per 100 stalks, infested and non-infested.

As has been indicated it is not enough merely to point out the tremendous difference between potential and actual borer population, for, after all, such information contributes but little to the actual control of the insect. It does, however, add to our knowledge of the possibilities of certain control measures in the various ecologic areas. Table 1 indicates, for example, that the ratio between actual and potential population varies. It is to be expected, therefore, that not only the kind but the intensity of application of whatever control measures may be adopted will likewise vary.

III. DESCRIPTION OF THE BEHAVIOR OF EACH STAGE OF THE EUROPEAN CORN BORER

1. LIFE HISTORY

E. G. KELSHEIMER AND C. R. NEISWANDER

The life history of the European corn borer is so well known that little need be said concerning this phase of the investigations (30). In this section an attempt will be made to outline briefly the more important facts relating to the life cycle and the seasonal occurrence of the insect.

With the exception of 1924, very little time has been given to the ordinary routine study of the life cycle in itself. The records for that year confirm for the most part the records of other workers (20). Such differences as exist are due, perhaps, in large part to variations in methods of handling individual larvae under insectary conditions.

TABLE 2.—**Duration of Adult, Pupal, and Egg Stages, 1924**

	Longevity, days			Number
	Average	Maximum	Minimum	
Adult stage				
Male	9	29	2	107
Female	13.4	28	2	118
Preoviposition	3.7	11	2	91
Oviposition	7	....	....	....
Postoviposition	3.3	....	....	....
Eggs per female	300	682	16	106
Pupal stage				
Pupal period for males	16.6	21	11	65
Pupal period for females	16.2	25	13	67
Egg stage				
Incubation period	6	7	5	25,952

Similar observations in 1926 on 36 males and females showed that the average pupal period was 13.8 days; longevity, 10.6 days; preoviposition period, 4.8 days; average number of eggs per female, 513.7, and the maximum number, 1051.

Since 1925 emphasis has been put on seasonal occurrence of the insect rather than on the details of its life cycle. With reference to

Table 3, 1924 and 1925 represent insectary records, and the last two years field records. Since the records of 1926 and 1927 showed a significant difference between field and insectary data and since the field data were considered more significant, the data for emergence and pupation in 1924 and 1925 were weighted. The records as given below for the four years are, therefore, comparable and represent behavior under natural conditions.

TABLE 3.—Showing Pupation and Emergence

	1924	1925	1926	1927
		Pupation		
First pupation	June 10	June 1	June 16	June 1
Peak of pupation	June 22	June 17	July 2	June 20
End of pupation	July 7	July 15	....	June 30
		Emergence		
First emergence	June 22	June 22	June 26	July 24
Peak of emergence	July 5	July 3	July 11	July 4
End of emergence	July 26	July 26	July 15	July 14

Certain observations in 1925 indicated that there might be an appreciable variation in the time of pupation and emergence, depending upon the particular type of immediate environment of the stalks containing the hibernating larvae. The stalks might be in a field that is again planted to corn, or sown to wheat, oats or some other crop. The larvae that find themselves in a field returned to corn are directly exposed to the sun, there being little or no protection, except by the stalks which harbor them. On the other hand, wheat or oats afford considerable shade and consequently the temperature of stalks is lower and more moisture is retained in them. Figure 2 shows rather clearly the influences of immediate environment.

It will be shown in Section 4, page 70, that the seasonal difference in development may vary because of certain conditions incident to farm practices. When fodder is stored in barns, pupation and emergence are greatly delayed as compared with outdoor conditions.

The European corn borer is typically a one generation insect in the part of Ohio now infested; there is, however, a variation in its seasonal occurrence. A study of the peak of adult emergence for the last four years indicates that the range was from July 4 in 1927 to July 11 in 1926; the peak of pupation for these years was June 20 and July 2, respectively.

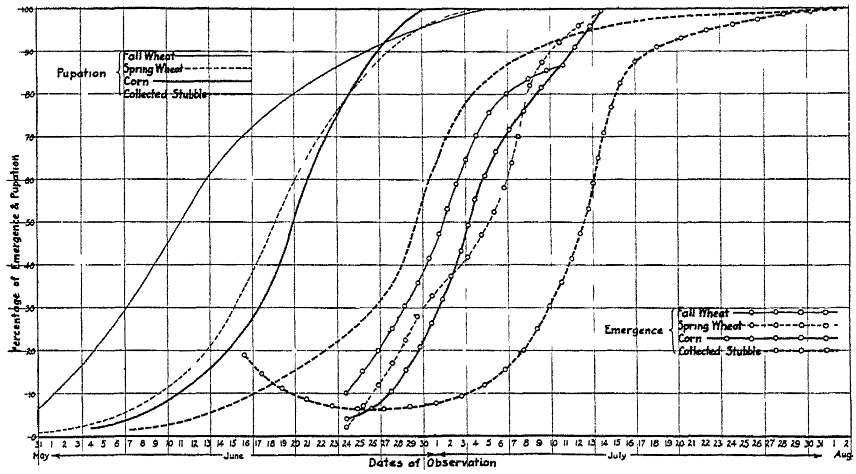

Fig. 2.—Pupation and emergence as influenced by differences in environment

The average number of eggs deposited per female in 1924 was 300, as compared with 513 in 1926. While it is conceded that variable seasonal conditions might have been responsible for these differences, it is felt that technic in handling the females was also of importance. Careful handling and favorable quarters encourage greater oviposition. Altho it has been impossible to determine how many eggs may be deposited by females under field conditions, it is apparent that when conditions are favorable to moth flight and moth behavior in general, the average number of eggs per female should be higher than under the opposite conditions. For purposes of discussion relative to the potentiality of the corn borer, 400 eggs is arbitrarily assumed to be the average number deposited per female under average field conditions.

2. THE ADULT

L. L. HUBER, E. G. KELSHEIMER, J. R. SAVAGE, AND C. R. NEISWANDER

The chief function of adult corn borers is to reproduce. It is necessary, therefore, that the female deposit her eggs on a suitable plant. The questions that at once arise are: How does the female find a satisfactory location for oviposition? Why does she prefer corn to other plants in Ohio and apparently prefer other plants to corn in parts of Europe? Why does she prefer the earliest and best corn to the late and poorest corn? To what extent do other physical factors, such as light or darkness, temperature, humidity, wind, and rain, inhibit or accelerate the reproductive function? It is obvious that before the actual abundance of the insect can be explained these and other questions concerning the adult must be answered at least in part. Moreover, it is also obvious that the agronomic phases of corn borer investigations, can be more intelligently conducted when more information relative to the causes of moth behavior is revealed.

Influence of Physical Factors

Little can be said of the influence of variable barometric pressure on the adult. It is probable that any variation sufficient to influence moth behavior is generally in the nature of an extreme which brings about storm conditions and consequently radical changes in other physical factors which exercise much greater influences. Altho it is probably true that violent winds and driving rains destroy some adults, it is not known whether any considerable number actually perish from these causes. However, there is evidence that hard rains do interfere with moth activity, altho gentle rains do not necessarily stop moth flight provided other conditions are favorable. A few moths were observed in flight during nights when rain was falling quite briskly. Despite the fact that some moths were flying, neither mating nor oviposition was noted under such conditions, hence, altho the adult may not be physically impaired, its reproductive responses may be delayed and if delayed long enough may be completely inhibited. It is probable, however, that under the conditions mentioned oviposition does sometimes occur.

TEMPERATURE

Table 4 shows the close correlation between weather and moth activity as indicated by egg deposition and flight. This table also gives the total number of eggs found at daily intervals on a unit area of corn. These data were taken in a field not more than a mile from the experimental plots, hence it has seemed of value to include the record of the relative abundance of the moths as they were observed over these plots.

The range in minimum temperatures for the period considered was from 52 to 77° F. Egg deposition increased rapidly up to July 4. It seems that the high temperature of the previous three days had accelerated egg development within the ovaries to the extent that oviposition was induced regardless of the low temperature of July 3. On July 4 and 5 relatively few eggs were deposited and, the abundance of moths was not normal, due, without doubt, to the prevailing low temperatures of 52° and 58°, respectively. On July 6 the maximum day temperature was 88°, hence, altho the minimum temperature was 60°, there was increased moth activity, due again possibly to accelerated physiological processes within the insect thru the day and the consequent response at night. The relatively low temperature of July 6 to 9, inclusive, was accompanied by a decrease in both moths and eggs. Altho the rise in temperature in July 10 was noticeable it is doubtful whether the number of eggs found on that date was entirely due to the higher temperatures. It seems likely that here again the number of eggs was excessive due to the fact that the prevailing low temperature of the previous few days had caused considerable inactivity of the moths and hence allowed but little oviposition. That this is the explanation is indicated by the fact that on July 11 the number of eggs was greatly reduced despite the same minimum temperature and a higher maximum temperature. It will be noted that when the minimum temperature rose to 72° on July 13 a larger number of eggs was again deposited. With the decline in the number of moths after July 14 the number of eggs deposited could be expected to decrease.

In connection with this investigation it may be of interest to note that Barber (2) believed the decrease in the borer population of 1923 in the New England area was due in part to the decrease in

TABLE 4.—Showing Correlation of Moth Activity and Temperature, 1927

Date	Maximum temperature	Minimum temperature	Eggs deposited	Moths observed over plots
	Degrees	*Degrees*	*No.*	*No.*
June 28	85	56	0	6
29	93	65	18	28
30	95	74	102	45
July 1	95	77	213	....
2	84	70	415	122
3	72	57	638	....
4	72	52	20	....
5	77	58	73	82
6	88	60	218	195
7	75	63	435	27
8	76	56	130	88
9	76	60	190	....
10	80	63	1538	....
11	91	63	905	187
12	....	....	1062	184
13	....	72	1452	
14	91	70	1112	No
15	82	69	1125	
16	87	70	639	records
17	82	65	432	
18	80	60	351	taken
19	74	57	228	
20	72	52	179	
21	82	66	137	
22	79	62	196	
23	77	59	19	

the number of eggs deposited in 1923 as compared with 1922. Barber shows that the average night temperature during moth flight in 1923 was 57.6°, whereas that of 1922 was 65.8°. If a variation in temperature from day to day will influence moth behavior and egg deposition, then it is logical to believe that a variation in temperature from year to year as Barber has pointed out will also affect oviposition. For if the temperature remain low thruout the period of moth flight, thus causing stupor and inactivity of the moths, they are likely to die before depositing their full complement of eggs.

HUMIDITY

During a period of dry, hot weather in July, 1927, it was difficult to keep moths alive in cages where artificial infestation experiments were being conducted. Regardless of protection from the sun by leaves of the various host plants used and the further protection afforded by the cage itself and often by an additional cover of cheesecloth the moths died. The following experiment was conducted by J. P. Sleesman, of the summer staff, to aid in explaining the high mortality.

TABLE 5.—Showing Effect of Humidity on Longevity of Moths

Date	Dry can		Wet can	
	Moths dead	Temperature	Moths dead	Temperature
	No.	*Degrees*	*No.*	*Degrees*
July 13	0	82	0	79
14	1	83	0	79
15	6	82	0	78
16	17	83	0	82
17	20	83	0	82
18	....	72	1	72
20	....	75	2	72
21	....	72	3	72
22	....	75	5	72
23	....	74	6	72
24	....	73	9	70
25	....	73	9	70
26	....	73	11	72
28	....	79	11	78
30	....	....	20	....

Twenty newly emerged moths were confined in small screen cages and the cages then placed in a lard can containing a false bottom and two inches of water. Four layers of cheesecloth and a layer of cotton were used to cover the top of the can. A second lot of twenty moths was similarly placed in a can without water. Table 5 gives the results. It will be noted that the moths kept in the dry can were all dead by July 17, whereas all in the wet can were living on that date.

Experiments conducted in 1926 and 1927 in an attempt to determine the effect of humidity upon oviposition threw light upon the effect of the same conditions on the longevity of the moths. Three series were run in 1926, the difference being in the type of coverings used on the cages which confined the moths. In the first series, burlap covered the entire cage; in the second, the cages were similarly covered except that oilcloth was added to the top; and in the third, no covering was employed. In all cages the tops were conical in shape. In each series, except the first, two cages were used, one over which water was allowed to run continuously and the other a check. Atmometers were placed inside the cages to record the amount of evaporation. Twelve female and twelve male moths were placed in each cage at the beginning of the experiment. The results are recorded in Table 6.

TABLE 6.—Showing Oviposition Responses Under Different Conditions of Humidity, 1926

Cage	Actual		Relative	
	Evaporation	Eggs	Evaporation	Eggs
	cc.	*No.*	*cc.*	*No.*
Wet..................	9	2137	6	55
Wet..................	38	3861	26	100
Wet..................	54	1235	37	32
Dry..................	62	968	42	25
Dry..................	91	741	62	19
Dry..................	147	207	100	5

The cages with the lowest evaporation were wet continuously for a period of 6 days. The fact that the tests were run at successive dates probably accounts for the variation in the evaporation. For example, the two cages with 9 and 62 cc. evaporation, respectively, were identical, hence, because of differences in air temperature and humidity, they could be expected to show a rate of evaporation different from the next set which showed an evaporation of 38 and 91 cc.

It is of interest to note that the total number of eggs deposited was inversely proportional to the rate of evaporation, there being but one exception. There was a significant difference between the number of eggs deposited in the two wet cages, which had an evaporation rate of 9 and 38 cc., respectively. The cause of this variation is a subject of further research.

Cages in Series 1 and 2 were covered on top with oilcloth. This type of covering was used in order to prevent the water from dripping on the plants in the cage. Cages in Series 3 consisted of wire cloth, 12 mesh to the inch, but without any cover. Water was run over one cage continuously; but the action of the wind and sun was practically unimpeded, as indicated by the relatively high rate of evaporation.

TABLE 7.—Showing Effect of Humidity on Oviposition and Longevity of Moths, 1926

AVERAGE OF SIX CAGES

Cage	Evaporation cc.	Moths used No.	Moths alive in 6 days No.	Egg masses No.	Eggs No.
			Series No. 1		
Wet	34	24	8	42	1206
Dry	100	24	4	12	320
			Series No. 2		
Wet	91	24	24	51	1902
Dry	122	24	9	62	1363
			Series No. 3		
Wet	170	24	4	50	1366
Dry	249	24	0	1	44

A similar experiment was conducted in 1927. The cage employed was of a slightly different type and much larger. The cages used in 1926 were 18 inches in diameter and 2½ feet high; that used in 1927 was 3 feet in diameter and 7 feet high. The entire cage except the frame consisted of 12-mesh-wire cloth. The top was conical in shape, having been constructed in such manner that water would be conducted downward rather than run thru the meshes. The bottom of the cage was provided with a trough to drain the running water away from the corn plants.

TABLE 8.—Showing Effect of Humidity on Oviposition and Moth Behavior, 1927

Cage	Evaporation cc.	Moths used No.	Moths alive in 6 days No.	Masses No.	Eggs No.
			Actual		
Wet	32	30	12	100	3165
Dry	140	30	1	15	317
			Relative		
Wet	44	...	100	100	100
Dry	100	...	8	15	10

From these experiments it appears that the higher humidities with their resulting lower temperatures are more favorable for egg deposition. The results also show that the conditions best suited to oviposition are also conducive to longer life for the moths. In all cases there were more dead moths in the control cages, where the temperature was higher and the humidity lower. Under laboratory conditions it has been repeatedly noted that abnormally low humidity causes the premature death of many moths The difference in rate of egg deposition when moths are subjected to different treatment in the laboratory is further evidence of the influence of temperature and humidity. In 1924 the average number of eggs deposited by 106 females was 300. These moths were in small screen cages which were inside a screened insectary but not otherwise protected from the heat of the sun. Similar experiments conducted under shaded conditions yielded averages of between 400 and 500 eggs per female.

Transeau was the first to point out that the rainfall-evaporation ratio largely determines the vegetation type of the plains, the prairies, and the forest areas of the United States. This ratio was determined by means of atmometers. It was believed that a similar but more intensive study of a smaller area would not only yield further information relative to the interpretation of plant associations and formations but would also throw some light on the causes of certain responses of insects. The fact that Jones (unpublished thesis) and the writers (9) together with Transeau (27) had already shown a correlation between both the Mexican bean beetle and the European corn borer and vegetation types, gave this study considerable impetus. The project was begun in 1926 in cooperation with the Department of Botany of the Ohio State University, and Neale Howard of the Bureau of Entomology, in charge of Mexican bean beetle investigations. There are now more than 100 atmometers distributed at various places in the State. During the last year the study was enlarged to include the Departments of Agronomy, Forestry, and Plant Pathology of the Experiment Station. The project is of such nature that definite conclusions can not be drawn in much less than five or ten years.

WINDS

One of the most discussed of the physical factors is the effect of wind on the adults. Due to the assumption that the original Ohio infestation came from Canada by flight of moths across Lake Erie, it has been suggested that favorable winds may have aided them in their flight. Such statements as have been made are based largely, of course, upon opinions rather than facts. It is reported that the moths can fly long distances (31), hence it does not take a great stretch of the imagination to attribute extraordinary powers of flight to them when favorable conditions prevail. While the exact influence of wind on long distance flight has never been determined it is possible that it plays an important role in moth dispersion.

Repeated observations have been made on moth flight at night. For example, the effect of wind on moth flight was noted in observations conducted during the entire night of July 14, 1927. During the early part of the night the weather was ideal for moth flight. It was warm (about 70° F.) with a very light breeze blowing rather steadily from the southwest. Two men equipped with five-celled flash lights were placed on each of the four sides of a corn field to observe flight into and out of the field. Up to 10 o'clock practically all moth movement was into the field, after that time the movement outward was pronounced. A total of 577 moths were observed to enter and 416 to leave the field. During the most active period the direction of movement was from the northeast to the southwest, or against the breeze.

Study of moth flight over the experimental plots has also shown that moths may, but do not always, fly against a slight breeze; and that they fly with the wind when it grows a little stronger.

It might be possible that the direction of flight, whether with or against the wind, may be influenced by the physiological processes within the moths. The fact that moth flight out of the field mentioned took place after mating and after the period of maximum egg deposition suggests that with the completion of the reproductive responses the insect may be disposed to travel rather promiscuously; whereas, before that period it may respond more definitely to the odors emanating from the corn fields.

During the season of 1927 observations were made on the top of the Union Trust Company building, Toledo, in order to discover whether or not corn borer moths might be in flight at higher altitudes. Altho several species of other insects were noted there were no corn borer moths. Adults have been repeatedly observed to fly at heights of 30 to 40 feet. Neither of these observations, of course, proves or disproves that the moths fly at high altitudes either with or against the wind.

Barber (2) has suggested that heavy winds alone may not only destroy some adults but that they prevent the moths from depositing a normal number of eggs. His experiments were conducted under laboratory conditions, where the wind was provided by electric fans and was continuous. The writers have conducted similar experiments. Under field conditions continuous winds do not occur thruout the moth flight period, hence it is not likely that this condition interferes with oviposition to any great extent.

Relative to strong winds, however, it may be said that when these occur, moths that are in flight immediately seek shelter on the corn plants, if over a corn field, or on other plants if not near corn. A striking example of this response to wind was observed on the night of July 11, 1927, when moths were particularly abundant. Flying conditions up to 9:45 p. m. were considered ideal, as evidenced by the large number in flight. However, at 9:45 p. m. a strong wind suddenly rose and continued for about three-quarters of an hour. During this period few moths were seen in flight, but after the wind abated normal activity was resumed. This phenomenon has been noted repeatedly. There may be exceptions under certain conditions, and unless there be exceptions it is not probable that long distance moth flight is favored by strong winds.

Winds have been considered as the chief agency affecting moth flight or spread into new territory. For example, the data collected by the Federal Bureau of Entomology seem to indicate that the spread of the insect has been least rapid towards the corn belt. That is, the spread has been faster in eastern Ohio, Pennsylvania, and New York than in northwestern Ohio and Indiana. In general the prevailing winds in Ohio are from the southwest. It has been suggested that these prevailing winds tend to check the natural spread of the insect, hence its progress towards the Corn Belt has been retarded. This suggestion seems to be an excellent one altho there is some evidence that the nutrition factor is perhaps of equal or greater importance.

LIGHT RESPONSES

One of the most popular questions, and at the same time one of the most difficult to answer, is that which concerns the phototactic responses of the corn borer moth. The common notion that all insects are attracted to lights has led to the assumption that the corn borer moths could be trapped in sufficient numbers to aid in control. The fact that the moths are night flyers has further strengthened this assumption.

The writers have nothing of importance to offer at the present time relative to phototaxis. One of the authors of this section has undertaken a series of studies dealing with phototaxis with the intention of publishing the results.

FOOD

In the preceding paragraphs it has been established that certain weather factors may inhibit or accelerate the activities of the adults. Another physical factor which is of major importance is nutrition. Since the chief function of the adult is reproduction, any factors that influence the activity of moths must have a bearing upon the propagation of the species. It is of interest, therefore, to note the responses of the adults to foods with special reference to oviposition.

Oviposition being an instinctive act is not thought to be performed until it is induced by some sort of external stimulus or, in the absence of such a stimulus, by the possible necessity of emptying the oviducts because of pressure of the developing eggs. What is this stimulus? This question has been under consideration for some time. It has been assumed that it is a chemotactic stimulus which, acting upon the olfactory sense organs, is chiefly responsible in guiding the moths to corn fields. This assumption presupposes that there is an odor given off by the corn.

It has been observed that not only do the moths select corn in preference to other field crops but that they differentiate sharply between corn representing a difference of only a few days in development. That is, a field of corn planted on May 20, other factors being equal, will have in it a greater number of moths than one planted May 25. As will be pointed out later, the moths are clearly able to differentiate between plots of corn planted on different dates even tho the plots be small. Moreover they are known to have differentiated between varieties planted side by side on the same date. Circumstantial evidence alone, therefore, points to the presence of a substance emanating from the corn plant which varies either in quantity or quality or both according to the stage of development of the plant. The moths detect differences in odor and, therefore, exercise a significant degree of selection.

Since 1926 particular emphasis has been given to the study of the behavior of the adults over the experimental plots. These plots, as described later, consist of many varieties planted at regular intervals of time from May 10 to June 20. Observations conducted during the period of most active flight proved that, for some cause or other, the moths were most abundant on the early planted corn, which in all instances was further developed than that planted at the later dates. The moths were least abundant over the plots that were planted last. (See Table 9). Observations made in neighboring fields showed that the moths behaved similarly in respect to stage of development of the corn. Reference to Tables 69 and 70 in Section 4, page 134, will show that stalk infestation and borer population occurred in the same order, that is, they were highest in the May-10 planting and lowest in the later plantings.

TABLE 9.—Showing Daily Moth Flight, 1927

Corn planted	Date of observation											Totals	Rel.
	June				July								
	27	28	29	30	2	5	6	7	8	11	12		
May 10.......	1	2	8	16	29	25	62	7	24	64	54	292	100
May 20... ...	2	4	9	10	35	13	45	6	26	54	34	238	81
May 31.......	....	..	3	5	20	16	50	2	18	22	48	184	63
June 6	...	...	6	8	6	20	20	3	16	25	22	126	43
June 10.......	..	....	1	3	23	6	16	6	4	19	16	94	32
June 15.......	....	....	1	3	9	2	2	3	0	3	10	33	11
Totals.......	3	6	28	45	122	82	195	27	88	187	184	967	

Egg counts were not made on the various date-of-planting plots in 1927, but the counts of 1926 showed the same order of abundance of eggs as that of the moths.

On the assumption that the number of eggs deposited on corn planted under various conditions and circumstances, is a definite measure of its attractiveness to the moths, certain field and laboratory experiments were begun in 1925. The project was carried further in 1926 and 1927.

The immediate object of one of the tests in 1926 was to obtain a record of the comparative number of eggs deposited in each of two types of habitats within a given field, the height of the plant being used as the index in selecting the plots to be studied. The plots selected were of the same variety of corn, planted at the same time, and in the same field. The outstanding difference in environmental factors was almost entirely a matter of soil constituency, which was manifest by its effect in accelerating or retarding the rate of development in the respective plots. The results of these investigations led to the initiation of a large series of retardation and acceleration experiments, reported in Section 3, page 121.

The neld selected for this work gave excellent early growth, thus indicating that it would be a favorable one for borer infestation and study. There was a low area in which the corn grew subnormally or spindling as compared with the corn on the higher and uniform portion of the field. The variety, a yellow dent, was planted about the twenty-fifth of May and was cultivated in the normal manner.

A plot five by six hills was marked off in each of the two sections of the field and on these plots daily egg counts were made thruout the egg-laying period, the eggs being removed at the time of each observation.

The observations demonstrated that the vigorous corn was consistently higher than the spindling corn thruout the moth-flying period and also that the number of eggs deposited was directly proportional to the respective heights of the corn in the two plots. The total number of eggs on the vigorous corn was 40.5 per plant while on the spindling corn it was 14.4. At the time of tasselling the two plots of corn looked fairly uniform, altho it is probable that if yield records had been taken a considerable difference would have been noted.

The results of this experiment indicated that moths were more vigorously attracted to the rapidly developing corn than to the spindling or slow-growing corn. Consequently during the season of 1927 an effort was made to determine whether the number of eggs deposited occurred in the same order as the height, when ranges of plant heights of different varieties of corn were considered.

With this in mind two varieties of corn were grown in the same field in which there was a difference the previous year. The field was all planted the same day, part of it being planted to Burr-Leaming, a late variety, and part to Wisconsin 25, an early variety. Normal and subnormal plots consisting of 100 plants each were selected in both the Burr-Leaming and the Wisconsin 25 varieties. The plots were located in the midst of the field and were selected in such a way that there would be four plant heights for comparison. Daily egg counts on all plots were made thruout the oviposition period, the eggs being removed each day. The experiment was begun several days before eggs were anticipated and continued a few days after the moths apparently had ceased egg deposition, thus a complete egg record for the locality was obtained.

At the time the experiment started the relative heights of the different plots, arranged in descending order, were: (1) normal

Wisconsin 25, (2) normal Burr-Leaming, (3) subnormal Wisconsin 25, and (4) subnormal Burr-Leaming. Reference to Table 10 will show that there was a marked difference in height between the normal and subnormal Burr-Leaming, while there was a lesser difference between the normal and subnormal Wisconsin 25, the latter being considered only slightly subnormal.

In the subsequent records of these four plots, as shown in Table 10, the normal Burr-Leaming grew more rapidly than the normal Wisconsin 25 and by July 15 was the highest plot in the series. As a consequence, the two growth curves cross at the height of the oviposition period.

TABLE 10.—Showing Weekly Height Record in Egg-Count Plots Chio Field, 1927

Variety	Average height of plants, inches						No. eggs per plot		Relative height of plants
	July 1	July 8	July 15	July 22	July 29	During egg period	Actual	Relative	
B. L. normal......	23.9	34.4	50.2	66.1	80.8	51.1	46.2	100	100
Wis. 25 normal....	26.5	36.1	49.3	60.9	74.9	49.5	39.8	86	96
Wis. 25 subnormal.	20.5	29.3	42.1	55.2	66.8	42.8	26.5	57	83
B. L. subnormal...	13.1	20.0	31.8	42.6	55.6	32.6	8.2	17	63

A comparison of the normal Burr-Leaming with the subnormal Burr-Leaming, where there was a marked difference in plant height, showed a marked difference in the number of eggs deposited, the normal Burr-Leaming averaging 46.2 eggs per stalk and the subnormal 8.2. In the Wisconsin 25, where there was but a slight difference in growth between the two plots, there was much less difference in the number of eggs deposited as compared with the difference between the Burr-Leaming plots. These data show the analogy between plant height and number of eggs deposited.

When the four egg-records and the four plant-height records are considered together the significance of the height factor as an index of attractiveness to the moths is clearly shown. The number of eggs deposited varied directly as the plant height in every case. It may be noted that there is just one irregularity in the oviposition data, the eggs on the normal Wisconsin 25 fell below the number on the normal Burr-Leaming. Coincident with this, however, the respective heights of the two varieties changed in the midst of the egg-deposition period. The daily egg-deposition record and the total eggs deposited for each plot are given in Table 11.

Corn borer moths may select a host which is not necessarily best adapted to their progeny. It is a notable and important fact that even when plots of corn of different types were planted on the same date, side by side, under the same environmental conditions, the female did not select the type most suitable for establishment of her young. This fact is brought out very strongly in an experiment cited below, in which Golden Bantam and Clarage varieties were used.

TABLE 11.—Showing Daily Egg Record on Two Varieties of Corn Representing Different Conditions of Growth

Date	Normal Burr-Leaming	Normal Wisconsin	Subnormal Wisconsin	Subnormal Burr-Leaming	Total eggs
	No.	*No.*	*No.*	*No.*	*No.*
June 28	0	0	0	0	0
29	0	18	0	0	18
30	19	68	15	0	102
July 1	60	89	47	17	213
2	234	122	45	14	415
3	297	270	64	7	638
4	20	0	0	0	20
5	73	0	0	0	73
6	89	60	64	5	218
7	182	94	125	34	435
8	18	46	30	36	130
9	20	82	14	74	190
10	566	569	302	101	1538
11	368	319	133	85	905
12	255	507	257	43	1062
13	589	420	368	75	1452
14	303	321	435	53	1112
15	557	134	356	78	1125
16	170	314	115	40	639
17	222	142	28	40	432
18	39	164	101	47	351
19	154	44	30	0	228
20	98	46	35	0	179
21	66	66	5	0	137
22	56	39	45	56	196
23	0	0	19	0	19
Totals	4616	3982	2654	819	.....

It has been commonly thought that sweet corn normally carries a heavier infestation than field corn and consequently that the corn borer prefers sweet corn to field corn. In order to determine whether the moths show a preference between the two types of corn a comparison similar to the one described above was made in a series of plots of Clarage and Golden Bantam planted side by side at different dates.

Egg masses only were counted, but the number of stalks examined was correspondingly higher. The regular 1/40-acre plots were used in this work, the number of stalks per plot being approximately 270. Table 12 shows that for all planting dates there was a heavier oviposition on the Clarage plot than on the adjacent Golden

Bantam plot. Likewise it may be seen that in every series the Clarage also surpassed the Golden Bantam in height.

The results obtained show that the Golden Bantam sweet corn is not more attractive to corn borer moths than is Clarage field corn when planted at the same time. On the contrary more moths were attracted to Clarage than to Golden Bantam. The fact that attractiveness was again coincident with height of host plant even when comparing types as distinctly different as the two used here seems significant. The impression that sweet corn is preferred to field corn is likely due in part to the fact that sweet corn is normally planted earlier than field corn, hence the plants are higher and possibly contain more of the attractive element than the normal field corn, which is planted later.

TABLE 12.—Showing Correlation of Oviposition and Height of Plant in Clarage and Golden Bantam, 1927

Type	May 10 planting		May 31 planting		June 15 planting	
	No. egg masses	Av. ht. of plant*	No. egg masses	Av. ht. of plant*	No. egg masses	Av. ht. of plant*
Actual height and number of eggs						
Golden Bantam...	194	30.1 in.	56	25.8 in.	4	16.6 in.
Clarage.......	364	42.5 in.	142	34.6 in.	14	19.8 in.
Relative height and number of eggs						
Clarage	100	100	100	100	100	100
Golden Bantam.. .	53	71	39	74	28	83

*Based on height averages taken on June 28 and July 20, which dates include the maximum egg-laying period.

It has appeared that attractiveness of the corn plant to corn borer moths may be directly correlated with height of host plant as shown by the fact that consistently more eggs were found on plots of tall plants than of relatively low ones, regardless of varietal differences. It is by no means maintained that height of plant itself is the attractive agent but the evidence indicates that whatever the attractive element may be it increases with the development and growth of the plant, at least up to a certain point.

CHEMOTAXIS

The early observations of adult behavior led to the conclusion that the corn plants give off some odor which attracts the moths. All field investigations up to the present time have confirmed this conclusion.

On the basis that the moths are attracted to corn by odors which vary either in quality or quantity or both, depending upon the stage or rapidity of development of the corn, certain laboratory experiments were begun in 1926. The purpose of the experiments was to determine if possible whether such attractants could be demonstrated. If they could be demonstrated it was proposed to investigate their function in the plant. It was recognized from the beginning that a problem of this sort would demand the attention of a physiologist and a chemist as well as of entomologists.

In 1926 extracts were prepared from corn leaves by the steam-distillation and ether-extraction processes, and in 1927 from the whole corn plant by the petrol-ether-extraction process. These processes are too well known to be described here. Samples of corn were taken from different varieties and at different stages of growth. In order to determine the effect of the attractive agent on the moths it was necessary to devise a special apparatus known as an olfactometer. The results of the investigations thus far will not be given at this time, since the methods of procedure for the two seasons were not identical. While the laboratory behavior of the moths toward the extracts prepared in 1926 was comparable to the field behavior, the responses in 1927 were not consistent. The most that can be said at this time as far as actual moth behavior toward the extracts is concerned is that the experiments tended to show that corn contains some odorous substance. Until the olfactometer data can be made to parallel the field records no positive conclusions can be drawn.

The evidence now available, while not sufficient to permit conclusions, seems to warrant a brief statement of the hypothesis which appears most tenable. It had been noted repeatedly, other factors being equal, that the most vigorous growing corn in a field receives the most eggs, indicating that it is most attractive to the adults. This observation suggests that the difference in the attractiveness of vigorous and spindling corn is due to or is associated with the metabolism of the corn plant. The rate of metabolism in a vigorous plant should be greater than in a spindling plant. The more rapid rate of metabolism suggests that there should be a greater quantity of by-products given off. According to plant physiologists, essential oils are not only by-products of metabolism but they are of an odorous nature. Moreover, the high degree of turgor associated with high metabolic rates may further contribute to the amount of odorous substances released. Other factors being equal, a greater abundance of odorous substance should attract a greater number of moths.

A certain field in the Bono area that had been in corn in 1923 was disked and planted to corn on June 4, 1924, a late planting date for the area. This field was the highest infested in the State in 1924 despite its lateness. Why? It also had the highest infestation in 1923, but the stalks were burned and in addition there is no evidence that the moths emerging from debris in this field would have remained unless the corn was attractive. It is of interest to note that measurement records in this field showed that the corn was up four days after it was planted, thus indicating that growing conditions were optimum. An early-maturing variety was planted. Due to the high moisture content of this marsh soil the corn continued its rapid growth. Turgor pressure was undoubtedly high. Metabolism was rapid. Might it not be possible that the corn in this field was very attractive because a superabundance of odorous substance was given off due to high turgor pressure or a high metabolic rate? Moth behavior suggests that this may be a possible explanation, for this phenomenon has been noted elsewhere.

The graph (Fig. 3) may be cited as an example of varieties of corn to which the moths responded quite differently. The number of eggs was greater on Clarage than on Van Wye for every date of planting. These plots were planted in triplicate in the same field and as far as could be determined had the same opportunity for development. The two varieties are known to be quite different in their inherent behavior, the differences in growth probably having

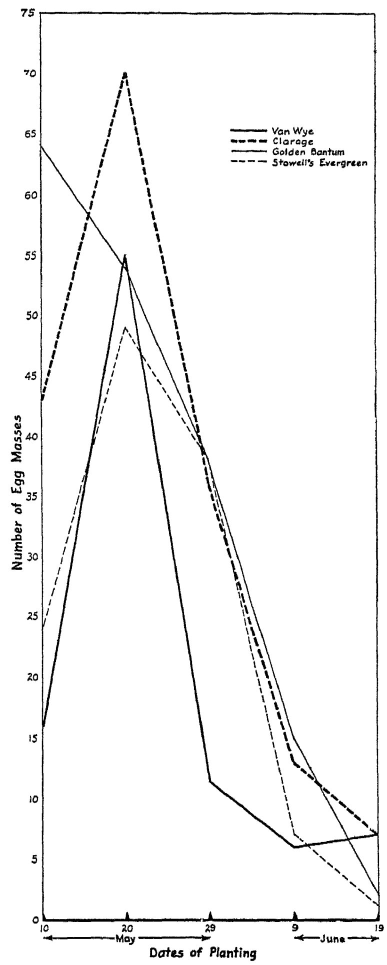

Fig. 3.—Graph showing response of adults to different varieties of corn

something to do with the apparent variation in degree of attractiveness. The same statements seem applicable to Golden Bantam and Stowell's Evergreen.

There is, therefore, the apparent probability that the stage of its growth, as well as its actual size, may influence the abundance or quality of odorous substance given off by corn.

MOTH BEHAVIOR IN DRY STORAGE

A practical question which has arisen during the course of investigations is, What is the effect of dry storage conditions on the behavior of the borer? Obviously both the adult and the larva must be considered. However, since the larva is more seriously influenced by such conditions than the adult and since the potential possibilities of the adult are contingent upon the fate of the larva it has seemed best to discuss both stages in Section 4, page 70.

BEHAVIOR OF MOTHS IN CAGES

To investigators it is generally known that the behavior of corn borer moths under caged conditions is very abnormal. In 1925 steel-frame cages 32 by 33 by 7 feet were erected in the varietal and date-of-planting field at Bono. Under these frames corn was planted at the optimum date for the Bono area. At the beginning of moth flight the frames were covered with 12-mesh wire cloth; at the end of moth flight the cover was removed. Debris that was known to contain a certain borer population was placed in quantity on the ground in these cages just after the screen was placed thereon. The amounts varied in the three cages. In one cage the debris carried the same population as that which remained on the ground in the average cleaned field of the community, in the second the amount was greatly in excess of the average, while in the third it was much less than the average. In the first and third cages there was scarcely a stalk of the grown crop infested and in the second cage which contained debris in excess the stalk infestation was less than that on the same variety and planted on the same date in the experimental plots adjoining the cage.

The purpose of the experiment was to determine the relative value of cleanup methods. Theoretically the corn in each cage should have carried a certain infestation; but since it did not, it seemed that the purpose of the experiment was not accomplished.

In 1926 in one of the cages Northwestern Dent, a very early variety, was planted May 15. The cage was again covered during moth flight. Shortly after the first of June approximately 2000 larvae in naturally infested debris were placed on the ground under the cage. Moths later emerged from these stalks. Theoretically there should have been 400,000 eggs deposited on the 243 stalks of corn in the cage. A 15 percent survival would have resulted in a borer population of nearly 250 per stalk. As a matter of fact the final population was less than two borers per stalk.

It was determined that the emergence of the moths in the debris inside the cage was practically 100 percent. Moreover, the time of emergence was not far from the normal. However, it was also observed that, instead of depositing all of their eggs on the corn, the adults oviposited on the frame of the cage, the wire cloth covering, or on the few small weeds inside the cage. In smaller cages moths were seen to insert their ovipositors thru the mesh of the wire cloth and drop the eggs on the outside of the cage.

It is also of importance to note that, in addition to the abnormal behavior of the adults, the corn did not behave normally after the cage was covered. During the five weeks while the cage was covered the corn became spindling and lodged considerably. Abnormal corn development was inimical to moth behavior and larval establishment.

Influence of Biotic Factors

Altho the physical factors influencing adult behavior are important, the biotic factors are unimportant. The adult, as far as is known, is comparatively free from attack by predators and parasites.

3. THE EGG

J. B. POLIVKA AND J. R. SAVAGE

In this section it is intended to discuss those physical and biotic factors which may affect the egg during its incubation period.

Influence of Physical Factors

It has been a common observation that egg masses are frequently dislodged from the leaf to which they were attached. As the eggs are extruded from the body of the female they are practically spherical. While still plastic they are pushed down on the leaf by the tip of the abdomen, or ovipositor, the abdomen moving from side to side as they are extruded. After one row is deposited another is placed in such fashion that it slightly overlaps. This operation continues until the mass becomes so large that the female either must move forward or fly to a new leaf. Such observations as have been made indicate that the eggs are secured to the leaf in a purely mechanical manner, for as the female presses them downward the plastic eggs become adapted to the ridges and grooves on the leaf.

A knowledge of the mechanics of the attachment of the egg masses and the habits of the plant in reference to leaf rolling suggest that as the leaf rolls and unrolls it would tend to loosen the egg mass, the result being dislodgment. This is exactly what happens. High temperatures accompanied by a low soil moisture content and drying winds are, therefore, conducive to the dislodgment of egg masses. In addition to rolling, the leaves are also subjected to the action of winds. The constant swishing and twisting of the leaves increases the chances of loosening the egg masses.

In order to ascertain the exact effect of these factors on dislodgment, Ralph Neiswander and H. G. Walker, of the summer staff, kept records of 107 egg masses under field conditions. Within a few hours after a mass was deposited it was marked. It was examined every day until it was lost or until the eggs hatched. It was found that 2.8 percent were either injured or destroyed by other insects, 11.2 percent were dislodged or lost, and 86 percent hatched on the leaf in position for the larvae to begin feeding. It was observed also that the flexing of the leaf, because of high transpiration, may injure the marginal eggs of the mass, whereas the remainder of the eggs may hatch normally.

Aside from dislodgment and consequent destruction of the egg mass, an effective check on hatching is a combination of high temperature and low humidity. For example, on July 12 W. V. Balduf and A. A. Bowers of the summer staff, observed larvae that were hatching normally between 9:20 and 10:34 a. m. At that time 22 larvae had not yet emerged from the egg shells, altho 12 of these 22 had punctured the shells in preparation for coming out. One larva succeeded in emerging shortly after 12 m., but the remainder made no further attempt to emerge, that is, those that had already made exit holes did not enlarge them and the others did not begin to make holes during the remainder of the day. Up until 1:10 p. m. the larvae inside the eggs were more or less active but after that time they became increasingly inactive, obviously due to desiccation. The moisture content of the eggs was decreased, undoubtedly by evaporation, and that of the larvae themselves was diminished, presumably by the same process.

While the eggs and embryonic larvae were undergoing this behavior the temperature rose from 78° F. at 9:30 a. m. to 91° at 11:20 a. m. (hygrothermograph in standard shelter) and 92.5° by standard thermometer in the insectary in the shade. The maximum temperature was 95° at 1:20 p. m. During the period there was a slight breeze.

The remaining larvae died in the shell. In other instances there were like casualties under similar conditions and larvae removed from the eggs were stiff. When desiccating larvae within the eggs were moistened they later hatched if desiccation had not gone too far. Moisture, of course, would also tend to lower the temperature, but, even so, temperature appeared to be the more operative of the two factors.

Experiments in which egg masses of known age were exposed in the same manner to the direct rays of the sun with a temperature ranging from 60° to 96°, showed a higher percentage of non-hatch than checks which were in the shade; the difference amounted on an average to 10 percent.

Corroborative evidence of the desiccation of eggs is shown by artificial establishment records for 1924, 1925, and 1926. When egg masses were removed from their original site of deposition, desiccation was encouraged. Due to desiccation together with other causes the establishment resulting from artificial infestation is likely to vary considerably, depending upon the age of the mass when removed and the treatment it receives thereafter. In case the temperature was not high enough to cause death, the direct rays of the sun hastened incubation. Larvae emerging from eggs so treated were brown, as would be expected.

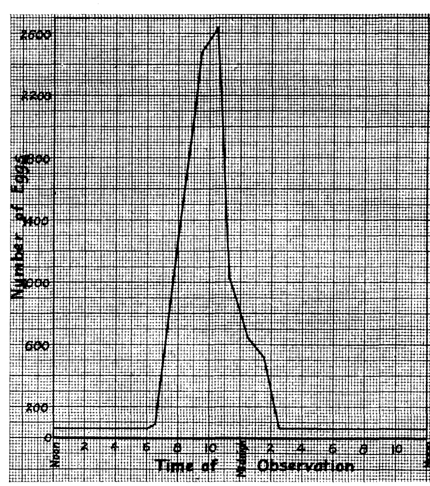

Fig. 4.—Graph showing time of oviposition

When it is considered that less than 14 percent of the eggs are on the upper surface of the leaves and that not all of them are exposed to direct rays of the sun, it is not likely that direct rays of the sun cause the desiccation of a very great number.

Figure 4 shows that egg deposition may occur at any time within a 24-hour period provided weather conditions are not unfavorable. Ralph Neiswander, of the summer staff, showed in 1927 that 90 percent of the eggs were deposited between 7 p. m. and 2 a. m. A total of 129 masses, containing 5116 eggs, or 48 percent, were deposited between 9 and 11 o'clock p. m. The peak of oviposition was reached at about 10:30 p. m. A few eggs were deposited during the day, the exact hour of deposition not being known.

Observations in 1927 of 1086 egg masses, averaging 16.5 eggs per mass, showed that 17.9 percent of the eggs were deposited on the sixth leaf, counting from the base of the corn plant, 16.9 percent on the seventh leaf, and 90 percent on the third to ninth leaves, inclusive. (Figure 5). As to the position on the leaves, 86.8 percent of the masses were on the under surface, beside the midrib. It appears that the curvature of the leaf and the channel next to the midrib facilitate the mechanics of egg deposition.

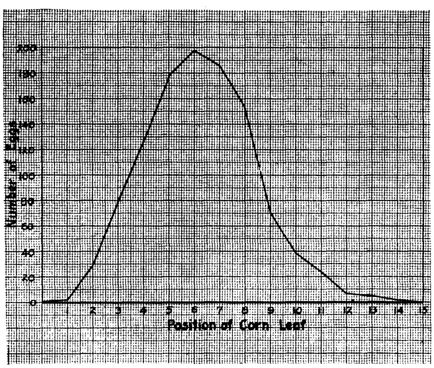

Fig. 5.—Graph showing distribution of eggs on corn plant

In the course of investigations relative to the egg stage an attempt was made to determine the number of heat units required for hatching. The age of each mass was accurately known. The number of hours of the incubation period was determined by calculating the difference between the time of egg deposition and emergence of the larvae. Temperature records were taken with standard equipment located in the insectary.

A record was obtained on 81 egg masses. The incubation period varied from 114 to 254 hours, the average being 181.6 hours. The record shows that 97.9 percent of the eggs hatched. Keeping the field data in mind, it would seem, therefore, that since about 14 percent of the egg masses deposited in the field are destroyed or lost and 97.9 percent of the eggs in undisturbed masses hatch, approximately 84 percent of the eggs deposited under normal conditions hatch upon the plant with the larvae in position to start feeding.

The length of the incubation period varies with the temperature. The period is long in cool weather and short in warm weather.

It has been shown by other investigators that the rate of development of insects is slowed up after a certain high point of temperature is reached. On the basis of this information the data relative to the incubation of the various egg masses were compared and the effect of the total number of heat units, two-hour-degrees, on incubation was checked. The two-hour-degrees above a certain arbitrary point were either discounted or not considered at all. It was found that the total number of two-hour-degrees between 65 and 85 degrees F. accumulated by the different egg masses was not widely divergent. The range was between 460 and 640 and the average 571. Within the 570 to 630 two-hour-degrees, 65 percent completed incubation.

The results, of course, are not exact due to the fact that temperature alone is considered. However, they seem to conform to the "straight line curve" suggested by Peairs, (18) Shelford, (24) and others, with the lower extremity of the curve being at 65 degrees and the upper extremity at 85. In cases where the incubation period was longest the average number of two-hour-degrees was low, indicating that there is a certain amount of development below 65 degrees but much slower than the rate above. This corresponds to the curve below the straight line. The data seem to indicate that the development of the embryo begins somewhere below 65 degrees, but after 65 is reached the rate increases in direct proportion to the temperature until 85 degrees F. is reached, after which it falls off rapidly.

Influence of Biotic Factors

Relative to the biotic factors inimical to the egg stage, there is no evidence that they are of significant importance in Ohio. While it is known that the common ladybird beetle, (*Ceratomegilla fuscilabris* Muls) devours egg masses, the exact percentage destroyed is not known, but it is probably very small. A red spider (species undetermined) is also known to play a part in biotic control, but here again no definite information can be given. The egg is undoubtedly attacked by other predators and parasites but it does not seem probable that any of them are of consequence in retarding the accumulation of the borer under Ohio conditions. Barber (2) showed that in the New England area, *Trichogramma minutum* Riley may be of considerable importance in some years, depending largely upon the weather factors. A larva of the genus *Chrysopa* was also observed to feed on a corn borer egg mass. The individual died before reaching the adult stage, hence the species was undetermined.

4. THE LARVA

C. R. NEISWANDER, J. B. POLIVKA, W. V. BALDUF, AND L. L. HUBER

Inasmuch as the larval stage is the destructive stage of the insect it is extremely important that every detail of the insect's behavior in this stage be known. It is indeed unfortunate that, despite the abundance of corn borer literature, there is at present so little specific knowledge on the behavior of the larva and the causes therefor. It is not too much to predict that the successful operation of such cultural and insecticidal control methods as may be found feasible in the future will in large part be based on an intimate knowledge of the behavior of the larvae.

Influence of Physical Factors

HATCHING

The larvae that are about to hatch can be seen to move within the egg shell. These movements are (1) chewing actions of the mandibles and (2) change of position of the whole body. Before emerging the larva lies in a more or less horse-shoe-shaped position within the egg, the ends sometimes slightly overlapping. Due to the convex upper surface of the egg shell, the larva can do no other than chew a hole into the edge of the shell. This hole at first is merely a transverse slit, highest directly in front of the mandibles and sloping down equally on each side. In further preparation of the exit hole the larva eats some of the shell, while other fragments are deposited about the hole.

In the act of hatching the larva assumes an S-shape, thus giving it leverage to push itself out thru the exit hole. The hole is not always quite large enough to allow easy emergence, and the larva sometimes backs up to enlarge it, the shell being so strong that it has never been observed to break or tear. Emergence itself usually requires about one minute but under some circumstances may consume considerably more time. In some instances, apparently depending upon the temperature and the location of the egg mass, the larvae eat a part of the egg shells after emergence.

HABITS OF YOUNG LARVAE

As suggested by field experiments, under optimum conditions of about 80° F., no rain, and ample shade, newly-hatched larvae remain close to one another giving the impression that they are gregarious. Perhaps it is natural to expect to find all the larvae grouped upon and near the shells from which they came, since the individuals appear in rapid succession after hatching begins. For example, one mass of 29 eggs was observed to hatch within a period of 15 minutes, with the exception of one egg from which the larva was delayed for more than an hour. The grouping habit is most common in cases where the egg mass has been deposited on the lower surface of the leaf. This is probably due to the shade factor, for when such leaves are turned to the direct sunlight the assemblage is dispersed almost immediately. When conditions are not favorable to the grouping habit, for example, when the sun is bright and hot, the larvae soon begin to wander about. This apparently aimless wandering sooner or later brings the small larvae to the margin or tip of the leaf. At this point, due either to accidental falling or perhaps to an impulse to go further, they adopt the aerial mode of transit, which may be described as spinning. The larva simply attaches a silken thread to the corn leaf and lowers its body much as a spider would do. No larva was ever seen to drop directly to the ground from want of a line. Descent is usually made by successive short drops. First instar larvae descend an average of four or five inches, seldom reach the ground, and often not even the lower leaves. A larva may dangle in the air for several minutes and then ascend to the leaf.

Spinning is a very common reaction of the first instar larvae. Several stimuli seem to be responsible for this behavior. First, most spinning occurs on leaves lightly blown by winds of low velocity, that is, about two miles per hour; winds with higher velocity, or 5 miles per hour, cause the young larvae to cling to the leaf surface. It seems that spinning is incidental to locomotion in that in crawling about on the wind-blown leaves the larvae frequently lose their foothold and save themselves from falling to the ground by spinning the silken line.

In the second place, spinning is stimulated by slippery leaf surfaces, such as upon the midrib, and particularly where the larva is passing up or down a steep incline near the base or tip of the leaf. This response is perhaps more common in mature larvae than among the early instars. Whenever footing becomes hazardous or the larva is disturbed, a silken framework is attached to the leaf surface by turning the head to one side then to the other, producing short lines placed diagonal to the long axis of the larva. Careful observation has shown that this ladder-like arrangement of silken threads serves as an aid to the larva in crawling. This particular habit was forcibly demonstrated in an attempt to evolve a field cage or trap for use in plowing experiments. Oilcloth was used because of its smoothness but it was discovered that unless it was placed at an angle the mature larvae could easily traverse a four inch strip by means of the silken ladder. Even with the cloth at an angle of 90 degrees the larvae could ascend part of the distance. Usually, however, the ladder broke from the weight of the larva before it had advanced the entire length of its body.

Lastly, it appears that larvae frequently descend from the edge of the leaf because of an impulse to wander further still. This occasion for dropping by means of the silken thread is perhaps the chief of all the reasons, inasmuch as it occurs on quiet leaves indoors as well as on wind-blown leaves out of doors.

Spinning is most common in the open when the wind is fitful, the lulls encouraging the larvae to crawl and the sudden stirring of the leaves by the wind catching them unprepared to hold fast. It may be said that the spinning habit is most manifest during the first two or three days after hatching, but it is common reaction for all stages of the larvae.

Silk is also spun when larvae crawl into a partially enclosed compartment, such as the leaf axil, the center of the plant, or the tassel head. Much time apparently is spent in building up a complete enclosure of silk, which, it seems, provides some protection and shelter for the larva in moulting, gives leverage in feeding, or perhaps serves to prevent intrusion of other larvae. The frass that is extruded from tunnels is also frequently interwoven and held together by silken threads, thus accounting for its accumulation around the entrance holes.

The larvae that survive their tendency to wander about on the leaf surface or to dangle from its edges commonly come to rest in one of two places on the plant, altho a small percentage may be found elsewhere. Their specific location within the plant depends in large measure on the stage of development the plant has reached. The usual entrance to the plant for the majority of the larvae is at the base of the leaves that form the top portion of the plant. The bases of these leaves at this time are contiguous below and their development has not reached the stage in which the ligules are visible at the angle of incidence of one leaf with the others.

TROPISMS

The leaves are thus in contact with each other and afford an excellent opportunity for the larvae to find shelter between the leaf layers. It is under such conditions that the larva gives its first exhibition of what is possibly one of its most important and most distinct tropisms, namely, the thigmotropic response, or the response to pressure.

Closely associated with thigmotropismic response of the corn borer, is that of phototropism. As a usual thing the two responses are rather closely allied. In order to get in contact with objects, the organism usually must move out of the light. In other words, a positively thigmotropic organism is usually negatively phototropic. It is not an easy matter therefore to ascribe either reaction as being the definite cause of the behavior of the insect in any specific case.

Except during the period which immediately follows hatching, the corn borer larvae are seldom seen in exposed places. This reaction to light and pressure is so marked that young corn borer larvae are often present in the fold of a leaf that has become doubled over. In fact they are commonly found in any place where there is subdued light. That most larval movement outside of the tunnels is at night is further evidence of this joint tropismic reaction. Even in a darkened chamber the larvae are not to be found in the open but in crevices, if there be any. Partially grown larvae are commonly found in the axil of the leaf in a position parallel with the ligule, with their exposed surface enclosed by a web. Even when feeding amid the tassel buds where the larvae are partially exposed the exposed portion is covered with a web.

When these tropisms are satisfied the larva ceases its wandering and begins to feed. It is very doubtful whether any larva regardless of size successfully feeds without first satisfying these tropisms.

In a number of experiments in which the movements of larvae in the different directions of the compass were carefully recorded there was found to be no consistent difference when the record extended over a period of several days and nights. The number moving in one direction was practically equivalent to the number moving in any other direction; altho there was usually slightly more moving north than south. In a series of turn table experiments, however, in which larvae were exposed to the direct rays of the sun it was found that they immediately oriented themselves in a direction away from the sun and moved rapidly in that direction. After turning the table so as to reverse the direction of the larvae an orientation to the opposite direction occurred at once. Corn borer larvae thus give a distinctly negative phototropic response.

LARVAL GROWTH PERIOD

As pointed out in the discussion of the egg stage, the oviposition period normally ends during the latter part of July. Accordingly by the first of August the borers are all either in the younger instars or range up to a little more than half grown.

In order to obtain the seasonal progression of the insect thru the larval instars, under normal conditions in the field, weekly records were taken by H. G. Walker, G. Sleesman, and others of the summer staff, on the stages of the larvae by careful dissection of a definite number of plants. In the 1927 record (Table 13) the study was started during the week of July 18, about a week before the close of the egg-deposition period. Twenty-five stalks a week were dissected in each of two fields thruout the remainder of the period of larval growth. The data obtained are combined in Table 13 to give the average weekly development record for the area.

It must be remembered that the period of egg deposition normally begins during the last few days in June or the first days of July. On July 18, therefore, the individuals found on the plants would range from eggs just deposited to larvae about two weeks old. Inasmuch as the larvae spend an average of a little less than a week in each of the first four instars it can be readily seen that there would be great variation in the larval stages at any one time.

In the dissections of July 18, 41 percent of the larvae were in the first instar, while a few were in the second and third. There were 49.7 percent still in the egg stage, but the number of eggs present was only 12 percent of the total number deposited, indicating that there already had been a high mortality. On August 30 the larvae were practically all sixth instar. The actual growing season of corn borer larvae was thus from about July 20 to September 1, a period of approximately six weeks.

FEEDING REACTIONS

The first food of young corn borer larvae consists largely, if not altogether, of the tender leaf tissue of the plant or other parts of similar nutritive value. Characteristic leaf feeding punctures are irregular in shape and may extend entirely thru the leaf tissue, altho there are usually some punctures that extend only to the opposite epidermis. In areas of severe infestation, leaf injury due to the feeding of young larvae becomes prominent before any other indication is seen. As positive evidence that this injury is due to corn borer larvae it may be stated that small particles of whitish

TABLE 13.—Instar Record by Weekly Intervals, Bono, 1927

Date	Stalks dissected	Total borers	Av. borers per stalk	Eggs		1st instar		2d instar		3d instar		4th instar		5th instar		6th instar	
	No.	*No.*	*No.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*
July 18–25	50	435	8.7	216	49.7	181	41.6	31	7.1	7	1.6	......	......	......	......	......	......
July 26–August 1	50	265	5.3	......	......	55	20.7	88	33.2	54	20.4	64	24.2	4	1.5	......	......
August 2–8	50	359	7.2	......	......	8	2.2	41	11.4	131	36.5	116	32.3	48	13.4	15	4.2
August 9–15	50	313	6.3	......	......	......	......	8	2.6	20	6.4	64	20.4	123	39.3	98	31.3
August 16–22	50	248	5.0	......	......	......	......	......	......	3	1.2	34	13.7	51	20.6	160	64.5
August 23–29	50	203	4.1	......	......	......	......	......	......	......	......	4	2.0	18	8.9	181	89.2
August 30–September 5	50	163	3.3	......	......	......	......	......	......	......	......	1	.6	......	......	162	99.4
September 6–12	50	190	3.8	......	......	......	......	......	......	......	......	......	......	2	1 1	188	98.9
September 13–19	50	122	2.4	......	......	......	......	......	......	......	......	......	......	......	......	122	100
September 20	50	159	3.2	......	......	......	......	......	......	......	......	......	......	......	......	159	100

frass are commonly seen at the margins of the eaten surfaces. No other species has been seen to leave the characteristic feeding punctures and also leave remnants of frass. The adult of the southern corn root worm *(Diabrotica 12-punctata* Oliv.), commonly causes leaf injury similar to that of young corn borer larvae. In case of injury by this beetle, however, there are never any fragments of frass.

Because of the conspicuousness of the injury by the young larvae to foliage of corn plants, it is sometimes said that they feed on the exposed surface of the leaves until they have reached the third or fourth instar. Behavior of this nature would involve the insect in a direct reversal of tropismic response, which is not the case. Almost immediately after hatching young corn borer larvae display the tropismic responses mentioned.

A more careful examination of the leaf injury caused by young larvae shows a preponderance of feeding on the part of the leaf nearest the base, with the feeding punctures increasing progressively toward the basal portion. This condition is explained by the fact that practically all the leaf feeding of young larvae is done while the bases of the leaves are still rolled. The larvae follow the leaves toward the base until they come within the roll where their tropisms are apparently satisfied. They are then between layers of tender leaves and can feed readily on either surface of their feeding chamber. During this time the leaves are growing rapidly and the injured portion soon appears outside of the roll. As much as two or three inches of leaf surface may be exposed within a 24-hour period. While the leaf is growing and becoming more and more exposed the young corn borers keep progressing in the opposite direction and remain in seclusion. The young larvae, if present, can always be found down in the crown of the plant amid the layers of the leaf roll.

When the tassel head first appears, a large percentage of the larvae are commonly seen to have eaten thru the surrounding leaf tissue and to be feeding in or amid the pollen buds. They frequently eat out the pollen bud or tunnel into it leaving only a shell. During this time the larvae are largely second or third instar. The size of the insect at tasseling time, of course, depends upon the correlation between the development of the corn and the development of the insect. Normally, however, first and second instar larvae feed upon the leaf tissue still in the rolled crown. Second and third and some fourth instar larvae feed on or in the pollen buds. Frequently, however, fourth instar larvae found feeding on pollen buds, have webbed together a number of buds and are feeding under the web. This may be true of third instar larvae as well. The reaction is probably explained by the fact that the food itself is very satisfactory, but there is not sufficient space within the tassel bud to enclose a larva.

As the tassel grows farther away from the leafy part of the plant and spreads out its branches the larvae continue to maintain their negative phototropic and positive thigmotropic responses. These tropisms may be satisfied in either of two ways; the larvae may burrow into the stems of the tassel and feed upon the pith permanently, thus becoming "borers" for the first time; or they may move downward and come to rest at the base of a leaf and the back of the leaf sheath whence they may bore into the plant. If the leaf sheath has not yet loosened from the plant but fits snugly around it, the larvae commonly feed under a web in the angle formed by the base of the leaf. In this manner they eat down into the leaf and occasionally live temporarily in a tunnel within the midrib, but usually they chew thru the ligule and bore into the stalk behind the leaf sheath.

The main food of the advanced instars of the corn borer consists of the pith of the corn stalk. Seldom do the larvae bore into the plant before they have reached the fourth instar, and many not until they are in the fifth. The number of larvae boring into the plants increases steadily as the larvae and plants grow. Coincidently, of course, the percentage of borers in other parts of the plant decreases. For instance, the number of borers feeding on the pollen buds and in the tassel stems at the time the tassel was first appearing was as many as 32.6 percent of all borers taken. As the tassel spread out, however, the number decreased rapidly, the larvae going to other parts of the plant.

Tables 14 and 15 indicate the position of the borers in the plant thruout the season. It may be seen that the percentage of borers inside the plant increased as the season progressed until maturity of the crop, when approximately 95 percent were within the stem. The tables also show that the number of borers in the ears was highest at the roasting ear period, and gradually decreased from that time until fall. Possibly the decrease in the percentage of borers in the ears is associated with the change in the moisture content or texture of the ears as they mature, or the nutritive value of the food in that particular part of the plant.

TABLE 14.—Position of Borers in Plant, 1926

		Dissection period					
		August 1-15	August 16-31	September 1-15	September 16-30	October 1-15	October 16-30
Plants dissected	No.	22	84	83	55	24	98
Total borers	No.	169	575	431	345	151	546
Borers in stalk	No.	70	407	379	314	140	522
	Pct.	41.4	70.8	87.9	91.0	92.7	95.6
Borers back of leaf sheath or leaf base	No.	58	82	25	10	3	10
	Pct.	34.3	14.3	5.8	2.9	2.0	1.8
Borers in shank of ear	No.	4	13	7	7	7	9
	Pct.	2.4	2.3	1.6	2.0	4.6	1.6
Borers in ear	No.	20	57	15	13	1	2
	Pct.	11.8	9.9	3.5	3.8	.7	.4
Borers in tassels and pollen buds	No.	17	16	5	1	0	3
	Pct.	10.1	2.8	1.2	.3	0	.5
Internodes							
1	No.	2	11	24	6	4	22
	Pct.	1.2	2.7	6.3	1.9	2.9	4.2
2	No.	4	45	57	26	13	65
	Pct.	2.4	11.1	15.0	8.3	9.3	12.4
3	No.	9	56	58	64	29	90
	Pct.	5.3	13.5	15.3	20.4	21.7	17.2
4	No.	9	48	51	50	27	79
	Pct.	5.3	11.8	13.5	15.9	19.3	15.1
5	No.	7	49	29	36	12	50
	Pct.	4.2	12.0	7.7	11.5	8.6	9.6
6	No.	3	45	30	38	16	41
	Pct.	1.8	11.1	7.9	12.1	11.4	7.9
7	No.	6	43	27	22	5	46
	Pct.	3.6	10.6	7.1	7.0	3.6	8.8
8	No.	6	26	25	15	12	35
	Pct.	3.6	6.4	6.6	4.8	8.6	6.7
9	No.	3	18	18	21	4	25
	Pct.	1.8	4.4	4.7	6.7	2.9	4.7
10	No.	3	10	23	7	3	27
	Pct.	1.8	2.5	6.1	2.2	2.1	5.2
11	No.	5	13	15	6	2	18
	Pct.	3.0	3.2	4.0	1.9	1.4	3.4
12	No.	6	15	9	15	7	14
	Pct.	3.6	3.7	2.4	4.8	5.0	2.7
13	No.	2	14	6	3	3	7
	Pct.	1.2	3.4	1.6	1.0	2.1	1.3
14	No.	5	10	4	2	2	2
	Pct.	3.0	2.5	1.1	.6	1.4	.4
15	No.	....	1	3	3	3	1
	Pct.	....	.3	.8	1.0	2.1	.2

TABLE 15.—Position of Borers in Plant, 1927

		Dissection period						
		July 16–31	August 1–15	August 16–31	September 1–15	September 16–30	October 1–15	October 16–30
Plants dissected	No.	100	100	125	100	125	75	50
Total borers	No.	484	672	526	322	365	232	109
Borers in stalk	No.	19	122	313	281	338	220	105
	Pct.	3.7	18.2	59.5	87.3	92.6	94.8	96.4
Borers back of leaf sheath or at leaf base	No.	265	194	92	13	9	3	1
	Pct.	54.8	28.9	17.5	4.0	2.4	1.3	.9
Borers in shank of ear	No.	0	2	16	14	5	4	1
	Pct.	0	.3	3.1	4.3	1.4	1.7	.9
Borers in ear	No.	18	65	48	11	6	1	1
	Pct	3.7	9.7	9.1	3.4	1.6	.5	.9
Borers in midrib of leaf	No.	43	69	6	0	0	0	0
	Pct.	8.9	10.3	1.1	0	0	0	0
Borers in tassels and pollen buds	No.	139	220	51	3	7	4	1
	Pct.	28.7	32.6	9.7	1.0	2.0	1.7	.9
Internodes								
1	No.	....	....	....	....	2	2	....
	Pct.	....	....	....	....	.5	.9	....
2	No.	1	1	4	17	21	8	4
	Pct.	.2	.2	.8	5.3	5.8	3.4	3.7
3	No.	4	6	22	44	51	30	13
	Pct.	.8	.9	4.2	13.7	14.0	13.0	12.9
4	No.	5	16	43	49	49	39	15
	Pct.	1.0	2.4	8.2	15.2	13.4	16.8	13.8
5	No.	3	17	44	37	71	49	26
	Pct.	.6	2.5	8.4	11.5	19.5	21.1	23.9
6	No.	1	16	38	26	36	29	9
	Pct.	.2	2.4	7.2	8.1	9.9	12.5	8.2
7	No.	....	13	36	36	33	22	12
	Pct.	....	1.9	6.8	11.2	9.0	9.5	11.8
8	No.	1	9	41	32	21	16	9
	Pct.	.2	1.3	7.8	9.9	5.8	6.9	8.2
9	No.	2	17	18	17	18	4	7
	Pct.	.4	2.5	3.4	5.3	4.9	1.5	6.4
10	No.	1	16	28	7	11	10	2
	Pct.	.2	2.4	5.3	2.2	3.0	4.3	1.8
11	No.	1	6	18	8	8	2	1
	Pct.	.2	.9	3.4	2.5	2.2	.9	.9
2	No.	....	3	5	4	9	5	3
	Pct.	....	.4	1.0	1.2	2.5	2.2	2.8
13	No.	......	2	9	3	6	3	2
	Pct.	....	.3	1.7	.9	1.9	1.3	1.8
14	No.	....	....	6	....	....	1	2
	Pct.	....	....	1.1	....	....	.4	1.8
15	No.	......	......	1	1	2	......	......
	Pct.	.....	.....	.2	.3	.5	....	....

Along with the movement of the larvae to different parts of the plant as the season progresses there was also a movement from the upper toward the lower internodes. Tables 14 and 15 show the location of the borers inside the plant stem by internodes. They indicate a rather uniform increase in the borer content of the first five internodes as the season advances. They also show a preponderance of borers in the lower portion of the stalk, the third, fourth, and fifth internodes containing nearly one-half of the total number. This is a direct indication of the downward movement of the borers within the plant.

The same progressive downward movement was shown when individual height measurements of the position of the borers in the plants were taken. From the records of the last two years (Table 16), it may be seen that there was a progressive increase thruout the growing season in the percentage of borers within a given height of plant. For instance, in the first two weeks of August in 1926 the number in 12-inch stubble was 8.3 percent of the total, while in the first part of October, or at the end of the growing season, it was 36.3 percent. In like manner in 1927, during the first half of August the number of borers in 12-inch stubble was 9.2 percent of the total, while in the first half of October it was 36.4 percent. This general increase may be seen to be true of all stubble heights up to 24 inches. Conversely, the number of borers above the 24-inch height decreased steadily.

The 1927 record was started two weeks earlier than that of 1926. An interesting point in a study of this longer period is the fact that there was a higher percentage of borers in each of the different plant heights for this first two-week period than there was for the following period. The foregoing statement may be explained by the fact that during this period the plant is growing vigorously and as a result the borers are carried upward by plant growth more rapidly than they move downward because of their natural tendencies.

The percentages below a given plant height were consistently higher in 1927 than in 1926. No definite cause is given for this variation. A notable coincidence exists, however, in the fact that 1927 was abnormally dry.

TABLE 16.—Showing Stubble Height and Population by Two-Week Periods

	July 16—31	August 1—15	August 16—31	September 1—15	September 16—30	October 1—21
Bono, 1926						
Stalks dissected......No. .	....	22	84	83	44	52
Total borers..........No...	... .	169	475	431	316	278
Borers below						
2 inches........... No...	....	1	6	13	4	9
Pct..	....	.6	1.3	3.0	1.3	3.2
4 inches........... No ..	....	3	21	33	14	19
Pct..	....	1.8	4.4	7.7	4.4	6.8
6 inches........... No...	....	3	45	59	31	37
Pct..	... .	1.8	9.5	13.7	9.8	13.3
9 inches........... No...	....	7	73	95	70	75
Pct..	....	4.1	15.4	22.1	22.1	27.0
12 inches........... No...	....	14	126	139	96	101
Pct..	....	8.3	26.5	32.3	30.4	36.3
18 inches...... .... No...	....	28	170	188	140	137
Pct..	....	16.6	35.8	43.6	44.3	49.3
24 inches........... No...	....	45	243	232	175	167
Pct..	....	26.6	51.2	53.8	55.4	60.1
Borers above 24 inches............ No...	....	124	232	199	141	111
Pct..	. ...	73.4	48.8	46.2	44.6	39.9
Bono, 1927						
Stalks dissected......No...	100	100	125	100	125	125
Total borers..........No...	484	672	536	322	364	341
Borers below						
2 inches........... No...	2	1	0	1	4	6
Pct..	0.41	0.14	0	0.31	1.09	1.75
4 inches.......... No...	12	5	9	14	20	21
Pct..	2.47	0.74	1.67	4.35	5.49	6.15
6 inches........... No...	21	14	20	32	38	40
Pct..	4.34	2.08	3.73	9.94	10.43	11.73
9 inches........... No...	42	39	52	64	83	98
Pct..	8.67	5.80	9.70	19.84	22.80	28.73
12 inches........... No...	62	62	75	94	128	124
Pct..	12.81	9.22	13.99	29.19	35.17	36.36
18 inches........... No...	96	110	137	138	192	190
Pct..	19.83	16.37	25.55	47.86	52.75	55.71
24 inches........... No...	151	147	181	176	228	235
Pct..	31.20	21.88	33.77	54.66	62.65	68.91
Borers above 24 inches............ No...	333	525	355	146	136	106
Pct..	68.80	78.12	66.23	45.34	36.35	31.09

LARVAL ESTABLISHMENT AND THE RATE AND PERIOD OF MORTALITY

During the period immediately after hatching there is an exceedingly high larval mortality. It is not unusual to find that 70 percent of the young larvae have disappeared by the first week of August. Those larvae which are found feeding on the plant are said to have established themselves. By some investigators it is held that the larva is established when it first feeds successfully; others hold that it is established when it succeeds in entering the plant; still others maintain that the insect is not established until it has successfully passed thru all the instars and has ceased activity because of the approach of the hibernating period; it has been suggested too that establishment is best measured by the number of moths emerging the following year. It seems obvious that establishment is, therefore, a relative term, which in its last analysis is misleading unless properly qualified by an indication of the time when the record was taken. It is of further importance to point out that the rate of establishment is influenced by the behavior of the corn plant, hence any attempt to compare the establishment of one year with that of another or in one area with that of another for the same year must be carefully considered.

Since the object of all such work is to determine the resistance of the environment to the potential of the insect it seems that the problem would be greatly simplified if the data included the number of eggs deposited, the number of larvae entering the hibernating period, the number entering the pupal period, and the number of moths emerging. The resistance to establishment could also be calculated for any other particular period or stage of development of the insect, if periodic records of establishment were available thruout the growing season. Thus far the writers have not been able to factor out the resistance of the environment for the various periods indicated above.

The meteorlogical conditions at the time the young larvae are hatching, or while they are yet outside the stalk have a very important bearing on the percentage of the larvae that become established upon the plant. Light fitful winds stimulate the larvae to spin down from the leaves and are sometimes carried to the ground whence they seldom reach the plant again. However, stronger winds of about five miles per hour or more, depending in part on the size of the plant concerned, are more favorable to establishment because the larvae react by clinging to the leaves until the wind slackens. A temperature of about sixty degrees Fahr. seems to reduce the gripping power of the larvae with the result that a five mile wind shakes some of them from the plant.

A dashing rain at or shortly after hatching is one of the factors affecting the reduction in population of small larvae. Especially rain falling upon the leaves dislodges the larvae and carries many to the ground where they are buried in the mud. But others are able to hold fast to the vertical surfaces of the foliage for hours and those on the under surfaces more often escape the mechanical action of the water in a quiet atmosphere. Still water, such as gathers in the crown or axil of small corn plants, is relatively harmless, and larvae have been observed to drink at these places and thereafter enter the water bodily with no apparent inconvenience, while others were found to have fed within large drops adhering to the under side of corn leaves.

In addition to unfavorable weather conditions, the nature of the feeding quarters and the food material itself also have a great effect upon the percentage of the larvae that become established. Regardless of variations in weather or in the nature of food material, however, the death rate is always highest while the young borers are first beginning to feed.

In 1927 in a field in which the egg deposition averaged 39.8 per stalk, the population on July 18, near the close of the egg-laying period, was 11.0 borers per stalk, giving a mortality of 72.4 percent. In this case 38.9 percent of the insects were in the first or second larval instar and a large proportion of the remainder were still in the egg stage. In another field, in which the egg deposition averaged 30.0 per plant, the population on July 22 was 6.4, a mortality of 78.7 percent. In this instance 65.6 percent were in the first and second instars. These records indicate that about three-fourths of the larvae were not able to reach the second instar in 1927.

In 1926 in a field in which the number of eggs deposited averaged 40.8 per stalk, the larval population on August 9, about two weeks after the close of the egg period, was 12.8 borers per plant, a mortality of 68.6 percent. At the time of this dissection record the larvae were about half grown, 57.3 percent being in the third and fourth instars.

These records for the two years show a high death rate in the early stages of the larva. A comparison of the mortality for 1927 with that of 1926, however, shows quite a variation, there having been a greater percentage of mortality up to July 18, 1927 than to

August 9 in 1926, in spite of the fact that in 1927 the larvae were fully two weeks behind in development. The difference in the death rate for the two years was undoubtedly due to differences in meteorological conditions, which affect both the food plant and the insect, the larvae in the early stages being very susceptible to both direct and indirect weather changes.

Records of infant mortality must be based on egg counts. Since egg counts were made in only one field in 1926, comparisons for that year must be drawn from the record of a single field. For progressive mortality thruout the season, however, the data are much more significant. In 1926, 10 or 12 plants from each of three fields were dissected for borer population each week; while in 1927, 25 plants were dissected weekly from each of two fields.

The larval mortality obtained in the study for the growing season of 1927 is shown in Table 17. The record was made from the weekly dissections from the two fields studied and compiled into two-week periods in order to reduce the error resulting from natural deviation thru small sampling.

TABLE 17.—Larval Mortality at Bono by Two-Week Intervals Thruout the Growing Season, 1927

Date	Plants dissected	Borers per plant	Mortality for period	Mortality to date
	No.	*No.*	*Pct.*	*Pct.*
Egg season	200	34.92*	0	0
July 18—Aug. 1	100	7.00	80.0	80.0
Aug. 2—15	100	6.72	4.0	80.8
Aug. 16—29	100	4.51	32.9	87.1
Aug. 30—Sept. 12	100	3.53	21.7	89.9
Sept. 13—Sept. 26	100	2.82	20.1	91.9

*Average total eggs deposited per plant.

In the series of dissections July 18 to Aug. 1 more than one-half of the larvae were in the first and second instars. The mortality up to that period, based on the average number of eggs deposited and the number of larvae per stalk at dissection periods, was 80 percent. For the remainder of the season the mortality was only 11.9 percent. This record cannot be accepted as showing the ordinary mortality for the periods given for any one year, because the death rate for a single period varies greatly from year to year, due to variation in direct and indirect influences of meteorological conditions.

The development to the full grown larval stage for the year 1927 was 8.1 percent, since 91.9 percent died. By way of comparison, the average of all dissections after Sept. 13 in 1926 in the one field studied thruout the season gave a population of 7.19 borers per stalk from 40.8 eggs, or an establishment rate of 17.6 percent. This rate is more than twice as great as the average for the two fields studied in 1927. Table 18 shows the mortality by two-week periods for the three fields in which weekly dissections were made in 1926. This record does not show the percentage of mortality up to the first of August, as egg counts, as mentioned, were not made in all of these fields. For the same reason the percentage of mortality and of larval establishment for the year cannot be computed. Larval mortality after Aug. 1, however, may be compared with that of 1927.

TABLE 18.—Larval Mortality at Bono by Two-Week Intervals Thru August and September, 1926

Date	Plants dissected	Borers per plant	Mortality for period
	No.	*No.*	*Pct.*
August 1—15	22	7.64	....
August 16—31	84	6.85	10.3
September 1—15	83	5.19	24.2
September 16—30	59	5.83	0

The reduction in borer population from 7.6 per stalk during the first half of August to 5.8 per stalk during the last half of September indicates a mortality of 23.7 percent for the period. The reduction in number from 6.72 to 2.82 for the same period in 1927 (Table 17) indicates a mortality of 58 percent. The death rate thru August and September 1927 was therefore about two and one-half times as great as in 1926.

A consideration of the probable causes for this high mortality rate in 1927 suggests a possible explanation. An analysis of the weather conditions in 1926 and 1927 shows that the two seasons were extreme in several respects. The month of August, 1927 was the coldest August in the region in the 56 years that the Toledo station has been operated; and August, 1926 had the most rain of any August within the period. Table 19 shows the August weather records for the two years in comparison with the normal for the same month.

TABLE 19.—Weather Records at Toledo, August, 1926 and 1927, in Comparison With Normal

(Courtesy U. S. Weather Bureau)

Year	Average daily humidity			Rainfall	Average mean daily temperature by 6-day intervals, degrees					
	8 a. m.	8 a. m.	Av.	August	1—6	7—12	13—18	19—24	25—31	Av.
1926	80	72	76	7.64	76.7	73.0	73.7	71.7	71.6	73.2
1927	75	59	67	2.20	66.2	69.8	68.0	64.7	65.1	66.6
Normal	....	....	....	2.70	73.0	72.2	71.7	70.5	69.3	71.3

August, 1926 had 9 percent higher average humidity, 5.44 inches more rain, and an average temperature 6.6° higher than August, 1927. The month was slightly supernormal in temperature and extremely supernormal in rainfall in 1926, while in 1927 it was slightly subnormal in rainfall and extremely subnormal in temperature. The influence of these separate factors on the corn borer larvae cannot be evaluated at present. It is probable, however, that herein lies a part of the explanation for the variation in the establishment rate. Probably the deficiency in moisture and the low temperature in August, 1927, each had an important bearing on the low establishment rate for that year. Since records of this nature have been kept for a short time only, it is impossible to give the normal establishment rate. It seems probable, however, that for August, 1926 this rate was considerably above, while that for 1927 was very much below, normal. If it were definitely known how much each varied from the normal, a more accurate interpretation of the causal factors could be made.

It may be stated that the varieties of corn grown in the cases cited above were not widely different and that they were planted at approximately the same time, namely, the normal optimum planting date for the area. It should be mentioned that the season of 1927 was abnormally late and that corn at first developed slowly. It is very probable that this also had a bearing on the low establishment rate even tho the fields under consideration had been planted at the optimum planting date. In either case, however, weather was probably the real cause of the lower survival.

HOST VARIATION

When variation in the nature of the food alone were considered, there was quite a variation in the number of larvae able to develop from a given number of eggs. This was noted particularly when comparing different host species; but it was also found to be true when a long-season variety, Burr-Leaming, was compared with a short-season variety, Wisconsin 25, planted side by side on the same date.

In making the establishment study two areas were marked out for investigation for each variety, the areas being determined by rate of corn growth. That is, there was an area in which the corn grew at an optimum rate for each variety, also an area where the corn grew slowly for each variety, the differences in the growth rates being due to edaphic variations. For purposes of distinction the corn of each variety in the area of optimum growth was designated as vigorous while that in the area of slow growth was designated as spindling. The establishment rate on the vigorous Burr-Leaming was then compared with that on the vigorous Wisconsin 25, and on the spindling of the one variety with the spindling of the other.

Daily egg counts on a block of one hundred plants in each of the four plots were made thruout the oviposition season. At the end of the corn growing season, when the larvae had attained complete growth, infestation and population records were taken on each plot. From these records the percentage of establishment, based on the number of larvae able to develop into the full grown stage, was computed for each plot. The comparative establishment records are given in Table 20.

TABLE 20.—Establishment Rates in Vigorous and on Spindling Wisconsin 25 and Burr-Leaming, 1927

Variety	Eggs per stalk	Percent infes-tation	Plants dissected	Pop. per inf. stalk	Pop. per stalk	Percent establish-ment
			Vigorous series			
Burr-Leaming	46.2	79.0	25	1.04	0.82	1.8
Wisconsin 25	39.8	97.0	25	1.64	1.59	4.0
			Spindling series			
Burr-Leaming....... ...	8.2	15	25	.52	.08	.95
Wisconsin 25	26.5	84	25	.54	.47	1.77

In the vigorous series it may be noted that, while the Burr-Leaming received more eggs per stalk than the Wisconsin 25, at the end of the season the Wisconsin 25 had nearly twice as many borers per stalk and had slightly more than twice as high an establishment rate. In the spindling series the Wisconsin received about three times as many eggs as the Burr-Leaming but matured nearly six times as many larvae. The rate of establishment in the two series was thus very closely analagous, the percent establishment for the Wisconsin 25 being just about twice as great as that for the Burr-Leaming.

HOST PREFERENCE

In a former paper (17) it was shown that corn borer larvae are able to feed on a number of hosts other than corn, even tho these hosts are not selected by the moths for oviposition. In all of the various hosts studied, corn borer larvae have shown a great variation in the manner in which they are able to use the available food.

They seem entirely unable to use some food hosts, while some other hosts are found to be more acceptable than corn itself.

The investigations reported immediately below were conducted by J. P. Sleesman of the summer staff. In conducting the host studies, plots of the different species of host to be investigated were planted some time before the moth flight period in order that the plants might attain a vigorous growth at the time of oviposition. As soon as sufficient moths were available, convenient numbers ranging from five pairs upward were placed in cages over a series of stalks of each species. It was originally planned to run five series of three stalks each for each host, the object being to subject the larvae on each host to various meteorological conditions and thus eliminate fluctuations due to favorable or unfavorable weather. It was found expedient, however, to vary the number of stalks of each species exposed at one time on account of the variation in the number of moths available. Accordingly the number of series was reduced from five to four and the number of stalks to the series varied from three to five. In one series also there was a variation in the exposure date for the different species.

The cages were left over the stalks for approximately five days, altho the period was lengthened a day or two when the weather remained cool. Meteorological conditions were noted, and the cages were removed before any of the eggs hatched. Upon removal of a cage the stalks were examined for eggs and the total number of eggs recorded for each host plant. Beginning fifteen days after the removal of the first cages and approximately every five days thereafter, dissections were made of one stalk of each species. The instar of the various larvae and the damage to the stalk were recorded.

This study was not intended to formulate a definite establishment index for the different species. It was conducted for the purpose of making comparisons of the suitability of the various hosts as food for the growing larvae. In order to show definitely how the larvae reacted to each host it was necessary to observe their feeding at different stages. It was found from dissections that the larvae recovered from the different hosts varied greatly in age. The comparison of the percentages recovered from the different hosts should give a fairly correct evaluation of the different plant species as hosts of the growing larvae.

Two species of smartweed *(Polygonum pennsylvanicum* and *P. persicaria)* were used during the season of 1927. Both were found to be very favorable hosts, *P. persicaria* having a slightly higher establishment rate than *P. pennsylvanicum.*

In 1926 sorghum was recorded as a poor larval host. Results in 1927 affirm this record. Only one-tenth of 1 percent of the number of eggs deposited was recovered as sixth-instar larvae in the two years. These records of low establishment are further substantiated by the fact that on the experimental plots at Bono the final infestation in all of the sorghums has always been zero. This was true regardless of the fact that some eggs were known to have been deposited upon these stalks in the field.

TABLE 21.—Showing Establishment in *Polygonum*, Corn, Sorghum, and *Abutilon*, 1927

Series No.	Exposure Date	Age* of larvae at dissection Days	Eggs deposited No.	Larvae recovered by instars, number							Total larva recovered Pct.
				1 No.	2 No.	3 No.	4 No.	5 No.	6 No.	Total No.	
Polygonum											
1	7—5	20.3	2,260	6	58	47	27	19	…	157	6.95
2	7—10	33.5	7,609	…	8	73	85	36	184	386	5.07
3	7—16	50.6	2,324	…	…	14	37	18	267	336	14.46
4	8—10	29	719	…	1	2	7	5	46	61	8.48
Total	…	…	12,912	6	67	136	156	78	497	940	7.28
Corn											
1	7—5	20.3	703	3	25	29	6	5	…	68	9.67
2	7—10	33.5	3,458	…	1	9	13	29	81	133	3.85
3	8—2	29.2	1,653	…	3	12	17	6	25	63	3.81
4	8—10	34	3,103	…	…	2	17	12	139	170	5.48
Total	…	…	…	3	29	52	53	52	245	434	4.87
Sorghum											
1	7—5	20.3	905	15	7	10	1	…	…	33	3.65
2	7—10	38.5	4,722	…	4	5	6	10	2	27	.57
3	7—16	45.5	2,415	…	3	2	…	1	8	14	.58
4	8—10	33	2,544	…	…	2	6	5	5	18	.71
Total	…	…	10,586	15	14	19	13	16	15	92	.87
Abutilon											
1	7—10	33.5	2,829	1	…	…	…	…	…	1	0.04
2	7—26	27.5	599	…	…	…	…	…	…	0	0
3	8—10	26	1,374	…	…	…	…	…	…	0	0
4	9—13	22	8,300	1	…	…	…	…	…	1	.01
Total	…	…	13,102	2	…	…	…	…	…	2	.02

*Approximate, computed from exposure date to dissection date with five days allowed for the egg stage.

The laboratory records indicate that young larvae were able to feed to a certain extent but apparently were unable to burrow into the stalk. Of the larvae recorded as being taken from sorghum, only 1 was taken from a tunnel within the main part of the stem and only 5 from tunnels in the tassel, making a total of only 6 larvae found in tunnels within the stalk out of 13,645 eggs that had been deposited thereon. All of the other recovered larvae were taken in the leaf folds, back of the leaf sheaths, or within the midribs of the leaves.

In velvet leaf, *Abutilon*, in 1926 not a single larva was taken from four stalks dissected on which 364 eggs had been deposited. In 1927, 2 larvae were recovered from a total of 13,102 eggs. Both were in the second instar. The establishment rate for the species may thus be regarded as practically zero.

TABLE 22.—Summary of Larval Recoveries in Selected Hosts, 1927

Host	Dissections	Total eggs deposited	Larval instars recovered						Larvae	Recovered
			1	2	3	4	5	6		
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*Pct.*
Smartweed	15	12,922	6	67	136	156	78	497	940	7.28
Corn	15	8,917	3	29	52	63	52	245	434	4.87
Spanish needle	15	8,046	4	27	58	72	32	64	257	3.19
Cocklebur	15	14,990	4	6	30	87	109	203	439	2.93
Sorghum	15	10,586	15	14	19	13	16	15	92	.87
Pigweed	15	17,762	10	23	9	3	5	21	71	.40
Tomato	15	4,512	0	1	1	3	1	1	7	.16
Velvet leaf	15	13,102	0	2	0	0	0	0	2	.02

The individual records for the remaining species are not included, but the totals for all species are recorded in Table 22. The eight hosts studied may be divided into four favorable hosts—smartweed *(Polygonum)*, corn, spanish needle *(Bidens)*, and cockle burr *(Xanthium)*, in the order named—and four unfavorable hosts—sorghum, pigweed *(Amaranthus)*, tomato, and velvet leaf *(Abutilon)*. In 1926 no larvae at all were recovered from pigweed. Inasmuch as this host is commonly infested in corn fields in the fall it had been tentatively concluded that, altho first and second instar larvae seemingly were not able to feed on this species, yet the larger larvae were. The 1927 record, however, shows that a number of larvae were taken from this host, some being taken in each instar. The percentage of recovery was extremely low, hence it is concluded that this species is a poor larval host.

THE BEHAVIOR OF BURIED LARVAE

Some of the earliest investigational work undertaken by the Ohio Experiment Station was a study of the value of plowing under infested stalks as a means of corn borer control. Inasmuch as the number of borers available for experimental work at that time (1923) was small, the tests were made by hand burials in which known numbers of larvae were buried at known depths and at definite time intervals. In this manner the specific behavior of the individual could be more closely checked.

The first plowing experiments indicated that plowing, itself, killed but few borers. When burial plots were small and traps were set up adjacent to them about 85 percent of the larvae were recovered. The remaining 15 percent were not killed by the mechanical process of plowing nor by the physical or chemical effect of the material covering them, as shown by the fact that scarcely any dead borers were recovered in the buried material when it was taken up. Since all larval movement under optimum conditions for migration had ceased within a week or ten days after the experiment was begun, there was insufficient time for the death of all larvae and disintegration of their bodies. Their disappearance must, therefore, be attributed largely to other causes.

The 85 percent that were known to come to the surface cannot be recorded as surviving the plowing process as there were indirect results of the burial that may, and normally do, cause high larval mortality. Since the larvae continue to maintain their negative phototropic and positive thigmotropic response, they accordingly, after reaching the soil surface, at once seek quarters for shelter in which they can satisfy these tropisms. If the field or burial plot is carefully and cleanly plowed the borers may be compelled to migrate long distances before finding shelter. During migration they are exposed to various predatory organisms, particularly birds, which undoubtedly destroy considerable numbers. The migrating larvae are also exposed to the weather. During dry periods desiccation from crawling over the warm, dry soil undoubtedly results in the death of many larvae. During migration they must also consume a great deal of energy by their wanderings and as a result are weakened. The number of borers that survive plowing, then, depends largely on the availability of debris upon the plowed surface. Other things being equal, fields that are most free of debris have the lowest percentage of borers.

The immediate behavior of buried larvae varied greatly with weather conditions. When the soil temperature was above 50° F. the larval movement to the surface began within 24 hours. Migration continued night and day until practically all larvae had left the buried portions. The one test discussed below will be sufficient to indicate the nature of the experiment and at the same time show the typical behavior of the larvae. In all of the burial experiments conducted in 1923, 1924, and 1925 the stalks to be buried were artificially infested with borers by making holes in the stalks, inserting the larvae, and closing the holes. This method had been checked by selecting naturally infested stalk sections, burying them at the same time, and observing the rate at which the larvae appeared at the soil surface. It was found that the artificial infestation of the stalks in no way interfered with the normal behavior of the larvae.

The recovery of borers from two lots of 100 larvae each, buried at three o'clock on May 27, 1924, is shown in Table 23.

TABLE 23.—Larvae Recovered From a Typical Burial Made on May 27, 1924

Date	Time	Recoveries			Total to date
		Lot I	Lot II	Total	
		No.	*No.*	*No.*	*No.*
May 28	4:30 p. m.	23	21	44	44
May 29	7:30 a. m.	18	13	31	75
May 29	4:30 p. m.	2	5	7	82
May 30	7:30 a. m.	9	10	19	101
May 30	4:30 p. m.	3	3	6	107
May 31	7:30 p. m.	1	7	8	115
May 31	4:30 p. m.	1	1	2	117
June 1	No observation	....	....	....	....
June 2	4:30 p. m.	13	8	21	138
June 3	4:30 p. m.	1	1	2	140
June 4	4:30 p. m.	3	6	9	149
June 5	4:30 p. m.	2	0	2	151
June 6	4:30 p. m.	1	0	1	152
June 9	4:30 p. m.	1	3	4	156
June 16	4:30 p. m.	3	6	9	165

The burial series was taken up on June 16. Two dead borers were found in stalks in Lot 1 and four in Lot 2. For the first three days after burial the record was taken in the morning and again in the evening in order to determine whether the larvae migrated by night or by day. It may be noted that borers were recovered in the traps at both the morning and evening observations.

During this experiment the soil temperature 6 inches below the surface, as shown in Table 23, was consistently above 50° F. The mean soil temperature on the day of starting the experiment was 52°, on the following day 55.5°. The reaction of the larvae was rapid, as 44 out of 165, or more than one-fourth, were recovered in the first 24-hour period. During the second and third 24-hour periods there were 38 and 25 larvae, respectively. Thus within 72 hours after the burial 64.8 percent of the total borers recovered were already in the traps.

This record is cited as a typical example of the behavior of buried larvae where environmental conditions are favorable for larval migration.

Unfavorable conditions, such as low temperature and lack of moisture, affect larval responses. As the temperature of the soil falls below 50° there is a decrease in larval activity. This has been observed in the fall of the year when the soil temperature is slowly falling. When it reaches 40° practically all activity ceases and the larvae become dormant. However, when the soil temperature goes above 40° in the spring larval migration to the surface begins, and increases as the temperature rises. By the time the temperature reaches 50° migration is at its maximum.

From September 29 to October 30 the soil temperature was slowly falling, and in general the migration curve (Fig. 6) follows that of the temperature curve, reaching its zero point when the soil temperature reached 40°. Between October 31 and November 22 there were three instances in which the soil temperature went above 40°, and it will be observed that there was a corresponding increase in larval activity. After November 22 practically all migration stopped and only once did the soil temperature reach 40°. The moisture factor was not significant thru this period, since the precipitation was evenly distributed.

From April 1 to 25 the soil temperature rose, reaching 40° on the 20th, after which larval migration to the surface was again noticeable. The soil temperature was above 50° from May 9 to 16, but the number of larvae recovered fell off, nevertheless. This was probably due to two causes: first, the majority of the larvae had already reached the surface; and second, dryness of the top soil checked the progress of larvae still migrating.

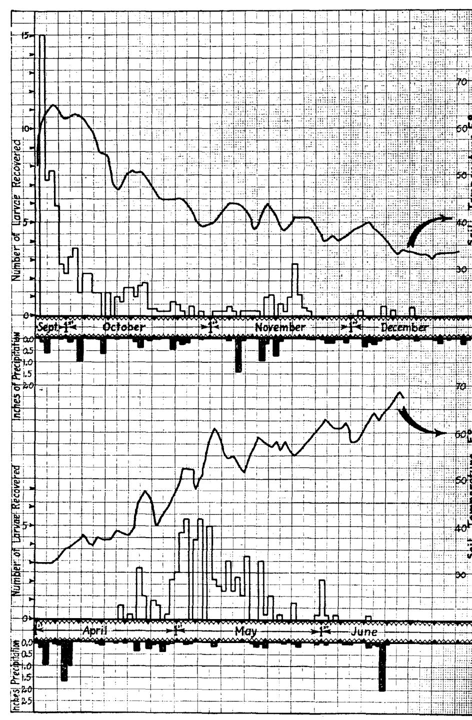

Fig. 6.—Graph showing influence of temperature and moisture on buried larvae

LARVAL MIGRATION

The distribution of the borer population in a given field may be attributed, in part at least, to the tendency of the larvae to crawl about from plant to plant. That this migration occurs is shown by the fact that one hill may have six or eight egg masses consisting of a hundred eggs and neighboring hills may have none; yet later the larval population per stalk will show but little variation. The same tendency is indicated by the large number of borers in weeds in corn fields. Larval migration is particularly conspicuous when the environment is unfavorable such as in the burial of infested stalks in manure piles, partial submergence of infested material in water, exposure to heat on bare soil surface, the plowing down of infested corn debris, desiccation of stalks, and competition for food and shelter among the larvae themselves. During the season of 1927 periodic larval infestation studies were conducted by A. A. Bowers, of the summer staff, on a number of the commoner species of plants, both within and outside of corn fields of the heavily infested area. The infestation records of eight common weed species as taken in heavily infested corn fields for 1927 and of twelve species outside of corn fields are given in Table 24. Several fields were used in the study, their selection having been based on the nature of the infestation and the presence of weeds. The investigator walked thru the fields and selected at random plants to be dissected.

Practically all of the weeds commonly found in corn fields are occasionally infested with corn borer larvae. There is a wide difference, however, in the frequency with which the different species are infested. Lambsquarters, Indian hemp, and Velvet leaf, altho common weeds in the corn fields of the area, were rarely infested. Of 1,533 individual plants of eight species taken amid infested corn, 514, or 33.5 percent, were infested. Of 1,937 plants of the same species and a few additional ones, taken outside of corn fields only 12, or three-fifths of 1 percent, were infested. This indicates that infestation in weeds is largely, if not altogether, by migration from nearby infested corn plants. In fields under observation in the Bono area the borer population in weeds varied from zero to about 2,300 per acre. The field with the highest record had an unusually abundant weed growth and a high borer population in the corn, which helped to account for the large number in weeds. The borer population in corn in this field was about 60,000 per acre, hence only 3.7 percent of the borers were in the weeds, even where the weeds were abundant.

The distance larvae will migrate cannot be stated definitely. It has been demonstrated, however, that they may readily crawl a distance of two or three hills from the source and enter other corn plants. In 1926, 100 practically full grown larvae were released in the middle of an uninfested plot of corn. The plants surrounding the point of release were later dissected for recovery of the larvae. It was found that 46 percent of the borers got back on the plants, the greatest migration distance being the third hill from the source. The greatest number, of course, were in the first tier of hills and only a few were as far as the third. It is probable that they will crawl much farther than this record indicates.

TABLE 24.—Showing Corn Borer Infestation in Various Species of Weeds

Host	Plants examined No.	Plants infested	
		No.	Pct.
In infested corn fields			
Ragweed, *Ambrosia artemesifolia*	175	110	62.9
Cocklebur, *Xanthium canadense*	308	153	49.7
Spanish needle, *Bidens sp*	170	72	42.4
Smartweed, *Polygonum sp*	385	123	31.9
Pigweed, *Amaranthus retroflexus*	165	33	20.0
Velvet leaf, *Abutilon theophrasti*	150	20	13.3
Lambsquarters, *Chenopodium album*	115	2	1.7
Indian hemp, *Apocynum cannabrium*	85	1	1.2
Total	1553	514	33.5
Not in corn fields			
Ragweed, *Ambrosia artemsifolia*	150	4	2.7
Spanish needle, *Bidens sp*	125	3	2.4
Cocklebur, *Xanthium canadense*	200	2	1.0
Smartweed, *Polygonum sp*	300	2	.7
Velvet leaf, *Abutilon theophrasti*	150	1	.7
Lambsquarters, *Chenopodium album*	100	0	0
Indian hemp, *Apocynum cannabrium*	50	0	0
Cat tail, *Typha latifolia*	75	0	0
Hollyhock, *Althaea rosea*	87	0	0
Sugar beet	200	0	0
Soybeans	300	0	0
Buckwheat, *Fagopyium esculeutum*	200	0	0
Total	1937	12	0.6

In an effort to determine the distance that borers will migrate in order to get into debris after being plowed down, a series of plowing experiments was planned with traps set at definite distances from the plowed-under material. In the plowing operation the infested stalks were laid lengthwise of the furrow and were completely covered by the plow. The surface was leveled down with a harrow and was kept free from debris. Traps consisting of corrugated paper strips on boards set on edge with an oilcloth barrier at the top, were placed at varying distances from the infested material that had been plowed down. Dissection of sample stalks previous to burial had given the approximate population for each lot of material used in the plowing test.

The areas varied from 40 inches square in hand burials to 30 feet square in the larger plowed plots. It was to be expected, of course, that the percentage of borers migrating into the traps would vary not only with the migration distance but also with the size of the burial plot. For instance, it would not be expected that many borers would be likely to migrate to the margin from the middle of the large plots.

The percentage of borers migrating the different distances is shown in Table 25.

TABLE 25.—Distance Corn Borer Larvae Migrated After Plowing

Series	Borers used	Distance between burial plot and traps	Size of burial plot	Borers recovered	
No.	*No.*	*Ft.*	*Sq. ft.*	*No.*	*Pct.*
1	2,100	Adjacent	11.1	1,423	67.8
2	8,971	Adjacent	900	3,451	38.5
3	6,411	10 to 12	900	1,014	15.8
4	4,248	15 to 20	900	205	4.8
5	2,053	25 to 30	900	72	3.5

The number of borers that reached a trap decreased rapidly as the distance to the trap increased. A distance of 25 to 30 feet was about the limit that borers crawled in significant numbers.

In the two series, 1 and 2, in which the traps were adjacent to the burial plots there was quite a difference in the percentage of borers recovered. This was due to the difference in the size of the plots. In series 1 the plots were so small that fewer borers became lost. Where the plot was as much as 30 feet square many borers did not reach the margin of the plowed area and thus did not get into a trap. It must be understood, of course, that corn borers have no way of knowing in what direction the traps lie, hence a given borer may come to the surface beside a trap and start crawling in another direction or it may crawl almost to a trap and then turn without entering.

Conditions as they existed in these experiments were not representative of the normal field, because the surface was kept clean. The object of the test was to determine the amount and distance of migration under conditions in which there is a distinct urge for migration.

LARVAL BEHAVIOR ON CLEAN SOIL SURFACES

During the spring of 1924 an attempt was made to determine whether corn borer larvae can complete their life cycle when nothing but clods and earth are available for transformation chambers, in other words, whether absolutely clean plowing would insure 100 percent mortality of the borers.

Several piles each of about a dozen clods of earth, ranging from one to three inches in diameter and composed of a heavy clay loam, were placed on a bed of lake sand three inches deep. Each group of clods was then covered with a screen cage measuring one foot square and eight inches high. The cage was pushed down approximately two inches into the sand to prevent the escape of the borers. The contents were entirely free from all kinds of debris. In their search for pupation quarters the borers had their choice of the sand, the clods, or the sides of the cage.

The cages, nine in number, were started June 5. Twenty-five larvae were inserted in each cage thru a small hole in the top, which was later plugged with cotton. Once each week a cage was opened and an observation made. The stage of the insects and their position within the cage are given in the recovery record, Table 26.

TABLE 26.—Showing Behavior of Larvae When no Debris Was Available for Pupation Quarters

Cage	Examined	Days cage in operation	Larvae			Dead as pupae	Known to pupate	Emerged		Re-covered alive
			Alive	Dead	Pupated					
No.	*Date*	*No.*	*No.*	*No.*	*No.*	*No.*	*Pct.*	*No.*	*Pct.*	*Pct.*
1	June 7	2	25	0	....	....	....	.....	.....	100
2	June 14	9	21	1	....	....	....	.....	.....	84
3	June 19	14	15	7	1	....	4	.....	.....	64
4	June 23	18	13	7	2	....	8	.....	.....	60
5	June 27	22	7	3	8	1	32	2	8	64
6	July 2	27	1	5	7	....	28	1	4	32
7	July 7	32	0	7	6	1	24	.....	.....	20
8	July 14	39	0	2	7	....	28	1	4	28
9	July 23	48	0	0	3	2	12	1	4	12

On considering the last five cages, in which pupation was well under way at the time of observation, it was found that an average of 24.8 percent of the larvae were able to pupate successfully regardless of the absence of debris. During this time 5 out of 125, or 4 percent, had emerged. Inasmuch as there were still 20 live pupae in the five cages at the time these records were taken, it seems probable that 10 to 15 percent would have been able to emerge to the adult stage. Only 12 borers of the 125 included in the last five cages pupated in clods or sand; the remainder pupated somewhere on the cage. All of the moths that emerged came from the clods or sand.

As a separate part of this experiment, a conical wire-cloth cage, about 15 inches in diameter at the bottom and 20 inches high, was used to cover a pile of 15 clods ranging in size from 2 to 5 inches in diameter. These clods were placed on a bed of lake sand on a bench inside the insectary and 48 larvae were introduced into the cage. The sand and clods were wetted at irregular intervals. This cage was started July 9, which was near the pupation period for all larvae used. On July 15 the contents were as follows:

Pupae in sand or under clods	23
Pupae in clods	7
Pupae on cage	3
Dead as larvae	3
Disintegrated or escaped	12

The 30 living pupae taken from the sand and clods were transferred to emergence cages, where 18 emerged by July 27. This number was probably higher than it would have been had the borers been left in the clods thruout the emergence period. Under these conditions 37.5 percent of the original 48 larvae emerged successfully.

A somewhat similar series of experiments was conducted during the spring of 1925. The series consisted of four cages. The sides of the cages were constructed of galvanized iron with all joints soldered. The bottom was 18-mesh wire cloth soldered to the frame. The top was left open except that a 4-inch flange of galvanized iron projected inward and slightly downward from the upper edge of the side walls of the cage. To the lower surface of this flange as well as to the side walls oilcloth was fastened by means of shellac to serve as a barrier to the larvae.

The cage, with the screened surface down, was placed in a pit 3 inches deep, the soil being packed closely around the outside. A layer of lake sand 1 inch deep was placed in the bottom so that the screen was completely covered and at the same time was in contact with the soil beneath. Twenty-five or thirty typical clods ranging from 1 to 3 inches in diameter were then thrown in a heap in the middle of the cage, and 200 active larvae were dropped among them. Poultry netting was placed over the top to prevent interference by birds.

The tests were begun at various times, as indicated in Table 27. The larvae were left undisturbed until the cage was taken up for examination.

TABLE 27.—Showing Corn Borer Transformation in Soil

Cage No.	Date started	Date closed	Larvae introduced	Dead larvae recovered			Live larvae recovered			Abnormal pupae
				On cage	In soil	Total	On cage	In soil	Total	
			No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
1	April 24	July 17	200	0	29	29	0	0	0	0
2	May 15	June 22	200	0	97	97	0	8	8	5
3	May 15	June 27	200	7	61	68	4	18	22	0
4	June 12	July 20	125	6	2*	8	4	0	4	0
Total	....	....	725	13	189	192	8	26	34	5

Cage No.	Live normal pupae recovered			Dead pupae recovered			Empty pupal cases	Total normal live or emerged		Total live or emerged from soil	
	On cage	In soil	Total	On cage	In soil	Total					
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*Pct.*	*No.*	*Pct.*
1	0	0	0	0	3	3	13†	13	6.5	11	5.5
2	0	16	16	0	2	2	0	24	12.0	24	12.0
3	1	26	27	0	0	0	0	49	24.5	44	22.0
4	2	0	2	1	7	8	50‡	56	44.8	36	28.8
Total	3	42	45	1	12	13	63	142	19.6	115	15.9

*Under ground, but attached to cage wall.

†Two moths dead in clods.

‡There were 38 moths in clods, 11 at angle of cage, 1 at surface of ground, and 2 unable to get out of tunnel, were dead in clods.

A total of 47 moths emerged from clods or soil in the four cages. Disregarding those emerged from shelter on the cage and also those still alive as larvae and pupae when the experiment was closed, 6.5 percent of the borers reached the adult stage in the soil. Since there were 68 additional larvae or pupae alive and apparently normal when the final record was taken, the total percentage of borers to develop from the larval to the moth stage would be somewhere between 6.5 percent, those actually emerged, and 15.9 percent, the possible record, if all remaining live larvae and pupae had emerged. The cages were observed repeatedly from the outside, however, and notes made on the behavior of the larvae. The larvae were found to crawl under and between clods and into earthworm burrows. Occasionally dead larvae were seen both under clods and in the open.

It may be noted from Table 27 that the percentage recovered alive increased with the delay in starting the experiment. The cage started in April gave a 5.5 percent recovery; the two in May, 17 percent; and the one in June, 28.8 percent. These variations were probably due to the fact that the larvae used last were more nearly approaching the pupation period and consequently did not use up so much energy in their aimless wandering in search for shelter.

These experiments tend to show that some of the corn borer larvae are able to complete their transformation to the adult stage even where no debris is present to furnish them shelter or pupation quarters. The same proportion of emergence is not likely in the open field where the borers are not protected, as by the cages, and where the clods and soil are occasionally disturbed by cultivation. In fact, the percentage surviving in any absolutely clean plowed field is undoubtedly negligible.

FENCE-ROW MATERIAL AS A HARBOR FOR MIGRATING LARVAE

The distance borers are able to migrate in significant numbers was shown on page 62. It is also important to consider their ability to get into other plants or pieces of debris after making the migration. In this respect the importance of fence rows as a harbor for borers has been considered.

Late in the fall of 1924 an experiment was started to determine the ability of larvae to find satisfactory hibernating quarters in ordinary fence-row material. In the locality where the test was conducted a dense rank growth of bluegrass had fallen down, making a thick mat. There were also a few weeds in the plot used for the test. A wire-cloth cage 2½ feet square was placed over the plot in such a manner as to prevent the escape of larvae. Care was exercised that the cage would not provide concealment for larvae.

On December 15, 50 larvae were dropped amid the grass mat, thru a small hole at the top of the cage. At the time the test was started the temperature was lower than the optimum for normal larval activity, but the larvae were able to crawl away and establish themselves in suitable quarters. On April 21 of the following year the cage was removed and the contents examined for borers, with the following result:

	Alive	Dead
Borers in weed stems	8	0
Borers in leaves	19	1
Borers on ground surface	0	1
Total	27	2

There was thus a recovery of 54 percent of the borers, which had successfully passed thru the winter in the grass and debris. It must be remembered, of course, that these borers were dropped amid a thick mat of grass and weeds, which undoubtedly served as a partial protection to them before they had constructed suitable quarters.

During the spring of 1925 another series of experiments was conducted in which borers were buried in an area parallel with a fence row at a distance of one foot from the grass edge. The larvae were thus compelled to migrate to the surface and thence into the fence row in a manner simulating conditions where larvae are plowed down in infested corn fields. In the first lot a burial of 1,000 active corn borer larvae was made at a depth of 10 inches and at a distance of about 12 inches west from the border of the fence row, which contained weeds, grass, leaves, and a wire fence with posts. A trap 12 by 15 feet in size was made to surround the burial and fence row.

In Table 28 it may be noted that 38 larvae, or 3.8 percent of the total, became established in the fence row. The number taken in the fence-row material compared favorably with the number going in the opposite direction and getting into the trap. Two borers crawled thru the fence row and came to rest in the trap back of it.

TABLE 28.—Showing Recovery Record in Fence-Row Experiment

Date started	Date examined	Total larvae buried	Borers in traps	Borers in fence row				Total	Percent
				In weeds	In leaves	In grass	Other debris		
Burial pit parallel to fence row at distance of 1 foot									
April 15	June 8–17	1000	95	7	26	2	3	38	3.8
Burial pit surrounded by fence row									
May 9	June 10–12	1000	112	23	172	28	24	250	25.0

In the second series of this experiment the cage construction was different from that of the first in that the fence row entirely surrounded the burial. In this case the number recovered in the debris was greatly increased, as would be expected. Of the 1,000 larvae, 250, or 25 percent, were recovered in the debris as larvae, pupae, or adults; in addition 112, or 11.2 percent, crawled thru the fence row and were recovered in the trap at the rear, making 362, or 36.2 percent, that crawled into the fence row and were recovered. Robins interfered with the experiment. They were frequently seen hopping about over the burial plot inside of the traps and were observed to pick up borers. Subsequent experiments indicated that birds had disposed of approximately 15 percent of the total borers used.

As a further test of the importance of fence rows, a typical fence row containing grass and weeds of various species was enclosed by a trap on the farm plot at Bono in the fall of 1925. During the fall-plowing season, 189 larvae were introduced into the cage. A final examination of the fence-row material in June of the following year showed that 10.6 percent of the total number had become established and had successfully passed the winter in the debris. In these experiments the traps were read each day during the active migration period.

It must be understood, of course, that in this series the conditions were artificial, the larvae in a measure being forced to seek quarters amid the fence-row plants. The experiments indicate that the borers under certain conditions, may find quarters in fence-row material, a few migrating as far as 25 or 30 feet.

Studies made in the open field, on the other hand, have shown repeatedly that high borer populations in fence rows are extremely rare. Where the fence rows were free from weeds borers were seldom found, while they were ordinarily uncommon even when weed stems were present.

LARVAL BEHAVIOR UNDER DRY STORAGE CONDITIONS

Corn borer larvae are dependent to a considerable extent upon moisture for the completion of their transformation to the pupal stage. Because of the common practice of storing corn fodder in barns for feeding, with the result that frequently a portion is left over in the spring, the behavior of corn borer larvae in stored fodder has been studied for some time in order to ascertain the importance of this source of reinfestation.

All Ohio Experiment Station records up to the present time indicate that the development of larvae is inhibited or retarded in stored corn fodder. Where no contact moisture was available the larvae after a time became somewhat shriveled thru desiccation and their movements became quite sluggish. They gradually became drier and drier and finally mummified. Coincident with the desiccation process larval activity constantly decreased until death. The cessation of physiological processes was apparently very gradual, as many borers that seemed dead reacted slightly to the touch. They may remain in this condition for several days.

During the season of 1927, E. A. Herr and H. G. Walker, of the summer staff, conducted experiments on the behavior of borers under dry storage conditions. Two lots, including a total of 865 larvae were confined in two cages; one cage was kept as nearly as possible under normal conditions and the other was kept in dry storage. The cages were continued under these conditions until after the temperature had become sufficiently low to prevent further transformation, when the stalks were dissected to ascertain the comparative development of the larvae. The following record was obtained:

TABLE 29.—Final Record of Dry Storage Experiment Based on Cage Dissection of Cornstalks at Close of Experiment

Cage	Date closed	Larvae remaining		Pupae remaining		Moths dead in tunnels
		Alive	Dead	Alive	Dead	
Dry storage.......	September 22	79	171	60	18	1
Normal............	September 22	1	19	1	4	6

Cage	Date closed	Percent failing to		Total borers used	Total moths emerged	
		Pupate	Emerge		Number	Percent
Dry storage.......	September 22	64.4	84.8	388	59	15.2
Normal......	September 22	4.2	6.5	477	446	93.5

Only 4.2 percent of the total larvae under normal conditions failed to develop beyond the larval period, as compared to 64.4 percent of those from dry fodder. At the time the experiment was discontinued 15.2 percent of the moths had emerged from dry storage while 93.5 had emerged under normal conditions.

The same general result was indicated by a series of weekly dissections of dry stalks that had been used for a seasonal history study under dry storage conditions. These stalks had also been kept in the dry since midwinter and the borers had not been disturbed at the date indicated, when sufficient stalks were dissected to obtain 50 borers. The results for the season are given in Table 30.

TABLE 30.—Showing Seasonal History of Corn Borer Larvae in Dry Storage

Dissection date	Live larvae	Dead larvae	Dead pupae	Pupation normal conditions
	Pct.	*Pct.*	*Pct.*	*Pct.*
June 27.....	80.3	18.0	1.6	88
July 5............................	78.0	20.0	2.0	100
July 12............................	65.7	28.5	5.8	....
July 19............................	47.0	41.2	11.8	....
July 26........	51.2	41.7	7.1	....
Aug. 8...........................	22.7	50.0	27.3	....

It may be seen from the column headed "Dead larvae" that there was a gradual increase from 18 percent dead on June 27 to 50 percent on August 8. It should be stated, however, that August, 1927, was abnormally cool—too cool for transformation even for normal larvae, had any existed at that time. If the August temperature had been normal there would probably have been a slightly lower mortality.

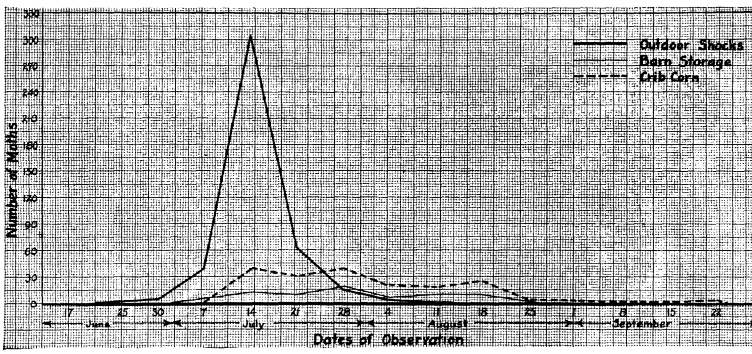

Fig. 7.—Graph showing influence of certain farm practices on emergence of adults

In addition to causing this high mortality rate, dry storage treatment resulted in the delay of transformation for those able to transform. In other words, dry storage caused a marked increase in the length of the larval period. The moth-emergence curve for dry storage (barn and crib) conditions (Fig. 7) shows that the flight period was much retarded as compared with normal.

Soon after dry storage material was supplied with moisture during the larval transformation period transformation proceeded rapidly. Some of the larvae were unable to respond to the added moisture treatment and the mortality was accordingly rather high. As an illustration of the reaction of partially desiccated larvae to added contact moisture the following experiment may be noted. In July 60 larvae cut from dry fodder stalks were divided into two equal lots and permitted to crawl into corrugated paper strips. The one lot was then sprinkled daily, while the other remained dry. The difference in reaction is shown in Table 31.

It may be observed that 20 of the 30 larvae supplied with moisture emerged in a short time, as compared with 2 of the 30 kept continually in the dry. The remaining larvae of both lots died without moth emergence, the mortality in the moistened cage being 33.3 percent and in the dry cage 93.3 percent.

TABLE 31.—Emergence From Dry Storage Material When Moistened and When Unmoistened

Date	Emerged moths	
	Dry cage	Moistened cage
July 30	0	2
August 1	0	4
August 2	0	6
August 3	0	1
August 4	0	2
August 5	1	0
August 6	0	4
August 7	1	0
August 17	0	1
Total	2	20

Weights of 8 desiccated larvae were taken on successive days after they had been supplied with moisture by wetting the corrugated paper strip that served as a shelter chamber. The weight records (Table 32) show that there was a gradual increase in weight for the first ten days of moistening. There was considerable fluctuation, due probably to the varying amount of energy consumed in the spinning of webs after the larvae had been disturbed. A comparison of the average daily weights by three-day periods shows a consistent increase in weight up to the end of the tenth day, which was approximately the time required for the larvae to become sufficiently adjusted to the added moisture supply to start transformation.

TABLE 32.—Showing Daily Weight Record of Corn Borer Larvae Following Addition of Contact Moisture

Date	Larvae weighed	Average weight per larva	Average weight for 3-day period
	No.	*Gm.*	*Gm.*
August 24	8	0.075	
August 25	8	.079	
August 26	8	.079	0.077
August 27	8	.078	
August 28	7 (1 dead)	.084	
August 29	7	.101	.088
August 30	7	.099	
August 31	5 (2 dead)	.089	
September 1	5	.098	
September 2	5	.096	.095

The behavior of larvae in crib corn is rather closely analogous to that in stored fodder. The borer content of ears in storage has been relatively low in Ohio up to the present time. As shown in Table 14 the borer population in the ears was highest at roasting ear time. The number greatly decreased by the time the kernels had become hard and the ears had approached maturity, the borers evidently leaving the ears and migrating into the stalks or perishing. The average of 13 fields at Bono, in which both stalk infestations and crib ear infestations were taken in 1926, showed the following relationship:

Number of records	13
Field infestation	73 percent
Crib infestation	4.3 percent

The field infestation was taken in the usual manner, while the crib infestation was based on the examination of 1,000 ears taken at random in each crib. In both cases the infestation was based on the external appearance of injury, such as entrance holes. Due to the extensive migration from ears at maturity and in storage, a considerable number of ears called infested were free from borers.

During the crib survey a total of 500 infested ears were selected and kept in cages for the daily emergence record. After all emergence had ceased the ears were dissected and the record of larval transformation obtained as follows:

Total number of larvae	355
Number of larvae failing to transform	144
Percent of larvae failing to transform	40.6
Number of larvae that transformed	211
Percent of larvae that transformed	59.4

Coincident with these experiments, five cages, each containing 100 infested ears, were placed in cribs amid corn. The ears were dissected at intervals thruout the emergence period. The final record from this series shows that 54 percent of the larvae had transformed, and that 46 percent had died in the larval stage. The final dissection was made September 24. Not all larvae were dead at the time of this dissection. Some were known to have lived a total of 16 months under these conditions.

The record of transformation from the ear cages checked rather closely with the crib record, there being 40.6 percent in the former and 46 percent in the latter that transformed successfully. The results of the two experiments indicate that a little more than one-half of the larvae in crib corn were able to transform without additional moisture as compared with one-fourth in dry fodder. A full explanation of this difference cannot be given at this time. Tests conducted by C. E. Dike, Department of Agronomy, showed but slight difference in the moisture content of the two, the shelled corn from the infested ears containing 13.30 percent moisture and the cobs 11.50 percent, as compared with 11.53 percent in the stalks.

Table 31 shows that emergence of adults from dry storage was seriously delayed even for the small percentage which finally emerged. It is of interest to note the behavior of such moths after emergence.

The length of life of the females was slightly greater in case of moths emerging from dry storage material than that of normal moths, and the incubation period of eggs laid by such moths was longer (Table 33).

TABLE 33.—Egg Record of Moths From Dry Storage as Compared With that of Normal Moths, Averages

Source of moths	Preoviposition period	Eggs per female	Egg hatch	Length of life of		Incubation period
				Female	Male	
	Days	*No.*	*Pct.*	*Days*	*Days*	*Days*
Dry storage material	3.61	431.5	95.6	22.6	21.5	8.6
Field fodder	4.10	467.8	95.4	19.4	21.2	7.0

As a result of this and other experiments it is concluded that material stored in barns or other dry places is negligible as a source of reinfestation. Only a small percentage of borers are able to emerge under dry conditions and the few that do emerge come out so late that they produce little or no damage.

WINTER MORTALITY

In obtaining mortality records the stalk dissections ordinarily were made from stalks that stood in the field thruout the winter in the normal manner for uncut fields. In the 1926-27 record, however, the material was taken from shocks of cut corn standing in the field. This possibly accounts in part for the low mortality rate for that year, as the larvae were in a measure protected.

The method used in computing winter mortality may be open to question in that the borer population per unit area decreased more than the winter mortality indicates. This may have been due in part to the fact that on warm days in the winter a few larvae for some cause migrated from their host and were not able to get back under shelter. It has been noted repeatedly that thruout the growing period of the larvae the population is constantly decreasing, yet but few dead bodies are found.

As shown by these records (Table 34) the winter mortality was always under 10 percent for normal field conditions when based on the dead borers actually found present within the tunnels or on the reduction in borer population per hundred stalks. Inasmuch as the corn borer has been under observation in Ohio five years and in that time has not had a year of high winter mortality, it seems unlikely that winter killing will ever be of vital importance in retarding the accumulation of the insect.

TABLE 34.—Showing Winter Mortality for Four Years

Year	Larvae observed	Mortality
	Number	*Percent*
1924	363	5.2
1925	2,433	6.4
1926	8,234	2.3
1927	2,183	6.1

Influence of Biotic Factors

PARASITES

At the present time parasitism is of slight importance in retarding the accumulation of the European corn borer or aiding in its control. The parasitism by all species, both native and introduced, was less than 1 percent. Among thousands of borers under observation during a season parasitized individuals were rare.

No native parasite has yet been found to attack the corn borer in sufficient numbers to be considered more than incidental. The fact that the corn borer is closely related to the rather heavily parasitized *Pyrausta ainsliei* Heinr. would lead to the hope that some of the parasites of *P. ainsliei* may also attack the European corn borer, *P. nubilalis,* particularly since *P. ainsliei* is a boring insect that occasionally gets into corn. There are also a number of other native borers that might be expected to furnish parasites for the corn borer. Among these are *Pyrausta penitalis* Grote, *Papaipema nitela* Guen., *Chilo plejedallus* Zinck., and others.

During the last few years the most important parasite of *P. ainsliei* has been reared from corn borers on several occasions. This species is *Microbracon caulicola* Gahan (determined by R. A. Cushman). It has been reared from all three of the common boring Pyraustids of this area, namely, *P. ainsliei* Heinr., *P. nubilalis* Hubn., and *P. penitalis* Grote. It seems to be the most common parasite of *P. ainsliei,* however, and is probably as yet incidental on the other two. This parasite is usually taken in clusters within the host tunnels. It winters within the cocoon, as many as three to twelve cocoons being found in a single cluster within a tunnel. As many as twelve parasites have been reared from one larval host.

The parasite seems to have developed a relationship to the plant host as well as to the larval host. At any rate specimens of *P. nubilalis* in smartweed *(Polygonum)* are commonly parasitized by this species, while seldom if ever are they parasitized by it in corn. In fact there is not a single definite record of this species parasitizing the corn borer in corn at the Oak Harbor Laboratory, altho there are one or two instances where the host plant was not recorded. It seems, however, that all of the three species are commonly parasitized when they occur in smartweed.

Another parasite that is frequently reared from the European corn borer is the commonest parasite of *Papaipema nitela* Guen., namely; the Tachinid, *Masicera myoidea* Desu. (identified by J. S. Hine). In two cases on record parasitism developed after exposing corn borer larvae to adult flies of this species confined in cages. In one case in which a puparium of what was thought to be *Masicera myoidea* was formed from a parasite of a corn borer larva, a colony of hyper-parasites came from the puparium. The species was determined by S. A. Rohwer as *Eupteromalus dubius* (Ashm.). This species has also been reared repeatedly from puparia of *Masicera myoidea* Desu. that had parasitized larvae of *Papaipema nitela* Guen. *Exorista nigripalpis* Touns. is another dipterous parasite that has been reared by the writers from the corn borer.

A pupal parasite, a small chalcid *Miotropis clisiocampae* Ashm., was reared from *Pyrausta nubilalis* Hubn. Twenty-five or thirty individuals emerged from the corn borer pupa. A number of the parasites were caged with corn borer larvae in an effort to parasitize additional borers but no parasitism resulted. This species was reported by Phillips, Underhill, and Poos as having been reared from the larger corn stalk borer, *Diatraea zeacolella.* Other pupal parasites reared from *P. nubilalis* are *Amblyteles rubicundus* (Cress) and *Hoplocryptus incertulus* (Vier); the former has been reared on a number of occasions, while the latter was taken just once. Another single specimen reared from the corn borer was rather doubtfully determined by Cushman as being *Labrorychus prismaticus* (Nort.).

PREDATORS

There has probably been a tendency to overestimate the importance of birds in combating the European corn borer, just as is the case with many other species of insects. In a few instances, however, birds have been known to lower the borer population of a rather small locality, such as a field or experimental plot of ground.

In one case during the summer of 1924 one field in eastern Ohio had approximately one-third of the infested stalks picked open in a manner characteristic of birds. When the stalks were examined the tunnels were usually found to be empty. This field adjoined a wood lot. The manner in which the stalks were mutilated indicated that the birds were probably crows.

In the course of experimental work carried on at Oak Harbor, robins repeatedly have been observed to feed on larvae that had come to the ground surface after having been plowed down. In fact robins became quite a nuisance by their interference with several experiments, as mentioned elsewhere in this bulletin. Several robins were shot and as many as eight corn borers were taken from a single stomach. Corn borer larvae attached to strings were also picked up by robins.

In order to determine the percentage of buried borers that were being eaten by birds the following experiment was conducted. In one series of cages, 200 borers were buried in each of two lots and surrounded by traps 40 inches square. The one lot was completely covered with poultry fence to prevent the entrance of birds. The other was left open. The results of the test are given in Table 35.

TABLE 35.—Showing Effect of Birds on Borer Survival in Hand Burials and on Plowed Ground

Lot	Borers buried No.	Recovered No.	Recovered Pct.
	Hand burials		
Protected from birds	200	150	75
Not protected	200	120	60
	Plowed ground		
Protected from birds	927	614	66.2
Not protected	927	470	50.7

The results indicate that the birds were responsible for the disappearance of 15 percent of the total borers buried.

In another series of experiments conducted as a part of the spring-plowing experiment in 1925 in cooperation with D. J. Caffrey, infested stalks were plowed down on each of two plots 30 feet square, 927 borers being the expected number plowed down in each case. One lot was completely and the other partially protected from birds. It required two days to construct the cage and during that time the birds were kept from both lots, a guard being stationed near the plots outside of working hours. The results of this experiment also are shown in Table 35.

In this experiment birds were evidently responsible for the destruction of 15.5 percent of the worms buried. This record checks closely with that of the hand burial experiment. However this record of mortality after plowing is likely higher than the average for the open field. The bird population in the area where the experiments were conducted was abnormally high.

During the season of 1927 the nitidulid beetle, known as the banded ips, *Glischrochilus fasciatus* Oliv., was repeatedly reported by farmers to be killing corn borers within the plant. The species was exceedingly abundant on corn thruout the season. It received so much publicity that attention was centered upon it for some time by H. R. Watts of the summer staff.

He closely watched 275 beetles for several days after they were placed in cages with known numbers of healthy and injured corn borers. It was found that the beetles readily attacked injured borers when a part of the tissue protruded thru the broken body wall. In only one instance was a beetle observed to attack a normal larva. In this case the hold of the mandibles was speedily dislodged by the vigorous movement of the corn borer.

This beetle has been known for some time to frequent situations where other insects have caused injuries to plants. The species is very commonly associated with the ear worm in the ear of corn, as many as 20 beetles being taken from a single ear. They feed largely upon the sap oozing from the injured part of the plant but may also attack injured insects. It is possible that they may attack normal corn borers, but the number they kill, if any, must be exceedingly small.

The spotted ladybird beetle, *Ceratomegilla fuscilabris* (Muls.), often has been observed feeding on corn borer eggs in the field. In 1924 one individual in captivity ate 244 eggs within five days. The species has also been observed to feed on young corn borer larvae.

Two specimens of *Lebia atriventris* Say, were taken in the axil of leaves of a corn plant where young corn borers commonly feed. They were not observed to feed upon corn borers out of doors but when placed in a vial with them they ate a great number of both first and second instar larvae. One of the large Calosomas, *Calosoma calidum* Fabr. was observed to kill and eat two full grown corn borer larvae placed near it on the ground.

A pentatomid, *Podisus maculiventris* Say, was found during the summer of 1927 with its beak inserted in a corn borer larva of the fifth instar. The borer had evidently been killed some hours before being seen as it was already somewhat discolored. The body of the larva was soft probably due to the fact that it had lost a great deal of blood.

In the summer of 1927, W. V. Balduf reported in his study of first and second instar corn borer larvae that he found an hemipterous species, *Triphleps insidiosus* Say, feeding on young corn borer larvae. During August the species was quite commonly found in the center of corn plants where small larvae normally occur in greatest abundance. The species is known to feed on eggs of the corn ear worm and the young of many soft bodied insects.

5. THE PUPA

J. B. POLIVKA AND E. G. KELSHEIMER

Perhaps the least considered of the four stages of the European corn borer is the pupa. Pupae are normally found within the tunnels made by the insects when in the larval stage. However, despite their apparent security, certain environmental conditions may seriously interfere with normal development.

Long continued periods of heat and drought may cause the death of many pupae. In 1925 all pupae observed in corn fields or unprotected places were killed during the first week of June, when for a period of 6 days there was an average maximum temperature of 99.3° F. A similar period of excessive heat in 1927 caused a 25 percent pupal mortality. Unfortunately, however, that hot period came after most of the pupae had transformed to adults, consequently the total number of pupae killed was much smaller than it would have been had the higher temperatures come ten days earlier.

It was thought that the extreme heat, even tho it did not cause the death of the pupae, in some way may have inhibited metabolism to the extent that the emerged adults, might not have deposited their full complement of eggs. However, experiments by E. A. Herr, of the summer staff, seem to indicate that, altho the moths may be undersized because of conditions prevailing during the larval and pupal stages, the normal number of eggs is not significantly lower.

The fact that the pupae cannot move about has led to the suggestion that plowing them under would be an aid in control. The pupation period comes in the main during the middle and latter part of June after the normal plowing season, hence the suggestion of plowing under during the pupal stage has little practical application.

Experiments have shown that moths may emerge from pupae buried in the soil, but such emergence is exceptional. When the soil becomes packed above the buried material it is impossible for the moths to come to the surface. From the hundreds of pupae buried, only one moth was recovered in the soil.

It has been noted that under conditions of barn storage the larvae may shrivel considerably from a lack of contact moisture. If there is too much desiccation the larvae will die. However, if the larvae succeed in reaching the pupal stage the mortality of pupae is negligible.

This stage of the insect is little affected by biotic factors.

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IV. AN ANALYSIS OF ENVIRONMENT WITH SPECIAL REFERENCE TO MECHANICS

INTRODUCTION

Larval mortality resulting from natural causes is relatively low after the corn crop is mature. When the larvae have reached the full grown stage and have entered the hibernating period their chances for continued survival are fairly good. It is obvious, therefore, that further reduction of population must come thru artificial means. Happily regular farm procedure results in the direct or indirect destruction of great numbers of larvae. The percentage of the borers destroyed depends, of course, quite largely upon the efficiency of the methods employed. In the immediate discussion an attempt is made to give an entomological evaluation of the different methods either individually or in combination or both.

It should be clearly understood, however, that the present discussion involves only the evaluation of different methods of farm procedure in reducing the level of the population of hibernating larvae. The effect of farm practices in reducing the population of the subsequent crop is still within the realm of speculation. While it is perfectly logical and safe to assume that mechanics is a biotic factor of undoubted importance yet, because of its close association with more powerful physical factors, it has been impossible thus far to assign it a definite value.

1. TREATMENT OF STUBBLE

C. R. NEISWANDER AND E. G. KELSHEIMER

In a study of mechanical control measures and their efficiency it is important that the exact position of the borers in the corn plant be noted at the time the treatment is being applied. It has been shown that borers feed almost exclusively on the corn plant and, with the exception of the short period of moth flight, spend their entire life therein. Where weedy fields are heavily infested there is a small percentage of borers in the weeds; weedy fence rows adjoining severely infested fields may also harbor some borers. It seems safe to say, however, that fully 99 percent of all borers in the corn fields of the Ohio area complete their transformation within the corn plant. Accordingly, the disposal of the corn crop residues alone will be discussed.

It was pointed out in Section 4 that the borers are distributed thruout the stem part of the corn plant, at the time of maturity. It is to be remembered of course that a short-stalk variety of corn is certain to have a larger proportion of its borers in the lower two feet of stalk than is a long-stalk variety. Some of the short stemmed sweet corns have close to 100 percent of their borers within the lower two feet of stalk, while tall varieties, like Burr-Leaming, have as few as 35 percent in the lower two feet of stalk. It is also quite probable that there are slight fluctuations from year to year because of variation in moisture content of the stalk.

VALUE OF CUTTING

In the heavily infested area of Lucas and Ottawa Counties approximately four-fifths of the corn is cut at maturity, as a normal procedure. As a means of mechanical control, cutting in itself is of no significant value. That is, borers are able to survive thru the winter in cut corn just as well as in corn left uncut, as will be shown later. However, the subsequent treatment of both the cut stalks and the remaining stubble gives a very important bearing to the height of cutting.

Some of the earliest work done by the Ohio Experiment Station dealt with a study of the importance of stubble as a carrier of borers thru the hibernation period. The efficiency of low cutting was stressed in 1923 as a result of the first year's work. Since that time the stubble has been a subject of intense interest in mechanical control. The development of the low-cutting attachment for corn binders was initiated the following year as a result of the cooperation of several agencies and thru the work of E. A. Silver.

TABLE 36.—Showing Borer Content of Low and of High Stubble

Field No.	Percent stalk infestation	Cutting height inches	Borers per acre in stubble and debris
1	42	6.5	480
2	36	16	1,376

The 1924-25 record of two cut fields showed clearly the efficiency of low cutting. These fields, of nearly equal infestation, were cut at different heights, but otherwise were similar. In the spring both were disked and seeded to oats. The stubble in each field was examined over five square rod areas; the height of stubble and the borer content were taken. Table 36 shows the borer population in the two fields to be almost directly proportional to the stubble heights.

Following the season of 1926 a comprehensive study of the efficiency of cutting was made as part of a survey of 50 fields in which all methods of cleanup were considered. The records were taken by the examination of all material over a square rod of surface in five different places in each field. The stubble were counted and the height of each individual stubble was recorded. They were then dissected and the number of borers noted. Small pieces of debris on the surface of the ground within the square-rod areas were also thoroly examined for borers.

In 22 of the 50 fields stubble records were taken. Reference to Table 37 will show that the borer population in these fields ranged from 6,723 to 38,102 before cutting and from 569 to 7,906 after cutting. The height of cutting ranged from 2.2 to 13.9 inches.

TABLE 37.—Showing Efficiency of Cutting

No.	Borers per acre standing	Height of cutting	Borers per acre						Efficiency of cutting
			In stubble		In debris		Stubble and debris		
	No.	*In.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*Pct.*
1	23,332	2.2	313	1.3	256	1.1	569	2.4	97.6
2	11,925	4.4	483	4.0	228	2.0	711	6.0	94.0
3	10,805	4.6	427	4.0	284	2.6	711	6.6	93.4
4	13,385	5.5	825	6.2	114	.8	939	7.0	93.0
5	23,307	7.2	1,479	6.3	227	1.0	1,706	7.3	92.7
6	25,200	13.2	1,877	7.5	341	1.3	2,218	8.8	91.2
7	6,723	5.6	512	7.6	114	1.7	626	9.3	90.7
8	16,434	6.9	1,422	8 7	199	1.2	1,621	9.9	90.1
9	25,380	13.4	1,906	7.5	398	2.4	2,304	9.9	90.1
10	15,674	6.9	1,593	10.2	256	1.6	1,849	11.8	88.2
11	30,262	10.0	3,071	10.1	768	2.6	3,839	12.7	87.3
12	38,102	10.6	4,579	12.0	256	.7	4,835	12.7	87.3
13	10,463	6.5	1,109	10.6	341	3.3	1,450	13.9	86.1
14	27,734	13.5	3,782	13.6	228	.9	4,010	14.5	85.5
15	22,365	5.3	1,593	7.1	1,905	8.5	3,498	15.6	84.4
16	11,178	9.7	1,735	15.5	227	2.1	1,962	17.6	82.4
17	16,400	9.0	2,375	14.5	711	4.3	3,086	18.8	81.2
18	29,970	9.7	4,920	16.4	825	2.7	5,745	19.1	80.9
19	29,318	13.7	5,318	18.1	1,820	6.3	7,138	24.4	75.6
20	12,890	13.5	2,332	18.1	768	6.4	3,100	24.5	75.5
21	30,643	13.9	6,825	22.3	1,081	3.5	7,906	25.8	74.2
22	17,957	13.1	4,693	26.1	540	3 0	5,233	29.1	70.9
Av.	20,429	9.0	2,417	11.3	510	3.2	2,957	14.5	85.5

The records of efficiency of cutting included herein are based on the assumption that all borers in the part of the stalk removed are in some way killed. On this assumption the efficiency ranged from 97.6 percent in the field with the best job of cutting, to 70.9 percent in the field with the poorest. The average efficiency of all 22 fields was 85.5 percent. The average number of borers per acre left was 2,957.

In Table 37 the fields are arranged according to the efficiency of the work done. Reference to the "Height-of-cutting" column will show that, in general, the low-cut fields are in the upper, or more efficient, part of the column, while the high-cut fields are in the less efficient part. Some of the fields, however, seem to be distinctly out of place in the column, if the height of cutting be considered as a criterion of borer population. This condition may be explained largely by the fact that there was a great variation in the amount of debris left on the ground outside of the stubble material. In binder-cut fields in particular there were always fallen stalks that were not picked up. Where these were permitted to remain on the ground the borer population was greatly increased. Field Number 15 was cut to a height of 5.3 inches. This is a comparatively low stubble and the field would be expected to rate high in efficiency. In this particular field, however, a great many borers were found in the debris, more in the debris than in the stubble, hence the field had a very low efficiency, as low as if the stubble had been cut at a height of 10 or 12 inches instead of 5.3.

A comparison of the two columns, "Borers per acre in the stubble" and "Borers per acre in debris", will show the relative importance of the two sources of borers. The debris column clearly shows that the fallen material must not be neglected in evaluating the height of cutting. Only 7 fields out of the 22 fell below 250 borers per acre. In other words, to make low cutting an effective method the corn must be cut as low as possible, and the fallen stalks must be picked up in order to reduce the number of borers in both stubble and debris.

The number of borers left after cutting will depend also in large measure on the borer population in the field. If the population is sufficient to cause much breaking of stalks there will be a large number of borers in small fragments lying on the ground.

EXPERIMENT WITH LOW-CUTTING ATTACHMENT, 1926

At the normal cutting time in the fall of 1926 a test was conducted with a low-cutting attachment on a corn binder in the heavily infested part of the plot field at Bono. The record in this field was taken in the usual way for cutting records.

While the corn was cut practically at the soil surface it was found that there was an average stubble length of 2.3 inches, measuring from the roots up. Out of five square rods examined, however, there were only two borers found. The original population per acre in this field was 10,136. The number in the stubble was about 57 borers per acre, giving the treatment an efficiency of more than 99 percent.

There was but little stalk breakage in this field, altho there had been 16 percent of the stalks with broken tassels, many of which were on the ground. In handling the cut stalks only the bundles were removed. There were a number of stalks scattered by the binder. These were left on the ground and were counted in with the debris. The test was made to simulate farm conditions where no fallen stalks are picked up, which is probably wholly or in part the normal procedure with the majority of farmers. In the debris there was an average of 1,193 borers per acre. In the stubble and debris together there were 1,250, which gives a total efficiency for the field of 87.7 percent, a very low rate. However, practically all of the borers in the debris were in fallen stalks, which could have been picked up. With the stalks removed, leaving only stubble to harbor borers, the efficiency would have been very high, 99.4 percent.

In order to give a severe test to the efficiency of cutting, an experiment was conducted in a field after the corn was thoroly ripe and dry. The object of this test was to simulate conditions under which the combine harvester type of machine will probably be used. As a preparation for this study two plots of one-fortieth acre each were marked out in the field and thoroly examined for borers in order to ascertain the average number per unit area before the test was made. The data from this record are presented in Table 38.

TABLE 38.—Showing Average Number of Borers per Unit Area Prior to Cutting

Lot	Borers per stalk	Size of plot examined	Stalks per plot	Borers per plot			Total per acre
				In corn	In weeds	Total	
	No.	*A.*	*No.*	*No.*	*No.*	*No.*	*No.*
A........	5.7	1/40	222	1,532	68†	1,600	64,000
B.........	8.0	1/40	214	1,477	52‡	1,529	61,160
Average ..	6.9	....	218	1,504	60	1,564.5	62,580

*Based on dissection of 50 stalks.
†Computed from examination of 1 square rod.
‡Computed from examination of 2 square rods.

After the population record was obtained, the field was cut with a binder, using the floating low cutting attachment. Two 1/40-acre plots were again measured off and a record taken of the total number of borers left behind by the binder after all bundles were removed. The data obtained from the stubble and debris record are presented in Table 39.

Table 39 shows that there was an average of 62,580 borers per acre before cutting, while the total left in the field after the bundles were removed was 12,380 per acre, an efficiency of 80.5 percent. This is an extremely low rate of efficiency. In other words, it is necessary that further work be done with the debris in order to make a satisfactory disposal of the borers present.

TABLE 39.—Record of Efficiency of Low Cutting Binder When Corn was Cut Late, 1926

Lot	Size of plot examined	Height of stubble*	Borers in stubble	Corn debris	Borers in corn debris	Borers in ears on ground	Borers in weeds	Borers recovered	Borers per acre left	Efficiency
	A.	*In.*	*No.*	*Ft.*	*No.*	*No.*	*No.*	*No.*	*No.*	*Pct.*
A......	1/40	2.9	37	206.8	214	4	14	269	10,760	83.8
B	1/40	3.0	54	204.6	267	4	25	350	14,000	77.1
Av....	....	2.95	45.5	205.7	240.5	4	19.5	309.5	11,380	80.5

*Includes all parts of stalk attached to root when under ten inches. When more than ten inches stalks are considered under corn debris

†Computed from preceding column in this table and last column in Table 38.

An analysis of the data shows that the corn was cut to an average of 2.95 inches. From the numerous field records taken it would seem that cutting at this height should be fairly efficient. The number of borers found in the stubble was 45.5 per 1/40 acre, or 1,820 per acre, which is 2.9 percent of the total borers originally present in the field.

The debris column in Table 39, however, shows that a large proportion of the borers were in short pieces of stalks left in the field. This may be explained by the fact that many stalks were so brittle as a result of borer injury and complete ripening that they broke into fragments during the cutting process. In general it may be said that the number of borers remaining when cutting is done at the optimum date will always be lower than when the cutting is done late.

THE STUBBLE SHAVER

In some section of Ohio there has developed the practice of cutting the stubble off at the soil surface by means of a sled type of implement to which long cutting knives are attached at an angle on either side in a manner similar to the old type of corn cutting sled but with the cutting knives much longer and lower. It was developed previous to the advent of the corn borer in an effort to prevent stubble interference with later farm operations. Stubble shaving in itself is of little or no value as an aid in corn borer control; but, inasmuch as it may facilitate better plowing or raking it is of some value.

THE CRUSHING EFFECT OF TRACTOR WHEELS

In order to determine the possibility of using tractors to crush larvae in stalks or stubble, tests were made on both standing corn and stubble. The tractor, a McCormick-Deering 10-20, was driven down the row so that the wheel passed directly over the stalks or stubble. Where the stalks leaned to the side out of the row so that the tractor wheel would not pass directly over them, they were drawn over so as to lie directly in the row.

The first test was made December 4, 1926 at a time when the temperature was near the freezing point. The borers were inactive but not necessarily rigid. The ground was not frozen so hard but that it gave under pressure of the tractor wheel lugs.

TABLE 40.—Showing Efficiency of Tractor Wheels as a Means of Crushing Larvae in Stalks and Stubble

	Borers recovered			Direct kill	Dying later	Efficiency
	Total	Live	Dead			
	No.	*No.*	*No.*	*Pct.*	*No.*	*Pct.*
Stalks	245	231	14	5.7	51	26.5
Stubble	20	18	2	10.0	4	30.0

A second test was conducted later in which the tractor was driven down and back on the same row. In this case, only stubble were used, these having been cut to a height of 12 inches. Fifty stubble were subjected to treatment in the experiment with the following result.

Borers killed outright	24 or 28.2 percent
Injured	12 or 14.1 percent
Apparently normal	49 or 57.7 percent

While the efficiency shown above is considerably higher than that of 30 percent in the first test, it is entirely too low to be considered of much value.

DISKING

Over certain sections of northwestern Ohio it was formerly the custom of many farmers to disk down the standing stalks and sow oats or spring wheat without further treatment. Disking when done in such manner that a large part of the stalk material is covered by earth will measure up to the standard of a poor plowing job and may result in approximately a 50 percent efficiency. Where disking is done for the sole purpose of providing loose soil to cover the spring grain crop its value as a means of destroying larvae is almost nil. In a number of cases in which the borer population was taken following the disking of stubble or standing stalks the borer content was found to be practically equivalent to the population before disking, thus indicating that the practice has but little value.

Where later treatment is planned in the way of further disposal of stalks or stubble after disking the work is really very much hampered by disking. The borers are commonly disturbed in their quarters without being injured and in migrating secure shelter in some of the numerous small fragments that have been supplied by the action of the disk. For this reason it is practically impossible to clean a field thoroly even by hand picking after it has been disked.

Where corn has been cut low and the stalk fragments remaining in the field are few, thoro disking is of value in disposing of a portion of the few surviving borers. In cases of this kind thoro disking may take the place of plowing where the latter is impracticable. The point should be emphasized, however, that disking should be practical where the borer content is made low by former treatment, such as low cutting, under which conditions there appears to be no reason why disking corn ground for fall grain should be discontinued.

The record of three fields studied in 1927 is given in Table 41. The average efficiency of disking in these fields was 13.2 percent, with a variation from 0 to 64.2 percent.

TABLE 41.—Showing Value of Disking

Field No.	Acreage	Population before treatment	Population after treatment	Percent efficiency
1	6.0	9,726	9,726	0
2	2.6	5,767	5,759	.1
3	6.4	4,006	1,434	64.2
Total	15.0	19,499	16,919	13.2

THE STUBBLE PULVERIZER

The stubble pulverizer is a new implement developed entirely for corn borer control work. It has been used but a short time and its status as a practical farm implement has not been established. A few records taken in 1927 as to its experimental efficiency, however, are worth considering.

In one field under observation during the spring of 1927 a population record was taken immediately preceding treatment by the pulverizer. The field was found to have a population of 3,424 borers per acre in the stubble. As soon as the pulverizer had passed over, the record was again taken. In obtaining this data larvae that showed any abnormality whatever were tabulated as dead. Larvae that behaved normally in every respect were tabulated as live. Under this test 1,152 live borers per acre were found after the stubble pulverizer, giving it an efficiency of 66.4 percent.

In another field the population of standing corn was 6,858 borers per acre. No stubble record was taken, but after the stubble pulverizer was used the field was found to contain 608 borers per acre, giving an efficiency for cutting and stubble beating togethei of 91.1 percent. Since the efficiency of cutting alone averaged 84 percent and the combined efficiency was 91.1 percent, the efficiency of the pulverizer alone would be 44.4 percent.

TABLE 42.—Showing Population Data for 6-inch, 12-inch, and 18-inch Stubble

Stubble height, inches	Lot No.	Rod rows in plot No.	Stubble No.	Borers per plot: In stubble No.	Borers per plot: In debris No.	Borers per plot: Total No.	Total per acre
6-inch stubble							
6	1	2	40	76	21	97	....
6	4	3	49	49	15	64	....
Total	....	5	89	125	36	161	....
6	2	3	47	60	20	80	....
6	3	2	39	46	9	55	....
Total	....	5	86	106	29	135	....
Series average	....	....	87.5	115.5	32.5	148	22,333
12-inch stubble							
12	5	2	37	94	7	101	....
12	8	3	51	99	17	116	....
Total	....	5	88	193	24	217	....
12	6	3	64	194	23	217	....
12	7	2	39	111	15	126	....
Total	....	5	103	305	38	343	....
Series average	....	....	95.5	249	31	280	39,143
18-inch stubble							
18	9	2	31	90	6	96	....
18	12	3	48	121	15	136	....
Total	....	5	79	211	21	232	....
18	10	3	46	89	13	102	....
18	11	2	35	85	7	92	....
Total	....	5	81	174	20	194	....
Series average	....	....	80	192.5	20.5	213	34,918

Note: 5 rows one rod long is the area considered as a square rod and used as the standard plot size in column three. This plot is more than a square rod, however, there being only 150.9 such plots to the acre.

A test was made on three stubble heights, 6, 12, and 18 inches, in a field in which the borers had severely damaged the crop. A plot of five rows extending entirely across the field was used for each stubble height. The corn was cut by hand to the height required. In order to obtain a record of the borer population for the given stubble heights, check plots were marked off at each end of the field and on either side of the plots studied. The check plots were so arranged that the two on opposite sides of a given test plot would make the equivalent of one square rod. There were thus two square-rod areas to serve as a check on mortality due to the use of the stubble pulverizer. In the plots prepared for the test all fallen stalks were removed.

The number of borers per acre was not directly analogous to the respective stubble heights. While the 18-inch stubble would be expected to have the most borers per acre it had fewer than the 12-inch stubble. This is explained by the fact that the borer population was not uniform over the field but gradually diminished from the front towards the rear. This decrease was not perceptible until the area in the vicinity of the third plot was reached. The corn had been drilled, hence it was impossible to have the plots extended in the direction of the decrease in population. Because of this variation the record is not as significant as it otherwise would have been. Error is also likely to be larger with the population varying as it did. However, since population records were taken in all of the localities studied the percentage of efficiency should be approximately correct even tho the numbers recovered are extremely variable.

Thru the courtesy of the United States Department of Agriculture in spring of 1927, one of the Federal stubble beaters was used in the test and operated by an experienced Federal employee. Immediately after the test was finished a survey was made of all of the debris left in five one square rod areas and the number of borers was noted. The number and total length of all pieces of stalk over 2 inches in length and the number of borers in them were recorded. The record of recovery for the debris plots is given in Table 43.

In the summation record (Table 44) it may be noted that the number of borers left after the stubble beater, varied with the height of the stubble to a much greater extent between the 12-inch and 18-inch stubble than between the 6-inch and 12-inch. This was true regardless of the fact that in the 18-inch stubble there were originally fewer borers than in the 12-inch, while the 12-inch had almost twice as many as the 6-inch. The record thus seems to indicate that there was a marked decrease in the rate of killing when stubble increased in length from 12 to 18 inches, while there was a slight increase in the rate from the 6-inch to 12-inch stubble.

TABLE 43.—**Showing Population After Stubble Pulverizer in 6-inch, 12-inch, and 18-inch Stubble**

Lot No.	Stubble height	Pieces over 2 inches			Live borers in leaves, etc.	Total live borers	Later deaths from injury	Later live total	Borers per acre	Efficiency
		Pieces	Length	Live borers						
	In.	*No.*	*In.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*Pct.*
A	6	34	360	20	16	36	....	....	....	....
B	6	36	480	28	23	51	....	....	....	....
C	6	20	216	18	15	33	....	....	....	....
D	6	31	468	25	24	49	....	....	....	....
E	6	42	564	36	20	56	....	....	....	....
Av.	....	32.6	417.2	25.4	19.6	45	2.4	42.6	6,428	71.2
A	12	48	706	32	24	56	....	....	....	....
B	12	36	360	28	28	64	....	....	....	....
C	12	44	468	37	16	53	....	....	....	....
D	12	41	540	39	15	54	....	....	....	....
E	12	50	720	48	12	60	....	....	....	....
Av.	....	43.9	558.8	38.4	19	57.4	4.4	53.0	7,998	79.6
A	18	61	1080	69	18	87	....	....	....	....
B	18	101	1680	104	35	139	....	....	....	....
C	18	79	1440	82	21	103	....	....	....	....
D	18	91	1200	74	11	85	....	....	....	....
E	18	86	1320	75	19	94	....	....	....	....
Av.	....	83.6	1344	80.8	20.80	101.6	.4	101.2	15,271	56.3

When the efficiency rate of the pulverizer is combined with the efficiency of cutting at the respective heights the results indicated in Table 45 were obtained. These were computed by deducting the number per hundred that the pulverizer would kill from the respective number left after cutting at the different heights. For instance, in the 6-inch stubble in this field 15.1 percent of the borers remained in the stubble. Since the stubble beater destroyed 71.2 percent of the borers in 6-inch stubble, 71.2 percent of the 15.1 percent remaining is 10.8 percent. This would leave 4.3 percent; the

TABLE 44.—**Summation of Debris Record After Stubble Pulverizer**

Series	Stubble height	Borers per acre			Efficiency of stubble beater
		In stubble	After stubble beater	Killed by stubble beater	
	In.	*No.*	*No.*	*No.*	*Pct.*
I....................	6	22,333	6,428	15,905	71.2
II....................	12	39,143	7,998	31,100	79.6
III....................	18	34,918	15,271	19,586	56.3

two practices would kill 95.7 percent of the borers. In like manner, in 12-inch stubble the efficiency would be 91.9 percent, and in 18-inch stubble 77.1 percent.

TABLE 45.—Showing Combined Efficiency of Cutting and Stubble Pulverizing

Stubble height	Cutting efficiency	Borers left	Pulverizer efficiency	Borers left	Combined efficiency
In.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
6	84.9	15.1	71.2	4.3	95.7
12	60.1	39.9	79.6	8.1	91.9
18	47.5	52.5	56.3	22.9	77.1

None of these efficiency rates is high enough to be considered of much consequence. It must be admitted, however, that this field provided extreme conditions, as the corn stood on the stalk until about the middle of November, when the test was made. By this time there was a considerable amount of natural breaking and many fragments of stalks contained borers. The amount of debris in this field at any time was large, but its importance was considerably increased by the lateness of this test.

In order to determine the relative killing power of the pulverizer on stubble of various heights when only the borers in the stubble are considered, the borers in the debris were deducted both before and after the pulverizer was used. This was done on the assumption that none of the borers in the debris were killed by the pulverizer. The number of live borers remaining after the stubble beater minus the original number in the debris would thus leave the number of borers that had been in the stubble and were not killed by the pulverizer. Table 46 gives the record of survival of borers in the stubble alone.

TABLE 46.—Showing Efficiency of Stubble Pulverizer Considering Borers in Stubble Alone

Height of stubble	Per acre				Efficiency of pulverizer on stubble alone
	In stubble alone	In debris alone	After stubble beater	After stubble beater if original debris had been removed	
In.	*No.*	*No.*	*No.*	*No.*	*Pct.*
6	17,429	4,904	6,428	1,524	91.3
12	34,466	4,678	7,998	3,320	90.4
18	31,825	3,093	15,271	12,178	61.7

The table shows but little difference in the way the beater handled 6 and 12-inch stubble, while the efficiency in 18-inch stubble was very low, only a little more than one-half of the borers having been killed. If this efficiency is combined with that of cutting for the different stubble heights the efficiency in 6-inch stubble would be 98.7 percent; in 12-inch, 96.2 percent; and in 18-inch, 79.9 percent. These are only theoretical efficiencies, as it would be practically impossible to pick up all of the debris on the ground in a field such as the one studied. Very small fragments, but little larger than a borer itself, often contained borers.

In fields that are heavily infested, such as the one used in this study, there is always a large amount of debris consisting of stalk fragments on the ground. When this field was ready for harvest it was approximately 90 percent detasseled and 25 percent of the stalks were broken. The fallen tassels themselves harbored large numbers of larvae. If all of the borers in the stubble were killed by the stubble beater, the treatment still could not be considered efficient because of the large number of borers in the small fragments of stalk and leaves that the pulverizer does not reach. Since the efficiency of the pulverizer on stubble alone was less than 92 percent at optimum stubble height, it must be concluded that the stubble pulverizer does not have a high rate of efficiency.

STUBBLE PLOWING

A general discussion of the investigational work on plowing is presented under disposal of standing stalks, page 96. The value of plowing down stubble is shown in Table 47. The plowing down of stubble even of normal height is an excellent procedure. The average efficiency of plowing alone was 88.9 percent, while the combined efficiency of cutting and plowing together was 98.3 percent.

TABLE 47.—Showing Value of Plowing Down Stubble

Field	Size	Field population per acre		Efficiency of plowing	Efficiency of cutting and plowing
		Before plowing	After plowing		
	A.	*No.*	*No.*	*Pct.*	*Pct.*
1	3.3	2,346	0	100	100
2	2.0	14,276	160	98.9	99.7
3	8.0	41,864	2,048	95.1	98.6
4	4.4	8,633	563	93.6	98.9
5	12.0	46,068	4,992	89.2	98.6
6	8.5	26,231	3,556	86.5	97.5
7	3.4	3,193	544	83.0	98.8
8	3.3	2,346	422	82.0	98.8
9	2.6	5,767	1,664	71.2	97.5
10	4.0	6,824	3,584	47.5	96.2
Total	51.5	157,584	17,533	88.9	98.3

2. TREATMENT OF THE CUT FODDER AND STANDING STALKS

J. B. POLIVKA, E. G. KELSHEIMER, AND L. L. HUBER

In the foregoing discussion of the value of cutting at various heights the efficiency was based on the borers in the stubble alone, on the assumption that all borers in the part of the plant removed were ultimately destroyed. Where corn is cut the part of the plant removed is normally handled in one of two ways. In dairy sections and in some general farming sections the entire crop is immediately ensiled. In the process there is practically a 100-percent mortality of the borers in the cut-off portion. If the material is not made into silage the crop is usually set up in shocks in the field and there permitted to dry out sufficiently for crib storage of ears and barn storage of the fodder.

SHREDDING

The following study was undertaken in the hope of ascertaining whether the shredding or cutting of corn fodder into small pieces, would materially reduce the chances of borer survival. Several experiments were conducted, using different types of "husker-shredders" equipped with shredder heads or cutter heads or combinations of both.

The work was begun in the spring of 1925 and was continued in the fall of that year in cooperation with D. J. Caffrey. The experiments will not be discussed here as the compiled data with full explanations appear in the U. S. Department of Agriculture, Technical Bulletin No. 53, Dec. 1927 pp. 51 to 54.

Since the borer content of the stalks was low in the material used in 1925, the shredding experiments were repeated in 1926 and 1927 with a greatly increased borer population. Accordingly, on November 23, 1926 three bundles of 50 stalks each were run thru a six-roll husker with a shredder head. The usual care was taken to clean the machine before and after the test so that all the infested material and no other would be considered. The fodder was collected in a large burlap wool sack held over the end of the blower and a canvass was spread beneath the husker to collect all the material that fell, including the shelled corn.

A dissection of 65 stalks beforehand had shown an average of 5.8 borers per infested stalk, making a total of 870 borers in the three bundles that were run thru the machine. In all of the shredded material 18 living, 29 injured, and 418 killed borers were found, making a total of 465 larvae recovered out of the expected 870. Of the larvae actually recovered, 96 percent were killed or fatally injured.

The 29 injured and the 18 living borers were set aside for further observation. Upon examination of the injured borers May 3, 1927, only 2 remained alive. Observation of these borers May 28 showed the 2 injured borers and 7 of the 18 apparently normal borers still alive. The total number of larvae failing to survive the treatment was 98 percent on May 28 when the experiment was closed. The experiment showed that the husker with a shredder head disposed of nearly all of the borers in the fodder.

Another experiment was conducted, December 21, 1927, in order to test out a husker equipped with a cutter head. In this test 150 stalks were run thru a four-roll husker of this type. The usual precautions were taken, as in the previous experiments, except that the shelled corn was collected in a separate sack. Table 48 shows the results.

TABLE 48.—Showing Mortality After Treatment With Husker and Cutter Head

Date examined	Borers in						Total borers		Mortality
	Shelled corn		Material that fell thru		Shredded fodder				
	Live	Dead	Live	Dead	Live	Dead	Live	Dead	
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*Pct.*
December 21.......	34	36	39	71	33	413	106	520	71.2
January 21........	22	48	22	88	24	422	68	558	89.1
February 25. ...	10	60	7	103	9	437	26	600	95.8

The table shows that 71.2 percent of the borers that were recovered were found in the shredded fodder. In all the material 106, or 16.9 percent, of the borers seemed normal, but when examined a month later, January 21, 38, or 35.8 percent of the number, were dead.

A dissection of 1076 stalks showed an average borer population of 6.25 per stalk. Therefore, in the 150 stalks that were run thru the shredder, 937 borers were expected, making the immediate efficiency of the "husker-cutter" 88.7 percent and the final efficiency of February 25, 97.2 percent, when based on the borer expectancy and the missing borers considered dead.

A comparison of the results from the cutter-head type of machine husker with those of the shredder-head type showed that the latter gave a slightly higher immediate and subsequent mortality rate. However, the efficiency of both machines was so high that there is no need in differentiating between them in making recommendations. The subsequent effect of storage under barn conditions, as described in Section 4 will eliminate practically all of the borers remaining under either treatment. In general, it may be said that the corn husker is an efficient machine, regardless of its type, in contributing to the reduction of potential adult population.

BARN LOT EXPERIMENTS

The practice of many farmers in Ohio has been to feed the whole or shredded corn fodder to livestock and then throw the uneaten portion into the barn lot to be trampled into manure. Information on the survival and death rate of corn borers found in the manure under this form of treatment was desired. Accordingly, several experiments were conducted in order to ascertain the relative importance of barn lots as a harbor for corn borer larvae.

On November 23, 1923, 50 larvae that had been allowed to bore into stalk sections 6 inches long, were buried in 6 inches of strawy manure. The manure was not tramped at any time, but it was well soaked and frozen thruout the winter. When the stalks were removed, April 1, 1924, the manure was still frozen, making it necessary to chop the stalks from the mass. The stalks were frozen to the extent that the borers were surrounded by ice. Upon dissection of the stalks, 49 live borers and 1 dead borer were found.

In another experiment 25 borers in stalks 6 inches long were buried December 5, 1923, in 6 inches of fresh horse manure mixed with straw. The entire pile of manure was about 8 by 10 feet and 3 feet deep. Thermometers placed in the manure pile were broken, indicating that the temperature of the mass reached a point somewhat higher than the thermometers were capable of registering, or 133° F. These stalks, which were enclosed in one thickness of cheesecloth, were removed from the manure December 18. The cheesecloth was decayed and burned, further evidence of extreme heating. The borers were all dead when examined.

In order to find out what effect the packing of shredded corn fodder into manure would have on the few borers that survived the shredding process, on November 26, 1925, 300 stalks were shredded and stored in a dry place. Then the shredded material was taken a little at a time with some manure and packed in a cage 4 by 6 feet. The cage was screened over in the spring of 1926 and closely observed each day for moth emergence. The expected number of borers originally in the fodder was 318. Three moths emerged from the manure pile making the efficiency of shredding and the action of manure together 99.1 percent.

Further experiments in barn lots were started in December, 1925. Infested stalks were buried under the following conditions: (1) no trampling; (2) very little trampling; and (3) well trampled by cattle and hogs.

TABLE 49.—Showing Borer Survival in Different Types of Barn Lots

Type of barn lot	Buried December	Taken up May	No. stalks buried	Number of borers			Percent survival
				Expected	Found alive	Found dead	
No trampling..........	21	5	50	50	11	6	22
No trampling....... ...	30	5	50	50	26	0	52
Little trampling......	20	7	200	200	0	153	0
Well tramped..	20	6	200	200	0	93	0

The material that was not trampled was buried in a manure pile composed largely of corn stalks. In the other two cases the stalks were buried in cow manure, which tends to pack without much trampling. However, one of these lots was well trampled. These experiments show that the action of fairly heavy manure alone tends to kill many borers, and that trampling still further reduces the number that might survive.

An effort was made in 1927 to obtain further data on the number of corn borers in the average barn lot. A number of barn lots were studied in the Bono area, by examining for borer content one square yard in each of two localities in each lot. The data included lineal feet of stalk material in the area examined; size of lot; exact condition of the manure in regard to moisture, packing, and composition; and the number of livestock in the yard. Table 50 gives the results of the survey made in barn lots where the fodder was fed whole and where shredded.

In the barn lots where the stalks were fed whole the live borer population was 20.7 per square yard, and in the lots where the fodder was shredded it was a 5.4 per square yard. The number of dead borers found in barn lots where fodder was fed whole was 28.4 percent, and in the lots where fodder was shredded 43.4 percent of the total number found. Approximately six times as many live borers per lot were found where fodder was fed whole as where shredded. This is additional evidence of the value of shredding.

The population of the average barn lot where fodder was fed whole was only about one-fourth as great as the average acre of corn ground before cleanup. A comparison with other records showed that if nothing were done to barn lots the average lot would contain as many borers as the average ten-acre field after being cleaned up. Even where the fodder was shredded or cut the borer content per lot was equivalent to more than two acres of ten average corn fields after being cleaned up. The data indicate that in some instances barn lots should be recognized as a source of reinfestation.

TABLE 50.—Showing Results of Barnyard Survey, in Bono District, 1927

Farm No.	Size of lot	Area examined	Length of debris examined	Borers in debris examined		Computed borers in lot	
	Sq. ft.	Sq. ft.	Ft.	Live No.	Dead No.	Live No.	Dead No.
			Fodder fed whole				
1	3,900	18	272	56	10	12,125	2,167
2	1,800	18	494	76	26	7,600	2,600
3	1,680	18	385	28	11	2,612	1,026
4	400	9	57	0	0	0	0
5	2,530	9	200	40	20	11,244	5,622
6	576	18	272	9	2	288	64
7	1,800	18	250	17	5	1,700	500
8	1,260	18	345	62	23	4,340	1,410
9	1,200	18	359	43	30	2,868	2,001
10	1,296	18	250	16	11	1,152	792
11	792	9	117	42	13	3,696	1,144
12	1,377	18	270	1	3	76	229
13	4,000	18	233	1	5	222	1,111
14	594	18	405	25	7	825	231
15	3,750	18	340	72	28	14,998	5,832
16	864	18	295	4	6	192	288
17	504	9	96	1	0	56	0
18	432	18	105	1	0	24	0
19	629	9	87	54	23	3,775	1,608
Average	1,595	16.6	273	30.7	12.7	3,662	1,450
			Fodder shredded				
1	638	27	....	1	2	24	47
2	1,882	9	....	4	9	836	1,882
3	660	18	....	3	12	110	440
4	2,754	18	....	24	7	3,672	1,071
5	374	9	....	0	3	0	125
6	540	9	....	0	0	0	0
7	945	18	....	0	0	0	0
Average	1,113	15.4	....	4.6	4.7	663	509

SPRING PLOWING EXPERIMENTS

Certain controlled experiments conducted in 1924 and 1925 showed that larvae may transform to pupae and that successful emergence may follow even tho the sheltering media be nothing more than sand or soil. A negligible percentage of larvae will, if necessary, pupate in or under clods. Successful emergence, however, is thought to be exceedingly rare under natural or field conditions. During the spring of 1925, in connection with some of the migration experiments, extensive soil siftings were made for recovery of borers in the soil. In one case where 1,000 borers were buried at plowing depth in the center of a 50-foot cage, in which there was no debris on the surface of the soil, only 17 were recovered in the traps at a 25-foot distance. When the buried stalks were taken up and examined only 6 live and 11 dead borers were found. Thus a total of only 34 borers were recovered, or 966 out of 1,000 had disappeared. It was considered probable that a great many of the borers were concealed amid or under clods. During the progress of the experiment an examination of clods would occasionally reveal borers beneath them. After the termination of the experiment, that is, after no more borers were being taken, extensive siftings of the soil were made over the plot with a screen fine enough to retain borers. Three square yards of surface were sifted down to plow depth and not a single borer was taken in all of the siftings.

A field having an estimated population of 34,944 borers per acre before plowing had 2,272 borers per acre, or 6.5 percent, alive after the plowing. This field had been carefully and cleanly plowed in May with the newly designed wide bottom plow. The infestation year after year in this field had been heavy in spite of the fact that it had always been very cleanly plowed. It was suggested that some of the borers might be coming thru to maturity in the soil. On June 20, 1927, more than a month after the plowing had been done, three areas of one square yard each were selected and the dirt to plow depth sifted. Not a single borer was taken in any one of the square-yard areas.

Altho laboratory experiments have proved rather conclusively that borers can pupate and the moths emerge successfully from the soil while confined closely within a small area, it is yet to be shown that this actually occurs in the field. Altho it has not been possible to account for every borer after a field has been plowed, this failure in no way detracts from the value of plowing under infested crop remnants. It may be desirable to know what actually happens to the borers, but it is not essential. It seems probable that some borers migrate about over the ground until they are devoured by birds or are attacked either alive or dead by ants and other predaceous and saprophagous insects. When debris is present they crawl into it; when not, they crawl about until death from some cause overtakes them. On the whole it is not likely that more than an infinitely small number of the borers survive and emerge amid clods and earth under natural field conditions, whether or not debris is present.

FALL PLOWING EXPERIMENTS, BONO, 1926

The fall plowing experiments at Bono were similar to those conducted at Oak Harbor in the spring, except that in most cases debris was placed on the surface equal in amount to that found under usual plowing conditions for the area. This series of experiments was repeated in cooperation with D. J. Caffrey (31). In general the results corroborated those of the preceding spring.

The most significant thing about the results in the fall in 1926 was the fact that the same percentage of borers was again recovered where they were compelled to travel 11½ feet to get into the traps, there being 27 percent in each case. In the larger cage, however, 21.8 percent were in the debris as compared with 14.5 percent in the debris in the smaller one. This indicates that a very large percentage of the borers that got into the traps would have gone into debris if there had been no traps present.

The records seem to show that 21.8 percent is near the efficiency rate of plowing where the amount of debris is the same as that noted here. The amount of debris present was equivalent to the average on farms of the vicinity for the period in which this experiment was conducted. The efficiency of plowing as practiced during the period was, therefore, approximately 78.2 percent.

The 1927 debris survey included 12 fields that had been plowed, 10 of which had been cut and the stubble plowed under, and two had been plowed after the standing stalks were raked and burned. The efficiency of the two methods is given in Table 51.

TABLE 51.—Showing Value of Plowing, 1927

Method	No. of fields	No. of acres	Borers per acre		Percent efficiency
			Before plowing	After plowing	
Stubble plowed	10	51.5	3,059	340	88.9
Standing stalks plowed after burning	2	27.7	2,134	690	72.4
Total or average	12	79.2	2,735	462	83.1

In all twelve fields the plowing was done by the farmer with his own type of plow. This average efficiency of 83.1 percent was much higher than in the two previous years, indicating either that the method of plowing was improved or that the stalk material was being more completely disposed of before plowing, or both.

In order to test the efficiency of plowing standing stalks an experiment was conducted with a new 18-inch bottom plow. As a check on the value of the new plow a 14-inch sulky plow was used on another plot in the same field. The results are tabulated below:

TABLE 52.—Comparative Efficiency of New Wide Bottom Type of Plow With a Common Sulky Plow

Type of plow	Borers per acre		Efficiency
	Before plowing	After plowing	
	No.	*No.*	*Pct.*
18-inch bottom..........	34,944	2,272	93.5
Sulky............	20,800	4,800	76.9

The new plow showed a very distinct improvement over the old type of plow, the efficiency of 93.5 percent being much higher than the efficiency records from former years. The sulky plow record on the other hand was not far different from the efficiencies of former plowing tests.

In general it may be said that the efficiency of plowing is largely dependent upon the thoroness with which the job is done. It has been definitely shown that plowing, in itself, kills but few larvae. The main object in plowing is to force the borers from the buried stalks and to prevent their having material on the plowed surface into which they may crawl for shelter. If the plowing is thoro its efficiency will be correspondingly high. On the other hand, if the fodder material is not covered, little is gained by plowing as far as reducing corn borer population is concerned.

SUMMARY OF MECHANICAL DISPOSAL METHODS

Each year since 1923 there has been a strenuous effort toward more complete disposal of the residues from the corn crop. As a result of educational campaigns for mechanical cleanup of fields the plant remnants of the corn crop have been materially reduced the last year or two over former years. Up to 1925 the percentage infestation and population was so low that no extensive survey of the borer content of crop residues was attempted. Following the 1925 crop, however, a study was made of the methods used in crop disposal and the remaining borer content in the debris.

As has been mentioned the efficiency of any method depends largely upon the thoroness with which the work is done. Accordingly there is great variation in the efficiency of a given method.

However, in this study it was the farmers' own methods that were under observation and the averages therefore represent the thoroness of their application by the farmers of the section.

TABLE 53.—Showing Cleanup Record, 1926

Field treatment	Fields		Debris per acre		Borers per acre		Dead	Live
			Corn	Weeds	In corn	In weeds		
	No.	Acres	*Ft.*	*Ft.*	*No.*	*No.*	*No.*	*No.*
Standing stalks broken, raked, burned, disked	7	95	13.155	64	681	0	489	681
Corn cut, stubble harrowed or disked	4	58	8.444	0	672	0	42	672
Standing stalks broken, raked, burned, plowed	8	83	3.624	235	450	12	4	462
Total or average	19	236	8.645	108	598	4	209	602

It may be noted from the table that of the three methods given, a much smaller number of borers survived the treatment where plowing was included. The first two totals indicate that disking of stalks or stubble had a very small part in borer reduction. The decrease in borer population after plowing as compared with that in fields not plowed was coincident with the decreased amount of debris on the surface of plowed ground. Another significant point in the record for the year is that fewer than 1 percent of the total number of borers recovered were in weed stems.

In the 1927 survey an attempt was made to obtain the efficiency of the various methods used in the cleanup. In order to do this it was necessary to determine the original borer population per acre for each field studied. This determination was made in the usual and accepted manner.

The average borer content of ten stalks was used as an index of the borer population per infested stalk in the field. The rows of corn and the number of stalks per row were counted for each field from which was computed the number of stalks per field. From the percentage infestation the number of infested stalks in the field was calculated, which, multiplied by the borer population per infested stalk, gave the borer population for the field.

In making this study 50 fields were selected for a heavy borer population. Lightly infested fields were completely ignored because it was recognized that error would be greatly reduced in computing efficiency if the borer content in the field was high before the mechanical cleanup was begun. For this reason only fields with an infestation of 50 percent or more were considered.

In Table 54, the results of the different methods used are given both as combinations and as single methods as far as possible. The records of some steps in the procedure are omitted because there were not sufficient data obtained to warrant including them. It was frequently necessary to include two treatments such as burning and disking, or burning and plowing in one record.

TABLE 54.—Cleanup Record, 1927

Method used	Fields		Total population		Efficiency
	No.	Acres	Before clean up No.	After clean up No.	Pct.
Summary					
Standing stalks, hoed or poled, raked, burned, plowed, handpicked	2	10.9	121,032	163	99.9
Corn cut, stubble hoed or sled cut, plowed, handpicked	3	10.2	172,049	1,149	99.4
Standing stalks, hoed or poled, raked, burned and plowed	12	151.9	4,095,054	48,409	98.8
Corn cut, stubble hoed or sled cut and plowed	10	51.5	1,032,589	17,513	98.3
Corn cut, stubble hoed or sled cut, disked handpicked	4	22.8	550,816	15,859	97.1
Standing stalks, plowed down (Ohio plots)	2	8.8	535,382	16,512	96.9
Standing stalks, plowed down and hand-picked	1	7.1	516,964	16,131	98.5
Standing stalks, hoed or poled, raked, burned, disked or not disked	12	126.4	3,285,612	208,101	93.7
Corn cut, stubble hoed or sled cut, disked	6	32.8	356,171	29,169	91.8
Single methods used					
Plowing stubble	10	51.5	157,548	17,469	88.9
Cutting*	22	140.3	2,964,081	395,868	85.5
Plowing standing stalks after burning	2	27.8	69,120	19,101	72.4
Handpicking after plowing	2	9.8	17,795	7,725	56.6
Handpicking after disking	2	6.8	7,845	4,339	44.7
Disking stubble	3	15.0	20,499	16,919	17.5

*Borers in part of crop removed were assumed to have been killed.

While the writers clearly recognize the practical limitations of a mechanical control program, it is, nevertheless, believed that considerable good can come thru such efforts. It seems obvious, however, that the details of such programs must be worked out jointly by investigators and farmers.

3. INSECTICIDES

J. B. POLIVKA

Practically all of the investigational work that has been done with insecticides has been conducted by the Federal Bureau of Entomology at its various field laboratories. Altho the investigations have been in progress since 1918, "The application of insecticides invariably has proved ineffective in protecting growing corn or other plants from injury by the European corn borer in all experiments conducted up to the present time (1926), altho it has been possible to destroy large numbers of the larvae in their early stages" Caffrey.

In addition to the attempt to kill the larvae during the period of establishment, attempts were made in 1925 to kill them during the period of hibernation. This experiment is reported in Technical Bulletin No. 53, U. S. Department of Agriculture.

The insecticide investigations conducted in 1927 by the Station were of a preliminary nature, consisting of both field and laboratory experiments. The laboratory work was designed to determine the toxicity of various dusts to the newly hatched larvae. The field experiments were conducted at Bono, Ohio, in an 8-acre field, using 6 acres for the dusted plot, 1½ acres for the check, and the remaining ½ acre as a buffer plot between the dusted and check plots. The material used was an 80 percent sodium fluosilicate dust. It was applied in the late evening, every five days, from July 1 to July 25, with a power duster at the rate of 10 pounds to the acre

The final infestation and borer population counts were made October 13. One hundred stalks from five different places in each of the plots were examined and twenty-five stalks from each plot were dissected to obtain the borer population.

TABLE 55.—Showing results of dust application, 1927

Plot	Stalks examined No.	Infestation Pct.	Broken tassels No.	Broken stalks No.	Stalks dissected No.	Borers per infested stalk No.
			Actual			
Check	500	38.0	33	42	25	1 2
Dusted	500	6.6	2	5	25	.5
			Relative			
Check	500	100	100	100	. .	100
Dusted	500	17	6	12		42

Previous to 1927 the writers had given the insecticide phases of the project but little emphasis. It has seemed that the limiting factor in insecticide work up to the present has been the inadequate knowledge of the details of larval behavior. An effort is now being made to develop a technic of procedure based on available knowledge.

V. ENVIRONMENTAL FACTORS—THE CORN BORER AND ITS HOST PLANTS

INTRODUCTION

The responses of the corn plant, as determined by its heredity and environment, tremendously affect the responses of the insect. Corn in certain stages of development is not only preferred by the adults but it influences the rate of establishment of the young larvae. A part of the explanation of the abundance of the borer therefore is found in the responses of the corn plant itself. Moreover the fact that the responses of the plant are reflected in the responses of the insect, and the behavior of the corn plant can be modified by human agencies irrespective of environment, is one of the hopeful indications that, despite the direct influences of a favorable environment, the corn borer will eventually be controlled.

The original program of European corn borer investigations as outlined in 1922 by the late H. A. Gossard, then chief of the Department of Entomology, and J. S. Houser, present chief, included the study of the relationship existing between the corn borer and the corn plant. It seemed desirable to have exact data relative to the effect of varietal differences and the date and rate of planting on the behavior of the insect. With the establishment of empirical data it was thought that the way would be prepared for the possible explanations for such behavior as was found to occur. The original program involved the planting of several varieties at periodic intervals thru May and June.

Since it was not feasible to include all the different varieties and strains of corn in such a test, it seemed best to select certain ones representing the range of characteristics found in local Ohio varieties. Length of time taken to reach maturity was the primary basis for this selection. Early, medium, and late maturing varieties of dent and sweet corn were, therefore, selected for growing where the corn borer was found in largest numbers, and also on the Station farm at Wooster, on the Paulding and Hamilton County experiment farms and the Ohio State University farm at Columbus.

The major lines of investigation of the corn borer project were carried on at Geneva, in northeastern Ohio, during 1923, but since that year they have been conducted in Lucas County, near Bono, on a part of a 1500-acre tract of land, known as the Howard Farms.

Thru the courtesy of the owner, P. C. Jones, the varietal plots have been located on the same field for four successive years. At Bono, 14 varieties of dent corn and 3 of sweet corn have been studied in some detail. In addition a number of other varieties have been under observation. The several varieties have been planted in triplicate fortieth-acre plots on a fairly uniform soil and on several dates, beginning about May 1 for the sweet corns and a few of the dents, and May 10 for a majority of the dents, and continuing at 10-day intervals until June 10 and 20.

It should be noted too that, thru the efforts of Prof. H. A. Gossard, it was arranged to conduct a similar set of experiments at the Federal laboratory at Sandusky. Thru the cooperation of D. J. Caffrey and F. W. Poos, of the Federal Bureau of Entomology, these tests were conducted during 1923, 1924, and 1925, but were discontinued when the main activities of the Bureau were transferred from Sandusky, Ohio to Monroe, Michigan.

Thruout the entire period from 1923 to 1927, inclusive, the growth and development of the corn were determined by its height at particular periods and by its time of tasseling or silking. With the exception of 1923, the calculation of yield for each variety for each planting date was determined by the Department of Agronomy. Since 1926 agronomic records pertaining to corn development have been taken by the agronomists, and thruout the entire period entomological data were taken by entomologists.

1. THE DEVELOPMENT AND YIELD OF CORN WITH RESPECT TO SOIL AND CLIMATE

F. A. WELTON AND R. M. SALTER

As a result of his brilliant work on many different kinds of plants, including both lower and higher forms, Klebs (13) concluded that, "The manner of development of a plant under ordinary conditions is only one of its many possibilities." "Nature," he said, "must be much richer than appears under the influence of ordinary environment." That corn is no exception among plants, that it is not fixed in the trend of its development, but varies with environmental conditions and is responsive to them, is shown by the variation in its growth under different soil and climatic conditions. A variation in the behavior of corn, the host plant of the corn borer, might be expected to induce a variation in the behavior of the insect itself. As the plant passes thru certain stages of development it imposes certain conditions on the borer which may or may not be favorable. It is of interest, therefore, to inquire into the behavior of the plant as influenced by soil and climate.

Influence of Soil

CHARACTER OF GROWTH

The stalks and leaves on the one hand and the grain or seed on the other represent two different types of growth in corn. The ratio of these to each other may vary and under extreme conditions there may be a preponderance of either vegetative or reproductive growth.

That these variations may be induced by soil conditions is shown by the fact that they occur in corn grown under the same climatic conditions but under different soil treatments. An illustration of this is afforded by the plants produced on the plots in the five-year rotation fertility experiment of the Ohio Station (Bul. 381). In this experiment, corn is grown in rotation with oats, wheat, clover, and timothy. Five tracts of land are used so that a harvest of each crop is secured every year. Each tract contains 30 one-tenth acre plots, all of which, except the checks are fertilized differently. The experiment was started in 1894. By selecting certain plots, for example, Plots 18, 20, and 19, a series is established representing a gradual decrease in fertility. Plot 18 receives manure at the rate of 8 tons per acre on corn and 8 tons on wheat; Plot 20 receives one-half that amount on each of the two crops; and Plot 19, lying between them, receives nothing. A duplicate of this experiment has been under way at the Northeastern district experiment farm at Strongsville since 1895 and the corresponding plots, therefore, represent a similar range in fertility.

TABLE 56.—Corn, Character and Quantity of Growth, With no Treatment and With 4 and 8 Tons Manure per Acre, Average 1895-1927

	Wooster			Strongsville		
	8 tons	4 tons	Nothing	8 tons	4 tons	Nothing
Total grain and stover..........Lb...	6204	5021	3391	5480	4855	3915
Ratio stover to grain.............Pct..	38.79	41.67	46.56	45.07	45.56	48.85
Ratio nubbins to merch. ears....Pct..	16.47	27.93	45.40	....	....	....

The effect of fertility on the type of growth is shown by the proportion of stover to grain produced on these three plots. The average percentages of stover produced during the 33-year period at Wooster and Strongsville are given in Table 56. At each place, it may be seen that, on the average, as the fertility of the soil decreases the proportion of vegetative growth increases. At Wooster this relationship holds in 22 out of 32 years, or in 69 percent of the cases. Only one of the ten exceptions is found later than 1907, or after the differences in fertility due to treatment had become marked. At Strongsville the relationship was less pronounced, there being many seasons in which the highest proportion of stover was found on the plot representing either the medium or higher state of fertility.

QUANTITY OF GROWTH

Fertility materially affects the quantity of growth made by the corn plant. This is shown by the average yields, including both grain and stover. At Wooster the decrease in fertility was accompanied by a decrease in yield in every year without exception after 1899. At Strongsville the decrease in fertility was accompanied by a decrease in yield in 25 of the 33 years.

QUALITY OF GRAIN

Fertility affects also the quality of the corn produced. At Wooster it has been the custom since the beginning of the experiments to sort the corn at harvest time into the grades; "merchantable" and "unmerchantable", the former consisting of the solid, well-matured ears, and the latter of the soft, immature ears or nubbins. The decreases in fertility of soil were accompanied by increases in ratio of nubbins (Table 56). Moreover this relationship held for each year of the test, except 1896, which was the first of the 31 years for which records are available but the third from the beginning of the fertilizer treatments.

The degree of variation possible in the rate of growth and maturity and in the final yield of the corn crop induced by natural soil differences is well illustrated by the results of a 2-year study of the development of corn at Wooster, in Wayne County and at Bono in Lucas County. In each year a single variety of corn, Burr-Leaming, was planted on approximately the same date at each location. Records of height of plants were taken at intervals thruout the season. The mean date of silking was also determined in the second year. Weight of grain and moisture content were determined at harvest.

The soil at Bono is a heavy, nearly black, calcareous, Toledo clay, naturally very productive. The soil at Wooster is a light colored, acid, Canfield silt loam of low fertility. Both soils are tile drained. No manure nor fertilizer was applied to either soil, nor had any such treatments been made in recent years. Curves showing the increase in height of plant for each year and for each location are shown in Figure 8.

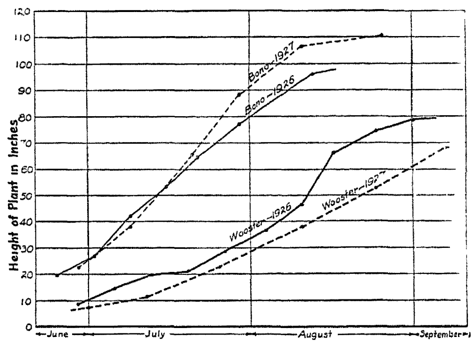

Fig. 8.—Graph showing the increase in height of plant for two years at Bono and Wooster

It is evident from Table 57 that the corn plant not only grew faster on the good soil at Bono than on the poor soil at Wooster, but that its cycle of development was materially shortened as shown by a difference of 28 days in the time from planting to silking for the two locations in 1927. That these differences in growth were largely the result of soil differences and not of climatic variations is strongly indicated by the climatic data for the two locations shown in Table 57. The principal climatic difference was that in rainfall, which was to the advantage of the Wooster planting.

TABLE 57.—Showing Temperature, Rainfall, and Development of Corn at Bono and Wooster, 1926 and 1927

Location	Days planting to silking 1927	Yield 15½ percent moisture		Moisture content at husking	
		1926	1927	1926	1927
Bono............	89	89.35	75.19	37.63	39.32
Wooster ...	117	42.06	17.70	42.94	38.10

	June		July		August	
	Wooster	*Bono*	*Wooster*	*Bono*	*Wooster*	*Bono*
Mean temp. deg. F.. .1926	64.5	64.8	71.4	72.8	73.1	73.2
Rainfall, inches.........1926	3.58	3.87	2.49	.83	2.75	7.64
Mean temp. deg. F.....1927	62.8	64.6	71.0	72.5	65.6	66.6
Rainfall, inches........1927	3.36	2.95	4.28	2.48	2.88	2.20

Influence of Climate

That the combined effect of the various elements called "weather" influences in a marked degree the growth of corn is illustrated by the yields obtained in the Station's continuous culture work, where corn has been grown every season for the last 34 years.

For example, on Plot 6, which receives manure at the rate of 5 tons per acre annuallv, the yield of grain and stover, expressed in pounds in successive years from the beginning of the experiment in 1894 to 1898, was as follows: 3145, 6005, 6887, 3525, and 5273. These and similar variations which characterize the test must be attributed to the "weather", because all of the yields were obtained on the same identical tract of land.

The effect of length of season, temperature, sunshine, and rainfall can be indicated in a statistical way by the construction of straight lines based on yield and on climatic records, kept by the Ohio Station since its establishment at Wooster in 1893.

To show the response of corn to variations in each of these factors the same method of handling the data was employed for each factor. It consisted in first arranging the years in the order of decreasing values of the climatological factor in question. After plotting these values a straight line was fitted into them by the method of least squares. The yield values were then plotted on the same ordinates and a straight line was fitted into them by the same method. Each set of straight-line values was then converted into percentages of their respective means, thus making them comparable and therefore presentable in the same graph. The fitted straight lines only are shown in the graphs.

The corn yields used consisted in all cases of the entire crop, including both grain and stover. At Wooster the yields selected were those obtained on Plot 6 in the continuous culture experiment, a description of which has already been given. On the district farms at Germantown, Carpenter, and Strongsville the corn was grown in rotation with other crops and hence on a different tract of land each year of a rotation. The climatological records in all cases are for the three months of June, July, and August. For example, the rainfall for any given crop year consists of the total precipitation for these three months.

LENGTH OF SEASON

The number of days from the time of planting corn to the time of the first killing frost in the fall was considered as the length of season. On this basis the seasons at Wooster in the last 32 years have varied 42 days; the shortest was 127 days, alike in 1897 and 1904; and the longest, 169 days in 1910. The straight line fitted into the season values and the one fitted into the yield values are given in Figure 9. They show that a shortening of the season was accompanied by a decrease in yield. The rate of decrease, however, as indicated by the slope of the straight line was not very marked, which would seem to indicate that it is not so much the *number* as it is the *kind* of days that affects the yield of corn. "Ninety-day corn" is more or less a misnomer.

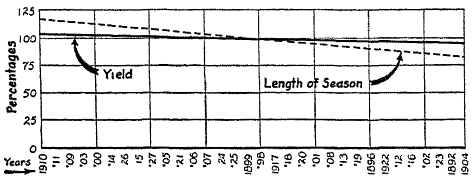

Fig. 9.—Graph showing influence of length of season on yield of corn

TEMPERATURE

In studying the effect of temperature on corn the minimum rather than either the maximum or mean was used, for it was thought probable that corn is most responsive to low temperature. The summation of the minimum temperatures for the three months did not vary widely from year to year, the extreme difference being 24.7°. A lowering of the temperature, however, was accompanied by a decrease in yield, as indicated in Figure 10.

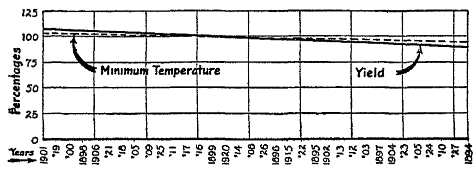

Fig. 10.—Graph showing effect of temperature on yield

SUNSHINE

That sunlight is indispensable to the growth of plants is, of course, well recognized. That variations in the intensity of sunshine may result in modifications in the character of growth of plants is indicated by the development of some of the cereals when grown under more or less shade, as for example, in too thick a stand. Under such conditions a preponderance of vegetative growth develops, and this often expresses itself in lodging.

The total hours of sunshine at Wooster during the three months of June, July, and August has varied in the last 30 years from 1,184 in 1916 to 780 in 1925. The two straight lines in Figure 11 indicate that a decrease in hours of sunshine was accompanied by a decrease in yield.

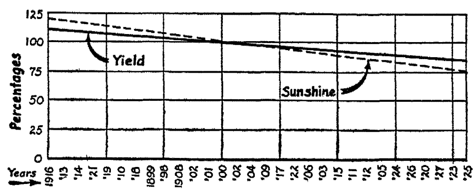

Fig. 11.—Graph showing influence of sunshine on yield

RAINFALL

The effect of rainfall on the development of corn was noted at Woostcr and at the three substations, Germantown, Carpenter, and Strongsville. At Wooster during the last 34 years the total rainfall for the three summer months ranged from 19.18 inches in 1920 to 4.37 inches in 1894, thus making a variation of 14.81 inches, or more than three times the minimum. At Germantown during the last 24 years the range was from 16.58 inches in 1906 to 6.64 inches in 1910, a variation of 9.94 inches. At Carpenter for the same period the range was from 22.96 inches in 1912 to 7.31 inches in 1913, a variation of 15.65 inches. At Strongsville during the last 33 years it was from 21.25 inches in 1902 to 4.87 inches in 1910, a difference of 16.38 inches. The straight lines in Figure 12 indicate that at all four places the decrease in rainfall was accompanied by a decrease in yield.

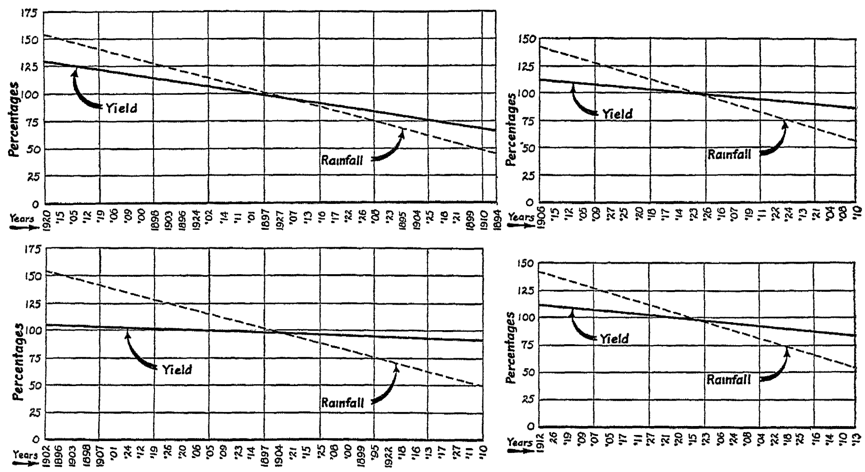

Fig. 12.—Graphs showing effect of rainfall on yield of corn at Wooster (upper left), Germantown (upper right), Strongsville (lower left), and Carpenter (lower right)

These results are in harmony with the findings of Smith (26), who observed a rather close correlation between the growth of corn in central Ohio for the years 1891 to 1910 and the rainfall for the months of July and August. He also found a correlation between the July rainfall and the yield of corn grown in the states of Ohio, Indiana, Illinois, Iowa, Missouri, Nebraska, and Kansas.

Having considered separately the effect of individual elements on the growth of corn, it is of interest to note their combined effect.

Such a picture is made possible by phenological records kept from 1883 to 1912, by Thomas Mikesell, Wauseon, Fulton County, Ohio. These records are given in Table 58 and show a wide variation from year to year in the rapidity with which corn attained the various stages of its development.

TABLE 58.—Phenological Data for Growth of Corn at Wauseon, Ohio From 1883 to 1912

Year	Date planted	Number of days from			Total days in season
		Planting to coming up	Coming up to blossoming	Blossoming to maturity	
1883..................	May 12	13	65	73	151
1884....................	16	8	61	53	122
1885	18	7	59	65	131
1886....................	11	8	59	60	127
1887....................	20	5	60•	53	118
1888....................	15	10	61	57	128
1889....................	15	8	72	58	138
1890	27	5	55	56	116
1891	12	10	66	53	129
1892..................	June 18	5	44	50	99
1893..................	May 18	10	58	49	117
1894....................	1	9	68	44	121
1895	1	6	76	50	133
1896....................	9	5	57	51	113
1897..................	22	14	45	54	113
1898.............	18	7	56	42	105
1899	18	9	51	44	104
1900	No record	....	....	....	....
1901....................	12	15	52	49	116
1902....................	No record	....	....	....	....
1903	No record	....	....	....	....
1904....................	7	10	69	47	126
1905....................	9	6	64	43	113
1906..................	10	6	62	55	123
1907...	April 26	10	85	35	130
1908....	May 21	7	63	47	117
1909..................	14	7	77	50	134
1910..................	11	10	72	60	142
1911.....	10	7	64	50	121
1912	10	10	63	42	115
Average...........	....	8.4	62.4	51.5	122.3

2. DEVELOPMENT AND YIELD OF CORN WITH RESPECT TO VARIETIES AND RATE AND DATE OF PLANTING

L. E. THATCHER AND J. T. McCLURE

The immediate discussion deals particularly with the yield and development of corn with respect to varieties and date of planting. The following data relative to development were secured for the dent varieties:

1. Height measurements at approximately ten-day intervals.
2. Average silking or tasselling date.
3. Yield of shelled corn from infested and non-infested stalks
4. Test weight per bushel.
5. Percentage of moisture at husking time.
6. Number of ears and nubbins per plot.
7. Weight of ears and nubbins per plot.
8. Percentage of marketable corn in crop.

Only such results are presented as seem at this time to be of major importance. Certain typical varieties were selected for consideration. These, arranged in order of maturity, are given in Table 59.

YIELD AND DATE OF PLANTING

In Table 59 the yield for the first planting date, May 8-10, is taken as 100 for each variety. The yields of all varieties decreased with the lateness of planting. The decreases were greatest for the late-maturing varieties. The results for 1927 are not in harmony with those of the three other years; the late planting having shown up more favorably than in the previous years. This fact was probably due to the highly abnormal weather that characterized the season of 1927, the conditions for growth and maturity of the crop having been more favorable in September than in August.

TABLE 59.—Yields of Corn Relative to First Planting Date, Taken as 100

Planting date	Year	Burr-Leaming	Leaming	Clarage	Golden Glow Medina Pride	N. W. Dent Van Wye Wisconsin 25
May 8-10......	1923, '24, '26	100	100	100	100	100
	1927	100	100	100	100	100
May 19-20.....	1923, '24, '26	97	102	95	106	101
	1927	102	99	97	101	88
May 29-31......	1923, '24, '26	101	96	93	102	99
	1927	100	96	99	97	107
June 9-10......	1923, '24, '26	88	84	80	87	89
	1927	93	83	93	101	142
June 19-20......	1923, '24, '26	70	73	69	85	75
	1927	99	98	101	105	167*

*Planting date June 15.

The relative yields, based on the highest yield of the highest yielding variety, Burr-Leaming, taken as 100, are shown in Table 60. It is evident from the data that so far as total yield of grain on a uniform moisture basis is concerned, the earlier maturing varieties were actually inferior to the late ones for late planting. This was true in spite of the fact that the late varieties contained more moisture at husking time, as shown in Table 61. It is possible, of course, that high moisture content at husking time might so increase the danger of spoiling under ordinary conditions of handling the crop that the use of late varieties for late planting would be hazardous. It is possible, however, that methods of artificially drying or otherwise handling soft corn now being investigated by agricultural engineers may offer a solution to this difficulty.

TABLE 60.—Yields Relative to Highest Yield of Burr-Leaming, Taken as 100

Planting date	Year	Burr-Leaming	Leaming	Clarage	Golden Glow Medina Pride	N. W. Dent Van Wye Wisconsin 25
May 8-10......	1924, '25, '26	100	82	81	77	63
	1927	98	91	86	82	44
May 19-20......	1924, '25, '26	96	85	77	82	62
	1927	100	90	83	82	40
May 29-31......	1924, '25, '26	100	81	75	79	60
	1927	100	96	85	80	48
June 9-10......	1924, '25, '26	88	69	66	67	55
	1927	93	83	80	83	63
June 19-20......	1924, '25, '26	69	60	60	68	46
	1927	99	98	87	105	74*

*Planting date June 15.

TABLE 61.—Maturity as Indicated by Average Percent Moisture at Husking Time

Planting date	Year	Burr-Leaming	Leaming	Clarage	Golden Glow Medina Pride	N. W. Dent Van Wye Wisconsin 25
May 8-10......	1924, '25, '26	26.8	31.6	25.7	36.88	20.3
	1927	39.32	35.98	36.44	34.19	36.62
May 19-20......	1924, '25, '26	28.6	27.8	25.9	32.41	21.9
	1927	41.78	37.72	39.62	34.97	37.18
May 29-31......	1924, '25, '26	33.1	31.0	29.2	33.07	22.0
	1927	36.0	32.95	32.34	28.46	43.36
June 9-10......	1924, '25, '26	37.3	34.5	31.9	35.38	23.9
	1927	44.24	42.07	37.89	37.22	24.75
June 19-20......	1924, '25, '26	44.1	42.9	37.8	39.36	28.3
	1927	34.12*	32.03*	31.35*	29.7*	22.81

*Planting date June 15.

For 17 years Clarage corn has been planted at Wooster at weekly intervals from about April 26 to June 10. Figure 13 shows the relative yield of these plantings, the highest being taken as 100, compared with Clarage planted at Bono for three years, and also the percentage of moisture in the ears at husking time. The fourth year, 1927, of the test at Bono is omitted because of abnormal seasonal conditions that favored the late planted corn. Altho the 3-year test at Bono is not long enough to warrant definite conclusions, it is interesting to note that the decrease in relative yield was less rapid than at Wooster. While climatic differences, especially the difference in date of the first killing frost, which averaged 13 days earlier at Wooster, probably played a part in causing the more serious effects of late planting on yields at Wooster, the slower development of the crop at Wooster, due to poorer soil conditions, was probably also an important factor.

The 17-year test at Wooster is long enough to give reliable data and to show what may be expected as an average with Clarage corn in this section of the State. The maximum yield of grain was secured by planting early in May, and the yields decreased rapidly with later plantings. The stover weights increased from the early planting to that of about June 1, and then decreased.

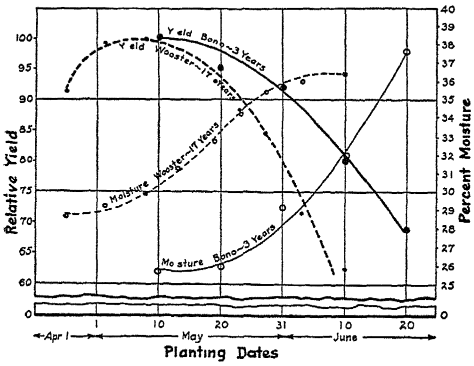

Fig. 13.—Graph showing relative yield of Clarage corn at Wooster and Bono and also the percentage of moisture in ears at husking time.

In the variety test at Bono, Burr-Leaming led in yield. The chief objection to this variety for grain production in much of Ohio is its lateness of maturity.

RATE-OF-PLANTING EXPERIMENTS

In the foregoing experiments there was a uniform stand of three plants per hill, or 10,668 plants per acre. An experiment was started at Bono in 1927 to determine whether the relative standing of the earlier, smaller-growing varieties could be improved by a thicker rate of planting. Five early-maturing varieties—Wisconsin 25, St. Paul White Dent, Minnesota 13, Wisconsin 8, and M. A. C. Yellow Dent were each grown at average rates of 3, 4½, and 6 plants per hill in triplicate plots planted June 10. The average yield of all the varieties was 59.3 bu. per acre for the 3-plant rate, 56.5 bu. for the 4½-plant rate, and 53.6 bu. for the 6-plant rate. Wisconsin 25 was planted at these three rates on each of six dates. The average yield of the 3-plant rate for all plantings was 41.9 bu., for the 4½-rate 47.9 bu., and for the 6-rate 39.2 bu. Obviously, one year's test is insufficient to answer the question, even for one section.

At Wooster in 1927, Wisconsin 25 was planted May 15 on heavily fertilized and manured land, with stands of 1, 2, 3, 4, 5, and 6 plants per hill, spaced 42 inches apart each way. The corresponding yields were 18.9, 37.0, 49.3, 52.0, 69.9, and 61.2 bu. per acre.

Some evidence to support the theory that early varieties can be planted thicker than late varieties is afforded by a five-year test at Wooster in which an early strain, Low Ear 84, and a normal-season variety, Wooster Clarage, were grown at the rates of 3 and 5 plants per hill. Five plants per hill increased the yield of the early sort 20.5 bushels and of the Clarage 9.4 bu. over the 3-plant rate. This evidence and the results secured at other experiment stations lend encouragement to the thought that the handicap of a lower yield for short season varieties may be overcome, in part, by thicker planting.

CORN DEVELOPMENT AS INDICATED BY MEAN-SILKING DATE

Mean-silking dates were used as an index by means of which the stage of development for different varieties planted on different dates could be compared. A study of the relation of average silking date to the planting date is of interest in this connection. This relation is shown in Figure 14 for six varieties included in the variety and date-of-planting test at Bono. The delay in silking

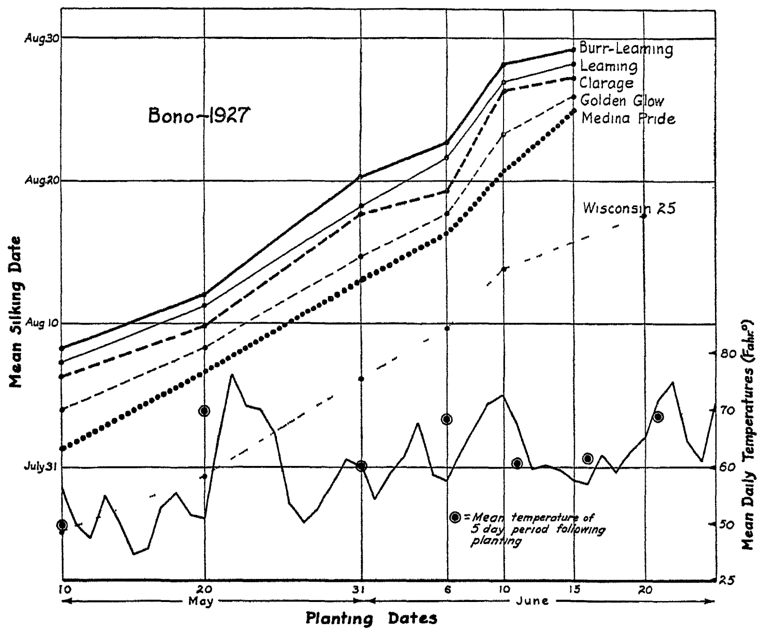

Fig. 14.—Graph showing relation of silking to planting date

incident to a given delay in planting was nearly the same for all varieties, irrespective of their seasonal requirements. This follows from the fact that the curves for the individual varieties are nearly parallel. The curves indicate a relation between delay in planting and delay in silking. A delay in planting of 36 days, May 10 to June 15, caused delays in silking as follows: Burr-Leaming 21 days, Leaming 21 days, Clarage 21 days, Golden Glow 22 days, Medina Pride 23 days, Wisconsin 25, 21 days, or an average 21.6 days. Each day's delay in planting delayed silking an average of ⅔ day. It will be noted that, with few exceptions, the direction of the minor deviations are the same for all curves, a rather remarkable fact, considering the range of varieties and the actual spread in silking date. The only explanation which the authors are able to suggest is that weather and soil conditions just after planting time were reflected more or less accurately by the silking date.

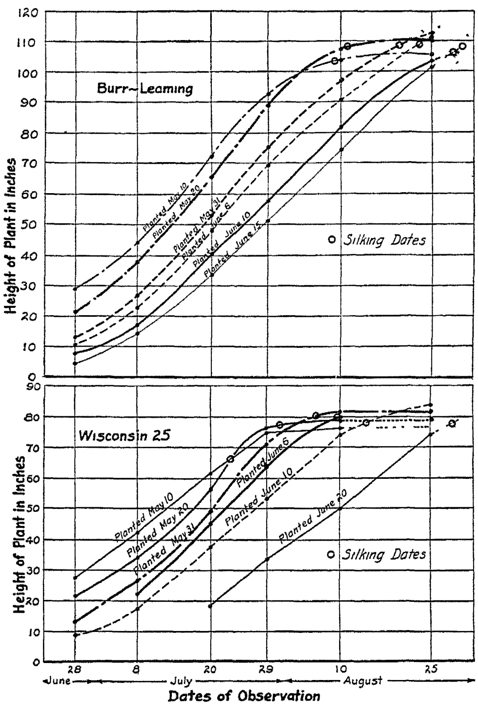

Fig. 15.—Graphs showing silking date and height of Burr-Leaming and Wisconsin 25 corn for six planting dates

The mean daily temperatures during the planting period are plotted in Figure 14 and the average temperature of the five-day period following each planting is indicated. A curve connecting these mean temperature points would in each case break in an opposite direction to the break in the silking date curves. It would appear that when a given planting date is followed by a period of low mean temperature, a delay in planting results in a delay in silking that is greater than that normally to be expected, and vice versa.

HEIGHT MEASUREMENTS DURING GROWING SEASON

The rate of development of the several varieties planted on different dates was determined by measuring the height of individual plants in each replicated plot at intervals thruout the growing season.

The heights of Burr-Leaming corn, a late, and of Wisconsin 25, and early sort, are shown in Figure 15, for six dates from June 28 to August 25, together with the silking dates for each date of planting. In each variety there is a decided change in the type of curve for height from the early planting to the late planting dates.

The plants continued to increase in height until the silking date was reached, and, with the exception of the May 10 planting of Wisconsin 25, silked at approximately the same height. The length of time from planting to silking was shortened with the lateness of planting, 40 days difference in planting date for Wisconsin 25, and 35 days difference for Burr-Leaming made a difference of 15 days in date of silking for each variety.

3. DEVELOPMENT AND YIELD OF CORN WITH RESPECT TO CULTURAL AND SOIL PRACTICES

R. M. SALTER, J. T. McCLURE, AND C. R. NEISWANDER

Attention has been called to the relation of corn borer infestation to the rate of development of the corn plant. It has also been shown that the rate of development of the crop may be markedly influenced by variations in soil productivity. The question has arisen as to what extent the development of corn may be influenced by various cultural practices and, what practices may have utility in relation to the corn borer problem. This question is being investigated from two standpoints. A study is being made of the effects of various kinds and amounts of fertilizers and methods of applying them in hastening the maturity and increasing the yield of late planted corn. The efficacy of delayed planting as a means of reducing corn borer population has already been demonstrated. An attempt is being made by various soil and cultural practices to retard the early development of corn planted at the normal time in order to reduce borer population. Combined with such practices are delayed applications of fertilizer designed to hasten the crop's development after the period of oviposition.

HASTENING THE DEVELOPMENT OF LATE PLANTED CORN

In 1926 and again in 1927 a series of fertilizer experiments was made on Burr-Leaming corn, planted on two dates at Bono and at Wooster. The soil at Bono, as previously stated, is a calcareous, dark colored Toledo clay of high natural fertility. None of the fertilizer treatments in either year produced any appreciable effect, either on yield or maturity of the crop at Bono. The data from selected plots of the 1927 planting presented in Table 62 illustrate the meager effects of fertilizers on this soil. Comparing the results for the fertilized and unfertilized plots, no appreciable difference in yield or moisture content at husking was observed for either the June-6 or June-16 plantings. There was on the other hand, some indication that the fertilizer treatments increased slightly the early growth of the June-6 planting, seen in the 1.4 inches greater height on July 12 and the 1 day earlier silking of the fertilized plots. The higher average infestation and borer population of these plots possibly resulted from this hastened development.

TABLE 62.—Showing Effect of Fertilizer on Burr-Leaming Corn at Bono, 1927

	Plots averaged No.	Yield 15½ moisture Bu.	Moisture at husking Pct.	Height July 12 In.	Days planting to silking No.	Stalks infested Pct.	Borers per acre No.
Planted June 6							
No treatment..........	6	88.2	35.4	16.8	75.7	46.1	3261
Fertilized*	9	88.8	36.5	18.2	74.9	52.8	4589
Planted June 16							
No treatment.........	6	67.3	44.0	7.2	80.2	....	....
Fertilized*	9	70.7	43.2	7.4	79.6	.. ..	.. ..

*Plots averaged include 4 plots receiving 200 pounds 3-12-4 in hill, 2 plots receiving 400 pounds 3-12-4 in hill, 1 plot receiving 400 pounds 4½-4½-4 in hill, and 2 plots receiving 200 pounds 0-12-4 in hill with delayed application of 100 pounds nitrate of soda. The carriers used in compounding the mixed fertilizers were nitrate of soda, superphosphate, and muriate of potash.

The results obtained at Wooster, on a noncalcareous, light colored Canfield silt loam of low natural fertility, were in marked contrast to those at Bono. In both years, the rate of development of the crop, its maturity, and yield were greatly influenced by certain treatments. These effects were most pronounced in 1927, probably due to the extremely backward season.[2] The extent to which the rate of development was increased, the maturity advanced, and yield augmented in 1927 by increased amounts of plant nutrients are shown by the data from selected plots presented in Table 63. The rate of development for corn planted on a normal date, May 13, and on a late date, June 3, as indicated by the time from planting to silking, was increased by each increment in nutrient supply. Similarly, maturity, as indicated by percent of moisture at husking and percent of nubbins, was regularly advanced and yield increased. A comparison of the average silking date for the treated plots of the June-3 planting, with the average silking date of the untreated plots of the May-13 planting, shows that each of the three heaviest treatments more than offset the three weeks delay in planting.

[2]Subnormal temperatures prevailed during much of the growing season. The mean monthly temperatures for June and August were the lowest recorded in 40 years at Wooster.

TABLE 63.—Showing Results of Fertility Treatment on Burr-Leaming Corn at Wooster, 1927

Treatment per acre	Planted May 13				Planted June 3			
	Days planting to silking	Moisture at husking	Nubbins	Yield (15.5 percent moisture)	Days planting to silking	Moisture at husking	Nubbins	Yield (15.5 percent moisture)
	No.	*Pct.*	*Pct.*	*Bu.*	*No.*	*Pct.*	*Pct.*	*Bu.*
None	117	48.34	71	17.7	110	69.07	76	5.5
Manure 8 tons 225 lb. 16% superphosphate broadcast	104	46.70	38	45.2	97	53.43	55	31.9
Same plus 100 lb. 3-12-4* in hill	99	37.91	37	55.9	93	50.65	42	33.3
Same plus 200 lb. 3-12-4* in hill	93	33.54	21	70.3	88	50.02	18	47.9
Same plus 400 lb. 3-12-4* in hill	90	31.36	12	80.6	86	46.01	19	56.9

*The carriers used were nitrate of soda, superphosphate, and muriate of potash.

TABLE 64.—Showing Results of Manure and Fertilizer Treatments on Burr-Leaming Corn at Wooster, 1927

Treatment per acre	Planted May 13				Planted June 3			
	Days planting to silking	Moisture at husking	Nubbins	Yield (15.5 percent moisture)	Days planting to silking	Moisture at husking	Nubbins	Yield (15.5 percent moisture)
	No.	*Pct.*	*Pct.*	*Bu.*	*No.*	*Pct.*	*Pct.*	*Bu.*
None	117	48.34	71	17.7	110	69.07	76	5.5
200 lb. 3-12-4 in hill	98	36.84	36	37.2	97	53.10	54	24.6
8 tons manure 225 lb. 0-16-0 broadcast	104	46.70	38	45.2	97	53.43	55	31.9
200 lb. 3-12-4 in hill 8 tons manure 225 lb. 0-16-0 broadcast	93	33.54	21	70.3	88	50.02	18	47.9

That the method of applying fertilizers to corn markedly affects their influence upon the rate of development of the crop is shown by the results of broadcast compared to hill applications. Data showing the effects of 300 pounds of a 3-12-4 analysis applied broadcast compared to an equal amount applied in the hill thru the fertilizer attachment of the planter are presented in Table 65. The data cited are for the planting of May 13, 1927, but are typical of the results obtained from the other plantings. Apparently, hill applications of fertilizer are better able to supply the nutrient needs of the young corn plant than are broadcast applications. In this respect applications of manure compare with broadcast applications of fertilizer. This fact is indicated by the data presented graphically in Figure 16 showing the curves for increase in height for plants receiving (1) no treatment, (2) 200 pounds 3-12-4 fertilizer in the hill, (3) 8 tons manure and 225 pounds 0-16-0 fertilizer broadcast, and (4) a combination of treatments (2) and (3). The corn receiving only 200 pounds of 3-12-4 in the hill grew more rapidly until about August 5 than the corn treated with 8 tons manure and 225 pounds 0-16-0 broadcast. At that time the crop apparently had exhausted the nutrients supplied by the hill fertilizer treatment, and being unable to obtain its requirements from the untreated, infertile soil between the hills, it fell behind the manured corn. Hill applications of fertilizer seemed best suited to supply the needs of the corn crop during its early growth, while manure and broadcast applications of fertilizer seemed best for its later growth. A combination of the two methods of treatment should then be best suited to maintain rapid growth thruout the season. The height curve for the combined treatment (Fig. 16) and the yield and development data (Table 64) for all of the foregoing treatments and for plantings of both May 13 and June 3, clearly indicate that such is the case.

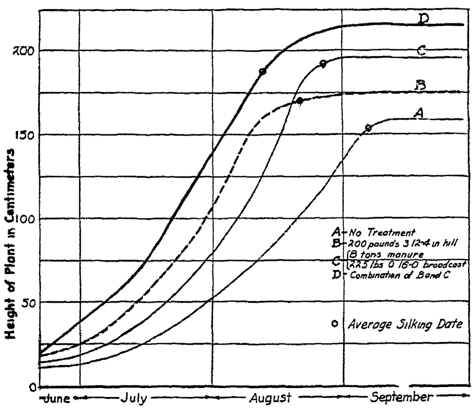

Fig. 16.—Graph showing silking date and height of Wisconsin 25 for six planting dates

TABLE 65.—Showing Results of Hill vs. Broadcast Application of Fertilizer on Burr-Leaming Corn at Wooster, Planted May 13, 1927

Treatment per acre	Days planting to silking	Average height Aug. 6	Moisture at husking	Nubbins	Yield (15.5 percent moisture)
	No.	*In.*	*Pct.*	*Pct.*	*Bu.*
None	117	27	48.34	71	17.7
300 lb. 3-12-4 broadcast	113	32	39.03	53	37.6
300 lb. 3-12-4 in hill*	96	57	36.85	31	39.2

*Average of plots receiving 200 and 400 pounds of 3-12-4 in hill.

From the evidence at hand it appears that in certain seasons on soils where the growth of the corn crop is limited by inadequate supplies of soil nutrients, its development may be hastened by manure and fertilizer treatments, and thus, the disadvantages of late planting may be partially counteracted. Hill applications of fertilizer are more effective than broadcast applications, but since they hasten development during the early stages of growth, their use may be expected to reduce the advantages of delayed planting in lowering corn borer infestation. It is possible that by delaying the time of application of fertilizer, growth will not be accelerated until after the moths have deposited their eggs. Future studies will be directed along this line.

RETARDING THE DEVELOPMENT OF CORN

Several treatments designed to retard early development were given to Clarage corn planted May 25, 1927 at Bono. The treatments included: (1) planting in furrows by the method known as listing, (2) removing the leaves of the plants July 1, (3) cutting the plants back to within 4 and 8 inches of the ground July 1, (4) incorporating straw with the soil by disking into the surface or plowing under at the rate of 4 tons per acre, and (5) placing sucrose in the hill at planting time at rates of 200 and 400 pounds per acre. The purpose of the straw and sucrose additions was to determine whether or not it is possible to retard the crop by temporarily reducing the supply of available soil nutrients by microbiological action. The experiment is based on the well-known fact that the incorporation of crop residues or other organic materials having a high carbon-nitrogen ratio leads to the rapid multiplication of soil microörganisms that utilize the added organic substance as a source of energy and compete with any growing crop for available nitrogen and mineral elements. Straw and sucrose were selected merely as typical examples of several materials that might be used. Each of the foregoing treatments was supplemented with a topdressing of 200 pounds per acre of a 6-12-4 fertilizer,[3] made on July 5 for the purpose of hastening growth after the moth flight period. In order to ascertain the effect of the fertilizer, the straw and sucrose treatments were duplicated with the omission of the fertilizer application.

Data on yield, rate of development as indicated by height of plants on July 12, and days from planting to silking, percent of plants infested, and the number of corn borer larvae per acre are shown in Table 66. The data for each of the straw treatments represent the averages of two plots, on one of which the straw was incorporated by disking and on the other by plowing under. Each of the special treatments was effective in retarding early development as indicated by the height on July 12 and the period from planting to silking. Correlated with the retardation of development there were reductions in the percent of plants infested and in the number of borers per acre. The greatest reduction in infestation was observed on the straw-treated plots and on the plot planted by the method of listing. Altho the yield was reduced by the use of straw or sucrose without the fertilizer treatment, any reduction was offset and in some cases the yield increased beyond the average of the untreated plots by the fertilizer treatment. The effect of listing is of especial interest since it is a practice which might be adopted without adding materially to the cost of corn production and which, in itself, might increase the yield on some soils. The results of the straw additions are also interesting in view of the probability that shredded or cut corn stover would have a similar effect. (The use of corn stover is being investigated.) While the data are too limited to permit drawing conclusions of a practical nature, they lend encouragement to future study of this general method of reducing corn borer infestation and damage. In Section 4, page 128 it will be pointed out that there is a definite relationship between retardation and acceleration of development due to cultural practices.

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[3]Carriers used were nitrate of soda, superphosphate, and muriate of potash.

TABLE 66.—Showing Results of Retardation Experiment on Clarage Corn at Bono, Planted May 25, 1927

Treatment	Plots averaged	Yield				Height July 12	Days planting to silking	Stalks infested	Borers per acre
		Field weights			Total 15½ percent moisture				
		Infested	Non-infested	Total					
	No.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*In.*	*No.*	*Pct.*	*No.*
No treatment	8	57.6	26.7	84.3	67.8	20.6	78.4	71.5	10,202
Straw 4 tons per acre									
Unfertilized	2	28.3	45.9	74.2	57.1	13.0	87.0	23.9	2,442
Fertilized*	2	40.6	52.7	93.3	67.8	15.0	86.5	29.6	3,133
Sucrose 200 lb. per acre in hill									
Unfertilized	1	47.1	41.8	88.9	69.1	15.0	81.0	58.3	5,469
Fertilized*	1	50.1	41.3	91.4	72.3	18.0	82.0	60.5	10,839
Sucrose 400 lb. per acre in hill									
Unfertilized	2	26.1	51.9	77.8	57.4	12.5	86.0	34.2	5,049
Fertilized*	1	43.6	52.0	95.6	73.3	15.0	85.0	54.9	8,198
Planted by listing*	1	33.7	68.4	102.1	77.3	16.0	81.0	27.6	2,208
Leaves removed July 1*	1	42.3	57.9	100.2	80.2	18.0	78.0	51.4	5,701
Plants cut off July 1*									
To 4 inches*	1	48.6	44.2	92.4	73.3	15.0	80.0	40.7	4,515
To 8 inches*	1	...	...	...	...	17.0	...	56.5	6,267
Average all treated	...	38.2	48.6	86.8	67.2	14.9	81.3	41.3	4,590

*Topdressed July 5 with 200 pounds 6-12-4 per acre.

4. CORRELATION OF CORN BORER POPULATION WITH CORN DEVELOPMENT

C. R. NEISWANDER, J. B. POLIVKA, AND L. L. HUBER

Sections 1, 2, and 3 clearly show (1) that either a single variety planted on different dates or any of several varieties planted on the same date will show a measurable degree of difference in the stage of development at a given time; (2) that these variations in the stage of development are determined by hereditary and environmental factors—variety, soil, and climate—; and (3) that the rate of development may be modified by certain soil and cultural practices. It will now be shown that borer population on the Bono plots to date is correlated with the stage of development of the corn at a given time.

The specific statements made in Sections 2 and 4, pages 26 and 55 relative to egg deposition and establishment rates in Burr-Leaming and Wisconsin 25, both normal and subnormal, are true in general for the varietal series grown at Bono. These data should be kept in mind as the following tables are discussed.

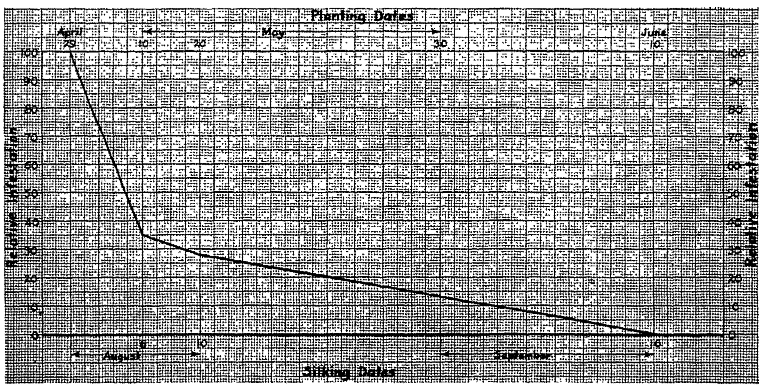

Fig. 17.—Graph showing relation of infestation to stage of development of corn, 1923

The graph (Figure 17) shows the results of the first year's investigations of the relation of corn borer behavior to its host plant. Continued investigation along the same line has confirmed the meager data of 1923 as is shown in Table 67.

A brief summary of important facts recorded on the Bono plots during the last four years is given in Table 67. The data for each variety represent the average of triplicate plots, except in 1924 when duplicates only were used.

TABLE 67.—Infestation of Varieties of Corn Planted on Different Dates

Variety	May 10						May 20						May 30					
	Plants infested	Borers per stalk	Stalks detasseled	Stalks broken	Av. height	Silking date	Plants infested	Borers per stalk	Stalks detasseled	Stalks broken	Av. height	Silking date	Plants infested	Borers per stalk	Stalks detasseled	Stalks broken	Av. height	Silking date
1927	*Pct.*	*No.*	*Pct.*	*Pct.*	*In.*		*Pct.*	*No.*	*Pct.*	*Pct.*	*In.*		*Pct.*	*No.*	*Pct.*	*Pct.*	*In.*	
Burr-Leaming.....	90.4	2.08	34.5	13.1	36.0	Aug. 8	83.2	1.69	28.5	9.8	31	Aug. 12	48.9	0.64	8.8	4.6	18	Aug. 20
Leaming	94.5	2.75	44.6	14.8	37.5	Aug. 8	83.1	2.23	36.4	15.6	28	Aug. 11	53.3	.72	16.8	9.5	16	Aug. 18
Clarage	97.4	3.43	60 5	22.9	37.0	Aug. 6	87.5	2.17	43.4	16.6	29	Aug. 10	66.7	1.24	20.5	12.1	19	Aug. 17
Medina Pride......	96.6	3.44	67.8	24.3	37.3	Aug. 5	86.8	2.41	54.8	19.1	30	Aug. 7	67.2	1.11	26.7	10.9	21	Aug. 15
Golden Glow.......	94.7	3.57	55.0	23.5	37.0	Aug. 4	87.6	2.53	39.6	15.7	28	Aug. 8	67.2	1.27	23.0	12.6	20	Aug. 15
Wisconsin No. 25...	94.5	4.36	78.9	34.5	34.0	July 29	87.2	3.19	61.3	24.8	26	July 31	70.6	2.12	42.3	10.4	18	Aug. 5
Average..........	94.7	3.27	56.9	22.2	36.4	Aug. 5	86.1	2.04	50.3	18.2	29	Aug. 9	64.9	1.31	28.9	9.5	19	Aug. 17
1926																		
Champion Pearl...	51.6	1.30	7.5	2.6	43.0	Aug. 10	52.5	1.10	7.9	3.0	40	Aug. 12	53.2	1.37	8.1	3.7	37	Aug. 16
Reid's Yellow Dent	57.5	1.59	11.5	4.9	46.0	Aug. 8	58.9	1.59	9.1	9.0	40	Aug. 11	46.5	1.04	9.0	7.9	37	Aug. 16
Burr-Leaming.....	65.8	1.43	15.6	7.7	45.0	Aug. 5	52.2	1.43	12.6	7.5	41	Aug. 6	48.2	1.13	12.5	5.2	37	Aug. 11
O. I. Low Ear......	61.6	1.15	22.1	5.0	38.0	July 31	59.2	1.35	15.8	1.3	37	July 30	49.1	1.31	22.0	2.1	32	Aug. 3
Leaming	67.7	1.47	16.7	9.5	45.0	Aug. 4	59.2	1.55	12.9	9.3	38	Aug. 5	50.6	1.20	9.0	7.9	32	Aug. 7
Low Percent Grain	65 9	1.61	13.3	11.1	46.0	Aug. 6	65.0	2.29	22.4	11.8	44	Aug. 4	52.7	1.88	10.1	8.8	37	Aug. 8
Medina Pride......	70.6	1.67	23.7	10.4	44.0	Aug. 2	67.3	1.57	22.9	11.3	43	Aug. 1	52.5	1.33	16.9	8.1	37	Aug. 4
Golden Glow.......	70.3	1.88	20.3	14.3	46.0	Aug. 4	64.4	1.80	15.6	11.0	41	Aug. 4	59.3	1.92	17.7	8.7	38	Aug. 4
Clarage	73.3	1.83	20.4	12.0	45.0	Aug. 4	69.8	2.05	22.5	10.2	43	Aug. 3	61.6	1.96	16.7	10.8	40	Aug. 4
High Percent Grain	69.7	2.13	22.1	7.1	45.0	July 30	58.1	1.60	18.1	9.3	40	July 30	61.5	1.56	18.6	11.8	37	Aug. 4
Van Wye..........	77.4	1.75	26.0	16.3	44.0	July 31	59.8	1.57	25.2	11.7	38	Aug. 2	62.1	1.32	15.0	13.7	34	Aug. 2
Average..........	66.5	1.62	18.1	9.2	44.0	Aug. 4	60.5	1.62	16 8	7.6	40	Aug. 4	54.3	1.45	14.1	8.0	33	Aug. 7

Height=Weighted to peak of emergence. Emergence in 1924 and 1925 weighted on average difference between insectary and natural conditions of 1926 and 1927. Difference was 4 days.

Data under silking=Date of first tassel in 1924.

TABLE 67.—Infestation of Varieties of Corn Planted on Different Dates—Continued

Variety	June 10						June 20						Average						
	Plants infested	Borers per stalk	Stalks detasseled	Stalks broken	Av. height	Silking date	Plants infested	Borers per stalk	Stalks detasseled	Stalks broken	Av. height	Silking date	Plants infested	Borers per stalk	Stalks detasseled	Stalks broken	Av. height	Silking date	Borers per 100 stalks
1927	*Pct.*	*No.*	*Pct.*	*Pct.*	*In.*		*Pct.*	*No.*	*Pct.*	*Pct.*	*In.*		*Pct.*	*No.*	*Pct.*	*Pct.*	*In.*		*No.*
Burr-Leaming...	15.5	0.39	2.6	1.5	10	Aug. 28	....	....	......	......	... ..	....	55.0	1.09	1.69	6.9	22	Aug. 18	77.8
Leaming.........	11.7	.50	3.5	1.7	9	Aug. 26	....	. ..	......	......	......	. ...	56.1	1.38	22.8	9.5	21	Aug. 17	103.3
Clarage.........	18.2	.56	5.3	2.1	11	Aug. 26	....	.....	......	......	. . ..	....	64.1	1.62	28.5	11.8	22	Aug. 16	130.6
Medina Pride...	26.1	.69	8.2	3.2	10	Aug. 21	....	.....	....	......	......	.. ..	67.0	1.70	35.9	13.7	23	Aug. 13	136.4
Golden Glow....	17.4	.59	3.6	2.5	11	Aug. 23	......	....	....	... ..	....	.. ...	62.9	1.75	27.0	12.4	22	Aug. 14	138.8
Wisconsin No. 25.	16.9	.79	7.4	2.2	9	Aug. 13	....	....	......	.. ...	......	....	64.7	2.31	43.2	15.3	20	Aug. 5	182.3
Average.........	20.8	.58	6.3	2.9	10	Aug. 23	......	....	.. ...	... ..	... .	....	63.5	1.61	33.8	12.5	22	Aug. 12	....
1926																			
Champion Pearl.	14.2	.89	1.5	1.2	22	Aug. 18	5.6	.29	.7	.3	11	Aug. 24	33.6	.95	4.7	2.3	30	Aug. 17	38.4
Reid's Yel. Dent.	16.4	.85	1.9	2.2	22	Aug. 16	3.6	.25	.3	.6	12	Aug. 24	35.7	1.07	5.8	5.2	31	Aug. 15	47.2
Burr-Leaming...	15.5	1.23	2.8	1.8	23	Aug. 17	3.7	1.06	.3	.1	11	Aug. 24	35.4	1.23	8.2	4.4	31	Aug. 13	46.1
O. I. Low Ear....	23.0	1.36	8.8	2.2	21	Aug. 10	6.3	.84	2.5	0	11	Aug. 17	38.0	1.16	13.3	2.5	28	Aug. 6	44.6
Leaming	22.4	.91	6.0	4.5	22	Aug. 16	3.0	.27	.4	1.1	10	Aug. 20	39.5	1.06	8.5	6.6	29	Aug. 11	51.1
Low Pct. Grain..	34.1	1.35	5.6	5.3	24	Aug. 16	1.3	.30	.4	.5	12	Aug. 21	41.2	1.40	9.4	7.0	32	Aug. 12	71.4
Medina Pride ...	22.3	1.28	6.7	5.4	24	Aug. 11	4.7	.76	1.9	.6	11	Aug. 17	41.5	1.25	13.2	7.1	31	Aug. 7	58.8
Golden Glow....	28.0	1.16	5.7	4.1	25	Aug. 12	3.8	.71	1.1	1.0	13	Aug. 18	42.5	1.44	11.5	7.4	32	Aug. 9	71.8
Clarage	29.0	1.49	5.9	5.6	24	Aug. 11	5.7	.46	.8	.5	12	Aug. 17	44.6	1.46	12.5	8.1	32	Aug. 8	78.7
High Pct. Grain	23.5	1.24	6.0	6.4	22	Aug. 9	3.6	.70	.8	1.1	10	Aug. 17	43.9	1.37	12.8	8.0	32	Aug. 5	69.3
Van Wye........	27.8	1.03	5.1	7.1	22	Aug. 9	2.0	.61	1.2	0	10	Aug. 17	42.8	1.24	13.4	9.2	29	Aug. 6	62.2
Average...... .	23.2	1.17	5.0	4.1	23	Aug. 13	3.9	.57	.8	.5	11	Aug. 19	39.8	1.24	10.2	6.	30	Aug. 10	....

Height=Weighted to peak of emergence. Emergence in 1924 and 1925 weighted on average difference between insectary and natural conditions of 1926 and 1927. Difference was 4 days.

Data under silking=Date of first tassel in 1924.

TABLE 67.—Infestation of Varieties of Corn Planted on Different Dates—Continued

Variety	May 10						May 20						May 30					
	Plants infest-ed	Borers per stalk	Stalks detas-seled	Stalks broken	Av. height	Silking date	Plants infest-ed	Borers per stalk	Stalks detas-seled	Stalks broken	Av. height	Silking date	Plants infest-ed	Borers per stalk	Stalks detas-seled	Stalks broken	Av. height	Silking date
1925	*Pct.*	*No.*	*Pct.*	*Pct.*	*In.*		*Pct.*	*No.*	*Pct.*	*Pct.*	*In.*		*Pct.*	*No.*	*Pct.*	*Pct.*	*In.*	
Burr-Leaming	21.6	......	2.0	1.3	45	July 28	10.9	......	0	0	36	Aug. 7	13.7	......	1.4	.3	34	Aug. 7
Low Percent Grain	14.5	......	1.0	1.3	50	July 29	17.4	......	1.5	.4	35	Aug. 4	14.6	......	1.1	1.4	31	Aug. 5
Leaming	17.8	......	1.4	1.3	47	July 27	17.4	......	1.1	.3	36	Aug. 1	11.1	......	1.1	.7	32	Aug. 4
Clarage	13.3	......	1.7	.7	46	July 23	15.6	......	1.5	.7	34	July 29	10.5	......	1.1	1.1	24	July 25
Van Wye	27.1	......	9.9	1.8	44	July 19	25.7	......	4 2	1.1	33	July 24	15.5	......	3.0	.4	28	July 30
Golden Glow	19.4	......	8.2	1.8	42	July 18	15.8	......	5.5	.6	36	July 24	18.8	......	7.3	1.1	28	July 25
Low Ear	13.3	......	5.8	1.3	41	July 17	20.4	......	6.8	.3	31	July 22	17.8	......	6.0	.7	29	July 25
Northwestern Dent	27.2	......	8.8	2.3	33	July 16	28.6	......	6.9	.9	31	July 17	14.9	......	3.4	.4	25	July 21
Average	19.2	......	4.8	1.4	43	July 22	18.9	......	3.4	.5	34	July 24	14.6	......	3.0	.6	29	July 29
1924																		
Reid's Yellow Dent	9.2	......	......	......	34	Aug. 2	11.4	......	......	......	34	Aug. 9	5.1	......	......	......	31	Aug. 10
Burr-Leaming	14.4	......	......	......	36	Aug. 2	14.5	......	......	......	33	Aug. 2	8.1	......	......	......	28	Aug. 7
Leaming	11.6	......	......	......	42	July 31	16.4	......	......	......	36	Aug. 3	6.3	......	......	......	27	Aug. 9
Clarage	16.6	......	......	......	41	July 29	7.0	......	......	......	35	Aug. 1	3.0	......	......	......	28	Aug. 6
Low Percent	9.4	......	......	......	40	July 27	10.3	......	......	......	32	Aug. 2	5.3	......	......	......	28	Aug. 7
Silver King	19.7	......	......	......	32	July 22	7.8	......	......	......	29	July 29	4.6	......	......	......	28	Aug. 4
Van Wye	14.3	......	......	......	39	July 22	16.5	......	......	......	31	July 28	7.0	......	......	......	25	Aug. 4
Ivory King	11.0	......	......	......	30	July 18	7.2	......	......	......	27	July 20	12.0	......	......	......	26	July 21
Northwestern Dent	27.6	......	......	......	40	July 17	24.4	......	......	......	32	July 19	12.8	......	......	......	26	July 23
Average	14.8	......	......	......	37	July 26	12.8	......	......	......	32	July 29	7.1	......	......	......	27	Aug. 3

Height=Weighted to peak of emergence. Emergence in 1924 and 1925 weighted on average difference between insectary and natural conditions of 1926 and 1927. Difference was 4 days.

Data under silking=Date of first tassel in 1924.

TABLE 67.—Infestation of Varieties of Corn Planted on Different Dates—Concluded

Variety	June 20						June 30						Average						
	Plants infested	Borers per stalk	Stalks detasseled	Stalks broken	Av. height	Silking date	Plants infested	Borers per stalk	Stalks detasseled	Stalks broken	Av. height	Silking date	Plants infested	Borers per stalk	Stalks detasseled	Stalks broken	Av. height	Silking date	Borers per 100 stalks
1925	*Pct.*	*No.*	*Pct.*	*Pct.*	*In.*		*Pct.*	*No.*	*Pct.*	*Pct.*	*In.*		*Pct.*	*No.*	*Pct.*	*Pct.*	*In.*		
Burr-Leaming...	1.3	.....	....	....	11	Aug. 14	1.7	.....	....	....	8	Aug. 21	9.8	.....	0.7	0.3	27	....	....
Low Pct. Grain..	3.0	.....	0	0	12	Aug. 14	1.7	....	0	0	8	Aug. 18	10.2	....	.7	.6	27	....	....
Leaming	1.7	......	0	0	11	Aug. 14	1.6	......	0	0	8	Aug. 18	9.9	.....	.7	.5	27	....	....
Clarage	4.3	.....	0	0	11	Aug. 10	1.7	......	0	0	9	Aug. 18	9.1	.....	.9	.5	25	....	....
Van Wye	2.2	.....	0	0	12	Aug. 8	1.7	......	....	....	7	Aug. 14	14.4	......	3.4	.7	25	....	....
Golden Glow.....	4.3	......	.4	....	11	Aug. 8	1.1	....	....	....	9	Aug. 16	11.9	.....	4.3	.7	25	....	......
Low Ear........	2.6	.....	.3	......	9	Aug. 7	1.6	....	0	0	7	Aug. 10	11.1	....	4.0	.5	23	.. ...	....
Northwest. Dent	3.0	....	.7	0	7	Aug. 2	1.1	....	....	....	4	Aug. 8	15.0	.....	4.0	.7	20	....	....
Average........	2.8	.....	.2	0	10	Aug. 10	1.5	.....	0	0	8	Aug. 15	11.4	.....	2.3	.5	25	....	....
1924																			
Reid's Yel. Dent.	4.1	......	....	....	24	Aug. 16	1.0	.....	....	....	11	Aug. 19	6.2	.....	.... ..	. .....	27	....	....
Burr-Leaming...	3.1	....	....	....	22	Aug. 11	4.5	.....	....	....	10	Aug. 16	8.9	....	....	....	26	....	....
Leaming	3.1	.....	....	....	23	Aug. 11	1.0	....	....	....	11	Aug. 12	7.7	....	....	....	28	....	....
Clarage	5.5	.....	....	....	25	Aug. 7	.2	.....	....	....	11	Aug. 16	6 5	.....	....	......	28	....	....
Low Percent....	4.0	......	....	....	22	Aug. 8	1.0	....	......	....	10	Aug. 16	6.0	.....	....	....	26	....	....
Silver King......	8.0	......	....	....	20	Aug. 6	2.0	......	... .	....	10	Aug. 14	8.4	.....	....	....	24	....	....
Van Wye.......	4.5	......	......	....	20	Aug. 5	2.0	....	.. ....	....	9	Aug. 14	8.9	.....	....	....	25	....	....
Ivory King	7.4	....	......	......	18	July 30	2.0	....	....	....	7	Aug. 1	7.9	.....	......	....	22	....	....
Northwest. Dent.	6.7	......	....	......	21	July 30	2.0	.....	....	......	11	Aug. 1	14.7	.....	......	......	26	... ...	....
Average.........	5.1	....	....	....	22	Aug. 7	1.7	......	......	....	10	Aug. 12	8.3	......	....	....	26	....	....

Height=Weighted to peak of emergence. Emergence in 1924 and 1925 weighted on average difference between insectary and natural conditions of 1926 and 1927. Difference was 4 days.

Data under silking=Date of first tassel in 1924.

It should be noted that the height measurements represent weighted averages at the peak of moth emergence and that the data relative to the vegetative period are not exactly comparable for the four years. The data of 1926 and 1927 represent the dates of average silking; those of 1924, date of first tasseling; those of 1925, of first silking. However, these differences in technic do not affect the conclusions.

INFLUENCE OF VARIETY ON BORER POPULATION

The average borer population per 100 stalks for five planting dates is shown in relation to the average silking date and height at moth flight (Table 68). The difference between the populations of the extreme varieties is significant. There were more than twice as many borers in the short-season variety. The data taken in 1926 do not demonstrate varietal differences in population in such a significant manner as those of 1927. A careful study of the records, however, shows that the same relationships existed but in a much less marked degree in 1926.

TABLE 68.—Showing Relation of Borer Population to Varieties

Variety	Average borer population for five planting dates-1927		Height at moth flight	Silking date
	Actual	Relative		
	No.		*In.*	*Aug.*
Wisconsin 25	182	100	29	1
Golden Glow	139	77	29	9
Medina Pride	134	74	28	9
Clarage	128	70	29	11
Leaming	103	57	28	12
Burr-Leaming	78	43	26	13

Having established the fact of varietal differences in population, it is of interest to consider the relationship between date of planting, or development, and borer population. This discussion is divided (1) as to stalk infestation and (2) as to borer population.

RELATION OF PLANTING DATE TO BORER POPULATION

Table 69 shows the number of infested stalks per hundred for the different planting dates. Moreover it will be seen that the infestation correlates with the planting date. Especial attention is directed to the relative average infestation for 1926 and 1927.

TABLE 69.—Showing Number of Infested Stalks per 100 for Each Planting Date at Bono, 1924-1927

Year	May 10	May 20	May 30	June 5	June 10	June 15	June 20	Average
1924	14.8	12.8	7.1	....	5.1	....	1.7	8.3
1925	19.2	18.9	14.6	....	2.8	....	1.5	11.4
1926	66.5	60.5	54.3	30.3	23.2	....	3.9	39.7
1927	94.7	86.1	64.9	51.1	20.8	7.8	....	54.2
Relative 1926 and 1927	100	91	74	50	27	....	....	....

RELATION OF BORER POPULATION TO SILKING DATE

It was first indicated in 1923 that there is a correlation between silking date and borer infestation (Figure 17). Records since that time have confirmed the original conclusion. An interesting result was obtained when larval population at the end of the season was correlated with date of silking. During the season of 1927 silking records were taken on individual stalks of all varieties for all planting dates. At harvest time the infested stalks of this series were dissected for borer population. It was found that regardless of variety or planting date the borer population per stalk correlated directly with earliness of silking as shown in Table 71.

TABLE 70.—Showing Borer Population per 100 Stalks for All Varieties and Each Planting Date, 1926 and 1927

Year	May 10	May 20	May 30	June 5	June 10	Average
1926	108	98	79	30	27	68
1927	318	176	85	43	12	127
Average	213	137	82	36	19	....
Relative av. borer pop.	100	64	38	17	8	....

While the stalks are arranged entirely according to date of silking, the fact must be recognized that those from short season varieties all occur in the first part of the table, while those from late varieties occur in the last part. The late tasseling stalks of early varieties fall in the same date-of-silking group with later developing varieties, and yet do not change the correlation.

TABLE 71.—A Correlation of Silking Date With Borer Population on All Varieties and All Planting Dates

	July 19—25	July 26—31	Aug. 1—5	Aug. 6—10	Aug. 11—15	Aug. 16—20	Aug. 21—25	Aug. 26—31	Sept. 1—8
Plants dissected	143	342	385	602	582	494	266	127	41
Total borers	523	1040	947	1183	719	342	168	63	30
Borer pop. per plant	3.66	3.04	2.46	1.97	1.24	.69	.63	.50	.73

The correlation is still more interesting when a single variety is considered and arranged for all planting dates as shown in Table 72.

TABLE 72.—Correlation of Population With Date of Silking at Five-Day Intervals, Wisconsin 25 Variety, 1927

Planting date	May 10	May 20	May 31	June 6	June 10	June 20	June 30	Totals
July 18—20								
Plants	23	....	....	....	....	....	....	23
Borers	90	....	....	....	....	....	....	90
Population per plant	3.91	....	....	....	....	....	....	3.91
July 21—25								
Plants	93	29	....	....	....	....	....	122
Borers	336	97	....	....	....	....	....	433
Population per plant	3.61	3.34	....	....	....	....	....	3.55
July 26—31								
Plants	97	137	35	7	....	....	....	276
Borers	332	406	75	19	....	....	....	832
Population per plant	3.42	2.96	2.14	2.71	....	....	....	3.01
August 1—5								
Plants	11	37	92	49	3	....	....	192
Borers	38	96	177	61	3	....	....	375
Population per plant	3.45	2.59	1.92	1.24	1.00	....	....	1.95
August 6—10								
Plants	3	15	62	114	31	2	....	227
Borers	10	28	105	104	21	0	....	273
Population per plant	3.33	1.87	1.69	.91	.68	.0	....	1.20
August 11—15								
Plants	....	4	30	42	49	19	....	145
Borers	....	9	46	38	24	9	....	125
Population per plant	....	2,25	1.53	.90	.49	.42	....	.86
August 16—20								
Plants	....	2	3	11	22	23	....	61
Borers	....	10	4	10	13	9	....	46
Population per plant	....	5.00	1.33	.91	.59	.39	....	.75
August 21								
Plants	....	....	3	3	9	4	8	27
Borers	....	....	4	2	6	0	2	14
Population per plant	....	....	....	.67	.67	.0	.25	.52
Totals								
Plants	227	224	225	226	114	48	8	....
Borers	806	646	411	234	67	17	2	....
Population per plant	3.55	2.88	1.83	1.04	.59	.35	.25	....

It may be noted that for a given planting date of this variety, Wisconsin 25, the borer population still correlated directly with earliness of silking in practically every case where the number of stalks dissected was large enough to make error negligible. In other words the earliset silking stalks in a given plot had a higher borer population than those of the same plot that silked five days later. This must mean that either plants are selected by moths according to stage of development or else a higher percentage of larvae are able to become established on the earlier-silking plants, or both.

The average height of corn at peak of emergence for each planting date during the last four years, the average silking date for two years, and the average stalk infestation are shown in Table 73. This height represents the condition of growth at the peak of emergence. The plantings of a given year therefore are comparable. If the statement be correct, as contended, that plant height is an index of attractiveness, then the number of eggs deposited on corn of the various planting dates must vary. This has been found to be true. Moths give first preference to the early planted corn. Since more eggs were deposited and since the rate of establishment was greater on early planted corn, the resulting higher borer population can be easily explained.

TABLE 73.—Average Height of Plants at Peak of Moth Emergence of All Varieties for Each Planting Date

Year	Average height of corn planted						All plantings	Silking date	Av. stalk inf.
	May 10	May 20	May 30	June 5	June 10	June 20			
1927	36	29	19	15	10	....	23	Aug. 14	54.2
1926	44	40	33	28	23	11	35	Aug. 6	39.7
1925	43	34	29	....	10	8	29	....	11.4
1924	37	32	27	....	22	10	29	....	8.3
Av. stalk inf.	48.8	44.5	35.2	....	12.9	....	....	....	....

It has been stated that infestation is due not only to the original number of eggs deposited but also to the rate of larval establishment. Two extreme varieties were selected for study (Table 74). The sequence of arrangement was made on the basis of date of silking. When a single variety is concerned it is expected that population will vary directly with silking date. In this instance, however, it will be observed that the populations of the two varieties did not follow the same sequence as silking date. The fact that the Burr-Leaming planted May 10 and May 20 had population out of the regular order indicates that the number of eggs deposited on those plantings of the variety was enough greater more than to make up for the lower rate of establishment due to its slower rate of development, as indicated by silking. On the other hand, its greater height would suggest that a greater number of eggs were deposited on the May 10 planting of Burr-Leaming than on that of Wisconsin 25.

There can be no doubt of the variation in population of different varieties planted on the same date and the same varieties planted on different dates. There was variation in the height of varieties planted at the same time. There were differences in the height and silking period of single varieties planted on different dates. If the moths select corn and the larvae become established in accordance with condition of growth, then population can always be expected to vary with variety and planting date, for, other factors being equal, the condition of growth varies with the type of variety and the time of planting.

TABLE 74.—Comparison of Population, Height, and Silking Date of Burr-Leaming and Wisconsin 25, 1927

Variety	Planting date	Population per 100 stalks	Height	Silking date
Wisconsin	May 10	402	34	July 29
Wisconsin	May 20	278	26	July 31
Wisconsin	May 30	149	18	Aug. 5
Burr-Leaming	May 10	188	36	Aug. 8
Wisconsin	June 5	58	14	Aug. 9
Burr-Leaming	May 20	141	31	Aug. 12
Wisconsin	June 10	13	9	Aug. 13
Burr-Leaming	May 30	31	18	Aug. 20
Burr-Leaming	June 5	23	15	Aug. 23
Burr-Leaming	June 10	6	10	Aug. 28

The difference in silking dates of the various plantings of Wisconsin 25 was 16 days. The difference in population per stalk between the extreme planting dates was 3.89 borers per stalk. There was therefore an average reduction of .24 borer per stalk or nearly 6 percent for each day's delay in silking for this particular variety. Obviously the greatest reduction occurred in the earlier plantings. The three days delay in silking between May 10 and May 20 plantings resulted in an average reduction of .48 borer per stalk or nearly 12 percent, while the delay between June 5 and June 10 plantings resulted in a reduction of .11 borer per stalk, or 2.7 percent.

Aside from the fact that borer population varies with development of corn, as determined by variety and date of planting, it seems proper to direct attention to certain other possibilities suggested in the preceding pages.

In Table 69 the average stalk infestation is seen to increase gradually from 1924 to 1927. In Table 70 the borer population in 1927 is shown to be nearly double that of 1926. On the other hand, Table 73 shows that the average silking date was 8 days later in 1927 than in 1926, and that the average height of corn was much less in 1927 than in 1926. If stage of development exerts so much influence, why was the population on the plots so much greater in 1927 than in 1926?

Why population on the plots was so much greater in 1927 than in 1926 would be clearer if it were known whether or not the corn borer had reached the saturation point. There is no evidence that the corn borer in the Bono area has reached a normal status where its numbers are likely to remain relatively constant. Despite the vicissitudes of weather and cleanup, it is apparent from data published by the Bureau of Entomology that the insect has continued to increase in northwestern Ohio. The increase over the entire infested area of the United States has been spasmodic, depending primarily upon environmental conditions. It seems very probable, therefore, that the increase in the Bono plots in 1927 despite a retarded condition of growth, was the partial result of a biotic potential that has not as yet reached the place where it is equalled by environmental resistance. A contrary conclusion would depreciate the belief that the borer is a pest. Unfavorable conditions also existed in 1925 as compared with 1926. Moreover, the growth conditions in 1925 were considered better than those in 1927 yet the percent of increase in 1925 was less than in 1927. Here again it is to be remembered that the area infested in 1924 was considerably smaller than in 1926 and, according to Chapman's experiments, it is probable that the size of the area may have influenced the abundance of the insect the following year.

There is still a second factor to be considered relative to the increase in 1927 regardless of the comparatively retarded condition of the growth of corn that season. The records indicate that, due to very late planting of corn in the Bono area, there was an influx of moths to the May 10 and May 20 plantings. As a matter of fact, the June 10 plantings of 1926 were more heavily infested than those of 1927, showing that the population curves actually cross for the two years. This may be partly accounted for by the fact that the plot plantings of June 10 were thrown in direct competition with the corn of the region, which was planted about June 8. In other words, later planting in the Bono area was chiefly responsible for the higher level of population in the early plantings of 1927.

FERTILIZER PRACTICES AFFECT BORER POPULATION

In Section 3 it was shown that the development of corn may be retarded by certain cultural and fertilizer practices. A comparison of the borer population of the plots receiving no treatment with those that were fertilized shows again that population correlates with the stage of corn development. That the insect is very sensitive to growth condition is indicated by the data in Table 75.

The fertilized corn was only 1.4 inches higher at the time of moth flight and silked but one day earlier than the unfertilized corn, yet the relative population per acre was 100 to 71.

Table 66 shows still more conclusively that the acceleration or retardation of corn development by cultural practices influences borer population.

TABLE 75.—Showing Influence of Fertilizer on Infestation of Burr-Leaming Corn at Bono, 1927

	Stalks infested	Borers per acre
	Pct.	*No.*
Fertilized	52.8	4,589
Unfertilized	46.1	3,261

It has been pointed out that borer population varies with the variety, with the planting date, and with the method and rate of application of fertilizers; or it varies with combinations of these and other factors. These various factors both individually and in combination largely determine the behavior or the development of the corn plant. Corn development has a tremendous influence on the behavior of the borer as indicated by its abundance, therefore, any evaluation of the physical factors influencing borer abundance must take the corn plant into consideration.

VARIATION IN POPULATION DUE TO RATE OF PLANTING

In a study of corn borer behavior, corn of one or more varieties has been grown at the rates 3, 4½, and 6 stalks per hill for the last three years, (Section 2, page 115). The first observations, which were based entirely on percent infestation, indicated that there was no significant difference in the resulting borer infestation. When the population count was taken, however, it was found that there was consistently a higher borer population per stalk in the 3-stalk rate than in the 6-stalk rate, and the 4½-stalk rate was intermediate between the thinner and thicker rates. On the other hand the number of borers per hill was always greatest in the 6-stalk hills, the 3-stalk rate being low, and the 4½-rate intermediate.

The explanation of the condition as indicated by the table is not clear. It is probable, however, that an equal number of eggs was deposited per unit area regardless of rate of seeding. That is, the three-stalk-per-hill plot probably received the same number of eggs as the six-stalk-per-hill plot. Since it is known that more young larvae are able to become established upon stalks with most foliage the greater number of borers per hill in the 6-stalk rate than in the others can be readily accounted for. If there were an equal number of eggs deposited per plot the number of eggs per stalk in the 3-stalk plot would be just twice as great as in the 6-stalk plot. The resulting number of borers per stalk in the 3-stalk rate was less than twice as great as in the 6-stalk rate. This again can be readily explained by the increased establishment rate in the 6-stalk hills.

TABLE 76.—Borer Population per Plant and per Hill at Three Rates of Planting, Wisconsin 25, 1927

Plants per hill	Date of planting					
	May 10	May 20	May 31	June 6	June 10	Average
	Borer population per plant					
6	2.78	2.33	1.71	.93	.55	1.66
4½	3.57	3.12	1.68	1.11	.60	2.02
3	4.36	3.19	2.12	1.08	.79	2.31
	Borer population per hill					
6	16.68	13.98	10.26	5.58	3.20	9.96
4½	16.07	14.04	7.56	5.00	2.70	9.07
3	13.08	9.57	6.36	3.24	2.37	6.92

In the Burr-Leaming rate-of-seeding series the same result was obtained where rates were 1, 3, and 5 stalks per hill.

It may be noted in this table that the percent infestation was fairly uniform regardless of the planting rate. The number of borers per infested stalk was inversely proportional to the rate of planting, while the number per plot was directly proportional to the planting rate.

TABLE 77.—Showing Infestation and Borer Population in Burr-Leaming Rate-of-Planting Series, 1927

Plants per hill	Plants per plot	Infested plants per plot	Percent infestation	Borers in 25 infested plants	Borers per infested plant	Borers per plant	Borers per plot
1	699	470	67.2	43	1.72	1.27	885
3	1,456	989	67.9	30	1.20	.86	1,258
5	2,297	1,389	60.4	23	.91	.59	1,360

It seems clear that each of the three factors, rate of planting, time of planting, and variety exert individual influences on population. Fundamentally, however, the causes of variation appear to be definitely linked with the behavior of the corn plant.

PROBABLE CAUSES OF VARIATIONS IN POPULATIONS

While there can be no doubt of the correlation between borer population and the stage of development of corn, yet it must be stated that the causes underlying this relationship are not definitely established. Future research must deal largely with this latter phase. It is obvious that as the insect is passing from the adult stage of one generation to the egg and larval stages of another and particularly as the larva is passing thru its various instars the corn plant is likewise passing thru various stages of growth. For example, in the preceding sections it has been shown that the behavior of the corn plant is determined by its heredity and environment. A variation in variety, temperature, sunlight, rainfall, cultural practices, etc. results in a difference in vegetative and reproductive growth. Over a period of years it was seen that the combined effects of all these factors affect the responses of the plants as indicated by the time required for corn to reach a certain stage of development. In Table 57 the time for corn to pass from the coming-up stage to the blossoming stage ranged from 45 to 77 days. It would appear that the variation in corn development from year to year might be so great that the fixed range of activities of the insect would not be sufficient to permit an optimum relationship. Every change in the plant, whether due to heredity or environment or both, presupposes a change in the immediate environment of the larvae.

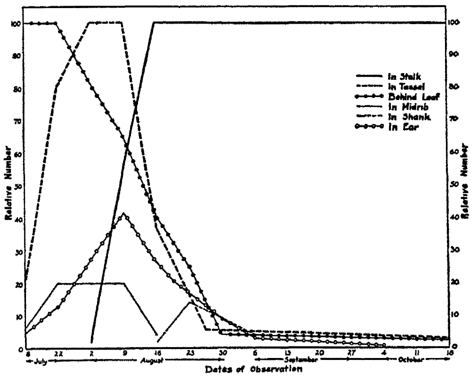

Fig. 18.—Graph showing position of larvae in corn plant at periodic intervals

The constant shifting of larvae thruout their various instars as a result of the development of the plant is graphically shown in Figure 18. If it were possible to deal only with a single instar independently for each day of the season, the movement curves would undoubtedly be much smoother. The data are recorded, however, at weekly intervals and include all instars, hence there can be no clear cut description of the movement of each instar. This, however, does not interfere with the general conclusions. It is obvious that during the first part of the season the big majority of larvae are found behind the leaf sheath; a few weeks later the majority are found in the tassel or the crown of the plant. Upon the emergence of the tassel from the leaf roll or crown of the plant the larvae enter the stalk proper. Thruout this entire period there is, of course, a high mortality, as was indicated by the constantly decreasing number of larvae found.

It is logical to assume that the corn most heavily infested will be that which is in the optimum stage of development at the time the greatest number of eggs are hatching. If the majority of the eggs are deposited on corn before or after it has attained this optimum stage then larval survival, other factors being equal, should be decreased. That this happens is evidenced by the fact that altho twice as many eggs were deposited on Clarage as on Golden Bantam yet the final population at the hibernating period was in the reverse order. Clarage was more attractive to the moths but Golden Bantam was more favorable to larval growth. Eggs deposited on corn long before or after it has passed the tassel-emergence stage are of less potential consequence than those deposited at a certain intermediate period. It would appear that the availability of certain food is very necessary to the successful establishment of larvae. Obviously the nutrition factor is of considerable consequence (7).

Under normal field conditions early developing corn has been most favorable to establishment of the young larvae. Theoretically, however, if there is a time of maximum synchrony, as is contended, then it should be possible to find certain varieties planted under very favorable conditions, so early that they would have passed the stage which is most attractive to moths or most favorable to establishment or both. There was some evidence of this in 1924. The early development of corn and a later than normal emergence of moths would contribute to this condition.

It is of further interest in this connection to note that a first instar larva is a very delicate creature. If it is to succeed in establishing itself it is logical to assume that the conditions imposed by a corn plant not in the optimum stage of growth would be such as to compel an undue exposure of the larva to various meteorological conditions. Larvae are negatively phototropic and positively thigmotropic. Before the larvae feed these tropisms must be satisfied. At the same time the food requirement is imperative. The behavior of mature larvae relative to boring thru lignified nodes and bast tissue suggests that a first instar larva would have but little success in feeding in such situations. Data show that the leaves surrounding the tassel are closely rolled, tender and succulent. The tassel within is equally succulent and probably more highly nutritious. Under such conditions, other factors being equal, the inherited activities of the insect should find a maximum expression.

5. CORN BREEDING IN RELATION TO THE CORN BORER PROBLEM

M. T. MEYERS,[4] J. S. CUTLER,[5] AND C. R. NEISWANDER

The object of the corn-breeding program of the Ohio Experiment Station is to develop varieties that will produce larger yields of sound grain under conditions of corn borer infestation than is now possible with ordinary varieties. Extensive selection in selfed-lines is being practiced to isolate strains that can be used in hybrid combinations to obtain larger yields and better quality. At levels of infestation where the actual damage by the corn borer is slight it should be possible to offset this damage by developing strains of greater inherent productiveness than the varieties now available. Under conditions of abundant infestation, however, it will be necessary to have varieties that are more resistant or tolerant to the corn borer or that can in large degree escape its attack. With this in mind, lines are being isolated as a first phase in the breeding program. As a second phase, these, and a large number of strains and varieties from other sources[6] are being studied to determine (1) the degree to which they become infested, (2) the degree to which they are damaged by approximately equal infestation, and (3) whether strains may be found or developed that can be planted later than usual and still produce a profitable yield of sound corn.

Differences in date of planting had resulted in striking differences in borer population. It seemed logical, therefore, to begin at this point.

Data were obtained on 252 crosses between inbred lines planted on May 13 and June 10 at Bono in 1927. The crosses were planted in single rows 9 hills long in the first planting and 10 hills in the second. All rows were thinned to 3 plants per hill, when possible, and all had a final stand of more than 20 plants per row. The number of days in the vegetative period, from planting to silking,

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[6]Thru the hearty cooperation of corn breeders in other States and of the U. S. Department of Agriculture, who have furnished seed of their breeding stocks as needed, it has been possible to have these experiments include a veritable cross section of corn types and strains.

was used as an inverse measure of the rate of development of the crosses. The mid-date of silking can be determined with precision. The crosses with the shorter vegetative periods will have passed thru relatively more of the vegetative stage on any given date than crosses with longer vegetative periods. The height of plant to the tip of the longest leaf was measured at the time of maximum moth flight to determine the possible influence of size on infestation. Infestation in the different progenies was measured by the ratio of infested stalks to total number of stalks at maturity. The ratio of broken infested stalks to the total number of stalks also was determined.

TABLE 78.—Means and Standard Deviations for Certain Measurements and Determinations in 252 Crosses Between Inbred Lines Planted on May 13 and on June 10, 1927, at Bono, Ohio

Determination	Planting	Mean		Standard deviation	
		Value	P. E.	Value	P. E.
Length of vegetative period, in days	May 13 June 10	86.54 72.90	0.21 .19	4.92 4.44	0.15 .13
Plant height during moth flight, cm. to tip of longest leaf	May 13 June 10	123.67 83.27	.51 .37	12.10 8.76	.36 .26
Stalks infested, percent of all stalks	May 13 June 10	69.70 25.10	.82 .65	19.30 15.22	.58 .46
Infested stalks broken, percent of all stalks	May 13 June 10	35.49 6.09	.83 .26	19.54 6.22	.59 .19

The mean and standard deviations for each determination for each planting are given in Table 78. The mean length of the vegetative period was 13 days less in the second than in the first planting. This is an interesting example of the tendency of later planted corn to "catch up" with corn planted earlier while conditions are less favorable for growth. The difference in mean plant-height is of little interest. The moths are active for nearly 30 days and the plants of the later planting were taller during the latter part of the oviposition period than those of the earlier planting during the beginning of this period. Consequently the coefficient of correlation between plant height within each planting and infestation provides a better measure of any influence of height on infestation. The greater average percentage of infestation and of broken stalks in the first than in the second planting affords further evidence on the important relation between time of planting on the one hand and borer population on the other.

The coefficients of correlation between certain of these determinations and also the more important regression coefficients for both plantings are shown in Table 79.

TABLE 79.—Coefficients of Correlation and Regression for the Percentages of Infested and Broken Stalks and Characters Influencing Them in 252 Crosses Between Inbred Lines of Corn Planted on May 13 and on June 10, 1927, at Bono, Ohio

Variable and symbol	Infestation (I)				Vegetative period (D)				Plant height (H)			
	Regression		Correlation		Regression		Correlation		Regression		Correlation	
	Of	Value	Value	P. E.	Of	Value	Value	P. E.	Of	Value	Value	P. E.
May 13 planting												
Vegetative period.....D..	I. D.	—2.19	—0.56	0.03	....	....	....	....	....	....	....	....
Plant height.....H..	I. H.	.61	.39	.04	H. D.	—0.90	—0.37	0.04	....	....	....	....
Breakage.....B..	B. I.	.78	.77	.02	B. D.	—2.73	— .69	.02	B. H.	0.51	0.32	0.04
June 10 planting												
Vegetative period.....D..	I. D.	—1.14	— .33	.04	....	....	....	....	....	....	....	....
Plant height.....H..	I. H.	.59	.34	.04	H. D.	— .42	— .22	.04	....	....	....	....
Breakage.....B..	B. I.	.23	.56	.03	B. D.	— .50	— .36	.04	B. H.	.11	.16	.04

In the first planting, the coefficient of correlation between the percentage of infestation and the length of the vegetative period is —0.56±0.03. Thus, 31.2 percent of the variation in infestation in this particular experiment was concomitant with variation in the length of the vegetative period. The regression of infestation on length of vegetative period is —2.19. That is, among the crosses as a whole, the infestation decreased 2.19 percent for each day that the vegetative period increased.

The coefficient of correlation between plant height and infestation in the first planting is 0.39±0.04, indicating that only 15.2 percent of variation in infestation was concomitant with variation in plant height during moth flight.

The coefficient of multiple correlation for infestation with length of vegetative period and plant height together is 0.59±0.03 in the first planting. Variation in both of these measures then accounts for 35.0 percent of the variation in infestation, or only 3.8 percent more than the length of the vegetative period alone. In fact, it is probable that this relation between plant height and infestation really is only another expression of the influence of stage of development. That is, it is probable that plant height was related to infestation largely thru its relation to stage of development. The coefficient of correlation between plant height and length of vegetative period in the first planting is —0.37±0.04, indicating that the earlier-silking crosses tended to grow somewhat more rapidly than those with a longer vegetative period.

The average infestation of the same crosses in the second planting was materially lower than in the first. The coefficients of correlation for infestation with length of the vegetative period and with plant height are also lower in the second planting. As relatively less of the vegetative period had elapsed at the time of moth flight, the crosses were relatively less differentiated than in the first planting, as shown by the lower standard deviations. This probably accounts for the lower correlations.

In determining the percentage of broken stalks, all broken infested stalks were counted as such, whether the break was above or below the ear, to obtain an index of the ability of the different crosses to stand in spite of infestation. Such ability to stand should be reflected both in a better yield and quality and in a greater ease in harvesting, whether by hand or machine. The breakage as determined was closely correlated of necessity with the percentage of infestation, the coefficient of correlation in the first planting being 0.77±0.02. The correlation between the percentage of broken stalks and the length of the vegetative period in the first planting is —0.69±0.02. This is significantly higher than the relation between vegetative period and percentage of infestation. Thus, not only were larger percentages of the stalks infested in the earlier silking crosses but larger percentages of the infested stalks were broken. It is known from other experiments that there is a positive correlation between the percentage of infested plants and the borer population per infested plant. Moreover, the earlier-silking crosses in general would be smaller stalked and would be the first to mature, after which they would break more easily. The excess breakage in the earlier crosses doubtless was a result of all of these factors.

The important relation between the stage of development at the time of moth flight and the necessity of including many widely diverse types in looking for possible resistance or tolerance to the attack of the corn borer have forced the experiment so far to be largely preliminary. The results are promising, however, and point clearly to the methods to be followed in the future.

The correlations between infestation and stage of development measured by mid-date of silking, or plant height during moth flight, are important. At the same time they are small enough to indicate that other factors also are causing variation in infestation. In fact, the coefficient of multiple correlation for infestation with length of vegetative period and plant height together indicate that only some 35 percent of the variation was accounted for in this way, leaving 65 percent due to other factors, including chance. Because of the small numbers of plants grown in these experiments and the consequent importance of chance variation it has not seemed worth while to attempt picking those crosses with lower percentages of infestation than would be expected from their dates of silking and plant heights during moth flight. The larger numbers of plants being used in current experiments will permit such treatment.

Again, as far as the breeding experiments described here are concerned, it has been impossible to differentiate between lack of attractiveness and difficulty of larval establishment as causes of lower final infestation in some progenies. Counts of the numbers of egg masses deposited and determination of the final numbers of borers per stalk in the different progenies will permit this differentiation. These data are to be obtained in current experiments and should furnish important evidence on questions to which there now are only partial or no answers.

6. DAMAGE RESULTING FROM CORN BORER ATTACK

J. B. POLIVKA AND E. G. KELSHEIMER

While late planting reduces infestation it also reduces yield. In case all other methods of control should fail in certain areas it may be advisable to plant late and suffer the consequent reduction in yield rather than suffer a greater loss caused by the borer. When damage by the borer exceeds reduction in yield due to later planting, then later planting is justified. The problem is to determine when and under what conditions and circumstances these two lines cross.

It is to be remembered that damage by the borer may be either direct or indirect or both. When damage is the result of the attack of the borer on any part of the corn plant it is considered direct. In severe infestation, the midribs of leaves are entered, causing the leaves to break down, thus depriving the plant of a part of its power to manufacture food. If the stalk is badly tunneled, translocation of the depleted food supply results and the stalk may or may not collapse. As pointed out heretofore, the location of the tunnels may be more important than their number. Under any of these conditions of infestation the proper development of the ear is involved. Moreover, a large percentage of the cobs may be not only entered but the developing grain may be directly damaged to a certain but lesser extent.

Indirect damage from borer injury may result from the entrance of bacterial and fungous organisms, which cause the stalks and ears to rot, thus greatly increasing the loss. This type of injury may depend of course not only on the severity of borer attack but also on the weather conditions. A season favoring the rapid growth of such organisms would increase the injury to the crop.

An accurate determination of damage involves a consideration of not only the corn plant but also the behavior of the insect. The corn under observation should be of the same variety, planted on the same date and subjected to the same environmental conditions, for varieties respond differently to borer attack and the same variety behaves differently when planted on different dates or under different conditions.

That the insect behaves differently in various habitats; that it behaves differently towards different varieties grown under the same conditions; that it behaves differently toward individual plants of the same variety, even tho planted under the same conditions; and that in other respects its behavior in relation to the plant may vary—all tend greatly to complicate the determination of the damage. Until more information is available relative to the inherent behavior of the corn plant and the corn borer and environment in general it is impossible to draw accurate conclusions.

Thruout the period of investigation, records were taken of stalk breakage due to corn borer attack. Reference to Table 68 will show the constantly increasing percentage of breakage with the increase in borer population. Table 80 shows the relative breakage and relative population of varieties and planting dates for 1927. It will be noted that the earlier varieties carried a heavier borer load per infested stalk, hence breakage was greater. The percentage of breakage was higher in the early than in the late varieties.

TABLE 80.—Relative Breakage Compared With Relative Population for All Varieties and All Planting Dates, 1927

Variety	Population	Stalk breakage	Tassel breakage
	Pct.	*Pct.*	*Pct.*
Wisconsin 25	100	100	100
Golden Glow	77	99	63
Medina Pride	74	89	84
Clarage	70	77	65
Leaming	57	62	53
Burr-Leaming	43	45	39
Average	70	79	67

In 1927 a special series of plantings was made in the field that was most heavily infested in 1926. Three varieties, typical late, medium, and early sorts, were planted on May 18. Table 81 gives some of the results.

TABLE 81.—Corn Borer Population of Plots and Damage Done, 1927

Planting date	Variety	Borers per 100 stalks	Stalks detasseled	Stalks broken
		No.	*Pct.*	*Pct.*
May 18	Wisconsin 25	160	74	30
	Medina Pride	138	56	18
	Burr-Leaming	61	17	7

The short-season variety, Wisconsin 25, carried the heaviest borer load and also had the highest percentage of broken stalks. It seems that differences in breakage and damage were the result of differences in population, maturity, and size of stalk, or some combination of these conditions.

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VI. ECOLOGICAL INTERPRETATIONS

INTRODUCTION

Because of the lack of certain critical experiments on corn borer behavior, the evaluation of the various constituents of the environment must be made largely by the processes of comparison and elimination. For example, if the vegetation type of a region is determined by the soil and climate of the region and since abundance of the borer can be correlated with vegetation type, is it not probable that the same environmental conditions that determine the plant formation also influence borer abundance? More specific still, since the rainfall-evaporation ratio is a major factor in determining the distribution of plant formations, is it not logical to suspect that this same phenomenon influences corn borer behavior? Furthermore, if in a field of corn where all conditions—weather, variety of corn, date of planting, etc., except soil type or soil fertility are uniform, there is a significant difference in population, should not the soil type and soil fertility be considered as important? On the contrary, if, all conditions except weather are the same and there is a difference in population, would it not be logical to attach importance to weather conditions?

It will be shown in the pages which follow that there are in Ohio areas of different vegetation types, of different soil types and of different degrees of soil fertility that can be correlated with corn borer abundance. It will be pointed out too that climate also may exert both direct and indirect influence on the insect. To the degree that it affects the corn plant and the corn plant in turn affects the behavior of the borer, to that extent climate is of indirect influence on the corn borer. An understanding of the indirect relationship of soil and the direct and indirect influence of climate and weather on the responses of the corn borer should facilitate interpretation and prediction.

1. ORIGINAL PLANT ASSOCIATIONS AS INDICES TO BIOTIC HABITATS WITH SPECIAL REFERENCE TO THE CORN BORER

H. C. SAMPSON[7] AND E. N. TRANSEAU[8]

The concept of natural plant associations as indices of biotic habitats is not a new one invoked to account for certain activities of the corn borer. It has been in use since the days of the pioneers. Since the development of the science of ecology a more critical and wider range of applications is possible.

Neither is the correlation of the accumulation of the corn borer with the distribution of certain natural plant associations exceptional, since it is but a particular instance of the biological laws of plant and animal distribution in nature. Each of the various climatic plant formations of North America is characterized by a particular fauna, and within each climatic plant formation one or more plant associations may be found in which certain species of these animals accumulate most abundantly. Since this is true alike for animals that feed directly on plants and those that do not, evidently the combination of habitat factors that enables the particular plant association to develop and persist for a considerable time also represents the most favorable set of environmental conditions for the reproduction and accumulation of certain species of animals. The presence, or absence, of a particular host used as a source of food has been pointed out as a limiting factor for certain species, but such a specialized food requirement is an additional limiting factor to the range and distribution of the species concerned (25).

The accompanying map (Fig. 19) gives in outline the general distribution of the more important climatic plant formations of the eastern United States. Within each climatic formation there are several or many edaphic plant formations. These edaphic formations in turn are composed of plant associations related to each other as successional series correlated with the gradual changes in the habitat. For instance, in the eastern Deciduous Forest Formation there are series of plant associations characteristic of sand dune areas, of swamps, of relict bogs, of eroding cliffs, etc. With increasing mesophytism and the accompanying soil changes in each of the habitats, the successional series of the several edaphic formations gradually merge toward a common association characteristic of the climate of the particular region (6).

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These various plant formations and plant associations represent an evaluation of the numerous factors of the environment over a period of years. Consequently they constitute readily available indices to biotic habitats. When the original vegetation of a habitat is cleared or otherwise destroyed the secondary associations that develop, if sufficiently understood, may serve as additional indices.

Fig. 19.—Map showing vegetation of the eastern United States. Transeau

The value of natural plant formations and associations as indices of biotic habitats lies not only in the fact that they represent an evaluation of the soil and atmospheric factors over a period of years but also that they may be used in predicting and interpreting. The writers (22) (27) and others (9) (16) have already pointed out such indices for particular cases.

A few general situations may be cited to illustrate further their use as a basis for prediction. When a correlation is once established between a particular plant association within a given area of its geographic range, the investigator has a guide, or working hypothesis, for further search of the phenomenon thruout the entire range of that association and for its presence in or absence from other associations. The phenomenon in question may be the behavior or distribution of certain plants or of certain animals. For purposes of research it may be of little consequence whether the correlation holds thruout the entire range of the association, provided the hypothesis serves as a guide to further research. Students of particular species of animals wishing to secure an abundance of material have saved much time and labor by collecting in those plant associations in which experience has shown that the species accumulates most abundantly.

Certain farmers of Madison County, Ohio, for example, have used natural plant associations for predicting the relative value of farms. They have advised the buying of Bur Oak and Post Oak lands rather than Beech lands. The Bur and Post Oaks have had very little effect on these soils, since they have but recently migrated into many of the areas where they are now growing. Their value lies in their being an index of the fact that the particular areas in which they are growing, in contrast to areas occupied by beech forests, were formerly occupied for perhaps thousands of years by slough and prairie vegetation, a condition that favors the accumulation of more organic matter in the soils than accumulates under a forest cover.

The use of natural plant associations as a basis of interpretation is limited (1) by the information available as to the factors controlling the distribution of the association, and (2) by the knowledge as to whether the factors that control the phenomenon under consideration are the same factors that control the plant association with which it has been found to correlate. Even if the phenomenon is controlled by some of the minor or indirect factors of the habitat, its correlation with the association may be of value in limiting the number of factors needing special investigation.

To discuss the information now available concerning the factors controlling the distribution of plant associations would require a rather large treatise. This information may be found among the accumulated data (1) on the relation of the physiology of plants to environmental factors, and (2) on the relation of environmental factors to plant behavior and distribution. The combined information from these two sources is now often sufficient to allow rather definite conclusions as to the factors controlling the distribution and succession of many plant associations.

Mention will be made here of those factors only that appear most important in interpreting the correlations that exist between the natural vegetation and certain activities of the corn borer.

Since the distribution of natural vegetation is controlled by the combined effects of several environmental factors, the importance of any single factor becomes evident only when it becomes dominant over limited areas. The two most promising attempts to combine the effects of several physico-chemical environmental factors in the form of indices that may be used in explaining the distribution of vegetation types are undoubtedly the Rainfall-Evaporation Ratio proposed by Transeau, and the recent genetic concept of Soil Types proposed by the Russian pedologists and just now coming into use in this country.

For a number of years attempts were made to interpret the distribution of natural vegetation on the basis of one or two independent environmental factors. For instance, before the vegetational history of the region and the relation of plant physiology to the numerous factors of the environment were as clearly appreciated as now, the geology, fineness of soil, deficiency of rainfall, humidity, temperature, and high winds were singly proposed to account for the treelessness of the American prairies.

The first successful attempt to account for the treelessness of the prairies by a summation of several environmental factors is represented in the rainfall-evaporation ratio map by Transeau (28). This moisture ratio includes the combined effects of rainfall, humidity, wind velocity, and temperature in so far as it applies to the moisture relations of a region and of the plants of that region. The correlation existing between the distribution of the prairie and certain rainfall-evaporation ratios is far superior to that of any single environmental factor. Similarly the rainfall-evaporation ratio is lower in regions occupied by Oak-Hickory than in regions occupied by Beech-Maple.

Still more recently Livingston and Shreve (14) in a comprehensive survey of the vegetation of the United States and of the environmental factors controlling it used both singly and in various combinations, came to the following conclusion:

> The importance of the moisture ratio in controlling the leading vegetation was shown by Transeau for eastern United States, and our investigation has served to confirm his deductions, as well as to extend their application to the entire country. The comparisons we have made between the vegetational areas and the various other climatic conditions have served to emphasize the importance of the moisture ratio, even more than was done by Transeau, since no other single datum has been found in our work to approach it as an expression of the controlling conditions for forest, grassland, and desert.

The new concept of soil type emphasizes the water and oxygen relations of the soil during the process of soil development. These two factors are undoubtedly the most important soil factors in the successional series of plant associations that are initiated in poorly drained habitats. The soil type is said to represent the combined effects of the geological history of the soil, the climate under which it developed, and the vegetation which grew upon it. The various soil types of any given climatic region are supposed to represent a sequence of phases in development toward the mature type for that particular climate. This recent genetic concept of the soil type parallels the genetic concept of the plant ecologist for the development of the vegetation of a given climatic region. Consequently for discoveries in either field there will undoubtedly be found applications and correlations in the other.

The rainfall-evaporation ratio and the soil type thus constitute two important physico-chemical indices of the environment that may be used in interpreting the behavior of plant associations. Within a certain domain one or the other may become the controlling factor and may thus be considered the index to biotic habitats within such a domain.

Furthermore, while an investigation of soil types and of vegetation types will be mutually helpful, it is possible also that one may have certain advantages where the other has limitations. For instance soil types as now classified are more numerous than the recognized plant associations. The Beech-Maple association, for instance, will be the dominant vegetation on a number of different soil types. The swamp formation within certain climatic plant formations and on numerous soil types is a general index to the habitats in which the corn borer has been most destructive in both this country and Europe. In this particular instance the nomenclature of the plant ecologist has the advantage of ease of generalization, and the natural index is readily recognized in rapid regional surveys. Since both moisture and the relative rate of development of the corn plant are factors favorable to the accumulation of the corn borer, future investigations may require an index to those areas within the swamp formation which are the most favorable of all to the corn borer. For this index perhaps the soil type will be superior to the natural vegetation, or fertility in a broad physico-chemical sense, or, as already pointed out, perhaps the growth of corn itself within certain areas of the swamp formation will be the best index available.

THE SWAMP FORMATION

A reconnaissance survey in Ohio, New York, Michigan, and Ontario during the summer of 1926 showed that the most serious borer infestation was in those areas formerly occupied by bogs, swamps, and swamp forests. It seemed desirable, therefore, that all areas in which this type of vegetation prevailed should be definitely located on a map for convenience in the study of methods of corn borer control. Furthermore, types of swamp formation are known to differ in origin and vegetational history. Some of the differences in vegetational history are reflected in the soil, such as the kind and amount of organic matter that has accumulated. Undoubtedly some of these differences will also be reflected in the behavior of the corn borer. Further ecological study of the swamp succession therefore seems desirable.

It is a curious fact that ecologists have practically ignored the swamp forest associations in published accounts of vegetation. Numerous papers describing the initial associations and successions in swamps up to the invasion by the swamp forest are available. In the majority of these papers but a few sentences at most are accorded the swamp forest. It is impossible therefore to secure from literature either a satisfactory compilation of the important variants among swamp forest associations or of the ecological significance of these variants.

The vegetational history of the swamp formation in the prairie areas of Ohio is very similar to that of the prairie areas of Illinois described by Sampson (21). The vegetational history of the bog areas of the State, many of which became occupied by swamp forest in recent times, has been described by Transeau (29) and by Dachnowski (8). For the various associations of marsh vegetation that have preceded the swamp forests of Ohio the papers by Jennings (12) and by Schaffner, Jennings, and Tyler (23) perhaps describe the more usual successions.

During the present survey, particularly during the more detailed survey by Sampson and Robert Gordon in 1927 (Fig. 20) it became evident that the various origins and phases of the swamp forest shôuld receive more attention. These differences are of interest to bontanists and foresters, and there are also indications that some of them may be correlated with differences in the behavior of the corn borer.

The physiographic sites in which the swamp forest of northern Ohio has developed are old lake beds, floodplains, and pre-erosion post-glacial flats.

The vegetational history that preceded the swamp forest in each of these habitats may be summarized as follows:

In lakes: aquatic vegetation followed (1) by associations of marsh or of prairie slough of varying duration in time, (2) by Willow-Poplar associations of low sand bars and beaches as they emerged, and (3) by the vegetation of bogs.

On floodplains: (1) stream margin and Willow-Poplar associations, and (2) the vegetation of stream margin bogs.

On pre-erosion post-glacial flats: perhaps wet tundra followed by spruce, balsam, birch, and hemlock.

Secondary associations of swamp forest species have followed the clearing of wet Beech-Maple forests, and of bog shrubs and conifer forests on relict bogs.

From the foregoing summary it is evident that the "swamp forest" is not a uniform vegetation type in all particulars.

The usual statement in the literature is that with increased drainage the Willow-Poplar association is succeeded by the Elm-Ash-Maple Swamp forest, which in turn is succeeded by Beech-Maple or other characteristic forest of the uplands. While this statement expresses a general truth, in detailed studies of the swamp forest in northern Ohio, it becomes necessary to recognize at least three different successive phases of the Elm-Ash-Maple Swamp forest. For convenience of discussion these phases may be designated as follows:

(1) The Elm-Black Ash-Soft Maple (either red or silver or both) association with such secondary species as pin and swamp white oaks, sycamore, sour gum, and yellow birch.

(2) The Bur Oak-Hickory Transition which is characterized by the addition of white ash, big shellbark hickory *(C. laciniosa)*, and Bur Oak as important secondary species in slightly better drained habitats.

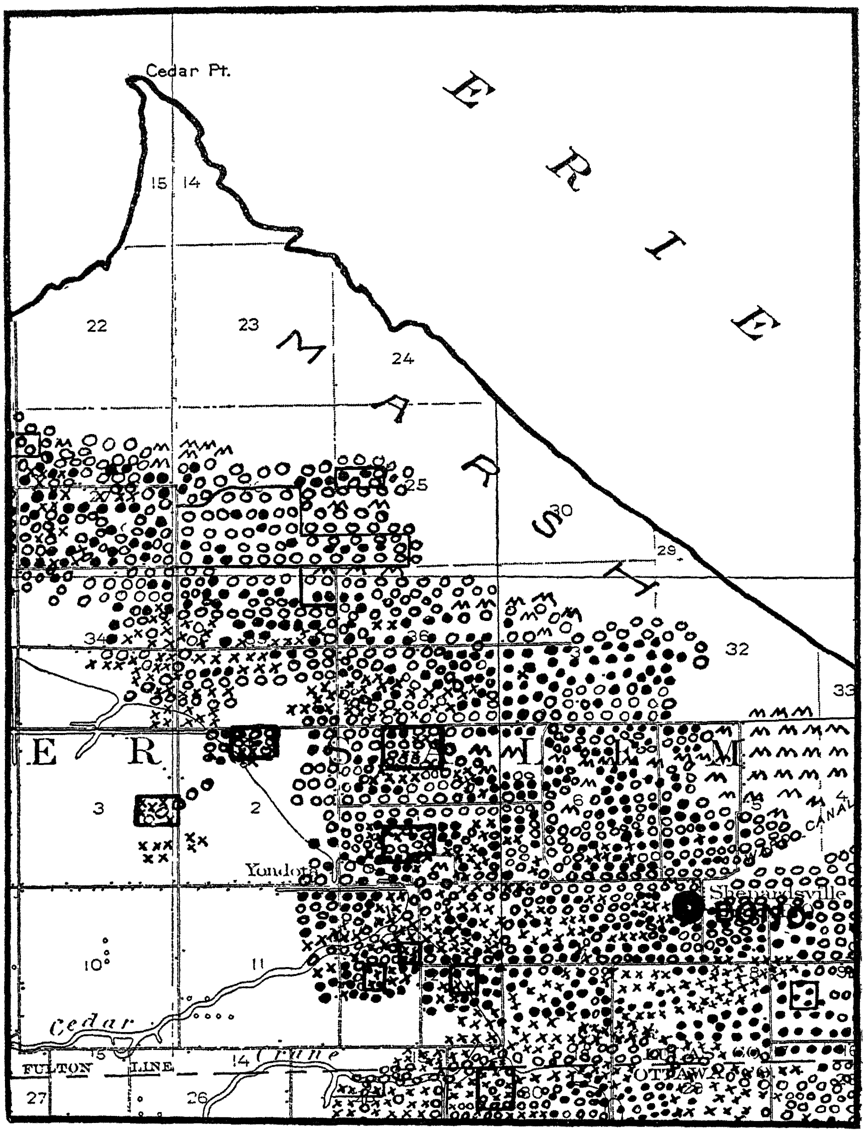

Fig. 20.—Map of reconstructed forest in the Bono area. H. C. Sampson

M=Muck, formerly marsh.
O=The Elm-Ash-Soft Maple swamp forest.
0=The Red Oak-Linden transition phase of the swamp forest on the better drained swamp areas.
X=Beech-Maple.

The locations of the "key" forests used as local bases for reconstructing the forests that formerly grew on present cleared lands are shown in rectangularly outlined areas.

(3) The Red Oak-Linden Transition, which is characterized by the addition of several other species to the association on still better drained areas, yet too wet for Beech-Maple. Some of the more common species added are red elm, linden, cherry, shagbark hickory; red and yellow oaks, bitternut hickory, and finally tulip, black and white walnuts, and magnolia just previous to the invasion by beech.

The farmers of the region claim that this last forest is an index to the best agricultural lands on the old lake bed.

Certain variants are evident, such as the relative infrequency of oak, shellbark hickory, and silver maple in northeastern Ohio, and a relative increase there of cherry, and sour gum, and the presence of yellow birch and occasionally hemlock. Tulip and walnut appear relatively more abundant when the soil is sandy. On heavy light colored clays swamp oaks and hickories are relatively more abundant. Perhaps there were originally primary forests of swamp oaks and hickories in certain regions now characterized by relict vegetation of prairie sloughs, but data at present are not conclusive.

Clearing of the swamp forest results in several different secondary forests. For instance, three different secondary forests of the swamp oak-hickory type are easily recognized as related to the three phases of the swamp forest listed above: (1) in the wetter areas pin oak, swamp and white oak, with no hickories; (2) in slightly better drained areas, bur oak and big shellbark hickory added to these oaks; and (3) in still better drained areas, red and yellow oaks, shagbark and butternut hickories are added.

The presence of white oak in secondary forests indicates that any one of five different upland forests originally occupied the area.

In addition to the main sand belts of the three major post-glacial beaches in northern Ohio numerous low sandy ridges varying from a few inches to a few feet in height are scattered over the swamp lands of the old lake bed. Where abundant there may be a dozen of these low sandy ridges within the distance of a single mile. The elevation of many of these low ridges is just sufficient to allow drainage favorable to Beech-Maple or Oak-Hickory. Other areas are similarly characterized by numerous low ridges of loam soils. In such areas the swamp forest prevails. The islands and narrow belts of mesophytic forests are permitted only by a slightly increased surface drainage locally. Perhaps such slight local differences in habitat will have little or no effect upon the accumulation of the European corn borer, except as they are reflected in the relative growth of corn from season to season.

Altho the vegetation survey of northern Ohio is still in progress, and not sufficiently complete for specific descriptions and maps of all areas, brief descriptions of the vegetation of certain lake counties are appended as sources of reference.

Lucas County.—The prevailing virgin forest for most of Lucas County east of the Maumee River is the swamp forest, interspersed with numerous small areas of Beech-Maple on low ridges, often of an elevation that insures scarcely more local drainage than is required by Beech-Maple. A detailed vegetation map of a portion of two townships (Fig. 20) shows the distribution of forests over much of the region known as the "Black Swamp" of northwestern Ohio. A large portion of about 6,000 acres of marsh bordering the lake in Jerusalem Township is now included in the "Diked Lands" and is under cultivation.

West of the Maumee River, beach and sand deposits are abundant on the old lake bed. The upland forests for this portion of Lucas County are the White Oak-Black Oak and the dry Oak-Hickory types. Beech-Maple is encountered again as the prevailing upland forest only in the extreme western part of the county. Swamp forests are local, frequently only in depressions between the sand dunes. Certain local areas of Washington and Adams Townships are swamp forest habitats, but they are partially obliterated by the presence of numerous oak-covered sand dunes and ridges.

Ottawa County.—The vegetation of much of Ottawa County is similar to that of eastern Lucas County, differing only in the relative percentage of Beech-Maple and swamp forest. That is, locally areas are either prevailing swamp forest interspersed with low ridges occupied by Beech-Maple, or prevailingly Beech-Maple with local areas of swamp forest. Most of the country surveyed is prevailingly swamp forest with varying percentages of Beech-Maple. Theodore Gumb of Oak Harbor, who has known this region for many years, says that Beech-Maple did not occupy half the area of Clay Township, still somewhat less of Benton and still less of Carrol Township.

The vegetation of the eastern part of the county, including mainly the peninsula between Sandusky Bay and the Lake, varied considerably, due in part to the outcropping of limestone. Red cedars are reported to have been abundant on Catawba Island and the upland forest of the peninsula was either Oak-Hickory or the mixed forest characteristic of limestone outcrops. Mr. Gumb reports that Bay Township was called the prairie township, and Andropogon prairie was more abundant than marshes, and that islands of pin oak and hickory occurred on the prairie. He is uncertain whether the Swamp Oak-Hickory forests of this region were virgin or secondary, but says they occurred on the toughest soils of the region. A report by H. H. Hardesty in the illustrated Historical Atlas, 1874, says, "That part of the country from the mouth of the Portage River, six miles west and five miles east, extending from the lake shore on the north to Mud Creek and Sandusky Bay on the south, containing about 30,000 acres, may properly be denominated prairie, interspersed, however, with small groves of timber." This "prairie" undoubtedly included marsh, Spartina sloughs, and Andropogon prairie. The variations in the composition of swamp forests in this area and similar areas in Erie County and perhaps also in parts of Wood County and eastern Sandusky County are yet to be determined. Perhaps swamp oaks and hickories were relatively more abundant, or even the dominant trees, in the swamp forests of these areas. This idea is suggested both by the prominence of swamp oaks and hickories in the secondary forest of these areas and by the prominence of Oak-Hickory shown on Sear's map of the virgin forests of Ohio on parts of these areas not sufficiently drained for a forest of the dry White Oak-Black Oak-Hickory type. Attention is called to this particular variant of the swamp forest because it seems probable that the maximum accumulation of the corn borer will not occur in this particular type of swamp habitat.

Erie County.—The prevailing virgin forest in the eastern part of Erie County, including Florence and Vermilion Townships and most of Berlin Township, was Beech-Maple and Oak-Hickory. The swamp formation in these townships does not cover extensive areas.

The upland forests in the western and central part of the county, at least as far east as the Huron River (Margaretta, Groton, Portland, Perkins, Oxford, Huron, and Milan Townships), are of the dry Oak-Hickory and Oak-Chestnut-Hickory types. Lists of trees given by early writers mention neither tulip nor beech for this part of the county. Moseley reports beech as rare along Pipe Creek southeast of Sandusky, and as infrequent along the Huron River in Milan. The amount of swamp forest in this part of the county is not definitely known, but the data in hand indicate that it was not extensive. The level tract of land including most of Oxford Township and portions of Groton, Margaretta, Huron, and Milan Townships was designated by the early writers as marsh and as prairie. Since this area has not yet been surveyed, and since neither of these terms was used by the early writers in a strict ecological sense, the relative amount of prairie and marsh on these townships is still to be determined.

Lorain County.—The prevailing virgin forest was Beech-Maple, interspersed with numerous local areas of swamp forest. The areas of highest percentage of swamp forest mapped to date are in Sheffield, Avon, and Ridgeville Townships, and on areas extending southwest of Elyria for a few miles. Much of the Beech-Maple forest is of the type that is succeeded by species of swamp forest on cleared lands.

Lake and Ashtabula Counties.—The prevailing virgin forest in Lake and Ashtabula Counties south of the old beach lines was Beech-Maple with small local areas of swamp forest. Beech-Maple was also the prevailing forest on a large portion of the old lake bed north of the beach lines which, from Cleveland eastward across the State, are but a few miles from the present lake shore. Areas of a high percentage of swamp forest are local, being most common just north of the old beaches, and are less frequent in Ashtabula than in Lake County. Mentor Township in Lake County, has a high percentage of swamp forest just north of North Ridge, especially in the western part of the township.

The vegetation on the old beaches differs markedly in passing eastward across the State. In Fulton, Lucas, and Wood Counties White Oak-Black Oak with some hickory is the characteristic forest of beach and sand deposits. In eastern Sandusky County, Beech and Tulip are locally abundant on sand deposits, while in Erie County, Oak-Chestnut and Oak-Hickory occupy the sand and gravel deposits. From Berlin Township, Erie County eastward, Oak-Chestnut and Oak-Chestnut-Tulip are only on the dryest sand deposits, Beech-Maple becoming the prevailing forest on the old beach lines. In Ashtabula County, Beech-Maple-Hemlock occurred locally.

2. SOIL FERTILITY AND SOIL TYPES AS INDICES TO BIOTIC HABITATS

G. W. CONREY

It has already been shown that the vigor and rate of growth of corn are influenced tremendously by soil fertility. Differences in borer population should be expected, therefore, to be reflected by the degree of soil fertility. The variations in soil fertility are indicated here not because they are new to science but because their specific consideration facilitates the interpretation of corn borer behavior. In the sections that follow an attempt will be made to demonstrate that the degree of borer population is modified by the rate of growth and stage of development of the corn plant.

That soils vary greatly in their natural fertility or productiveness is generally recognized. These differences in natural productivity can be correlated more or less certainly with physical characteristics, which can be readily recognized by field examination.

Soils are produced by the action of soil-forming processes on material of different kinds. The soil material may have been accumulated or deposited by any one of several agencies. In the northern part of the United States a large portion of the soil material was deposited by glaciers. Wind-blown deposits, in the form of loess or of sand dunes, exist in parts of the same region. Streams have laid down alluvial deposits. Lacustrine deposits have accumulated in lakes. Elsewhere the soil material has been formed by the weathering of consolidated materials, such as solid rocks laid down in a former cycle of deposition.

The soil material, deposited by any agency, is acted upon by the soil-forming processes of disintegration and decomposition. These processes are largely determined by climatic conditions—climatic forces are the dominant soil-forming agencies.

Within any region, as a result of the action of the climatic forces, the soil material is gradually changed so that there is a gradation in soil characteristics from the surface downward. When these variations are pronounced the soil is said to be mature. Most of the soils on the gently-rolling, well-drained uplands in the glacial region are of this character. Where there is little variation in characteristics from the surface downward the soil may be called a young soil, as is the case in the river flood plains.

Altho time is an important factor in the development of soils, the conditions of drainage may modify greatly the action of the climatic agencies. Most of our very poorly drained soils are young soils in that they show little development of natural horizons.

The vegetative cover of the land has also been an important factor in soil development. Thus soils high in organic matter, and hence dark in color to considerable depth, have been formed under a grass vegetation. Where the land has supported a timber growth, the dark colored organic layer is very shallow. Changing conditions of climate or of topography and drainage may result in gradation phases.

Thus it may be seen that soils have been developed by the action of climatic agencies on the various soil materials. The effect of the climatic agencies has been modified by the conditions of topography and drainage under which the soil has existed, resulting in a marked diversity of soil conditions.

In general the dark colored soils are considered the best corn soils, altho artificial drainage may be necessary for successful crop production. The naturally well drained light colored upland soils rank next. The poorly drained light colored soils are commonly not so good. Most alluvial soils are very fertile and are used extensively for corn.

Information concerning the soils of the area in Ohio infested by the European corn borer has been accumulating for a number of years (16). A reconnaissance, or general, soil survey of the whole State was completed in 1912 and since that date detailed soil surveys have been completed in twelve counties in northern Ohio and an equal number in other parts of the State. Whatever correlation is found between soil conditions and infestation by the European corn borer should be of interest in other states, for soil surveys are being made over the entire Corn Belt.

A brief statement is presented here of the soils in the region of maximum infestation in Ohio. Observations on the correlation of soil conditions with corn borer infestation will follow in the next section.

IMPORTANT SOILS IN THE AREA OF MAXIMUM INFESTATION

Two physiographic provinces are included in the region of maximum infestation in northern Ohio: the glacial lake plains and the glacial till plains. The first infestation by the corn borer in Ohio was observed in the glacial lake plains near Lake Erie, and at the present time the area of highest infestation is still confined within 10 miles of the Lake.

A further major soil boundary is that separating the region with limestone bedrock of western Ohio from that with sandstone and shale of eastern Ohio. This boundary line touches Lake Erie near Sandusky and extends approximately south across the State.

These variations give four major soil areas:

1. Glacial Lake Region in the limestone area.
2. Glacial limestone area not in the Lake Region.
3. Glacial Lake Region in the sandstone and shale area.
4. Glacial sandstone and shale area not in the Lake Region.

Within each of these areas various soils have been developed as a result of difference in topography, natural drainage, character of parent material, and climatic conditions.

GLACIAL LAKE REGION OF NORTHWESTERN OHIO

BEACH RIDGES

The best drained soils of the region are confined to narrow beach ridges, and other elevated areas, usually of a sandy nature. These soils have developed under conditions of good drainage and are naturally well aerated. On the gravelly beaches reddish-brown soils have been formed (Fox gravelly loam, beach ridge phase) which are well supplied with lime and are naturally fertile. They are excellent small grain and alfalfa soils and very good for corn. On the beach with deep sands the soils are yellowish brown (Plainfield fine sand, Berrien fine sand) of rather low natural fertility and somewhat acid. Associated with these latter soils are dark colored sands (Newton fine sand).

LAKE FLATS

On the level areas within the lake beaches, the soils have developed under conditions of poor drainage and aeration. Previously much of the area existed as a swamp and required extensive ditching and tiling before it could be utilized for crop production. The dark colored soils of the lake flats are the most extensive soils of the region and the best corn soils. Altho these soils were developed under swamp conditions, the soil layer, which is high in organic matter, is shallow, 5 to 7 inches. The most important and extensive types are Brookston clay, derived from glacial drift, and Toledo silty clay, derived from lacustrine silts and clays. There are limited areas of very dark soils (Clyde clay and Maumee silty clay) in which the organic layer is not only darker but also thicker than in the Brookston or Toledo. These soils are also excellent for corn.

Thruout the lake flat, in association with the dark colored soils, are light colored soils, "the clay spots", which, altho slightly higher in elevation than the dark soils, are naturally poorly underdrained because of a tight impervious subsoil. These soils (Napanee clay loam and Fulton silty clay loam) are low in organic matter, usually somewhat acid, and commonly produce much poorer corn than the associated dark colored soils.

Between the extremes of sands and gravelly soils on one hand and clays on the other are gradational types somewhat limited in extent, including fine sandy loams, very fine sandy loams, loams, clay loams, etc., both light and dark in color. The dark, heavier textured soils would all be classed as good corn soil. The lighter textured soils are especially desirable for early sweet corn.

GLACIAL LIMESTONE SOILS EXCLUSIVE OF THE LAKE PLAIN

Outside the borders of the lake plain are characteristic glacial soils derived from calcareous till. Under various conditions of drainage and aeration, soils differing in color have been produced. On the more rolling areas the soils are well drained and brown in color (Bellefontaine silt loam); in the depressions and level areas the soils are naturally poorly drained and are dark in color, due to a high content of organic matter (Brookston silty clay loam and Clyde silty clay loam). In intermediate positions the soils are grayish-brown in color and on the more level areas may show imperfect underdrainage, as indicated by mottled subsoil colors (Miami silt loam and silty clay loam, Crosby silt loam and silty clay loam). The dark soils are naturally the best corn soils; the better drained soils rank next; the light colored poorly drained soils are only fair.

GLACIAL LAKE REGION IN THE SANDSTONE AND SHALE AREA

This area in northeastern Ohio is confined to a narrow belt bordering Lake Erie. Here within a few miles are various beach ridges and other lacustrine deposits. East of Sandusky the bedrock is largely noncalcareous sandstone and shale. This difference in source of material is reflected in an acid reaction of the soils.

The beach soils are derived largely from sandstone and shale gravel (Chenango gravelly fine sandy loam, beach ridge phase), tho in places the ridges are quite sandy (Berrien fine sand). Dark colored soils (Lorain silty clay loam and silty clay) are not so extensive as are the dark soils in the western part of the State, light colored soils (Caneadea silty clay loam, etc.) occupying a much larger proportion of the lake flat. Gradational soils, such as fine sandy loam, etc., are also fairly extensive.

In this narrow belt, the sandy soils are used extensively for truck crops; considerable sweet corn is grown. The dark heavy textured soils are used quite extensively for field corn, but do not rank with the heavy calcareous dark soils of western Ohio.

GLACIAL SANDSTONE AND SHALE SOILS EXCLUSIVE OF LAKE REGION

South of the lake plain is the glacial upland. In the counties near Lake Erie, shale is the predominating bedrock; further south, as in central and southern Wayne County, sandstone predominates. The result of this distribution of bedrock is a belt of heavy soils near Lake Erie. This shale and sandstone drift has weathered under various conditions of topography and drainage to give the soils of the region.

The soils derived from the heavy drift commonly are not well aerated and oxidized even on a moderately rolling surface. The Ellsworth silty clay loam is somewhat mottled in the lower subsoil, whereas the Mahoning silty clay loam is mottled from the surface down. In the low lying depressions, gray soils (Trumbull silty clay loam) have developed in topographic situations similar to those of the dark colored soils of western Ohio, but these are in limited areas in the northeastern counties. All of these heavy soils are rather late and cold, warming up slowly in the spring. The short growing season in the northeastern Ohio counties with the possibility of early frost, together with the fact that these soils are not especially well adapted to corn, have served to limit much of the corn production of these counties to ensilage corn.

South of this belt is an area of soils with rather open, porous subsoil. On the more rolling tracts these soils are naturally well drained (Wooster silt loam); on the smoother areas under drainage may be fair (Canfield silt loam) to poor (Volusia silt loam); in the depressions, the soils are commonly gray in color and very poorly drained (Trumbull silt loam). Because of the porous subsoils, these soils can be easily drained by tiling. In these areas both the climatic and soil conditions are somewhat more favorable for corn than in the counties in the extreme northeastern corner of the State. Altho these soils are naturally acid in reaction and of moderate fertility, they respond quickly to treatment, and hence with good soil management will produce fair crops.

Of minor extent, but of considerable importance locally, are the alluvial soils of this region. The stream flood-plain soils (Chagrin silt loam and Holly silt loam), which are naturally more fertile than surrounding upland soils, are used extensively for corn, producing good crops.

The terrace, or second bottom soils, with gravelly subsoils, derived from sandstone and shale gravel (Chenango loam and silt loam), are usually fairly fertile and produce good crops. These soils are generally much earlier than those on the surrounding upland, hence corn can be depended on to ripen in most years.

Within this region a wide range of soil conditions exists, ranging from excellent to poor corn soils. Since corn development is different on various soil types and since borer population is influenced by condition of corn growth, then there should be a correlation here between soils and borer population.

3. CORRELATION OF BORER POPULATION WITH VEGETATION TYPES

C. R. NEISWANDER, H. C. SAMPSON, AND E. G. KELSHEIMER

In section 1, page 152, it was shown that plant formations and plant associations constitute indices to biotic habitats. This section will show that the behavior of the corn borer has varied in the several biotic habitats of which vegetation types are indices.

During the course of these studies several regions have been under observation (9). The entire northern part of Ohio has received close attention, while certain areas in Pennsylvania, New York, Indiana, Michigan, and Ontario have been visited periodically. The only important center of infestation not visited by all of the Ohio investigators is that of Massachusetts. The senior authors, however, have seen a part of this region. At the end of the season's work in 1926 the correlation between vegetation types and intensity of borer population seemed so clear that, at the suggestion of the entomologists, Dr. E. N. Transeau was sent to Europe by the U. S. Dept. of Agriculture to give such aid as possible to investigators working in Europe.

EUROPE

During the summer of 1927, Dr. Transeau, with the aid of Federal entomologists working in Europe, made a similar reconnaissance survey in the regions where the borer has been known for many years. The most serious infestations that have occurred in Europe, like those in America, have been in areas formerly occupied by the swamp formation. In the drier, better-drained areas, and in the open grasslands of Roumania and southern Russia, which are similar ecologically to the American Great Plains grasslands, the borer has not been a constant and serious pest to corn.

NEW YORK

The infestation at Schenectady, New York, was discovered in 1919. The only area where the accumulation has been notable is along the Mohawk River Valley, the region of the best corn land of the territory. The borer population per 100 stalks for 1922, 1924, and 1926, according to the Bureau of Entomology, averaged 49.6. A relatively low figure.

The Silver Creek, New York, region also is known to have been infested since 1919. There has been considerable time, therefore, for the insect to have attained a high level of population, or perhaps even its equilibrium. This area is typically swamp forest. In scope it is much larger than the Schenectady area and is better adapted to corn growing. According to Caffrey, the average borer population for three years, 1922, 1924, and 1926, was 115.8 per 100 stalks. The ratio of population between Silver Creek and Schenectady, therefore, is about 100 to 43. The ratio of population per 100 stalks for the lake plain and the upland areas of the Silver Creek region is more significant than the ratio between Silver Creek and Schenectady. Data on infestation for 1927, as furnished by the Bureau of Entomology, show that the ratio for the first and second tier of townships, that is, the lake plain or lowland townships, and the upland townships, was 100 to 24. The lowland is swamp forest and the upland is Beech-Maple and Beech-Maple-Hemlock. Records for previous years in this region indicate a similar ratio.

In Pennsylvania the ratio of borer population for the lake plain townships and the second tier of townships adjacent on the south was about 100 to 13 for 1927. Federal data for other years also indicate similar ratios. The lake plain is typically swamp forest and the adjacent townships are Beech-Maple-Hemlock vegetation type.

A study of these data suggests that the effect of the Silver Creek environment is considerably different from that at Schenectady. Moreover the Silver Creek region itself consists of two rather well defined habitat areas. These data are still more significant when it is considered that the field records from which the ratios were calculated were not secured in a strictly ecological manner, hence the ratios are probably more divergent than actually indicated.

OHIO

Population studies conducted by the writers, for the most part, have been made intensively in restricted habitats rather than extensively over large areas. Table 82 shows the average population for six habitats for the years 1925, 1926, and 1927. These habitats, so far as known, were all originally infested at the same time, hence the insect has had the same period in which to increase in numbers.

TABLE 82.—The Corn Borer in Six Habitats in Ohio, Average Population for 1925 to 1927, inclusive

Habitat	Actual population per 100 infested stalks	Relative population	Vegetation type
	No.	*Pct.*	
Jerusalem	114	100	Marsh
Oregon	78.1	68.5	Swamp forest
Lake	46.1	40.4	Swamp forest
Ashtabula	37.9	33.2	Swamp forest
Erie	9.1	8.0	Beech–Maple–Oak–Chestnut–Hickory
West Lucas	1.4	1.2	Oak–Hickory

The differences in population in the Ohio areas as well as in the neighboring states are significant. It would appear that the factors which determine vegetation types likewise affect borer abundance.

The difference in the population of the Jerusalem and West Lucas habitats, which are not more than 30 miles apart, is so great that it can not be explained except by environmental variations. The same is true for the Jerusalem and Oregon habitats, which are adjacent. These are cited as examples. Section 1, page 152, clearly indicates the differences in vegetation types in the various regions.

Unfortunately no population records were secured for the Lorain habitat in 1926, hence three-year averages cannot be given. Such data as are available, however, show that the Lorain habitat had a relatively low population, exactly as would be expected when the vegetation type is considered. Ottawa and Wood habitats are not included in the table because they were not first infested at the same time as the other habitats, hence are not comparable. The average relative population for 1925-1927, inclusive, was Ottawa 32.3 and Wood 2.1.

In the light of present knowledge it is not only clear that population varies in the different habitats now infested, but that the variation correlates without exception with vegetation type, which is the resultant of many environmental factors. It follows, therefore, that an evaluation of all these environmental factors should make it possible to predict where the borer is likely to accumulate most rapidly in the future. The least that can be said is that we now know that whatever control measures we may ultimately adopt, it is not probable that they will be of a uniform nature.

4. CORRELATION OF BORER POPULATION WITH SOIL FERTILITY AND SOIL TYPES

G. W. CONREY, J. B. POLIVKA, AND L. L. HUBER

There is little to be said at this time relative to the soils of the Corn Belt. Because it is maintained that good soil produces good corn and good corn is favorable to borer abundance, it does not follow that the good soils of the prairie sections will indirectly be responsible for a high borer population. For, altho the soil of the Corn Belt is a good corn soil, yet it is different from that in the now infested area. Furthermore, the direct influence of a different climate may more than counterbalance other factors.

It will be shown in this section that the variation in soil types can be correlated with borer population. Investigations conducted in northwestern Ohio in 1923 (11) indicated that the corn borer was most numerous in the best fields of corn. It was likewise plain that the best fields of corn were those that had been planted earliest and on the best soil. Since 1924, therefore, the population studies made each fall have taken into consideration the general soil fertility of the region studies. During 1927 the scope of this work was enlarged to include a study not only of soil fertility in its widest sense, but also of specific soil types (16).

In Sections 1 and 2, pages 108 and 163 respectively, it was shown that soil greatly influences corn development. An attempt will now be made to show that corn development influences moth behavior and larval establishment and that soil conditions, therefore, indirectly influence borer accumulation.

In Sections 2 and 4, pages 15 and 38 it was shown that height of corn at moth flight is an index of attractiveness of the corn to the adults. The most rapidly developing corn is most attractive and, therefore, is the recipient of the greatest number of eggs. Since larval establishment is greatest on early developing corn, soil conditions in so far as they influence the vigorous growth and physiological development of corn also influence infestation.

It has been shown that there are two major soil regions in Ohio (Section 2, page 163). Corn development is slower in the sandstone-shale region of eastern Ohio than in the limestone region of western Ohio. There are, however, local areas of high soil fertility within the eastern region and local areas of low productivity within the western region. If borer population is influenced by corn development, then the population of the two regions and of the local areas within these regions should vary.

As further proof of the indirect influence of soil condition on infestation, the specific soil types in a field may be cited. In such instances weather variations in the same year cannot possibly be of much importance, hence they may be ignored.

COMPARISON OF BORER POPULATION IN WESTERN AND EASTERN OHIO

In 1923, two years after the infestation in Ohio was first discovered, the infestation in the lowlands of Lake and Ashtabula Counties had reached a maximum of about 10 percent, but the infestation of the upland region had not reached 1 percent. Data collected cooperatively with the Federal Bureau of Entomology in 1925 showed a decided tendency for more rapid accumulation in western than in eastern Ohio. Three tiers of townships in northern Ohio were selected for study—16 townships directly adjacent to the Lake and within the Lake plain; 17 in the third tier; and 17 in the fifth tier of townships back from the Lake. The townships in these three tiers were then divided according to whether they are in the limestone or sandstone region. Table 84 shows the actual and the relative borer population per 100 stalks in three tiers of townships in the limestone and in the sandstone regions in 1925.

TABLE 83.—Actual and Relative Population per 100 Stalks, 1925

Townships	Actual		Relative			
	West	East	West to East		West tiers	East tiers
Border	12.7	10.3	100	81	100	100
Second tier	.8	.4	100	50	6.3	3.8
Third tier	.3	.07	100	23	2.4	.6

Data collected by Worthley and Caffrey and published as mimeograph reports for the 1927 survey show similar results. It should be mentioned that the survey of 1927 covered a much wider area and the general level of infestation was higher than in 1925, hence the conclusions are more significant. It is not intended that the two years should be compared as to specific populations, for the townships included and the method of study pursued were not identical.

TABLE 84.—Showing Actual and Relative Population per 100 Stalks, 1927

Townships	Actual		Relative			
	West	East	West to East		West tiers	East tiers
Border	45.7	30.9	100	67	100	100
Second tier	17.4	2.0	100	11	38	6
Third tier	6.4	1.7	100	26	14	5
Fourth tier	4.2	1.3	100	31	9	4
Fifth tier	1.6	.3	100	19	3	.9
Sixth tier	.5	.07	100	14	1	.2

It is generally assumed that the lake townships were infested at the same time. If all environmental factors were equal, including quality and quantity of corn per unit area, soil types, and climate, it might be expected that the borer would accumulate with equal rapidity in both regions of the State. Borer population data, however, for 1925 and 1927 show that the borer has increased at a more rapid rate in the western than in the eastern region.

The rate of increase in the townships south of the originally infested border townships shows this tendency very clearly. Whereas the ratio of population in the border townships to second tier townships in western Ohio was 100 to 6.3 in 1925; it was 100 to 38 in 1927. At the same time similar areas in eastern Ohio had a relative ratio of 100 to 3.8 in 1925 and 100 to 6 in 1927. This evidence indicates a possibility that the insect has reached the saturation point in parts of eastern Ohio, or at least will attain it sooner there than in the western part of the State.

These tables also show that in eastern Ohio the insect has increased more rapidly within the Lake plain. This was to be expected, if accumulation is indirectly influenced by soil types and soil fertility.

NEW YORK

The correlation between corn borer accumulation and soil fertility is true not only in Ohio but in neighboring states as well. During the course of investigations in Ohio frequent visits were made to some of the heavily infested districts of New York. The most heavily infested section in New York, as reported by the Federal Bureau of Entomology, is at Silver Creek, not far from Buffalo. Soil conditions are similar to those in parts of Ohio.

The area near Schenectady, New York, has a similar history. The only commercial damage in the eight or nine years that it has been infested, was in a few hundred acres located in the Mohawk River Valley where the soil is fertile and where the best corn of the region is grown.

CANADA

Canadian entomologists report the most severe damage in Kent and Essex Counties, Ontario, both of which correspond to the lake plain of Ohio and New York.

CULTURAL PRACTICES

Crop rotation and the time of plowing, may have considerable influence on infestation. During 1926 and 1927 it was observed that, other factors being equal, corn that followed a leguminous crop, such as alfalfa, always had a high infestation. This became so noticeable that it gave rise to the popular belief among farmers that the corn borer is propagated in alfalfa and sweet clover, hence corn following these crops would carry a heavy population. The most heavily infested field in Ohio in 1927 was an alfalfa sod in 1926. Highly productive soils, other factors being equal, promote rapid growth which in turn is favorable to corn borer accumulation.

In western Lucas County a small and rather unfertile sandy field was covered with a liberal supply of garbage hauled from Toledo. When this field was subsequently put to corn in 1927 it carried more than the average borer population indicating that the acceleration of corn development resulted in a greater population.

The time of plowing the land for corn influences subsequent infestation. Instances where a part of a field was plowed in the fall and a part in the spring have shown significant differences in infestation due, it is thought, to the greater amount of moisture in the fall-plowed land. The greater supply of moisture promoted a more vigorous and more rapid growth of corn, which in turn was more attractive to the corn borer moths and apparently more favorable to larval establishment.

SOIL TYPES

The foregoing instances have related to the infestation in general soil regions, such as limestone as compared with sandstone and shale, or lowlands as compared with uplands. It is of still greater interest to note the difference in infestation on specific soil types within a local area or general region. It has long been noted that the infestation in different fields in a local area, or in parts of the same field, may vary greatly.

As already mentioned, general observations of the relation of soil fertility to corn borer behavior indicated the need of more specific information. Thru the cooperation of soil survey officials of the United States Department of Agriculture an intensive study of the soils of the most heavily infested areas in Ohio was begun in 1927. It was possible in this survey for the soil investigators and entomologists to work together mapping the soils and at the same time recording the percentage of infestation and borer population of certain fields within each soil type. The following discussion of the influence of specific soil types on infestation is based on the results of the examination of 350 fields.

In eastern Lucas County, east of Toledo, the area of greatest infestation in Ohio at the present time, the soil is fairly uniform, consisting of a dark colored silty clay (Toledo silty clay) with scattered, more or less irregular light colored areas (Fulton silty clay loam). There is also a limited amount of Maumee silty clay, a gradation between Toledo silty clay and the muck lands. This combination is very limited in extent, most of it being in the vicinity of Bono, eastern Jerusalem Township.

It is interesting to note the borer population of the several areas covered by this survey. The Bono section is of particular interest since the highest infested fields in 1923, 1924, 1925, and 1926 were located in this area on a combination of muck, peat, and Maumee silty clay soils. The average population of 34 fields in Lucas County in 1926 was 190 borers per 100 stalks; the average of 12 of these fields that are located on Maumee silty clay or some gradation between it and muck or peat was 283 borers per 100 stalks—a ratio of the 12 fields to all 34 fields of about 100 to 67.

The significance of this is not fully understood, but it is probable that the difference in infestation was due in large part to soil condition and its indirect influence on egg deposition and larval establishment.

Outside this limited section, the highest infestation has been for the most part on areas of Toledo silty clay. Most of the corn fields of eastern Lucas County are of this type, but many include some of the light colored soil (Fulton silty clay loam) on which the corn invariably is poorer and the infestation less than on the dark soil. For example, one field showed 12 percent infestation on the light colored soil, 38 percent on the gradation soil, and 86 percent on the dark soil. The corn was poor, average, and good on the three sites.

Another example consisted of a 6-acre field in Lorain County that was planted to Longfellow flint corn on May 15. The soil on the west side of the field was Caneadea fine sandy loam, that of the middle and one corner was a gradation soil, and the remaining portion was Lorain clay loam, dark colored phase. The infestation on the Caneadea aws 39 percent; on the gradation, 54 percent; and on the Lorain clay loam, 87 percent. An equal area of the same field that was planted to a dent variety on the same dates showed an average infestation of 8 percent. The soil was a combination of Lorain clay loam, Caneadea loam, and fine sandy loam. The flint corn on the dark colored phase of Lorain clay loam was exceptionally good corn.

Nowhere in northwestern Ohio in areas of glacial limestone soils to the south of the lake plain has the infestation as yet reached such proportions as to provide an adequate opportunity for studying the soil relationships.

Lake County, east of Cleveland, is typical of northeastern Ohio. Here there is a narrow belt of lake plain soils, and also a considerable area of glacial sandstone and shale soils. In this county, sweet corn has shown high infestation. In 1927, 12 fields averaged 54 percent, with 3 above 80 percent. Practically all of this corn was grown on fine sandy loam soils within the lake plain, especially on the gravelly beach ridges.

The upland, or glacial sandstone and shale soils (Mahoning silty clay loam, Volusia silty clay loam, and others) in the southern part of Lake County have always shown a low infestation, the ratio of the two areas being about 100 to 6. A part of the explanation for this low infestation lies in the fact that these soils are not well adapted to corn and, therefore, the corn is usually very late. Moreover, climatic conditions a short distance back from the Lake are very unfavorable for this crop, altho it would seem that the difference in climate within the two or three miles south of the lowlands would not be as great as the variation in the soil. The environmental conditions characteristic of the region northeast of Cleveland and back from the Lake, result in late corn of only fair quality. Altho the corn borer has been in this region as long as in northwestern Ohio, the infestation has been very low on the heavy light colored soils that characterize the region south of the lake plain.

An exception to this was noted in the case of the gravelly terraces (Chenango loam and silt loam) and river flood plains (Chagrin silt loam) in New York areas. These soils are earlier, more fertile, and better drained than the average upland soil in northeastern Ohio and, therefore, grow fairly good corn, which in average years matures earlier than on the upland. In such sites the infestation has been higher than on the upland. Ordinarily the flood plain of Silver Creek has carried the heaviest infestation but in 1927 the corn on the gravelly terraces was more heavily infested due undoubtedly to earlier developing.

In the light of present knowledge it would appear that the state of fertility of the soil has considerable indirect influence on corn borer infestation. It must not be concluded, however, that all parts of western Ohio will have an equally serious corn borer problem or that all of eastern Ohio can ignore the corn borer. Since soil fertility plays such an important role in infestation it can be expected that some of the local fertile areas of eastern Ohio may have more than average infestation. Wayne County, for example, is one of the best corn counties in the eastern region and, barring possibly those lying in the lake plain, other factors being equal, ultimately should have the greatest borer population in eastern Ohio. On the other hand there are a few local areas in Paulding County, one of the best corn counties in Ohio, where the corn borer will likely be of little consequence.

Unless edaphic factors be given primary consideration, how can it be explained that in any one season there may be a variation in population in various parts of a single field, or in parts of a restricted habitat?

5. INFLUENCE OF CLIMATE ON CORN BORER ABUNDANCE

L. L. HUBER, C. R NEISWANDER, AND J. R. SAVAGE

Altho the variation in infestation in local areas in any particular year, as has been shown, was the indirect result of soil fertility, an attempt will now be made to show that the yearly variation in infestation in these same areas, aside from the natural increase expected in a new area of establishment, was largely the result of climatic or seasonal differences. While the effect of soil on infestation is indirect, that of weather or climate is not only indirect but also direct. It is indirect in that it influences corn development and hence borer population, and direct in that it influences degree of infestation regardless of the corn plant.

In a discussion of the influence of weather on corn borer abundance it is evident that the question of greatest moment to Ohio farmers is: To what extent does weather influence the annual fluctuation of abundance and what role will it play in determining the ultimate level of population? In the discussion of this question it should be remembered, of course, that the corn borer has been in Ohio only since 1921, to the best of our knowledge. Hence, it has not reached a normal status in the present infested area. According to the records, the insect has increased in abundance in Ohio each year since 1921, altho the rate of increase has varied considerably from year to year.

In the discussion which follows a distinction is made between climatic and weather conditions. For example, the extreme northeastern part of Ohio differs climatically from the remainder of the State. Perhaps other areas also may be said to have certain climatic differences, but for the most part such variations may be considered under weather. Climatically, Ohio differs widely from the prairie regions of the west. It differs still more sharply from the plains. Weather on the contrary is operative over smaller areas within these climatic regions and may vary tremendously from year to year. The sum total of the weather conditions operative over any region for a period of years constitutes the climate of the region.

EUROPE

In connection with the discussion of climatic factors in relation to the corn borer it is of importance to review the history of the European corn borer in Europe. Among the most authoritative statements relative to the effect of climate on the corn borer in Europe have been those made by Babcock (1). He has pointed out that there are certain areas in Europe, Hungary for example, where the corn borer has one generation per year; certain areas, as in the Po Valley in Italy, where it has two generations per year; and areas where there is a fluctuation between one and two generations, these areas being designated as transition zones between the strictly one and two generation habitats.

Babcock states that "in a comparison of the typical and stable two-generation area of the Po Valley in Italy with the one-generation area of Hungary, the outstanding difference is the fact that the former is generally warmer and wetter thruout the year. The greatest point of separation in temperature occurs during the latter part of the hibernation period, altho the period as a whole is warmer in the Po Valley. The temperatures during the spring, however, in each of these areas are not greatly different, those during May being identical, but the difference in precipitation is considerable, the Po Valley receiving nearly an inch and a half more rain than the plains of southern Hungary."

The transition zone climate includes "all trends of deviation from the stable one or two generation climate, and the seasonal cycle would tend to fluctuate annually or develop a comparatively stable rhythm for the majority of years, depending upon the approach of the normal climate to one or the other stable types." The zone of separation climatically between areas having different seasonal cycles is not definitely marked, but consists of the wide range of environmental types comprising a "borderland of separation", which does not produce a stable seasonal cycle.

NEW ENGLAND

This discussion may be further elucidated if preceded by a review of the findings of other investigators relative to conditions in other states. Practically all of the work of consequence bearing upon the question of weather has been conducted by the Federal Bureau of Entomology and by Canadian Entomologists. The data which will be referred to most often were collected particularly in Massachusetts and in New York, where with a few known exceptions the areas are fairly comparable.

In a discussion of the relative annual abundance of the corn borer in Massachusetts during the years from 1921 to 1924, inclusive, it has been of interest to review briefly the work of Babcock, Barber, Caffrey, and others. The fact that the analyses of these investigators were made independently and from the same data makes their conclusions and opinions of considerable interest.

TABLE 85.—European Corn Borer Abundance in the New England Area, 1921-1924, as Given by Babcock

Year	Borers per 100 stalks
1921	132.89
1922	466.29
1923	49.90
1924	40.00
1925	71.60
1926	29.60

It will be noted that in 1922 the number of larvae increased greatly over that in 1921, but that there was a great decrease the following years. Babcock states (1), in speaking of 1921 to 1924, inclusive, that "a certain percent of this increase must, of course, be attributed to the normal increase usual in a new area of establishment, but enough abnormality in abundance existed to show the effect of climate during this period." Without going into detail relative to the type of observations and investigations by which Babcock reached his conclusions, it may be said that, apparently, he believes that the fluctuations in abundance of the insect from year to year are, in the main, in response to variations in weather. He emphasizes the point that annual fluctuations in weather tend to be cumulative in their effects upon the borer, for according to his data the year 1921 was a "good" borer year, 1922 was a "bad" year, yet the great increase came in 1922.

Worthley and Caffrey (31) in discussing the same data appear to give considerably more weight to the possible influence of a thoro cleanup in 1923 than to weather factors, altho they point out that weather conditions and parasites undoubtedly exerted some influence.

Barber (2) in summarizing the same data is careful to point out that no one factor was responsible for the decrease in infestation in the Boston area in 1923. However, he emphasizes the direct influence of natural factors as compared with such factors as late planting and clean farming. In his analysis of the factors responsible for the 1923 decrease he states that the "midsummer flight of moths resulting from the first generation larvae of that year, consisted of a number somewhat in excess of the midsummer flight of moths in 1922. No reduction had as yet taken place. But, while the progeny of the midsummer flight of moths in 1922 were very numerous, the progeny of the corresponding flight of moths in 1923 were relatively much less abundant." In other words, despite the cleanup measures and other modifications of environment following the devastating infestation of 1922, there were more moths in flight in 1923 than the preceding year when the infestation was heavy. It would appear, therefore, that the factors responsible for the actual decrease made themselves manifest after the cleanup. Barber goes on to show that, whereas, the night temperatures of 1922 were favorable to oviposition, the temperatures of 1923 were unfavorable; that, due to dry weather, a larger percentage of the 1923 eggs failed to hatch; that "a parasite *(Trichogramma minutum* Riley) attacked the eggs, particularly the later deposited ones, in 1923 in considerable numbers and, since the number of eggs was already reduced, the controlling effect of this parasite was magnified beyond its usual importance." He also points out that certain plant successions removed certain weed areas and thus reduced the available food supply in 1923. It will be remembered too that the Boston area has a partial second generation. Barber cites this habit as a probable factor in its reduction in 1923. He states that "during the fall of 1922, 1923, and 1924 an important proportion of the larval population was found entering hibernation as small, weak individuals, that sometimes were only half the size of the normal larvae of the same instar. Whatever the cause of these weak individuals, they were poorly fitted to survive and produce abundant, vigorous progeny." In other words, the species tended to commit "suicide".

NEW YORK

Another area outside the Corn Belt which demands some consideration is the Silver Creek area in western New York. The soils of this area were discussed in previous sections. The greater part of the corn produced in the Silver Creek area is grown on the lake and river-flood plains. In some instances a great many acres of corn were on the terraces of rivers. In fact, some of the best as well as the most heavily infested corn in New York in 1927 was in these areas, and in large measure accounted for the increase over the region as a whole. Since the soil conditions in the area remained practically constant thruout the period of observation it would appear that weather must be held in large part responsible for the fluctuation in population. It can, of course, be argued successfully that modification of farm practices had something to do with the general level of population. A careful analysis, however, will hardly show that cleanup measures were controlling, altho it is probably true that they were contributing factors. For example, the part of this area cleaned up in 1921 had an increase of infestation in 1922 (31). There was a decrease reported in 1923 despite the fact that no intensive cleanup campaign was conducted in that spring. There was a marked increase in 1924 and scarcely any increase in 1925, altho cleanup operations were similar for both years. The cleanup of 1927 was exceptionally thoro, yet according to published data there was an increase for the area. It is a little difficult to explain why the increase in 1925 following a fair cleanup was less than in 1927 following an excellent cleanup if other physical factors are not given major consideration.

It is perhaps possible, of course, that the depleted number of moths in the Silver Creek area was augmented by a flight from Canada in 1927, hence accounting at least in part for this continued increase. This, however, is only a supposition which is further weakened by the fact that the 1927 cleanup in Canada was the best since the insect was introduced.

Relative to an evaluation of the factors responsible for the annual fluctuation in abundance of the borer in western New York, Chapman states in a recent article (5) "that in western New York environmental resistance had a value of 487.7 between 1921 and 1922, 311.1 between 1922 and 1923, and only 48 between 1923 and 1924. The change in environmental resistance in the critical period of 1926 to 1927 seems insignificant as compared to the changes which took place in other years in western New York. Consequently we find that we are not justified in drawing any conclusions with regard to the cause of the reduction in infestation in 1927 or what portion of the reduction of infestation was due to control measures."

One of the oldest infested areas of New York is located in what is known as the Schenectady region. A study of the infestation data for that region shows a similar fluctuation in annual abundance. There is little reason to doubt that this fluctuation in the main was due to the direct or indirect influence of weather just as in the previous case.

The writers have discussed the findings and interpretations of other investigators relative to other areas as preliminary to their own investigations in Ohio. It is only fair to state that published records indicate a wide difference in the interpretation of the data now available. According to the entomological data, New England infestation has been largely influenced by weather, parasites, and clean farming. One investigator seems inclined to stress weather as being the controlling factor. Another worker likewise emphasizes weather; but at the same time states that, due to meteorological conditions unfavorable to the corn borer, the value of parasites was considerably increased. They gave cleanup measures a lower evaluation than natural factors. Still other investigators place greater emphasis upon cleanup measures than upon other environmental variations. Relative to the variation in infestation in other parts of the United States and Canada the same differences in interpretation exist. Numerous published statements place almost unrestricted emphasis upon the importance of clean farming to the practical exclusion of natural factors. On the contrary there are other investigators who are inclined to reverse the order of these two conditions, giving natural factors the greater emphasis and mechanics a place of second importance.

OHIO

Before proceeding with the discussion of the Ohio data, attention is again directed to the methods employed in calculating borer populations. There are many distinct and separate habitats in Ohio and neighboring states. The populations of these habitats in any year should be expected to vary because of the variation in environmental conditions. Moreover, if the population of one year is to be compared with that of the following or previous years it should be calculated in the same areas. For example, if seasonal fluctuation is to be determined the population of 10 counties in a state cannot be compared with the population of 20 counties the following year because such factors as the size and composition of habitat and the time of the initial infestation are thereby ignored.

A careful study of Table 36 will show at once the same tendencies as already pointed out. In every habitat where data were taken, there was either a decrease in population or only a slight increase in 1925 as compared with 1924. In 1927 there were decreases in three habitats, slight increases in two, and rather sharp increases in three. There is some evidence as to the probable causes of the slower accumulation of 1925.

As has been mentioned, the weather records taken in the Oak Harbor area, Ottawa County, showed an excessively hot and dry period from May 31 to June 6, 1925. These records also showed a very dry spring, the average rainfall for April and May being but one-third of normal for this region. The high temperatures of the first week of June, which reached a maximum of 91° to 100° F. and a daily average of 74.7° to 87° were sufficient to cause the surface soil to become abnormally warm. Records taken by the writers on June 4 at 10:00 a. m. with a thermometer placed in the pith of a cornstalk lying on the ground showed a temperature of 105°, and with a thermometer between the leaf sheath and the stalk of corn 108°. At 11:30 the following day a temperature of 110° was recorded on the ground surface and 120° between the stalk and leaf sheath. Examination of exposed corn stalk debris in corn and sugar beet fields disclosed that the larvae in these situations had left the stalks and, inasmuch as they could not be found, it was assumed that they had died.

It has been shown in Section 4, page 128, that the degree of development of the corn at the time of moth flight as well as during the period of egg hatching is an important consideration. Here again, however, there is insufficient data relative to the growth of corn over Ohio as a whole during 1925. Growth measurements on the experimental plots for 1925 showed an apparently normal development despite the drouth of the early spring months. This normal development was the result of conservation of moisture due to early plowing and frequent fitting of the experimental field. However, observations over the general area showed that, due to the abnormally dry season, a great percentage of the land was not plowed during the time when it ordinarily is plowed. Many farmers delayed plowing, hoping that it would rain and thus put the land in condition for plowing. Rain did not come in quantity until after June 6, hence the land was plowed late and before the rains and consequently was cloddy and in poor condition for corn planting. It is known that in some fields under observation the corn either did not sprout because of dry soil or else sprouted very weakly and in many instances produced spindling plants. Corn measurements over the area in 1925 would without much doubt have shown poorer than normal corn at the period of moth flight, a condition which would have influenced both egg deposition and larval establishment, the consequence being a lowering of the expected level of population. There is at the same time the additional possibility that weather conditions directly affected larval establishment.

It is to be stressed again that the reduction in the rate of increase obtained over the entire one-generation area of the United

States in 1925. Soil was inherently the same as in 1924 or 1926. Cleanup in 1925 was not as thoro as in 1926, hence this factor must be ruled out as a controlling one. That the one set of factors known to vary greatly in their direct and indirect influence was weather conditions is obvious.

While the infestation of 1925 indicated a tendency to maintain status quo, that of 1926 showed an unprecedented rise in practically every habitat in Ohio. As pointed out elsewhere, 1926 was a favorable year to larval establishment. Due to good growing conditions corn was at least normal as to growth up to and during moth flight. The condition of the soil was more favorable for corn in the spring of 1926 than in 1925. Excessive temperatures and drouth did not interfere with the behavior of overwintering larvae and pupae. Larval establishment in 1926 was favored indirectly by corn development and perhaps directly by weather conditions. At least survival at the hibernating period was higher in 1926 than it was the previous year.

In 1927 the records show that the insect had a tendency to maintain status quo just as in 1925. The behavior of the insect in 1927 is of particular interest due to the fact that two abnormal conditions obtained in all the habitats. In the first place, weather conditions of 1927 were of such nature that they indirectly exerted an inimical influence on the insect, and secondly there was an exceptionally thoro cleanup.

The normal planting date for corn in Jerusalem Township, Lucas County, the heaviest infested area in 1926, is about May 25. Due in part to the constantly wet period during the last half of May, 1927, little corn was planted except in those local areas which were exceptionally well drained. The last of these continuous showers occurred on May 31. The majority of the corn in Jerusalem Township, therefore, was planted during the first two weeks of June, the average being about June 8. Consequently corn was practically two weeks late in this area. Late corn is not only less attractive to the moths but it is inimical to larval establishment. Borer population therefore was automatically reduced in 1927.

It may be observed here that due to the relatively high infestation of 1926 in the Maumee silty clay area in the Jerusalem Township habitat where the infestation was greatest, many farmers planted late, not only because of necessity but by choice. They planted late by choice because they had observed that late developing or late planted corn always had fewer borers than early developing corn. This tendency on the part of the farmers is a hopeful one in that it shows that the corn growers will be quick to adopt any practices which in their judgment are justified.

It is of further interest to note that in this same area there was a marked reduction in acreage. This reduction was particularly noticeable in the pump land habitats which had the most damage in 1926 and which it will be remembered had carried consistently the highest infestation since 1921. The significance of this observation must not be underestimated. Whereas the records show a significant decrease in population in Jerusalem Township, there was an increase in Oregon Township just to the west. How can weather cause or help to cause a reduction in the one township and not in the other? As was pointed out before, the region of heaviest infestation in 1926 and the area of maximum infestation for every year since 1923 with the exception of 1927 has been a small local area near Bono. This area is exceptionally wet, being a remnant of a former marsh. The water table is not only high and the drainage naturally poor but the soil type is not as early as some in Oregon Township. Consequently when later planting was the rule here in 1927, and somewhat earlier planting was possible in the Oregon habitat, especially the western part, a higher infestation occurred in Oregon. The slightly earlier corn of the Oregon habitat, earlier not because of different weather alone but because of different soil type, was, as would be expected, more heavily infested than that in Jerusalem. Even so, it will be noted that the population in the two areas was not widely divergent. The fact that the population in Jerusalem Township went down and that in Oregon Township went up indicates that with the pump-land corn thus handicapped the remainder of the area tended to approach an equality with the pump lands. However, had weather conditions favored the early planting of corn it is not improbable that, other factors being equal, the infestation would have been still greater in Oregon Township than was actually the case. In as far as weather conditions are responsible for late corn they indirectly reduce borer population.

On the other hand while weather conditions were exerting this tremendous influence on the borer thru the medium of corn development, and while there was a reduction in acreage in the most favorable areas, certain other factors were at work. It is doubtful whether any other field crop pest has been the object of a more vigorous effort to destroy it than the European corn borer was in 1927. The Jerusalem habitat in particular, was as free of crop remnants as was possible to make it. Many acres were hand-picked by farmers and hired workers. Oil burners were used effectively in fields that were not cared for otherwise. A census of the borer population before and after the use of these special methods showed that it is possible greatly to reduce the level of the overwintering population beyond that attained by practical farm procedure. It must be concluded therefore that if there had been no special effort to clean up the Jerusalem habitat there would have been a greater volume of moths to deposit eggs on the new crop.

In the light of present information, however, it does not follow that this greater number of moths would have proportionately increased the population of the on-coming crop, for the lateness of the corn in the area was inimical to moth attraction and larval establishment. Because of this complicating factor, namely, the abnormal behavior of corn in 1927, the value of the intensive cleanup in actually reducing the borer population of the new crop can not be stated at present.

There can be but little doubt that meteorological conditions constitute a set of physical factors which are tremendously important in affecting corn borer behavior. The ramifications of these factors and the factors associated with or dependent on them are so extensive and so intricate that analysis is made extremely difficult. Fortunately, however, even tho analysis is complicated yet it is perfectly possible and justifiable to at least consider the combined influences of all factors and to continue to attempt to single out those factors that appear to be dominant.

SUMMARY

The object of the investigations herein reported was to determine how corn can be grown profitably under conditions imposed by the European corn borer. This insect is of economic interest only because of its potential and actual abundance. It has been thought, therefore, that the attainment of the objective would be accelerated by an attempt to describe, analyze, and interpret the behavior of the insect with special reference to the factors which determine its abundance.

The working basis of these investigations is the truism that the responses of all plant and animal life are determined by their heredity and their environment—heredity determining the range of behavior and environment determining the differences in the expression of the behavior. It follows, therefore, that the responses of the corn borer would be expected to vary in accordance with the degree of harmony and synchrony existing between the inherited potential and the environmental resistance.

The individual factors which constitute the environment do not operate with equal intensity in all of the regions now infested. There are in Ohio and neighboring states many definite areas, or habitats, which differ in size and composition or both. The size and composition of these habitats are indicated by differences in vegetation and soil types and by the quantity and quality of corn produced.

The value of natural plant formations and associations as indices of biotic habitats is twofold: first, they represent an evaluation of numerous environmental factors over a period of years and, second, within certain limits, they may be used in interpreting and predicting. In certain regions the soil type may be more helpful in designating biotic habitats by reason of the fact that, as now classified, soil types are more numerous than the recognized plant associations. The quality and quantity of the corn produced in many instances are the best indicators of the composition of the habitat.

Western Ohio is a distinct habitat as compared with eastern Ohio. The two regions are of nearly equal size but differ markedly in composition. This difference is indicated by the soil and vegetation and the quality and quantity of corn. However, there

are certain areas in eastern Ohio that compare favorably in composition with areas in western Ohio, but they differ greatly in extent. Within these general areas are many smaller units which also vary in like manner. The abundance of the corn borer in any habitat appears to depend upon the conditions that obtain in that and adjacent habitats.

Habitats showing considerable superficial similarity may not necessarily offer the same degree of resistance to the borer. A different alignment of environmental factors or a variation in their relative importance may interfere with the responses of the insect to a greater extent than with the behavior of the corn plant.

The factors of the environment are classified as biotic and physical. The former include parasites, predators, and competitors. Up to the present time parasites and predators have been of negligible consequence in affecting borer abundance. It is hoped, however, that imported parasites may prove of value in the ultimate corn borer control program. In Ohio the corn borer population has not become so large that individuals of the species seriously compete with one another. Man, however, may be said to be a strong competitor. Regular and special clean farming practices are known to result in lowering the level of populations. A lower adult population, other factors being equal, should result in a lower borer population in the new crop. Unfortunately, however, this lowering of the level of larval and adult populations may not be adequate to produce control. The writers have no data which justify a statement of the relative value of this biotic factor. At the present time it seems safe to state that it is a factor which contributes to, but does not necessarily effect, control.

It has been demonstrated that corn borer abundance can be correlated with climate and weather, vegetation types, and soil types; it can be correlated with soil fertility, and cultural practices such as date of planting, variety, kind of rotation, time of plowing, and fertilizer application; and, more significant still, it can be correlated with the quantity and quality of corn at the period of moth flight. It is important to note, however, that these correlations do not necessarily explain the causes influencing or determining the numerical abundance of the insect; their chief value lies in the fact that they serve to limit the number of factors needing special investigation and to designate those which seem of greatest importance.

The difference in the abundance of the borer in the various habitats of the present infested area in Ohio and neighboring states has been due in large part to the direct or indirect influence of physical factors. Among the more important of these factors are nutrition, temperature, humidity, and light. These factors are especially important in their influence on the behavior of the adult and on the rate of larval survival.

The stage of corn development with respect to its influence on the behavior of the insect can be regulated within certain limits. This objective may be attained by date of planting, rate of planting, and other cultural practices. The most promising of these methods of modifying stage of development is the date of planting. Since the fundamental principle involved is the stage of corn development in relation to the behavior of the insect, it follows that the same end may be attained, at least in part, by planting varieties that are inherently different in their habits. Other factors being equal, a late variety of corn always carries a lower population than an early variety.

Moreover, since the development of corn in respect to corn borer behavior so greatly influences population, it has seemed advisable for corn breeders to attempt to develop new varieties or strains which will be more resistant or will escape attack to a greater degree than the best commercial varieties.

An interpretation of the information now available suggests that, until all factors are properly evaluated, either individually, in combination, or perhaps both, it will be quite impossible to state definitely the extent of distribution, accumulation, fluctuation, and other responses of the European corn borer are due to any single factor. It would be desirable to measure more accurately the influence of the nutrition factor, but because of the fluctuation of other physical factors such measurements are made difficult. Indeed, it would be especially desirable to be able to determine the relative value of clean farming, but before this can be done it will be necessary to measure other environmental factors associated with it. The fact that the nutrition factor, or corn development, so greatly influences the responses of the insect has thus far complicated the attempts to evaluate mechanics.

During the five years of the present investigations it has become apparent that the formulation of the European corn borer problem is simpler than its solution. Description, analysis, and interpretation of the behavior of the insect have been possible only within certain limits. Consequently there is as yet insufficient evidence to warrant a prediction as to the exact future significance of the corn borer in Ohio agriculture. However, there is justification for the statement that the insect will never be of equal economic importance in all parts of the State and that corn will continue to be the major crop even tho later planting be necessary in the most favorable corn borer areas. This prediction presupposes, of course, that the research now in progress will be carried to its ultmate conclusion.

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