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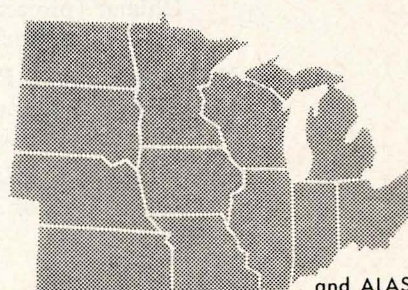
SOME FACTORS INFLUENCING POPULATIONS OF THE EUROPEAN CORN BORER, *Ostrinia nubilalis* (Hubner) IN THE NORTH CENTRAL STATES:

Resistance of Corn, Time of Planting and Weather Conditions Part II, 1958-1962

Agricultural Experiment Stations of Alaska, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin, and the U.S. Department of Agriculture cooperating



AGRICULTURE AND HOME ECONOMICS EXPERIMENT STATION
IOWA STATE UNIVERSITY of Science and Technology
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PREFACE

This bulletin is Part II of a contribution from the North Central Regional Cooperative Project NC-20, "Factors Influencing European Corn Borer Populations." The experiment stations of the North Central States and the Entomology Research Division of the Agricultural Research Service, U. S. Department of Agriculture, cooperated.

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SUMMARY

A cooperative project was conducted by the agricultural experiment stations of Iowa, Minnesota and Ohio and the U. S. Department of Agriculture to study the effects of weather, planting date and resistant hybrids as factors influencing populations of the European corn borer, **Ostrinia nubilalis** (Hübner). Identical studies were carried out at Ankeny, Iowa; Waseca, Minnesota; and Wooster, Ohio, during a 10-year period, 1953-1962.

The first 4 years of the study (1953-56) were reported by Everett et al. (1958). The work reported herein is a companion bulletin to the Everett et al. (1958) publication and deals with the results of experiments conducted during 1958-1962.

The experimental design was a randomized block, split plot with five replications. The whole plot treatments were four hybrid-planting date combinations consisting of early- or late-planting dates and susceptible or resistant hybrids. The subplot treatments consisted of a factorial arrangement of all possible combinations of three levels of infestation (zero, natural and natural + 3 egg masses) by first brood and the same three levels of infestation by second-brood borers. Temperature and rainfall records were kept at each of the three stations. Borer population and injury to the plant were recorded at the end of the first brood and in the fall. Yield data were collected.

As expected, and reported by Everett et al. (1958), weather patterns varied widely from year to year within locations and from location to location within years. Attempts to associate particular weather phenomenon with borer populations at all locations within years were fruitless. The data collected during the last half of the study could not be used to substantiate findings from the first half.

Data collected on abundance of the corn borer in Boone County, Iowa, from 1950 through 1964 were assembled, and efforts to correlate these data with weather variables were made. Weather data were broken down into five 7-day periods during both first- and second-brood emergence, oviposition and developmental periods. The midseason population in Iowa was highly correlated with inches of rainfall between June 17-23 and June 24-30 and with nights with wind over 8 mph at 10 p.m. between June 24-30. The June 17-23 rainfall was beneficial to high borer survival, but the other two variables relating to precipitation gave negative correlations. Fall populations in Boone County were positively correlated with nights with wind over 8 mph at 10 p.m., August 15-21; inches of rainfall, August 15-21; and inches of rainfall, August 22-28. The same data for Minnesota and Ohio were not available.

Levels of infestations in the three states were not associated with each other. The level of larval establishment and survival from the natural and artificial infestations varied from state to state and year to year.

Fewer first-brood larvae survived on the resistant hybrid than on the susceptible hybrid at the time of midseason dissections. The percentage reduction calculated as borers surviving per 100 plants at that time indicated that the resistance factors of the resistant hybrid exhibited their influence more strongly as the level of borer infestations increased. An average percentage reduction in excess of 60 percent due to late planting was obtained over the 5-year period in Iowa and Ohio. The same late planting produced higher first-brood infestations in Minnesota.

Planting dates had very little effect on the survival of second-brood borers in Minnesota, were slightly more effective in Ohio and were highly effective in 4 of 5 years in Iowa. The greatest advantage was gained by using resistant corn in Ohio, while the combination of planting dates and hybrids was most effective in Iowa.

When all years and locations were included, the variation in numbers of borers found in the different treatments at the time of second-brood dissections makes statements inadvisable concerning the effects of first-brood infestations on second-brood infestations.

Data pertaining to yield losses during 1958-1962 were combined over years and locations and analyzed. Significant differences in yields were determined for the influence of years, the influence of locations and the interaction of the two.

The early-planted corn outproduced the late-planted by an average of 6.8 bushels per acre. However, within the three locations, the difference ranged from 5.4 bushels in Iowa to 6.3 bushels in Minnesota and 8.6 bushels in Ohio (table A-9).*

Averaged over all treatments and years, the susceptible hybrid outproduced the resistant hybrid by an average of 11.6 bushels per acre in the early planting and by 9.3 bushels per acre in the late planting, for an average of 10.4 bushels per acre (table A-9). The variation in these data is indicated when it is noted that the susceptible hybrid outproduced the resistant hybrid by 9.8, 15.6 and 6.0 bushels per acre in Iowa, Minnesota and Ohio, respectively.

When sprayed vs. natural oviposition infestation pressures are considered, the data indicate that increases in yield of about 2.5 bushels per acre can be expected by spraying for first-brood infestation, 2.8 bushels by spraying for second brood and about 3.3 bushels per acre by spraying for both broods.

When we considered 5-year average losses in yield due to a first-brood infestation compared with losses due to a second-brood infestation (table 18), the resistant hybrid showed its effects primarily against the first brood. Reduction in yield from a second brood was similar in the two hybrids. The resistant hybrid also

*Numbers preceeded by A indicate tables found in Appendix A.

had more effect in reducing the number of larvae (table A-7), cavities (table A-14) and lesions (table A-11) under a first-brood infestation than under a second-brood infestation. This phenomenon is not surprising because inbred lines or hybrids resistant to a first-brood infestation (leaf feeding) are not necessarily resistant to a second-brood infestation.

The susceptible hybrid (WF9 x M14) outyielded the resistant hybrid (Oh43 x Oh51A) in spite of a corn borer infestation. The yielding ability of WF9 x M14 is considerably greater than that of Oh43 x Oh51A. Therefore, a higher level of first-brood infestation than occurred in our plots would be required to recommend planting Oh43 x Oh51A in preference to WF9 x M14. Oh43, in combination with other inbreds, has given much higher yields than reported here. Penny and Dicke (1959) reported yield losses of susceptible x susceptible, susceptible x resistant and resistant x resistant crosses under a heavy first-brood infestation. All resistant x resistant crosses had a distinct advantage in yield compared with the susceptible x susceptible crosses. WF9 x N16 had yield loss of 30.4 bushels per acre; the susceptibility of WF9 appeared completely dominant to the resistance of N16.

Efforts were made with yield data from Iowa to establish loss in yield formulas that considered the numbers of borers per stalk found at midseason and fall dissection time. The formulas were calculated by using both quadratic and logarithmic functions; however, neither proved satisfactory.

Some Factors Influencing Populations of the European Corn Borer, *Ostrinia nubilalis* (Hübner), in the North Central States: Resistance of Corn, Time of Planting and Weather Conditions Part II, 1958-1962

by A. N. Sparks, H. C. Chiang, C. A. Triplehorn,

W. D. Guthrie and T. A. Brindley

Regional Project NC-20 entitled "Factors Influencing Corn Borer Populations" was initiated in 1953. Intensive field plot studies were begun in Iowa, Minnesota and Ohio in cooperation with the Entomology Research Division, Agricultural Research Service, U. S. Department of Agriculture to obtain information on borer survival and damage in relation to planting date and hybrid as affected by weather conditions. A tremendous amount of data was collected. Basic information was obtained on the fluctuation of induced populations of both the first and second brood of the borer as affected by planting date, hybrid, geographical location and ecological habitats. A comprehensive report of the first 4 years of the project (1953-56) has been published (Everett et al., 1958).

The basic design of the experiment was changed after the 1957 growing season. The data reported herein were analyzed by location for each year and by combining over years and locations. Because of the technicalities involved with this type of statistical analysis when changes in the basic experimental design are involved, the 1957 data are not included. This bulletin is a companion bulletin to the Everett et al. (1958) publication and covers work conducted during 1958-1962.

Before the initiation of this study in 1953, considerable work had been directed toward methods of evaluating and reducing plant damage done by the borer. Most of the work had been concerned with either first-brood or second-brood damage. Everett et al. (1958) reported the effect of the corn borer on plant height, types of feeding by the different larval instars, type of damage done by each brood and the general interrelationships between the borer and the plant. They published several pictures showing types of damage to the plants and to hybrid yields; hence, these subjects will be discussed to a lesser extent here.

REVIEW OF LITERATURE

Vinal (1917) was the first to report the European corn borer, **Ostrinia nubilalis** (Hübner), as a pest in the United States, having found this pest in sweet corn fields in Massachusetts. Smith (1920) investigated possible sources of entry into the United States and concluded that broomcorn shipped from Hungary or Italy between 1909 and 1914 was the most probable source.

At the time of its discovery in the United States, the borer was known as **Pyrausta nubilalis** (Hübner). Voluminous literature was published under that scientific name before Marion (1957) placed **nubilalis** in the genus **Ostrinia**, and in recent literature, it appears under that name.

The borer is capable of using upward of 200 plant species as hosts, and it arrived without natural enemies and was afforded millions of acres of corn for a food supply. The stage was set for the biotic explosion that followed. The potential seriousness of the pest was recognized early, and in 1927 the U. S. Department of Agriculture attempted an eradication program. The effort was doomed to failure, however, because all the corn and many other host plants could not be destroyed. Currently, the corn borer is known to exist in at least one county of all states east of the Continental Divide (fig. 1) except Florida and New Mexico (U. S. Dept. Agr., 1965). Estimates of financial losses caused by the European corn borer during the 10-year period 1953-1962 ranged from 65,044,000 to 191,614,000 bushels of corn and represented a cash income loss averaging $127,702,700 per year.

The literature pertaining to the ecological factors that affected European corn borer populations through 1956 was reviewed and published by Everett et al. (1958). A review of significant developments in European corn borer research was published by Brindley and Dicke (1963).

EXPERIMENTAL PROCEDURES

The study was carried out in Iowa, at the Ankeny Research Farm; in Minnesota, at the Southern Agricul-

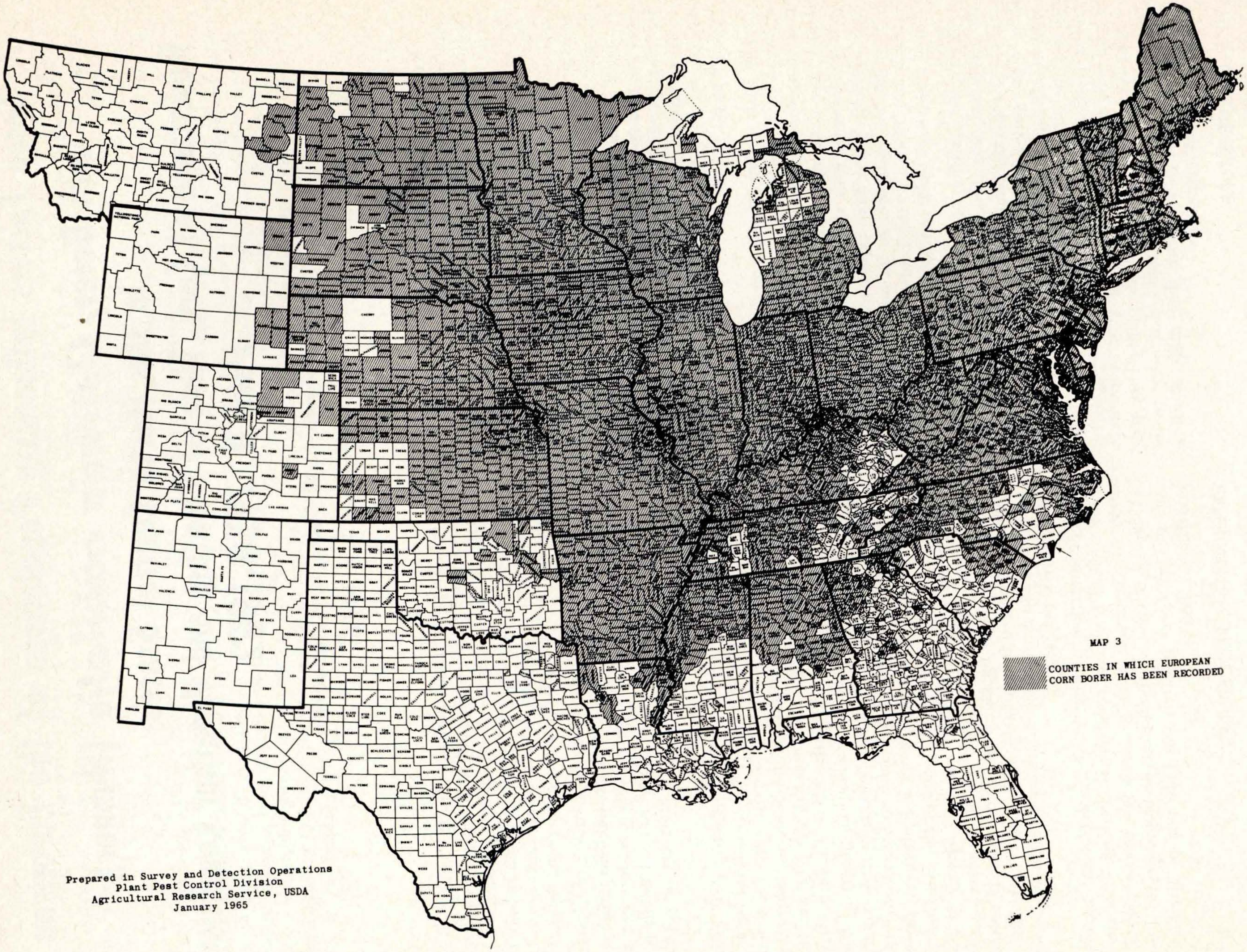


Fig. 1. Distribution of the European corn borer, January 1965.

tural Experiment Station, Waseca; and in Ohio, at the Ohio Agricultural Research and Development Center, Wooster.

At each of these stations, the sites of the experimental plots were different each of the 5 years. The plots were located in fields that had not been planted to corn the previous year and that, in the scheme of crop rotation, would normally be planted to corn.

Agronomists in cooperating states assisted in selecting two single-cross hybrids suited to growing conditions in each of the states and of similar maturity, one susceptible (WF9 x M14) and one resistant (Oh43 x Oh51A) to leaf feeding by the European corn borer. The early planting was made in each state when corn was first being planted by farmers in the area. The late planting was made about 14 days later, near the end of the normal planting period. The seed was planted in hills spaced 40 inches apart. To insure a uniform stand, six kernels were placed in each hill. The stand was thinned to three plants per hill when the corn was about 10 inches tall.

Commercial fertilizer (200 pounds of 6-24-12 and 200 pounds of ammonium nitrate per acre) was broadcast and disked under in the spring. A side dressing of commercial fertilizer (5-20-10) was applied after germination.

The experimental design was a randomized block, split plot with five replications. The whole plot treatments were four hybrid-planting date combinations, early susceptible (ES), early resistant (ER), late susceptible (LS) and late resistant (LR). The subplot treatments consisted of factorial arrangements of all possible combinations of three levels of infestation (none, natural and natural + 3 egg masses) by first-brood and three levels of infestation by second-brood borers. These treatments are given in table 1.

The same basic field design (fig. 2) was used at all three locations. Each state was responsible for randomizing the subplot treatments. A subplot, diagrammed in fig. 3, was 6 hills wide and 7 hills long. The outside row surrounding the plot served as a buf-

Table 1. Treatments used in studying factors influencing corn borer populations, 1958-1962.

Treatment No.	First brood	Second brood
1	Spray[a]	Spray[b]
2	Spray[a]	Natural
3	Spray[a]	Natural + 3 egg masses
4	Natural	Spray[b]
5	Natural	Natural
6	Natural	Natural + 3 egg masses
7	Natural + 3 egg masses	Spray[b]
8	Natural + 3 egg masses	Natural
9	Natural + 3 egg masses	Natural + 3 egg masses

[a] Sprayed with 0.5 pound of actual EPN per acre.

[b] Sprayed with 1.0 pound of actual DDT per acre.

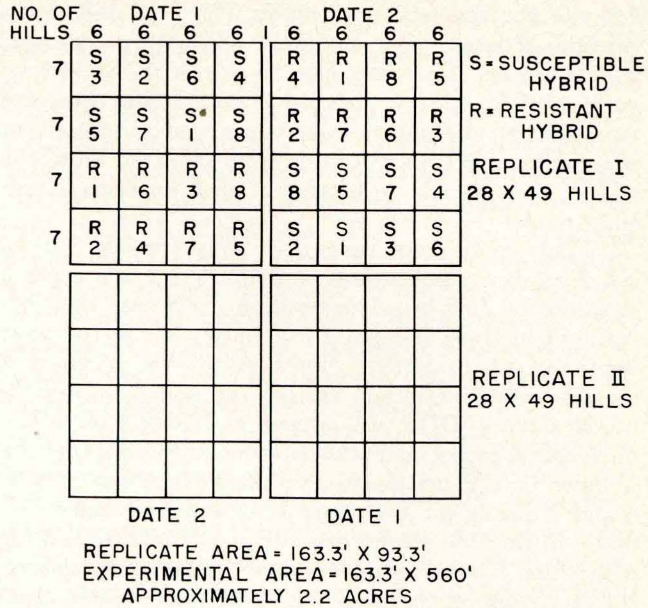


Fig. 2. Basic field design of plots, 1958-1962.

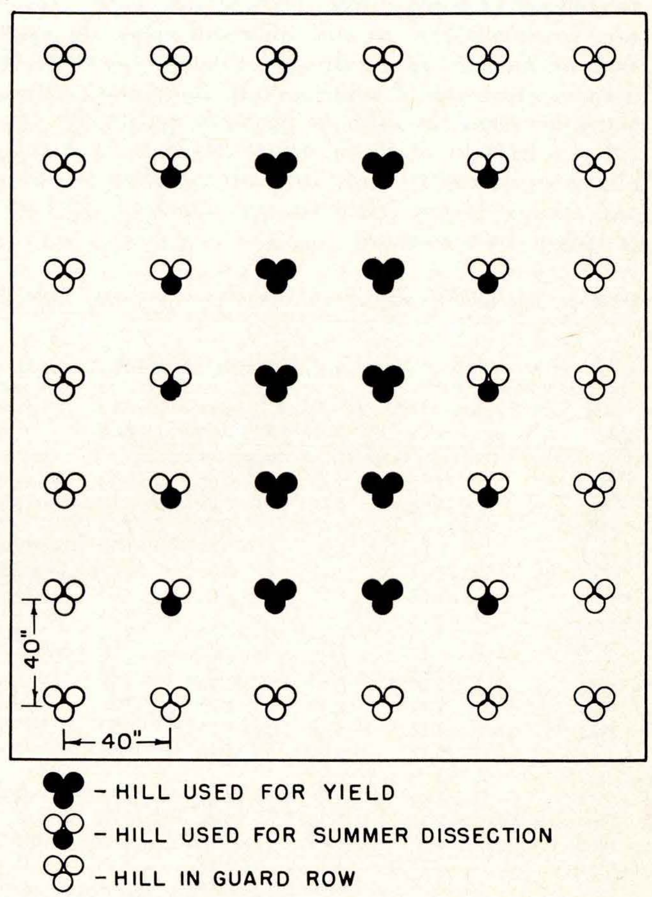


Fig. 3. Diagram of subplot arrangement.

fer row for the rest of the plot. The 2 x 5 hill center portion of each plot was used exclusively for yield measurements. The rows on each side of the yield rows were used for observations on plant development, egg mass counts, midsummer dissections and miscellaneous observations. Weather records were obtained from the official weather station located at each experiment station.

Plants to be kept borer free were sprayed with a hand sprayer. Applications of EPN were made every 5 days during first-brood oviposition. EPN was used because of its short residual effect since some of the plots kept free of first-brood borer infestation received a second-brood infestation. During the period of second-brood activity, DDT was applied at 10-day intervals.

Natural oviposition was determined by counting the number of egg masses on two plants in treatments 1, 4 and 7 during the first generation and treatments 2, 5 and 8 during the second generation. All plants used for oviposition counts were marked with white garden stakes to insure checking the same plants each time. Counts were made three times each week.

Midseason dissections were made during the latter part of July. Six plants were taken at random in subplots receiving treatments 1, 4 and 7. The number of living forms per plant, their stage of development and number of cavities were recorded.

Fall dissections were made in late October or early November. One plant from each of the 10 yield hills was randomly selected and dissected. Records were kept of numbers of larvae and cavities. Location of cavities was recorded under one of three categories—above or below the primary ear node and in the ear. All ears from the 2 x 5 hill center section of each subplot were harvested, identified with the plant by label and allowed to dry. Yield was computed on the basis of 15.5-percent moisture.

The data were analyzed by location each year, then further analyzed by combining over years and location. The error variances for locations, even within years, however, indicates that these variances possess an attribute common to most biological data, heterogeneity. This attribute dictates that only data for differences within a given location and year can be tested with a given level of significance. Therefore, when we list *, significant at the 5-percent level, the exact level of significance of the test is unknown, but believed to be high.

EXPERIMENTAL RESULTS

Weather Conditions in Relation to Borer Infestation

Huber et al. (1928) concluded that conditions favoring good corn growth were also favorable for the European corn borer. L. M. Thompson (1962) applied multiple curvilinear regression analysis to separate the effects of weather from the effects of technology on the trend of higher corn yields in Illinois, Indiana, Missouri, Iowa and Ohio. He concluded that the most significant weather variables, in order of importance, for the states, included in this study were Iowa—June temperatures, July rainfall, July temperature and August temperature; Ohio—July rainfall and August temperature. Minnesota was not included in Thompson's studies.

Weather data obtained from official weather stations located at each of the experimental farms in each state were used to compare with the accepted normal obtained from the Weather Bureau for that location. These data are presented in table 2, along with the mean infestation of artificially infested plots (treatments 7 and 3) measured at midsummer and fall dissections, respectively.

IOWA

According to L. M. Thompson (1962), the best

Table 2. Precipitation and mean temperature in May, June, July and August for Iowa, Minnesota and Ohio. 1958-1962.

	Precipitation (inches)					Mean temperature (°F)					Av. borers/100 plants on manually infested plots	
Item	May	June	July	Aug.	Total June-Aug.	May	June	July	Aug.	May-Aug.	First brood	Second brood
Iowa												
1958	3.18	3.07	9.90	0.94	13.91	62	66	70	73	69	233	47
1959	6.54	3.55	1.57	1.57	6.69	62	71	72	77	73	34	189
1960	6.21	4.56	3.34	7.54	15.44	61	68	72	73	71	64	357
1961	1.32	3.90	5.94	1.99	11.83	58	69	73	72	71	85	207
1962	5.22	2.55	3.05	2.30	7.90	68	70	73	73	72	91	328
Normal	3.63	5.05	2.96	3.83	11.84	62	72	77	75	74	...	...
Minnesota												
1958	1.20	2.64	2.45	3.56	8.65	61	63	69	71	66	140	31
1959	5.06	3.66	2.60	4.79	16.11	61	70	71	75	69	77	244
1960	7.03	5.09	2.26	2.59	9.94	58	65	77	72	67	131	117
1961	5.87	0.98	6.73	5.65	13.36	56	68	70	71	66	53	113
1962	3.56	3.49	5.11	8.53	17.13	62	66	68	69	66	100	33
Normal	3.62	4.50	3.18	3.47	11.15	59	68	73	71	68	...	...
Ohio												
1958	3.02	3.87	11.02	5.00	19.89	59	63	72	69	68	292	147
1959	2.28	2.72	3.85	3.55	10.12	63	67	70	73	70	186	391
1960	3.70	3.83	3.70	7.48	15.01	56	67	67	71	68	209	424
1961	2.13	5.37	6.57	3.54	15.48	53	64	69	70	68	261	118
1962	2.65	2.46	3.56	1.12	7.14	64	67	68	67	67	151	364
Normal	3.89	4.21	3.73	3.65	11.59	59	69	73	71	71	...	...

weather conditions (i.e., good corn borer weather (Huber et al., 1928)) for Iowa include: (1) less than average rainfall and higher than average temperature in June, (2) higher than average rainfall and lower than average temperature in July and (3) higher than average rainfall and lower than average temperature in August.

A statement often repeated around the European Corn Borer Research Laboratory at Ankeny, Iowa, was that a cool, dry June severely reduced first-brood populations of the corn borer. Table 2, however, indicates that the heaviest first-brood oviposition and infestation occurred in 1958, the year with the lowest mean June temperatures and the second most deficient in rainfall. On the other hand, in 1959 no rainfall was recorded for the first 26 days of June, and consequently a very low population of borers was found at midseason dissection time.

The survival of second-brood borers in Iowa varies according to low mean temperature of August and the total seasonal, as well as the average rainfall in August (Everett et al., 1958). The year producing the highest survival of second-brood borers, 1960, had the highest seasonal and August rainfall, but had near-normal mean August temperature. Second-brood borer survival in Iowa compares favorably with observations of Everett et al. (1958). Fig. 4 summarizes temperature-rainfall data for all 5 years in Iowa.

MINNESOTA

Weather data for Minnesota are shown in table 2 and fig. 5. Temperatures varied much the same as in Iowa. Seasonal rainfall was greater than the long-term average for 3 of the 5 years and only slightly below normal the other 2 years. Slightly less than 1 inch of rain fell in June 1961, the year of the lowest survival of first-brood borers in Minnesota. The largest second-brood population was found in 1959 when higher than average rainfall and temperatures occurred in Minnesota.

OHIO

Rainfall at Wooster during the growing season was above normal for 3 of the 5 years reported in this study. The rainfall and temperature data for Ohio are shown in table 2 and fig. 6. L. M. Thompson (1962) concluded that corn production in Ohio was favorably affected by higher than normal temperatures in June and July and that July rainfall was a major factor for growing corn in Ohio. Again, looking at the suggestion of Huber et al. (1928) that weather conditions favorable for corn growth are favorable for corn borers, one cannot integrate the two conclusions and reach a logical answer. The year with the lowest average June temperature produced the highest first-brood corn borer infestation. Everett et al. (1958) found that first-brood infestation varied with the mean rainfall in May and June. Our data tend to verify their findings; however, their findings that second-brood infestations vary inversely with total precipitation for August and total seasonal precipitation could not be substantiated.

Summary of Weather Effects

Chiang and Hodson (1959) state that the fluctuations in European corn borer populations recorded from 1948-1957 at Waseca, Minnesota, conform with the views of W. R. Thompson (1956), Cole (1954) and Schwerdtfeger (1958). These authors encompassed the role of the element of chance in the control of insect populations and concluded that, in nature, all factors conducive to population changes are interacting in complex ways, bringing random components into the system through the vagaries of weather.

In a discussion of populations of European corn borers in field corn, Chiang et al. (1961) concluded that weather conditions greatly influence borer populations, both favorably and unfavorably. They concluded that a cool, windy June caused a decrease in spring-to-summer population in 1955 in Boone County, Iowa. Favorable weather conditions in 1956, however, caused an increase in spring-to-summer populations. Similar statements were made concerning populations and weather conditions in other localities of their study.

At the European Corn Borer Research Laboratory in Ankeny, Iowa, some 15 years' data on borer population fluctuations from early spring through post-harvest were available for study. These surveys were taken in conjunction with the over-all NC-20 program. Weather data were collected from the official weather station at Boone, Iowa, and all parameters of weather were correlated with parameters of corn borer populations, both first and second brood. Correlations of midseason populations, egg masses per 100 plants and predator forms per 100 plants with early spring populations, oat acreages in Boone County and several weather parameters were made. Five weather paramenters were broken down into five 7-day periods. The parameters

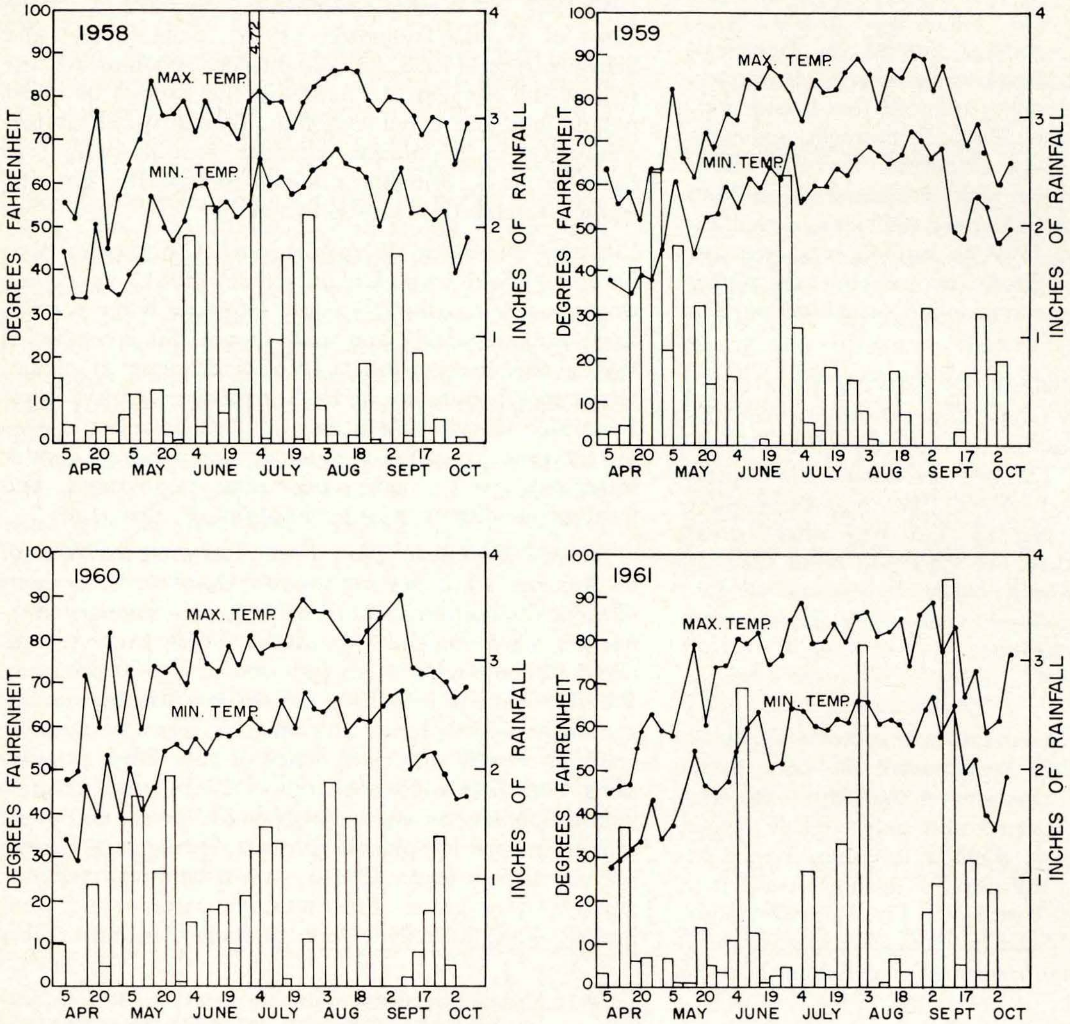
Table 3. Correlations among midseason data pertaining to first-brood borer populations and other parameters, especially weather, known to affect populations. Boone County, Iowa, 1950-1964.

Variables correlated	r value	Significance
Midseason population with:		
Acres of oats in Boone County	+0.6285	**
Inches of rainfall, June 17-23	+0.5163	*
Inches of rainfall, June 24-30	-0.5716	*
Number of rainy days, June 24-30	-0.7937	**
Nights with wind over 8 mph, June 24-30	—0.5139	*
Predator forms with:		
Inches of rainfall, July 1-7	+0.5974	*
Egg masses/100 plants, first brood with:		
Inches of rainfall, June 17-23	+0.7605	**
Early spring population	+0.5827	*

* Significant at 5-percent level

** Significant at 1-percent level

were: accumulated borer-degree days, number of days in which the minimum temperature fell below 58°F, inches of rainfall, number of rainy days and number of nights in which wind velocity averaged over 8 mph at 10 p.m. The 7-day periods were June 10-16, 17-23, 24-30, July 1-7 and 8-14. With 15 years' data from Boone County (1950-1964), a complete matrix was calculated in which r values were obtained for all listed variables. Table 3 shows only those r values that tested significant.



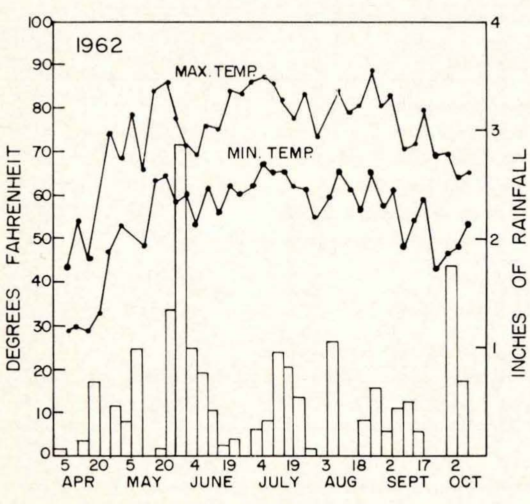
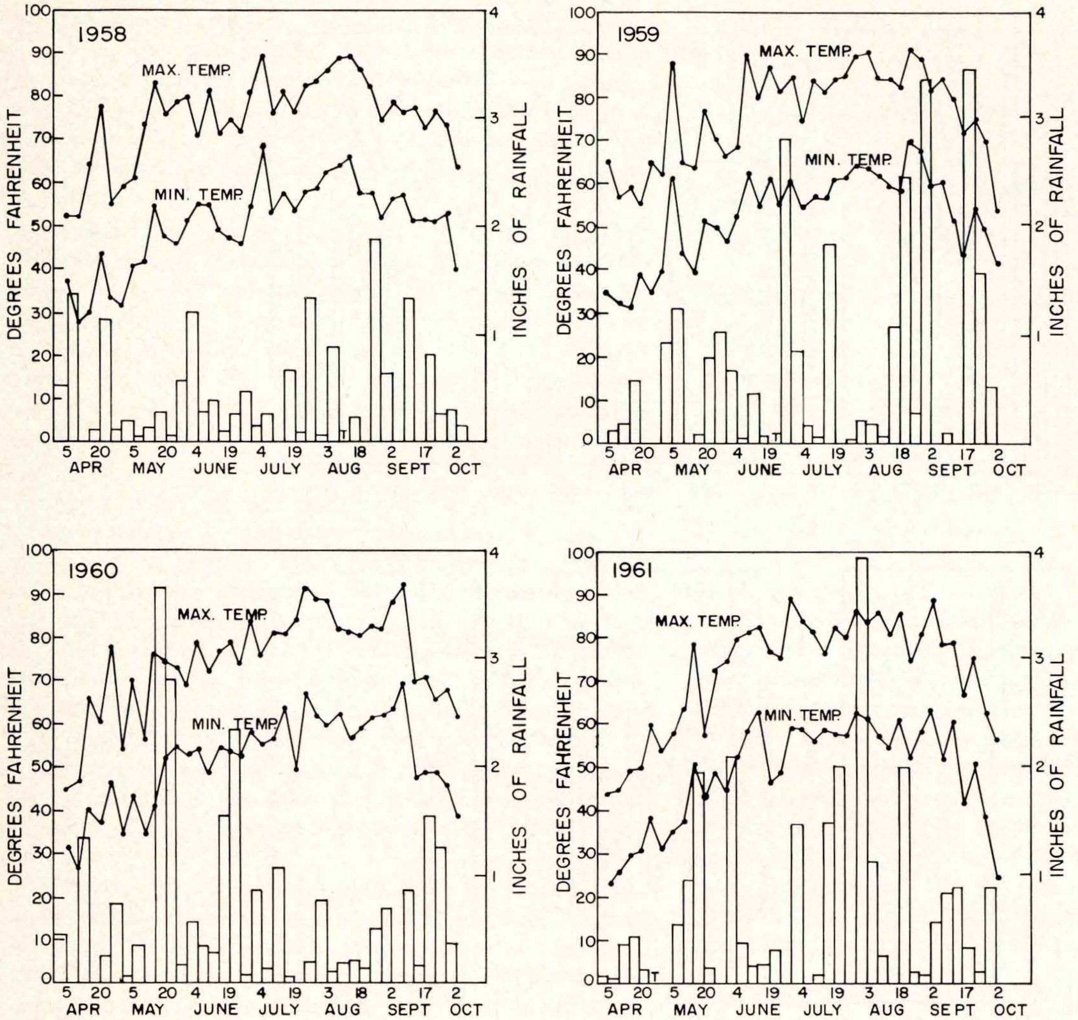


Fig. 4. Minimum and maximum temperatures averaged over 5-day periods and rainfall totaled for 5-day periods at Ankeny, Iowa, 1958-1962, inclusive.

A highly significant correlation exists between midseason population and acres of oats in Boone County. This was expected because most of the surviving overwintering populations are in oat fields planted to corn in the previous year. Deep plowing is very detrimental to overwintering corn borers.

The first-brood season was divided into five 7-day intervals to determine the critical areas of weather par-



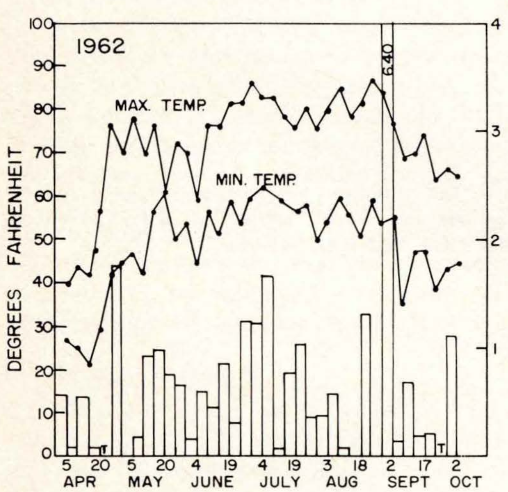


Fig. 5. Minimum and maximum temperatures averaged over 5-day periods and rainfall totaled for 5-day periods at Waseca, Minnesota, 1958-1962, inclusive.

correlated positively with inches of rainfall June 17-23 and the early spring population. Evidently rainfall between June 17-23 is beneficial to the corn borer in Iowa for two reasons, oviposition and survival.

The data pertaining to second-brood infestations were correlated with midseason infestations, egg masses per 100 plants, predator forms per 100 plants and the five weather parameters. The active second-brood development period was divided into five 7-day intervals as before. Those intervals were July 25-31 and August 1-7, 8-14, 15-21 and 22-28. The variables that were significantly correlated and meaningful are listed in table 4.

The fall populations of borers in Boone County, Iowa, were highly correlated with egg masses per 100 plants, inches of rainfall during the periods August 15-21 and 22-28, and surprisingly, with number of nights in which wind speed was over 8 mph at 10 p.m. during August 15-21. Egg masses per 100 plants are highly correlated with both rainfall and nights with wind speed over 8 mph at 10 p.m. during August 15-21 and 22-28.

These data indicate that wind speed over 8 mph is advantageous to fall borer populations during the latter part of August. The reason behind these significant positive correlations of fall borer populations and night wind speeds in excess of 8 mph at 10 p.m. can only be surmised. It could be that these wind speeds (calculated for the 3-foot height) are beneficial in that they are forceful enough to cause a slight breeze in the tall corn. This light wind movement may be helpful in disseminating a sex attractant, enabling the moths to locate and mate. On the other hand, the wind speed at night during these two periods is correlated with rainfall.

Predator forms per 100 plants are correlated positively with accumulative borer-degree days during August 8-14 and correlated negatively with nights in which the minimum temperature dips below 58°F during the same period. These data indicate that higher temperatures during the second week of August increase predator populations.

With 15 years of corn borer population data for Boone County and access to pertinent weather data, it was anticipated that, by taking several of the most highly correlated variables, one could fit the data to a multiple-regression prediction equation and be able to predict corn borer populations for any given time of the year. It was further anticipated that, if the Boone County populations could be estimated in such a manner, then probably the midwestern populations could be predicted by extending the process. This type of arithmetic processing could not be used on the data.

Table 4. Correlations among fall data pertaining to second-brood borer populations and other parameters, especially weather, known to affect fall population size. Boone County, Iowa, 1950-1964.

Variables correlated	r value	Significance
Fall population with:		
Egg masses/100 plants, second brood ..	+0.9331	**
Nights with wind over 8 mph, Aug. 15-21	+0.8676	**
Inches of rainfall, Aug. 15-21	+0.6790	**
Inches of rainfall, Aug. 22-28	+0.7895	**
Predator forms/100 plants with:		
Accumulative borer degree days, Aug. 8-14	+0.8326	**
Nights with min. temp less than 58°F, Aug. 8-14	—0.7659	**
Egg masses/100 plants, second brood with:		
Inches of rainfall, Aug. 15-21	+0.8068	**
Inches of rainfall, Aug. 22-28	+0.9236	**
Nights with wind over 8 mph, 10 p.m. Aug. 15-21	+0.9617	**
Nights with wind over 8 mph, 10 p.m. Aug. 22-28	+0.5856	*

* Significant at 5-percent level

** Significant at 1-percent level

Infestation Fluctuations

When the first 4 years' work on this project was published, Everett et al. (1958) stated that the bivoltine behavior of the population was predominant in the area studied. Since that time, Beck and Apple (1961) and Sparks et al. (1966a,b) have published results of experiments indicating that geographical populations of corn borers may be separated into biotypes based on their diapause characteristics. Evidence was presented to show that diapause in the European corn borer is determined genetically in addition to other factors demonstrated to cause the condition. However, to develop a more orderly discussion, fluctuations of corn borers will be treated under titles of first- and second-brood infestations. The first brood develops from the overwintering larvae, and the second brood develops from the midseason (first-brood) population.

FIRST-BROOD INFESTATION

The infestation levels considered in this portion of the experiment were developed from three sources. The three levels and their mechanism of development are: (1) "Zero" level (treatment 1) resulted from treatment of plots with ½ pound EPN per acre, (2) "Natural" level was developed from natural oviposition and (3) "Natural + 3 egg masses" was developed from natural oviposition and manual infestation of each corn plant with 3 egg masses.

Oviposition

Thompson and Parker (1928) pointed out that a large proportion of young European corn borer larvae die even under the best of conditions. Chiang and Hodson (1959) reported a mortality of at least 10-15 percent among eggs of European corn borer throughout a 10-year study in southern Minnesota and suggest that the two factors—death of young larvae and mortality of eggs—combined to produce an intrinsic weakness of the species. Many workers have found this excessive mortality following egg hatch and have also noted failures of egg masses to hatch.

The amount of natural oviposition varied from year to year and even moreso from location to location. Natural oviposition was insufficient in Ohio to warrant the time to collect the information.

Oviposition data for Iowa and Minnesota are presented in table 5. First-brood oviposition was greater in Iowa for 4 of the 5 years. In 1960, however, Minnesota recorded 20.8 egg masses per 100 plants while Iowa recorded 3.3. An examination of the weather data (table 2) gives no satisfactory explanation for this reversal; therefore, it is suggested that the initial population of first-brood moths must be responsible for this difference.

Midsummer Population

The midsummer or first-brood borer population was measured by dissecting six plants in each of three treatments. Treatments 1, 4 and 7 were dissected to show the effect of three levels of infestation—zero, natural oviposition and natural oviposition + 3 egg masses. The data for all 5 years in the three states are given in table 6.

One-half pound of EPN at 5-day intervals throughout the oviposition period kept the plots relatively free of corn borers. Natural oviposition in the plots exhibited its influence quite strongly at midseason dissection time. Iowa plots received more natural oviposition and had more borers at midseason. Although reports from Ohio indicated negligible amounts of first-brood oviposition, midseason dissections revealed higher numbers of borers per 100 plants in Ohio than in Minnesota.

An unexpected element of this geographical study is noted when one examines the borers surviving from natural + 3 egg mass infestations for the three areas. Since Iowa plots received the most natural oviposition and had the highest number of borers per 100 plants surviving on the natural oviposition plots, it would follow that the Iowa plots should have the highest survival on the natural oviposition + 3 egg mass plots. This was not the case. Indeed, the 5-year average in the natural + 3 plots shows 101.4, 100.1 and 220.0 surviving borers per 100 plants for Iowa, Minnesota and Ohio, respectively. When these figures are corrected for natural oviposition survival, they read 77.2, 93.5 and 203.0, respectively. These data add some evidence to the suggestion by Everett et al. (1958) that a density-dependent factor was adversely affecting larval survival when the addition of 6 egg masses to the natural infestation did not always give substantial increases in the number of larvae at midsummer compared with the addition of only 3 egg masses.

Table 5. Egg masses per 100 plants from a natural first-brood infestation.

Year	Iowa	Minnesota
1958	45.7	1.0
1959	28.3	.0
1960	3.3	20.8
1961	35.0	5.0
1962	23.3	12.2

Table 6. First-brood borers per 100 plants at the time of midsummer dissection, averaged over dates and hybrids.

	Iowa			Minnesota			Ohio		
	Treatment			Treatment			Treatment		
	1	4	7	1	4	7	1	4	7
Yr.	Spray	Nat.	Nat.+3	Spray	Nat.	Nat.+3	Spray	Nat.	Nat.+3
1958	4.8	84.0	233.0	.0	6.6	140.0	23[a]	34	292
1959	0.8	8.0	34.0	3.3	6.6	76.6	0	7	186
1960	0.8	4.2	64.2	1.9	5.0	131.2	0	27	209
1961	.0	11.6	85.0	4.9	3.4	52.9	4	11	261
1962	2.9	13.3	90.8	1.7	11.5	99.8	1	3	151
Average	1.9	24.2	101.4	2.9	6.6	100.1	6	17	220

[a] No insecticide applied to Ohio first-brood plots in 1958.

SECOND-BROOD INFESTATION AND OVIPOSITION

Second-brood natural oviposition is given in table 7. The data were obtained by examining two plants in each of treatments 2, 5 and 8 three times each week. No data were collected for Ohio plots. Natural oviposition during the second-brood period was higher in Iowa than Minnesota for 4 of the 5 years. The natural second-brood oviposition counts in Iowa in 1959 were the lowest of the 10-year study. This could possibly be accounted for by observing rainfall data for July and August of that year. A large percentage of second-brood oviposition occurred during late July and throughout August when only 1.57 inches of rain fell during each of those months in 1959. Minnesota's second-brood oviposition varied considerably; however, no reasons are surmised for any year being more or less suitable for oviposition.

INFESTATION AT FALL DISSECTION

Records of fall larval infestations for all nine treatments were obtained by randomly selecting and dissecting one of the 3 plants in each of 10 yield hills of corn per plot. The results of fall dissections for all three

Table 7. Egg masses per 100 plants from a natural second-brood infestation.

Year	Iowa	Minnesota
1958	41.7	9.9
1959	15.8	26.9
1960	41.7	25.0
1961	71.7	7.6
1962	74.2	20.5

states are summarized in table 8. These data do not show effects due to planting date or hybrid of corn.

Treatment 1 should be relatively free of borers since these plots were sprayed with ½ pound EPN at 5-day intervals throughout first-brood oviposition and with 1 pound of DDT at 10-day intervals throughout the second-brood oviposition period. Treatments 4 and 7 should indicate the numbers of larvae from a natural and an extra heavy first-brood infestation that entered diapause each year. In some years, there are only slight differences in numbers of borers per 100 plants that enter diapause, even though the relationship in egg masses per 100 plants was quite different. These data indicate that more first-brood borers enter diapause in Ohio than in Iowa or Minnesota.

Comparisons between numbers of second-brood borers per 100 plants surviving due to natural infestation and natural infestation + 3 egg masses per plant can be observed in treatments 2 and 3, respectively. In all years and at all locations, more second-brood borers survived in plots where plants received three extra egg masses per plant.

Comparisons among larvae surviving per 100 plants due to natural infestation both broods, natural first- and heavy second-brood infestations, heavy first- and natural second-brood infestations, and heavy infestation both broods may be observed in treatments 5, 6, 8 and 9, respectively. Differences in numbers of borers surviving per 100 plants between treatments 6 and 9 were not significant, indicating that naturally infested first-brood plots receiving three extra egg masses per plant during the second-brood oviposition period produced about as many borers in the fall as plots receiving natural oviposition + 3 egg masses per plant during the oviposition periods of both broods.

Effect of Resistance in Single-Cross Hybrid Corn on Populations

All facets of resistance, as defined by Painter (1951), have been implicated in the complex interrelationship between corn and the European corn borer. The corn borer adult shows preference in selecting a site to oviposit. This preference was determined by earlier workers to be due to physical height of the corn. In oviposition, however, the adult responds preferentially to an array of corn lines, which indicates that factors other than plant height are involved.

Antibiosis as the mechanism of resistance of corn to the first-brood infestation has been the subject of extensive work. Research investigations indicating that chemical factors were partially responsible for the differential numbers of larvae that survive when placed on susceptible and resistant inbred lines and hybrids of corn accelerated when Beck and Stauffer (1957) disclosed the presence of three chemical inhibitors of corn borer growth in corn tissues, one of which was 6-methoxybenzoxazolinone (6MBOA). Some 9 years later, Klun and Brindley (1966) published results of extensive studies indicating that 6MBOA is of little consequence in the corn borer resistance phenomenon but that precursors of 6MBOA may play an active role.

Table 8. Larvae per 100 plants at fall dissection averaged over both plantings and hybrids.

State Year	Treatment[a] 1	2	3	4	5	6	7	8	9
Iowa									
1958. .	36	40	47	103	90	93	182	172	153
1959. .	<1	19	189	2	29	195	2	23	146
1960. .	7	100	357	13	99	405	10	81	334
1961. .	7	108	207	4	84	247	9	73	240
1962. .	6	188	328	6	188	413	5	128	274
Minnesota									
1958. .	6	12	31	3	11	41	12	20	41
1959. .	<1	43	244	1	47	23	2	30	13
1960. .	11	36	117	6	36	92	13	38	114
1961. .	17	37	113	23	43	110	39	57	127
1962. .	6	11	33	10	15	45	17	22	63
Ohio									
1958. .	42	40	147	43	51	158	126	126	217
1959. .	30	108	391	26	100	390	42	94	338
1960. .	64	174	424	67	166	482	130	213	470
1961. .	18	44	118	27	52	128	60	100	196
1962. .	8	47	364	15	60	460	60	118	394

[a] See table 1 for description of treatments.

Tolerance, in this case referring to standing and ear-holding qualities, has been studied by various workers. A comprehensive review of important developments in European corn borer resistance studies was published by Brindley and Dicke (1963).

The importance of the development of the corn plant affecting the degree of infestation of European corn borer was examined in detail by Everett et al. (1958). They compared the progressive development of WF9 x M14 (susceptible) with Oh43 x Oh51A (resistant) for 4 years at three locations and concluded that certain persistent differences in plant development existed between locations within years and among years within a single location. A summary of their findings follows.

The early planting was more advanced in its development until near the end of the season when the late planting in some cases exceeded the early planting in height. The resistant hybrid developed more rapidly after an extended leaf height of 30 to 40 inches was obtained. The resistant hybrid, regardless of planting date, year or location, tasseled and silked from 1 to 4 days earlier than did the susceptible hybrid. The post-pollination ripening period was more prolonged in the resistant than in the susceptible hybrid, resulting in earlier maturation of the susceptible hybrid, although the resistant hybrid was pollinated first.

The same type of data were taken all years in Iowa, 2 years in Minnesota, but not in Ohio. The general conclusions drawn by Everett et al. (1958) fit the Iowa data quite accurately; therefore, discussion of relative

Table 9. Egg masses per 100 plants deposited by first- and second-brood moths on resistant and susceptible corn hybrids planted on different dates.

Year	Hybrid	Iowa First brood	Iowa Second brood	Minnesota First brood	Minnesota Second brood
1958	ES[a]	80.0	10.0	1.0	3.3
	ER	100.0	0	0	3.3
	LS	3.0	30.0	0	20.0
	LR	0	120.0	0	13.3
1959	ES	46.7	16.7	0	39.6
	ER	63.3	3.3	0	13.2
	LS	3.3	30.0	0	23.1
	LR	0	13.3	0	29.7
1960	ES	10.0	30.0	49.5	19.8
	ER	3.3	33.3	33.3	29.7
	LS	13.3	63.3	0	39.6
	LR	0	33.3	0	9.9
1961	ES	33.3	40.0	3.3	6.6
	ER	60.0	50.0	9.9	3.3
	LS	16.7	66.7	0	3.3
	LR	30.0	130.0	0	13.2
1962	ES	46.6	46.6	20.0	0
	ER	33.3	19.9	13.0	16.0
	LS	10.0	106.6	6.0	23.0
	LR	3.3	123.2	10.0	43.0

[a] ES = early-planted susceptible hybrid, ER = early-planted resistant hybrid, LS = late-planted susceptible hybrid, LR = late-planted resistant hybrid.

development of the two hybrids of corn used in the experiment is limited to Iowa.

FIRST-BROOD NATURAL OVIPOSITION

As shown by Everett et al. (1958), first-brood moths had no consistent preference for oviposition on either of the hybrids used in this experiment. The oviposition data for both first and second broods are given in table 9. Data for the Ohio location were not taken. First-brood oviposition was very light in 3 of the 5 years at the Minnesota location. In Iowa, higher first-brood oviposition rates were observed on the early-planted resistant hybrid than on early-planted susceptible hybrid in 3 of the 5 years.

First-brood moths consistently preferred early-planted to late-planted corn for oviposition, but were inconsistent in showing a preference for susceptible or resistant hybrids.

SECOND-BROOD NATURAL OVIPOSITION

Oviposition data for Ohio were not taken. The late-resistant hybrid was preferred for oviposition by second-brood moths in 3 of the 5 years in Iowa and 2 of 5 years in Minnesota (table 9). In all years at both locations, except Minnesota in 1960, the late-planted corn received more oviposition than the early-planted.

These data indicate that, although some oviposition preference for resistant and susceptible corn is exhibited, this preference is not clear-cut for either brood in either early- or late-planted corn. In general, first-brood moths prefer early-planted corn and second-brood moths prefer late-planted corn.

Table 10. First-brood European corn borer larvae per 100 plants at midsummer dissection in treatments 1, 4 and 7.

		Iowa			Minnesota			Ohio		
		Treatment			Treatment			Treatment		
		1	4	7	1	4	7	1	4	7
Year	Hybrid	Spray	Nat.	Nat.+3	Spray	Nat.	Nat.+3	Spray	Nat.	Nat.+3
1958	ES[a]	3	213	400	0	7	243	40	40	400
	ER	13	103	180	0	3	60	33	53	287
	LS	0	13	290	0	7	187	17	27	317
	LR	3	6	63	0	10	70	3	10	163
1959	ES	17	67	213	10	0	12	0	13	280
	ER	17	63	130	0	3	47	0	10	117
	LS	7	20	107	0	83	93	0	3	260
	LR	0	10	20	3	13	57	0	0	87
1960	ES	0	7	83	4	4	79	0	33	270
	ER	0	10	30	0	4	42	0	40	180
	LS	3	0	93	3	7	32	0	27	297
	LR	0	0	50	0	6	25	0	7	90
1961	ES	0	20	130	0	3	97	0	20	450
	ER	0	0	27	7	0	30	7	20	287
	LS	0	23	147	7	10	80	7	3	243
	LR	0	3	37	0	0	3	0	0	63
1962	ES	7	37	223	3	23	172	0	7	260
	ER	0	10	37	3	10	50	0	3	113
	LS	3	0	87	0	10	139	3	3	187
	LR	0	7	17	0	3	40	0	0	43
5-year Av.	ES	5	69	210	4	7	142	8	23	332
	ER	6	37	81	2	4	46	8	25	197
	LS	3	11	145	<1	23	106	5	13	261
	LR	<1	5	37	<1	6	39	<1	3	89

[a] ES = early-planted susceptible hybrid, ER = early-planted resistant hybrid, LS = late-planted susceptible hybrid, LR = late-planted resistant hybrid.

RESISTANCE TO FIRST-BROOD LARVAL SURVIVAL

First-brood borer infestations were sampled in the latter part of July when most of the larvae were in the fifth instar and pupation had just begun. Table 10 shows larval counts from three levels of infestation for the three locations by years. Treatments 1, 4 and 7 represent zero, natural and natural + 3 egg masses per plant levels of infestation, respectively. Plots receiving treatment 1 were sprayed, treatment 4 was the result of natural oviposition, and treatment 7 was accomplished by adding three egg masses per plant to the natural oviposition in that plot.

The data were analyzed by location each year. A summary of analyses of variance is given in table A-1. Differences referred to will be significant (5-percent level) or highly significant (1-percent level); i.e., differences termed significant will be at the 5-percent level as a minimum.

In the early years of this experiment, a treatment of natural infestation + 6 egg masses per plant was used (Everett et al., 1958). These researchers concluded that three egg masses per plant approached the optimum number for maximum larval survival in most cases and that additional egg masses decreased survival to the point that infestations resulting from six egg masses per plant were equal to or only slightly greater than infestations resulting from three egg masses per plant. Therefore, we dropped the six egg masses per plant treatment and used the zero level of infestation for comparisons.

Planting dates showed highly significant differences in 1958, 1959 and 1962 in Iowa and in 1958 and 1961 in Ohio (table A-1). Also, significant differences in planting dates were found in Ohio in 1959 and 1960. Planting dates in Minnesota produced nonsignificant differences in midseason larval survival. When the data were combined and analyzed over years and locations (table A-2), highly significant differences are indicated. These data simply imply that, over the years in Iowa, Minnesota and Ohio, early-planted corn will have more first-brood borers than late-planted corn. The magnitude of this difference is shown in table A-6.

Highly significant differences in borers surviving at midseason due to hybrids (susceptible vs. resistant) were shown in 1958, 1961 and 1962 for Iowa and Minnesota and in 1958, 1959 and 1962 for Ohio. In addition, significant differences were indicated for 1959 in Iowa, 1960 in Minnesota, and 1960 and 1961 in Ohio (table A-1). When analyzed over locations and years, the data indicate that a highly significant larger number of first-brood borers survive on the susceptible compared with the resistant hybrid (table A-6).

Only two planting date x hybrid interactions occurred at the three locations in 5 years. The significant interactions were found in Iowa in 1962 and in Minnesota in 1961. These interactions indicate the failure of the hybrds to act the same in both planting dates to a first-brood infestation. The planting date x hybrid interaction tested nonsignificant when the data were combined over years and locations.

Highly significant differences were found in numbers of larvae at midseason (first brood) due to treatments for all three locations and all 5 years (table 10). Treatment 1 was sprayed at 5-day intervals with EPN and would naturally have very few surviving borers. The natural oviposition + 3 egg mass plots had larger numbers of surviving borers per 100 plants than the naturally infested plots. Generally, higher numbers of borers survived in naturally infested plots in Iowa, followed by Ohio and Minnesota. However, in the natural infestation + 3 egg masses per plant plots, greater numbers of borers per 100 plants survived in Ohio, followed by Iowa and Minnesota. These differences in numbers of borers surviving in the various treatments at the different locations show their effect in the analyses of variance under the treatment x date and treatment x hybrid interactions in the 5-year summaries of analyses of variance (table A-1).

A significant treatment x hybrid interaction indicates that the two hybrids reacted differently to the three levels of infestation. Table 11 shows data for comparison of borer survival rates in the two hybrids at the locations and in the years that significant treatment x hybrid interactions occurred. The primary reason for all the interactions was the disproportionate change in rate of survival of larvae on the two hybrids

Table 11. First-brood borers per 100 plants on hybrids Oh43 x Oh51A (resistant) and WF9 x M14 (susceptible) in years when a treatment x hybrid interaction occurred.

State	Year	Hybrid	Treatment 1 Spray	4 Natural	7 Nat.+3
Iowa	1958....	Susceptible	3	216	690
		Resistant	16	109	243
	1959....	Susceptible	24	87	320
		Resistant	17	73	150
	1961....	Susceptible	0	43	177
		Resistant	0	3	64
	1962....	Susceptible	10	37	310
		Resistant	0	17	54
Minnesota	1961....	Susceptible	7	13	187
		Resistant	7	0	33
	1962....	Susceptible	3	33	311
		Resistant	3	13	90
Ohio	1959....	Susceptible	0	16	540
		Resistant	0	10	204
	1960....	Susceptible	0	60	567
		Resistant	0	47	270
	1961....	Susceptible	7	23	693
		Resistant	7	20	350
	1962....	Susceptible	3	10	447
		Resistant	0	3	156

after they had been artificially infested with three egg masses per plant.

As the level of infestation increased, the reduction due to the resistant hybrid increased also. These data lend supporting evidence to the suggestion by Everett et al. (1958) that the advantage of growing resistant corn is greater during outbreaks than when low levels of borer populations exist.

The over-all effect of hybrid resistance and date of planting on first-brood corn borer infestations are shown in table 12. These data were compiled by averaging the number of borers per 100 plants found at midseason over the 5-year period. The percentage reduction attributed to the resistant hybrid and late planting was calculated from these averages.

In plots where infestations developed from natural oviposition, late planting was more detrimental to the borers than the resistance factors in both Iowa and Ohio. Infestations developing from natural oviposition on late-planted corn in Minnesota were greater than those developing on early-planted corn; however, these Minnesota infestations were relatively small on both early- and late-planted corn. The individual analyses for Minnesota midseason dissections show nonsignificant differences in borer survival at midseason due to planting dates (table A-1).

When percentage reduction are considered in borer survival from plots with higher borer infestations (natural + 3 egg masses), these data indicate that the factors of resistance reduced the survival of first-brood borers at all three locations more than did late planting. The magnitude of the difference between planting date and between hybrids is shown in tables A-6 and A-7. From these data, as well as those presented by Everett et al. (1958), it is evident that the level of infestation is important when discussing the relative effectiveness of late planting and resistant hybrids to reduce borer survival. The percentage reduction of borers due to resistance increased as the borer population increased; the reduction of populations of borers due to late planting in Iowa and Ohio, however, decreased as infestations increased.

The percentage of mature borers or pupae found at midseason is listed in table 13 by years for each location. These data serve as an index to the physiological effect of the resistant hybrid on the development of the borer and, as pointed out by Everett et al. (1958), can only be compared within a given location and year. Comparisons between years and locations in this instance are not legitimate because of the many factors that have been proved to affect borer development, primarily temperature, photoperiod and nutrition. These data do indicate that, without exception, a higher percentage of first-brood borers reaches maturity at midseason on susceptible than on resistant corn. In four of the possible 15 individual comparisons (Iowa 1961, Minnesota 1959, Ohio 1959 and 1962), the late planting produced higher percentages of mature borers by

Table 13. Relative maturity of first-brood borers in the midsummer population expressed as percentage mature borers or pupae.

Year	Hybrid	Iowa	Minnesota	Ohio
1958	ES[a]	94	64	73
	ER	87	47	68
	LS	90	53	69
	LR	73	25	59
1959	ES	91	59	69
	ER	89	47	67
	LS	50	93	76
	LR	50	45	69
1960	ES	100	74	65
	ER	70	77	42
	LS	80	74	51
	LR	73	49	38
1961	ES	91	59	50
	ER	60	36	40
	LS	84	51	34
	LR	80	23	5
1962	ES	93	20	53
	ER	82	8	59
	LS	96	9	81
	LR	71	5	79

[a] ES = early-planted susceptible hybrid, ER = early-planted resistant hybrid, LS = late-planted susceptible hybrid, LR = late-planted resistant hybrid.

Table 12. First-brood borer infestation and percentage reduction in infestation by resistance in Oh43 x Oh51A vs. WF9 x M14 and by late vs. early planting. (Five-year averages.)

		Iowa			Minnesota			Ohio		
		Treatment			Treatment			Treatment		
		1	4	7	1	4	7	1	4	7
Item	Hybrid	Spray	Nat.	Nat.+3	Spray	Nat.	Nat.+3	Spray	Nat.	Nat.+3
Borers/ 100 plants	Susceptible	9.0	28.0	92.8	0.1	15.4	124.2	6.7	17.6	296.4
	Resistant	5.8	15.6	36.9	1.3	5.3	42.2	4.3	14.3	143.0
% reduction by resistant hybrids		35.6	44.3	60.2	36.0	66.0	66.0	35.9	18.8	51.8
Borers/ 100 plants	Early	6.6	31.0	76.3	2.7	5.8	93.8	8.0	23.9	264.4
	Late	8.2	12.1	52.3	0.7	14.9	73.6	3.0	8.0	175.0
% reduction by late planting		−19.5	61.0	31.5	76.0	−15.6	22.7	62.5	66.5	33.8

midseason than the early planting. For the most part, these data agree with the conclusion by Everett et al. (1958) that resistant hybrids and late planting retard the development of first-brood borers.

RESISTANCE TO SECOND-BROOD LARVAL SURVIVAL

European corn borer infestations in the fall were quite variable because of the design of the experiment. As outlined under "Experimental Procedures," three levels of first-brood borer infestations were imposed on three plots each. For second-brood larval-survival tests, three levels of borer infestations (spray, natural and natural + 3 egg masses) were superimposed on each of the three levels of first-brood borer infestations.

Plots receiving treatments 1, 4 and 7 showed relatively low levels of borer infestations because they were sprayed with 1 pound of DDT per acre at 10-day intervals throughout the second-brood oviposition period. Infestations in plots receiving treatments 2, 5 and 8 represent natural second-brood infestations following the zero, natural and natural + 3 egg mass levels of first-brood infestations, respectively. Infestations in treatments 3, 6 and 9 represent the heaviest second-brood infestations following the three levels of first-brood infestation.

Second-brood larval survival data are shown in table 14 for each of the 5 years at each location. Skeleton analyses of variance are shown by location and year in table A-1. The results of the analyses after combining the data over years and locations are shown in table A-2.

The discussion of topics as related to resistance to second-brood larval survival will follow the sources of variation listed in the skeleton analyses of variance in table A-1. The discussion of the effects of planting dates will be followed by a discussion of the effect of hybrids and other variates.

Data analyzed by year and location indicate highly significant differences in planting dates for 4 of 5 years in Iowa and highly significant differences in 2 of 5 years in Ohio. The Minnesota location showed non-significant differences in planting dates with regard to second-brood larval survival for all 5 years. In all analyses that indicated significant differences due to planting dates, the late-planting date produced more borers.

Significant differences in larval survival due to hybrids were indicated in 10 of the 15 analyses. Highly significant differences were noted for Minnesota in 1958, 1960 and 1961; Ohio in 1959-1962; and Iowa

Table 14. Larvae per 100 plants in plots at fall dissection.

State Yr.	Hybrid	Treatment[a] 1	2	3	4	5	6	7	8	9
Iowa										
1958	ES[b] ...	32	72	188	20	68	154	44	78	132
	ER ...	18	74	158	38	80	178	38	78	130
	LS ...	52	138	242	66	88	180	40	108	164
	LR ...	42	130	142	36	122	176	64	108	194
1959	ES ...	0	20	250	2	16	234	0	20	216
	ER ...	0	12	144	2	18	186	2	20	140
	LS ...	2	26	242	2	50	252	2	22	164
	LR ...	0	18	120	0	30	108	2	30	142
1960	ES ...	2	72	424	16	66	386	10	50	400
	ER ...	4	76	360	2	72	452	4	48	386
	LS ...	16	146	326	24	132	412	18	110	284
	LR ...	6	106	320	10	126	372	10	118	268
1961	ES ...	4	76	202	0	90	260	6	60	294
	ER ...	6	50	200	2	30	266	6	62	218
	LS ...	12	164	208	10	130	238	14	82	226
	LR ...	6	142	218	6	88	226	10	90	222
1962	ES ...	10	118	312	8	114	450	4	82	222
	ER ...	0	108	288	0	74	312	4	50	106
	LS ...	10	266	370	12	374	498	8	264	368
	LR ...	2	260	340	4	190	390	2	116	398
Minnesota										
1958	ES ...	4	6	24	2	12	50	10	20	48
	ER ...	0	6	12	2	6	16	8	22	36
	LS ...	8	12	44	4	4	40	16	24	42
	LR ...	0	10	26	2	10	28	2	8	24
1959	ES ...	2	38	268	0	38	302	22	22	220
	ER ...	6	48	274	18	112	284	20	14	196
	LS ...	14	52	238	20	60	208	38	34	200
	LR ...	12	32	196	14	34	272	10	50	178
1960	ES ...	15	28	117	7	42	145	12	33	95
	ER ...	5	36	64	5	32	64	5	35	97
	LS ...	20	54	200	12	42	127	28	48	170
	LR ...	5	17	85	0	28	30	7	35	93

Table 14. (continued)

State Yr.	Hybrid	Treatment[a] 1	2	3	4	5	6	7	8	9
1961	ES ...	22	22	132	26	52	168	62	60	132
	ER ...	8	42	114	18	32	82	16	48	94
	LS ...	24	52	136	28	50	132	52	82	174
	LR ...	12	30	170	20	38	58	36	36	108
1962	ES ...	6	4	44	14	16	60	24	16	58
	ER ...	0	10	14	6	18	36	8	12	50
	LS ...	8	14	56	8	14	56	16	30	64
	LR ...	8	14	16	12	12	26	18	28	40
Ohio										
1958	ES ...	44	16	188	28	36	170	136	184	258
	ER ...	50	42	132	64	44	172	120	104	214
	LS ...	42	74	132	48	68	140	170	142	254
	LR ...	34	30	136	32	56	148	78	72	142
1959	ES ...	46	68	452	18	76	502	48	124	366
	ER ...	10	68	342	16	90	350	32	60	356
	LS ...	34	188	458	44	112	422	54	106	404
	LR ...	28	110	312	26	122	286	36	88	224
1960	ES ...	82	156	396	74	136	438	158	254	536
	ER ...	42	126	350	60	138	570	86	170	460
	LS ...	82	228	628	50	212	556	174	246	550
	LR ...	52	186	324	84	176	364	100	182	336
1961	ES ...	16	56	148	26	52	166	104	148	254
	ER ...	22	36	80	26	52	114	36	126	208
	LS ...	24	46	160	38	64	152	64	70	186
	LR ...	10	38	84	18	38	78	36	54	136
1962	ES ...	2	8	386	32	52	494	112	130	496
	ER ...	6	26	260	4	18	346	40	58	298
	LS ...	12	108	530	16	122	712	64	202	486
	LR ...	10	46	282	8	50	286	22	84	298

[a] See table 1 for description of treatments.
[b] ES = early-planted susceptible hybrid, ER = early-planted resistant hybrid, LS = late-planted susceptible hybrid, LR = late-planted resistant hybrid.

in 1959 and 1962. A significant difference was noted in Iowa in 1960. In all analyses indicating significant differences due to hybrids, the susceptible (WF9 x M14) supported more borers than the resistant (Oh43 x Oh51A).

Only one significant hybrid x date of planting interaction occurred (Minnesota 1959). This interaction was the result of the early-planted resistant hybrid producing more larvae than the early-planted susceptible hybrid.

In the combined analysis (table A-2), dates of planting show nonsignificant differences in second-brood larval survival. However, the effect of hybrids is indicated to be highly significant, with the susceptible hybrid producing more larvae. The magnitude of the difference between hybrids is recorded in tables A-7 and A-8. The significant hybrid x date of planting interaction found in the combined analysis was because differences of the same magnitude were not obtained from the hybrids on each of the planting dates.

The level of natural second-brood infestation is indicated under treatment 2 in table 14. The plots receiving treatment 2 were sprayed with ½ pound of EPN at 5-day intervals throughout first-brood oviposition and used for natural oviposition plots during second brood. The second-brood infestation varied considerably from one location to another within years and also from year to year within locations. The greatest variation within one year occurred in 1962 when the average number of borers per 100 plants was 11, 47 and 188 for Minnesota, Ohio and Iowa, respectively (table 15). The extremes in numbers of second-brood borers per 100 plants for each location during the 5-year period were: Iowa 19-188, Minnesota 9-43 and Ohio 41-174 (table 15).

The effect of the three levels of first-brood infestation on a second-brood infestation was determined by comparing treatments 2, 5 and 8 (table 15). These plots were sprayed, received natural and natural + 3 egg masses, respectively, during first-brood, but all were used as natural oviposition plots during second brood. Everett et al. (1958) state that plots heavily infested by first-brood borers are generally less susceptible to second-brood borer attack. This was not necessarily the case throughout the last 5 years of the study. Numbers of larvae present in treatments 2 and 5 closely approximate each other when all years and locations are considered. When treatments 5 and 8 are compared, however, treatment 8 had slightly fewer borers than treatment 5 in 4 of the 5 years in Iowa; treatment 8 had more borers than treatment 5 in 3 years and less in 1 year and treatments 5 and 8 approximate each other 1 year in Minnesota; in Ohio, treatment 8 had more borers than treatment 5 in 4 of the 5 years.

Table 15. Mean number of larvae per 100 plants in treatments 2, 5 and 8 at fall dissections. Averaged over planting dates and hybrids.

State	First brood / Second brood	Treatment 2 Spray / Natural	Treatment 5 Natural / Natural	Treatment 8 Nat.+3 / Natural
Iowa	1958	103	90	93
	1959	19	29	23
	1960	100	99	82
	1961	108	85	74
	1962	188	188	128
Minnesota	1958	9	8	19
	1959	43	61	30
	1960	34	36	38
	1961	37	43	57
	1962	11	15	22
Ohio	1958	41	51	126
	1959	109	100	95
	1960	174	166	213
	1961	44	52	100
	1962	47	61	119

These data, plus significant treatment x date of planting and treatment x hybrid interactions shown in table A-1, as well as significant treatment x date of planting, treatment x hybrid, treatment x year, and treatment x location interactions shown in table A-2, all indicate that general statements concerning the effect of first-brood infestations on second-brood infestations are not advisable.

In summary, planting dates had very little effect on the survival of second-brood borers in Minnesota, were slightly more effective in Ohio and were highly effective in 4 of 5 years in Iowa. The greatest advantage was gained by using resistant corn in Ohio, but the combination of planting dates and hybrids was most effective in Iowa. When all years and locations are included, the variation in numbers of borers found in the different treatments at the time of second-brood dissections makes statements inadvisable concerning the effects of first-brood infestations on second-brood infestations.

The combined analysis (table A-2) indicates significant differences in treatments. As expected, plots receiving infestations of natural oviposition + 3 egg masses per plant (treatment 8) had higher fall populations of borers than the natural oviposition plots (treatment 5). The natural oviposition plots had higher borer populations than the sprayed plots (treatment 1). The facts of primary importance in the combined analysis are the highly significant interactions noted for location x year, hybrid x date of planting, treatment x hybrid, treatment x date of planting, treatment x year and treatment x location. All these interactions demonstrate a failure of factor (A) to act the same way for all levels of factor (B).

An example is the hybrid x date of planting interaction. Averaged over all years and locations, the resistant hybrid appreciably reduced the borer populations; however, the magnitude of the reduction was greater for first-brood borers than for second-brood borers. At the high infestation level (natural oviposition + 3 egg masses), the resistant hybrid reduced the first-brood borer population by 59.1 percent, and the second-brood population by 25.9 percent (table A-7). Inbred lines or hybrids that are resistant to a first-brood infestation (initial establishment in the whorl by first- and second-instar larvae) are not necessarily resistant to a second-brood infestation (initial establishment primarily on pollen accumulated around the collar and behind the sheath, by first- and second-instar larvae). For example, inbred Oh43 is highly resistant to a first-brood infestation but susceptible to a second-brood infestation. Oh51A is intermediate in resistance to a first-brood infestation, but intermediate to susceptible to a second-brood infestation. Inbreds WF9 and M14 are susceptible to both first- and second-brood borers (Guthrie et al., 1960; Pesho et al., 1965).

Damage by European Corn Borer

As mentioned earlier, Everett et al. (1958) adequately described the damage of the borer to the leaves, stalk and fruiting body of the corn plant. This discussion will be concerned primarily with the effects of the various levels of first- and second-brood infestation on yield of the corn plant.

Losses in yield because of the corn borer are due to several factors. Under severe first-brood infestations, several leaves may be almost completely girdled around the collar; this injury plus leaf blade lesions, caused by larvae feeding in the whorl of the plant, reduce surface area needed for carbohydrate production necessary for high yields. Cavities interfere with translocation of phytosynthetic products throughout the plant and offer sites of entry for stalk rot and other diseases of the corn plant. Cavities also increase lodging of whole plants as well as dropping of ears. The last-mentioned characteristic of cavities is probably the most serious late-season damage caused by the corn borer, especially since the advent of mechanical harvesters.

Estimates of yield for each of the nine treatments are averaged over the 5-year period and shown according to planting date and hybrid in table 16. These yield estimates do not take into account the number of ears that normally would have been lost if harvested by a mechanical harvester. All ears produced on the plots were harvested and included in the estimates of yield, adjusted to 15.5-percent moisture.

As stated by Everett et al. (1958), one objective of the experiment was to test the yielding ability of the two hybrids in spite of corn borer infestations. The most useful method for comparison was to determine the percentage reduction in yield due to corn borer infestations. In table 16, one column shows the average yield of plots receiving treatments 2 through 9. This average was compared with the average yield of plots receiving treatment 1 (sprayed both broods), and a percentage reduction in yield was calculated. This reduction in yield is attributed to the borer.

Within planting dates, the loss in yield due to the corn borer was always greater in the susceptible hybrid plots than in the resistant hybrid plots, except at the Ohio location when a reversal occurred in the early planting. At all three locations, the late-planted susceptible hybrid was more vulnerable to a reduction in yield by the borer than the late-planted resistant hybrid. Average losses in the late-planted susceptible plots were 4.2, 4.8 and 6.1 percent of the yield for Iowa, Minnesota and Ohio, respectively (table 16). Translating the percentage loss to bushels per acre, the figures read 4.5, 5.1 and 5.3 for Iowa, Minnesota and Ohio.

A yearly breakdown of yields for Iowa, Minnesota and Ohio is shown in tables A-3, A-4 and A-5. These tables show estimates of yields by location, year, planting date-hybrid combination and treatment. A skeleton analysis of variances of yields is shown by year and location in table A-1, and table A-2 shows the skeleton analysis of the yield data combined over years and location.

Figs. 7, 8 and 9 depict effects by various levels of corn borer infestations on yields of the four planting date-hybrid combinations in Iowa, Minnesota and

Table 16. Yield in bushels per acre at 15.5 percent moisture and percentage reduction due to infestation by both broods of European corn borer. (Average of 5-years' data.)

	Treatment[a]									Av. yield	%
State Hybrid	1	2	3	4	5	6	7	8	9	2-9	reduction
Iowa											
ES[b]	114.3	116.4	114.0	114.4	114.0	111.1	104.0	104.4	101.6	110.0	3.8
ER	102.5	100.4	99.7	101.0	101.7	99.2	99.4	98.8	97.4	99.7	2.7
LS	108.4	109.1	104.4	110.8	110.5	104.9	100.3	97.5	93.5	103.9	4.2
LR	98.7	98.5	93.6	99.1	95.6	92.8	95.9	93.6	89.6	94.8	4.0
Minnesota											
ES	112.7	106.5	107.6	110.9	110.5	104.8	103.1	101.6	98.2	105.4	6.5
ER	94.5	96.6	89.9	94.8	92.3	90.9	90.5	90.3	84.9	91.3	3.4
LS	105.4	105.4	100.4	105.5	102.9	97.0	98.8	97.7	95.0	100.3	4.8
LR	85.8	85.7	80.8	87.6	85.2	84.1	84.2	82.6	83.5	84.2	1.9
Ohio											
ES	99.2	101.0	97.6	95.5	96.5	90.6	90.3	90.4	84.7	93.3	5.9
ER	89.4	88.1	86.2	85.0	86.4	82.5	80.8	81.0	79.3	83.7	6.4
LS	86.4	85.2	82.7	85.1	85.2	79.9	77.9	79.5	73.0	81.1	6.1
LR	81.5	82.2	78.0	79.4	81.9	77.3	79.5	78.9	75.1	79.0	3.1

[a] See table 1 for description of treatments.

[b] ES = early-planted susceptible hybrid, ER = early-planted resistant hybrid, LS = late-planted susceptible hybrid, LR = late-planted resistant hybrid.

Ohio. For example, in the lower left-hand corner of fig. 7, the effects of three levels of first-brood borer infestation on the late-planted, resistant hybrid are shown by years. The darkly shaded areas represent the average yield for the 5 years. First-brood effects are derived by comparing treatments 1, 4 and 7 representing sprayed, natural oviposition and natural oviposition + 3 egg masses per plant levels of infestation.

Second-brood effects are derived by comparing treatments 1, 2 and 3. Plots receiving treatment 1 were

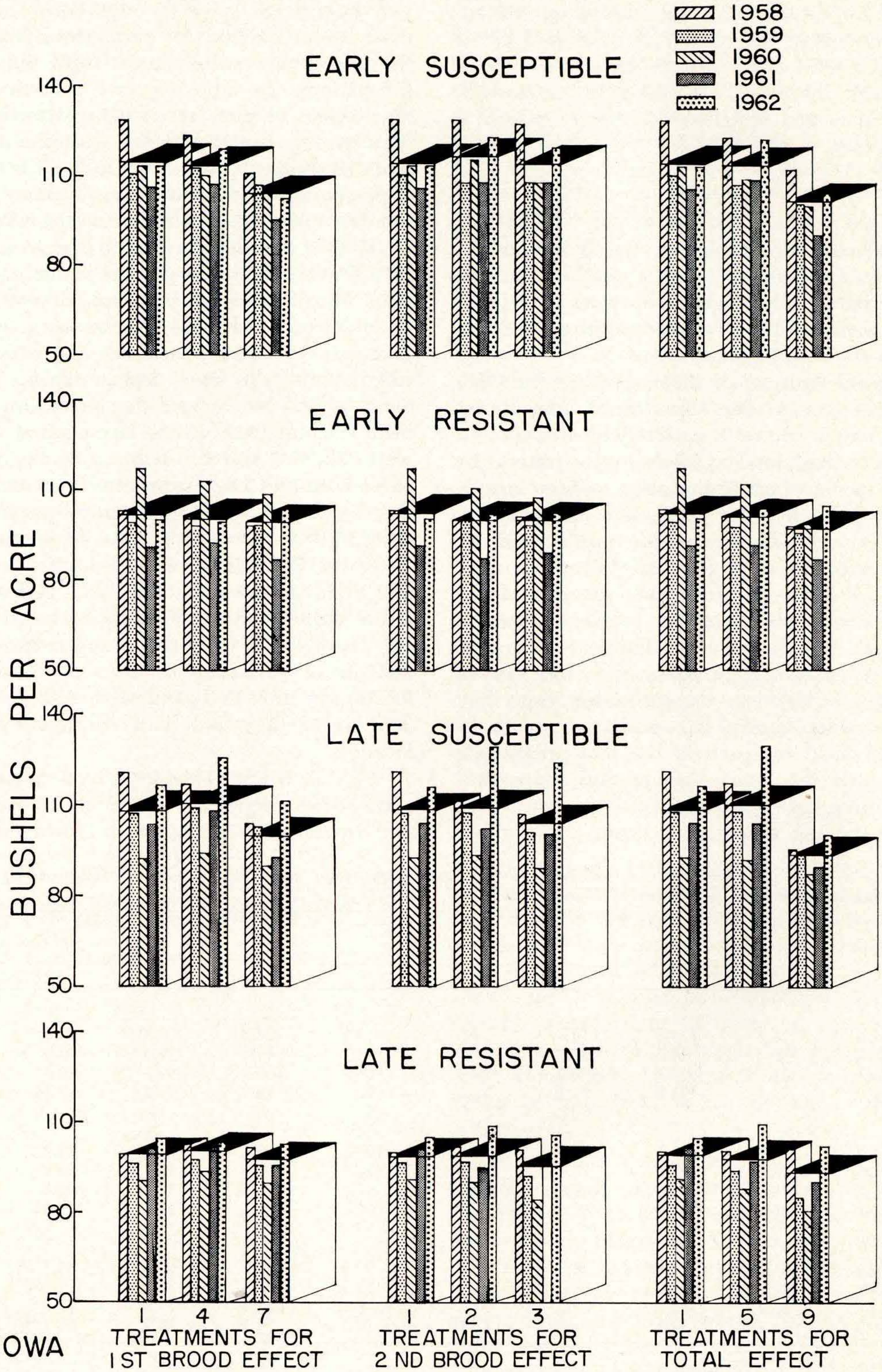


Fig. 7. Mean yields for Iowa shown by planting date-hybrid combination, year and 5-year average.

kept borer-free by spraying. Treatment 2 included a spray for first brood and allowed natural oviposition throughout second brood. Treatment 3 involved eliminating the first brood by spraying and supplementing the natural second brood infestation with 3 egg masses.

In the right-hand column of figs. 7, 8 and 9, treatments 1, 5 and 9 are shown for comparison. These

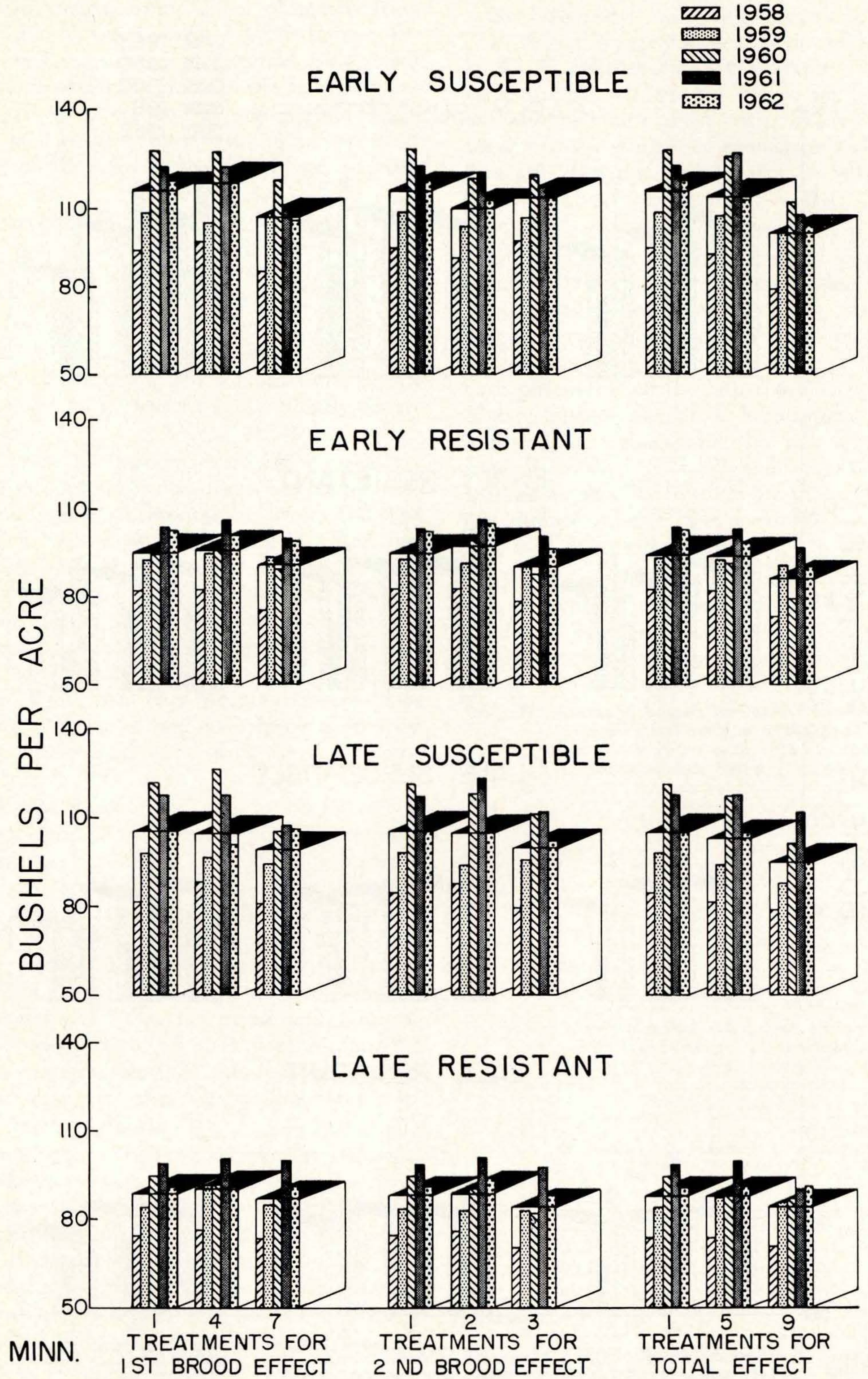


Fig. 8. Mean yields for Minnesota shown by planting date-hybrid combination, year and 5-year average.

treatments represent yields from plots that were sprayed both broods (treatment 1), were allowed natural oviposition populations both broods (treatment 5) and were infested with natural oviposition + 3 egg masses per plant during each brood (treatment 9). These comparisons summarize the effects of zero, natural and heavy infestations of borers throughout the entire season.

The effect of a heavy first-brood infestation on yield is detected rather easily at all locations. The 5-

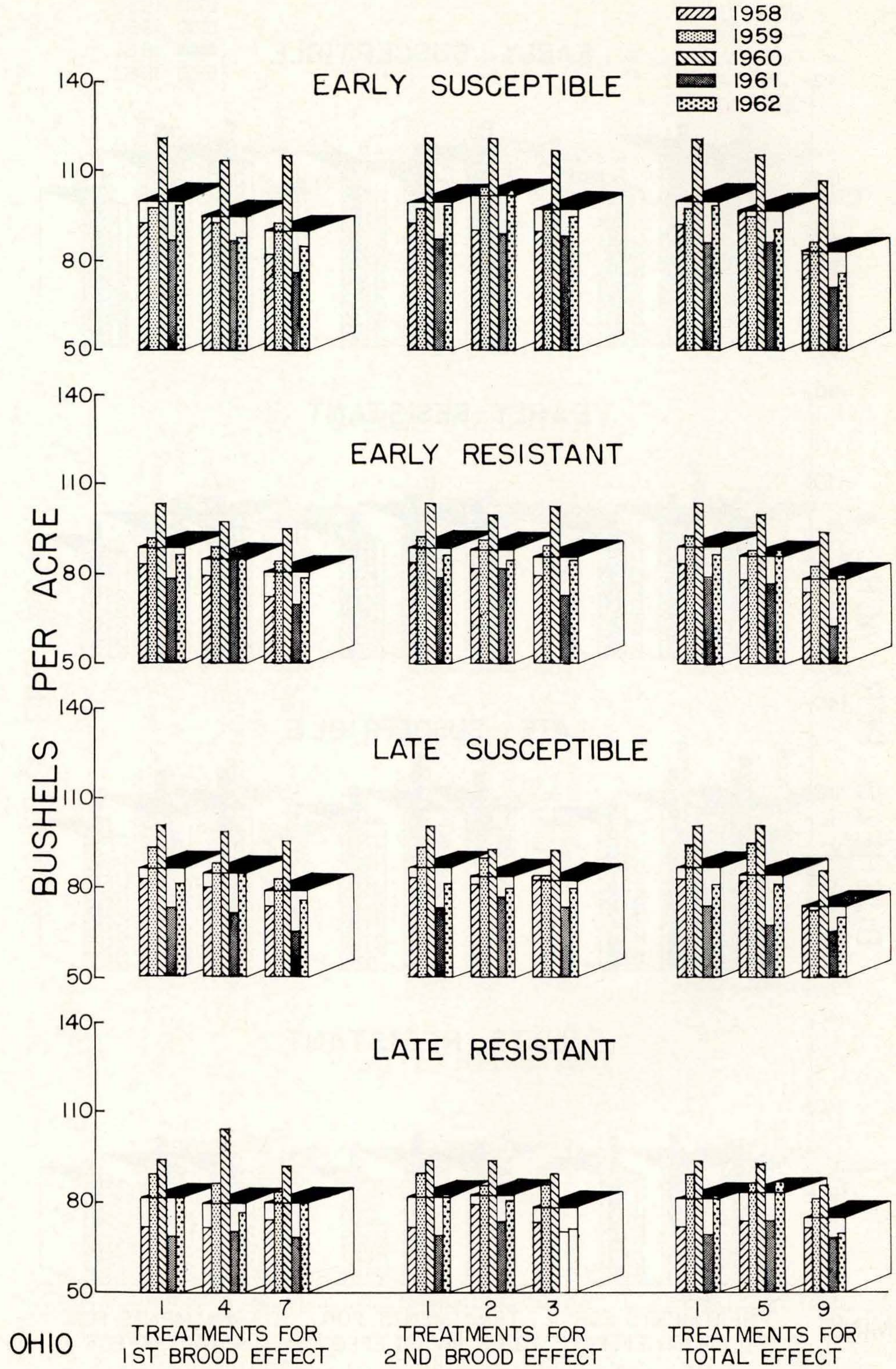


Fig. 9. Mean yields for Ohio shown by planting date-hybrid combination, year and 5-year average.

year average yields (heavily shaded areas) were consistently lower in the heavily infested plots than those obtained from the plots infested by natural oviposition. Ohio was the only location to show consistently that a first-brood infestation developed from natural oviposition will reduce yields from those obtained from sprayed plots. The 5-year average yield figures for comparing sprayed vs. natural oviposition plot yields in Iowa and Minnesota indicate that the naturally infested plots yield equal to, and in some cases better than, the plots that were sprayed with ½ pound EPN at 5-day intervals throughout the first-brood oviposition period.

The center column in figs. 7, 8 and 9 show effects of the three levels of second-brood infestation. Ohio was the only location to show consistently lower 5-year average yields in the heavily infested plots compared with the plots that were naturally infested. Lower 5-year average yields in the heavily infested plots were shown for all planting date-hybrid combinations except the early susceptible in Minnesota and the early resistant in Iowa.

When the 5-year average yields of the sprayed vs. natural oviposition second-brood plots are compared, there are no noticeable differences in Iowa, and the advantage gained by spraying fluctuates in Ohio and Minnesota. These data indicate that the practice of spraying field corn for second-brood borer infestations to increase yields during this 5-year period was debatable in Iowa and helpful only on early-planted susceptible hybrid in Minnesota and on late-planted, susceptible hybrid in Ohio. All ears produced were harvested; losses in quality, as well as losses customarily associated with mechanical harvesting, were not recorded.

The columns near the right margin of figs. 7, 8 and 9 show yearly and 5-year average yields from plots receiving treatments 1, 5 and 9. The three treatments represent three levels of infestation (zero, natural and heavy) during each of the two broods. The effects of the heavy level of infestation during both broods on yield was very evident. Table 17 summarizes these 5-year average losses due to the heavy infestations during both broods (treatment 9) as compared with natural oviposition infestations during both broods (treatment 5). These data reemphasize that the resistant hybrid shows its effect more on the heavier infestations of corn borer than on the lighter.

Table 18 summarizes 5-year average losses due to a first-brood infestation compared with losses due to a second-brood infestation. The resistant hybrid showed its effect primarily against the first brood. Reduction in yield from a second brood was similar in the two hybrids. As stated previously, the resistance of Oh43 x Oh51A is against a first-brood infestation. WF9 x M14 and Oh43 x Oh51A were almost similar in performance (susceptible) against a second-brood infestation.

The analysis of variance resulting from combining the data for yield over years and location (table A-2) is a good index of what actually occurred in this experiment over the years.

The first section of the analysis indicates significant differences in yield for the influence of years, locations and locations x year interactions. The significance of these differences on yield is unquestionable and has been shown in many studies, reviewed and also reported by L. M. Thompson (1962). Also noted is that these same three variables are significant for the combined analysis for borers and cavities in the fall. It is not surprising to the student of ecology to rediscover that factors affecting the environment in which an organism lives also affect the organism.

The second portion of the analysis indicates significant differences for the effects of planting dates and planting date x location interaction on yield. Individual analyses indicate higher yields for early planted corn in Minnesota and Ohio and 2 out of 5 years in Iowa. Within the limits of this experiment, the early-planted corn out produced the late-planted corn by an average of 6.8 bushels per acre. Within the three locations, however, the magnitude of this average difference ranged thusly: 5.4 bushels in Iowa, 6.3 bushels in Minnesota and 8.6 bushels in Ohio (table A-9). The last figures are the reason for the significant planting date x location interaction.

The third portion of the analysis deals with the effect of hybrids and their interactions on yields. Averaged over locations during this 5 years of the study, the susceptible hybrid outproduced the resistant hybrid by

Table 17. Losses in bushels per acre from four planting date-hybrid combinations due to the addition of 3 egg masses per plant during each brood as compared with natural infestations each brood (Five-year average).

	Planting date-hybrid combination			
State	Early susceptible	Early resistant	Late susceptible	Late resistant
Iowa	12.4	4.3	17.0	6.0
Minnesota	12.3	7.4	7.9	1.7
Ohio	11.8	7.1	12.2	6.8

Table 18. Losses in bushels per acre from a first-brood infestation (treatment 1 minus treatment 7) compared with a second-brood infestation (treatment 1 minus treatment 3).[a] Summary of treatments 1, 3 and 7 from table 16 (Five-year average).

	Planting date-hybrid combination							
	Early susceptible		Early resistant		Late susceptible		Late resistant	
State	First brood	Second brood	First brood	Second brood	First brood	Second brood	First brood	Second brood
Iowa	10.0	0.3	3.1	2.8	8.1	4.0	2.8	5.1
Minnesota	9.6	5.1	4.0	4.6	6.6	5.0	1.6	5.0
Ohio	8.9	1.6	8.6	3.2	8.5	3.7	2.0	3.5
Average	9.5	2.3	5.2	3.5	7.7	4.2	2.1	4.5

[a] Treatment 1 = Insecticide treated for both broods.
Treatment 3 = Natural oviposition + 3 second-brood masses; insecticide treated for first-brood control.
Treatment 7 = Natural oviposition + 3 first-brood masses; insecticide treated for second-brood control.

10.4 bushels per acre (table A-9). That significant hybrid x planting date, hybrid x year and hybrid x location interactions exist cannot be overlooked. The hybrid x planting date interaction indicates that the hybrids did not react identically with respect to the two planting dates. The susceptible outproduced the resistant hybrid by 11.6 bushels per acre in the early planting and by 9.3. bushels per acre in the late planting (table A-9). The yielding ability of WF9 x M14 is greater than that of Oh43 x Oh51A. Many combinations of resistant x resistant crosses have outyielded susceptible x susceptible crosses (Penny and Dicke, 1959). The hybrid x year interaction occurred because of irregularity of difference in production of the two hybrids. During the 5 years, those differences in yield between the susceptible and resistant hybrid ranged from 6.0 to 15.6, but averaged 10.4 bushels per acre (table A-9). The hybrid x location interaction is because the susceptible outproduced the resistant hybrid by 9.8, 15.6 and 6.0 bushels in Iowa, Minnesota and Ohio (table A-9). Again, this interaction was significant because of the magnitude of differences at the three locations. The fourth and final portion of the analyses deals with the effect of the levels of borer infestation and their interactions with date of planting, hybrid, location and years on yield.

The number of significant interactions, as shown by individual year-location analyses in table A-1, leads us to believe that almost every factor interacts with the borer to affect yield. When the location and year effects are withdrawn as individual components in the combined analysis, however, most of the interactions of borer infestation with the other variables were nonsignificant.

Treatments in the combined analysis are averaged over years, locations, planting dates and hybrids. Table 19 shows the average yields of various combinations of treatments chosen to indicate the over-all effects of three levels of first brood, second brood and both broods on yield of corn. These data indicate that, under natural oviposition infestation pressures, one can expect increases of about 2.5 bushels per acre by spraying for first-brood infestation, 2.7 bushels per acre by spraying for second brood and 3.3 bushels per acre by spraying for both broods. As expected, the greatest increases were obtained by spraying when the infestation pressure was high. Compared with the sprayed plots, natural oviposition + 3 egg masses per plant decreased the yield 8.2 bushels per acre for the first brood, 5.5 bushels per acre for the second brood and 12.3 bushels per acre for plots infested with both broods. Before these decreases in average yield computations are taken too seriously, two things should be pointed out. First, natural oviposition counts have rarely exceeded 100 egg masses per 100 plants since the early 1950's, and when a natural oviposition + 3 egg masses per plant is encountered, the egg masses per 100 plant count approach 325-375 for each brood. Second, the yield figures quoted include ears of corn that dropped because of lodged stalks or broken shanks, which would have been lost with a mechanical harvester.

The resistant hybrid reduced the first-brood infestation. However, the susceptible hybrid (WF9 x M14) outyielded the resistant hybrid (Oh43 x Oh51A) in spite of a corn-borer infestation. The yielding ability of WF9 x M14 is considerably greater than that of Oh43 x Oh51A. Therefore, a higher level of first-brood infestation than occurred in our plots would be required to recommend planting Oh43 x Oh51A in preference to WF9 x M14. Oh43 in combination with other inbreds has given much higher yields than reported herein. Penny and Dicke (1959) reported yield losses of susceptible x susceptible, susceptible x resistant and resistant x resistant crosses under a heavy first-brood infestation. All the resistant x resistant crosses had a distinct advantage in yield compared with the susceptible x susceptible crosses. WF9 x N16 had a yield loss of 30.4 bushels per acre under a first-brood infestation; the susceptibility of WF9 appeared completely dominant to the resistance of N16.

In the past, several methods have been used to evaluate European corn-borer damage on yields. Patch et al. (1938) used the number of larvae per plant as an index to yield loss with the univoltine strain of borer. Later, Patch et al. (1942) were responsible for what became known as a standard index for reduction in yield due to the borer. They estimated a 3-percent loss per borer per plant, based on numbers of larvae in the fall. Everett et al. (1958) demonstrated an inverse relationship between leaf lesions resulting from first-

Table 19. Yield in bushels per acre as affected by various levels of European corn borer infestations. Data averaged over years, locations, planting dates and hybrids.

Treatment or	First brood			Second brood Treatments			Both broods		
comparison[a]	1	4	7	1	2	3	1	5	9
First brood	S	N	N+3	S	S	S	S	N	N+3
Second brood	S	S	S	S	N	N+3	S	N	N+3
	99.8	97.3	91.6	99.8	97.1	94.3	99.8	96.6	87.6
S vs. N	+2.5			+2.7			+3.3		
S vs. N+3	+8.2			+5.5			+12.3		
N vs. N+3		+5.7			+2.8			+ 9.0	

[a] S = sprayed
N = natural
N+3 = natural + 3 egg masses

brood infestation and yield, but concluded that the best index of yield loss was the number of cavities or larvae per plant at the time of midseason dissections. Everett et al. (1958) and later Kwolek and Brindley (1959) showed that the number of cavities in the stalk was a more reliable index of yield loss than the number of larvae.

Using data from the 1958-59 NC-20 plots, Jarvis et al. (1961) found that, when yield losses occurred, the reductions were due to either infestation by first- or second-brood larvae, or a summation of the two, without an additional effect due to an interaction of infestation by both broods. They also found that first-brood infestation resulted in greater yield losses than did infestation by the second brood, that greater reductions per unit of damage occurred in late rather than in early planting, and that cavities and leaf lesions were a better index of damage than larvae. Jarvis et al. (1961) state that the "3-percent loss per borer per plant," based on the number of larvae found in the fall, is not an accurate measure of borer damage because first-brood larvae do the greatest damage, but

Table 20. Number of leaf lesions per 100 plants in plants at midsummer dissection (first brood).

		Iowa			Minnesota			Ohio		
		Treatment			Treatment			Treatment		
		1	4	7	1	4	7	1	4	7
Year	Hybrid	Spray	Nat.	Nat.+3	Spray	Nat.	Nat.+3	Spray	Nat.	Nat.+3
1958	ES[a]	43	510	883	0	40	1330	23	43	250
	ER	63	313	473	0	0	116	33	33	130
	LS	20	23	700	0	23	700	13	10	200
	LR	6	30	117	0	7	126	7	13	87
1959	ES	17	67	213	0	20	1300	3	40	213
	ER	17	63	130	10	20	330	13	57	117
	LS	7	20	107	120	130	1580	0	0	293
	LR	0	10	20	10	30	310	3	6	140
1960	ES	3	50	227	235	155	1600	13	107	220
	ER	0	47	110	42	32	412	23	70	197
	LS	0	7	223	22	184	2810	7	13	260
	LR	3	0	87	0	43	462	7	3	57
1961	ES	7	123	621	0	77	1087	7	20	250
	ER	20	137	247	40	0	177	0	30	147
	LS	3	40	813	7	113	710	0	3	113
	LR	7	23	213	17	20	77	3	0	30
1962	ES	50	120	646	6	30	156	7	20	143
	ER	53	110	250	23	13	113	10	3	60
	LS	10	10	446	0	13	16	10	17	313
	LR	37	54	246	0	10	70	13	13	90

[a] ES = early-planted susceptible hybrid, ER = early-planted resistant hybrid, LS = late-planted susceptible hybrid, LR = late-planted resistant hybrid.

Table 21. Cavities per 100 plants in the stalks at midsummer dissection (first brood).

		Iowa			Minnesota			Ohio		
		Treatment			Treatment			Treatment		
		1	4	7	1	4	7	1	4	7
Year	Hybrid	Spray	Nat.	Nat.+3	Spray	Nat.	Nat.+3	Spray	Nat.	Nat.+3
1958	ES[a]	3	320	583	0	13	310	54	93	437
	ER	16	173	257	0	0	138	67	57	317
	LS	3	13	330	0	7	193	23	40	310
	LR	3	0	63	0	10	80	7	17	123
1959	ES	0	33	200	17	3	150	3	67	460
	ER	3	30	70	0	17	70	7	60	243
	LS	0	0	27	0	20	197	3	3	327
	LR	0	0	17	3	13	97	0	0	130
1960	ES	0	60	147	42	45	340	0	93	377
	ER	0	37	163	32	25	187	3	63	220
	LS	7	3	270	12	54	368	0	27	257
	LR	0	0	103	15	33	157	0	3	90
1961	ES[a]	3	70	490	3	20	207	0	57	527
	ER	3	70	180	10	0	53	10	30	273
	LS	10	43	430	10	10	157	3	0	147
	LR	0	3	160	3	0	20	0	0	47
1962	ES	23	123	593	3	43	177	3	27	350
	ER	20	83	223	10	3	100	0	20	163
	LS	3	10	260	0	13	143	7	10	267
	LR	0	53	117	0	10	37	0	0	60

[a] ES = early-planted susceptible hybrid, ER = early-planted resistant hybrid, LS = late-planted susceptible hybrid, LR = late-planted resistant hybrid.

Table 22. Cavities per 100 plants in the stalks at fall dissection (first and second brood).

State	Yr.	Hybrid	Treatment[a] 1	2	3	4	5	6	7	8	9
Iowa											
	1958	ES[b]	130	236	546	322	426	624	544	538	686
		ER	52	220	446	188	260	350	244	334	598
		LS	152	354	628	184	334	564	368	578	682
		LR	76	340	436	72	358	470	184	300	492
	1959	ES	8	50	742	38	142	740	206	334	808
		ER	4	42	460	80	98	576	92	114	546
		LS	6	94	658	8	132	688	60	140	612
		LR	2	94	392	2	68	466	18	96	476
	1960	ES	34	188	942	124	242	804	270	440	998
		ER	12	196	826	40	272	980	102	224	848
		LS	42	344	720	84	346	838	250	464	812
		LR	68	123	738	40	326	810	140	374	740
	1961	ES	14	244	618	70	336	678	374	448	876
		ER	10	192	392	52	180	686	106	286	658
		LS	34	434	696	40	414	728	274	516	662
		LR	16	326	530	30	270	536	122	314	600
	1962	ES	36	352	836	118	428	1076	528	700	1046
		ER	6	228	684	106	252	610	164	296	652
		LS	12	558	1068	38	756	1086	258	840	1000
		LR	6	496	744	20	400	718	116	374	820
Minnesota											
	1958	ES	29	22	150	24	40	154	364	262	258
		ER	24	32	84	14	40	98	86	124	204
		LS	32	30	138	12	40	132	174	222	264
		LR	4	46	100	12	40	96	76	68	198
	1959	ES	7	28	227	10	41	259	101	117	266
		ER	5	45	219	19	28	244	51	36	191
		LS	15	44	175	18	46	175	87	100	204
		LR	11	31	166	10	44	208	34	72	174
	1960	ES	93	120	368	53	145	403	200	270	388
		ER	32	116	264	33	116	286	125	120	400
		LS	64	144	468	28	140	380	216	264	638
		LR	15	67	250	23	93	196	100	140	270
	1961	ES	120	106	416	128	154	460	318	300	662
		ER	38	108	312	78	124	184	138	164	298
		LS	92	184	476	110	156	416	196	358	514
		LR	52	72	262	58	112	300	108	126	342
	1962	ES	34	26	170	74	88	256	246	244	274
		ER	4	36	142	24	88	252	114	94	188
		LS	28	56	254	32	78	222	158	194	430
		LR	18	50	154	48	62	222	84	138	266
Ohio											
	1958	ES	160	124	430	176	146	450	528	608	778
		ER	108	108	302	132	124	352	374	410	542
		LS	108	152	294	84	162	322	536	508	612
		LR	102	78	240	68	114	282	224	236	342
	1959	ES	102	170	1016	96	264	1188	438	592	1136
		ER	34	154	864	74	314	944	284	296	1026
		LS	96	536	1180	118	342	1092	344	566	1096
		LR	60	346	896	68	372	866	212	368	830
	1960	ES	148	268	792	200	334	880	562	662	1106
		ER	82	214	534	144	264	832	266	370	780
		LS	122	430	972	84	388	968	546	670	1102
		LR	88	284	556	114	318	666	262	370	602
	1961	ES	64	136	318	98	152	390	518	494	792
		ER	20	108	188	50	138	240	252	384	480
		LS	44	104	400	82	146	394	238	298	566
		LR	20	100	208	38	74	192	112	166	294
	1962	ES	16	26	772	58	144	994	356	422	1014
		ER	8	50	534	6	54	624	174	174	586
		LS	12	252	966	22	228	1206	490	490	1022
		LR	10	100	506	16	116	496	178	178	542

[a] See table 1 for description of treatments.
[b] ES = early-planted susceptible hybrid, ER = early-planted resistant hybrid, LS = late-planted susceptible hybrid, LR = late-planted resistant hybrid.

very few first-brood larvae are found in the fall. Their data indicated that, regardless of the criterion used, the damage index is subject to change from year to year and probably from location to location.

Numbers of leaf lesions found on plants at the time of midseason or first-brood dissections are shown in table 20. At the high level of infestation (natural oviposition + 3 egg masses) and averaged over all years, both planting dates and all locations, the susceptible hybrid had significantly more lesions than the resistant hybrid (614.1 vs. 171.4 per 100 plants) (table A-11). The early and late plantings had about the same number of lesions (tables A-10 and A-11).

Cavities produced by the first-brood borers, as measured in treatments 1, 4 and 7, are shown in table 21, and cavities at the time of fall dissections are given in table 22. The data from these two tables support work previously reported by many researchers. There are definite differences in the numbers of cavities found in the susceptible and resistant hybrids. The results of individual year-location analyses of variance of cavities at midsummer and in the fall are shown in table A-1. These data indicate that a general index of yield losses based on cavities would encounter a multiplicity of problems. Note that, within years, a tremendous amount of variation in cavities is found and that years within the same locality produce equally-much variation. These facts are further complicated by the numbers of significant interactions at the three locations.

The data for cavities found at midseason and in the fall were combined over years and locations for analyses (table A-2). The significant location x year interaction in the midseason cavities analysis indicates a failure of the borers at each of the locations to affect the corn in the same relationship to each other year after year. In other words, the ranking of locations by numbers of cavities might read Iowa, Minnesota and Ohio in one year and then read Minnesota, Ohio and Iowa in the following year. Averaged over years and locations, the early-planted corn had significantly more cavities at midseason than did the late-planted (111.9 vs. 61.0 per 100 plants) (table A-12), and the susceptible hybrid had more cavities than the resistant hybrid (117.6 vs. 55.3) (table A-12). As expected, the natural + 3 egg masses per plant infestation produced more cavities (301.0 per 100 plants for the susceptible hybrid vs. 131.9 on the resistant hybrid) (table A-14) than the untreated natural infestation which produced more than the sprayed plots. However, interactions of treatment x hybrid and treatment x planting date are indicated.

In the combined analysis for cavities in the fall, significant differences due to location, year and a location x year interaction are shown (table A-1). The year x location interaction exists because Minnesota had as many cavities as Iowa in 1959 and more than Ohio in 1961. Means for cavities per location over the 5-year period were approximately equal for Iowa and Ohio and both had significantly more cavities than

Minnesota. More cavities were found in 1961 than in other years.

Nonsignificant differences were determined for cavities found in the fall due to planting dates and their interactions with years and locations. The susceptible hybrid had significantly more cavities in the fall than the resistant hybrid (358.1 vs. 239.4 per 100 plants) (table A-13).

The combined analysis for cavities in the fall indicates significant differences due to treatments and all two-factor interactions involving treatments. These data indicate that treatments produce unequal numbers of cavities and that the magnitude of these inequalities depends upon hybrids, planting dates, year and location of the study.

Simple correlation coefficients for borers, cavities or lesions with yield are shown for the Iowa midseason dissection data in table 23. The correlation coefficients were computed with data taken from plots receiving treatments 1, 4 and 7. The same type of computations were made on the Iowa fall data using all treatments. These simple correlation coefficients are shown in table 24.

The correlations for the Iowa midseason data are erratic. More significant correlations were found in the susceptible hybrid than with any of the remaining variables, regardless of planting date. The same statement is applicable to the correlation coefficients computed by using the fall data, except that the late resistant planting date-hybrid combination shows highly significant correlation coefficients for both larvae and yield, and cavities and yield for the years 1959, 1960 and 1961.

Table 23. Correlations of various midseason indices of borer infestations with yields. Iowa, 1958-1962.

Planting	Variables correlated	df	r value and significance				
			1958	1959	1960	1961	1962
Early planting	leaf lesions and yield	28	−0.136	−0.007	−0.018	−0.340	−0.234
	larvae and yield	28	−0.088	−0.145	−0.019	−0.184	−0.071
	cavities and yield	28	−0.123	−0.059	−0.129	−0.294	−0.224
Early susceptible	leaf lesions and yield	13	−0.734**	−0.442	−0.530*	−0.779**	−0.641**
	larvae and yield	13	−0.886**	−0.482	−0.384	−0.791**	−0.639
	cavities and yield	13	−0.836**	−0.600*	−0.413	−0.829**	−0.648**
Early resistant	leaf lesions and yield	13	−0.431	−0.123	−0.453	−0.431	−0.238
	larvae and yield	13	−0.462	−0.149	−0.579*	−0.578*	−0.323
	cavities and yield	13	−0.445	−0.089	−0.547*	−0.361	−0.457
Late planting	leaf lesions and yield	28	−0.245	−0.102	−0.048	−0.652**	−0.488**
	larvae and yield	28	−0.257	−0.449*	0.007	−0.482**	−0.295
	cavities and yield	28	−0.233	−0.187	0.038	−0.518**	−0.413*
Late susceptible	leaf lesions and yield	13	−0.864**	−0.345	−0.486	−0.757**	−0.703**
	larvae and yield	13	−0.874**	−0.481	−0.406	−0.567*	−0.662**
	cavities and yield	13	−0.869**	−0.434	−0.534*	−0.660**	−0.717**
Late resistant	leaf lesions and yield	13	−0.161	−0.089	−0.426	−0.524*	−0.235
	larvae and yield	13	−0.148	−0.325	−0.485	−0.194	−0.005
	cavities and yield	13	−0.101	−0.282	−0.500	−0.315	−0.251
All plots	leaf lesions and yield	58	..	..	0.012	−0.496**	−0.364**
	larvae and yield	58	..	..	−0.016	−0.273*	−0.171
	cavities and yield	58	..	..	−0.033	−0.402**	−0.331**

* Significant at 5-percent level
** Significant at 1-percent level

Table 24. Correlations of borers and cavities with yield; data taken during fall dissection. Iowa, 1958-1962.

Planting	Variables correlated	df	r value and significance				
			1958	1959	1960	1961	1962
Early planting	larvae and yield	88	0.013	−0.161	−0.156	−0.053	−0.186
	cavities and yield	88	0.087	−0.214*	−0.147	−0.072	−0.123
Early susceptible	larvae and yield	43	−0.088	−0.413**	−0.339**	−0.164	−0.223
	cavities and yield	43	−0.509**	−0.592**	−0.546**	−0.393**	−0.227
Early resistant	larvae and yield	43	−0.168	−0.129	−0.564**	−0.230	−0.147
	cavities and yield	43	−0.303*	−0.246	−0.594**	−0.295*	−0.016
Late planting	larvae and yield	88	−0.134	−0.281*	−0.142	−0.251*	−0.053
	cavities and yield	88	−0.184	−0.360**	−0.191	−0.399**	0.029
Late susceptible	larvae and yield	43	−0.252	−0.556**	−0.327*	−0.094	−0.013
	cavities and yield	43	−0.618**	−0.682**	−0.546**	−0.421**	0.206
Late resistant	larvae and yield	43	−0.018	−0.558**	−0.460**	−0.518**	0.091
	cavities and yield	43	−0.012	−0.586**	−0.595**	−0.578**	0.077
All plots	larvae and yield	178	..	..	−0.146	−0.128	−0.134
	cavities and yield	178	..	..	−0.167	−0.204**	−0.055

* Significant at 5-percent level
** Significant at 1-percent level

Tables 25 and 26 show the results of pooling over years and locations and computing correlation coefficients for several variables from data collected at midseason and in the fall. Correlation coefficients for the midseason indexes of borer infestations and yield indicate that borers and yield were highly and significantly correlated for all planting date-hybrid combinations. The data also indicate that cavities and yield are better correlated in the early than in the late plantings. Borers and cavities, as shown many times before, are highly correlated. Correlation coefficients were computed and found highly significant for cavities found in midseason with borers found in the fall.

The combined correlation coefficient data for fall dissections (table 26) reemphasize the high correlation between borers and cavities. These two variables were the only ones highly correlated for all planting date-hybrid combinations. Borers and yield, as well as cavities and yield, were highly correlated with respect to the susceptible hybrid only. With the data averaged over years and location, correlation coefficients for borers and yield and cavities and yield were not significant when early or late planting, the resistant hybrid or all plots were involved.

Guthrie et al. (1960) found that leaf feeding ratings, as an index to the degree of damage caused by first- and second-instar larvae and lesion counts, as an index to the degree of damage caused by third- and fourth-instar larvae, are good criteria for determining the degree of resistance of most inbred lines to a first-brood infestation. Leaf feeding ratings were not taken in this experiment. However, the magnitude of the difference between the susceptible and resistant hybrids was much greater in the lesion data than in the larval data (tables A-7 and A-11).

Pesho et al. (1965) used the degree of stalk and ear-shank damage (cavities) as criteria for evaluating resistance or susceptibility of inbred lines to a second-brood infestation.

Plant damage as an index of relative resistance in inbred lines or hybrids to a first- or second-brood infestation is used in resistance investigations in preference to insect counts because many factors, including insect diseases, predation and parasitism, can result in the absence of viable insect forms at the time of examination even though extensive plant damage is present (Guthrie et al., 1960; Pesho et al., 1965).

The NC-20 plots at the Iowa location were used in an effort to determine the percentage loss due to both first- and second-brood borer infestations. Yields for 1959-1962 were converted to percentage loss by using treatment 1 (sprayed both broods) as the base so that the equations give an estimate of percentage loss in yield per borer using both first- and second-brood borers. The general equation for computing percentage loss was of the form:

Table 25. Correlations of various indices of borer infestations and yield. Data collected at midseason from all locations. 1958-1962.

Planting	Variables correlated[a]	df	r value and significance
Early planting	borers and yield	448	–0.181 **
	cavities and yield	448	–0.128 **
	borers and cavities	448	0.851 **
	cavities (m) and borers (f)	448	0.384 **
Early susceptible	borers and yield	223	–0.312 **
	cavities and yield	223	–0.245 **
	borers and cavities	223	0.873 **
	cavities (m) and borers (f)	223	0.356 **
Early resistant	borers and yield	223	–0.301 **
	cavities and yield	223	–0.253 **
	borers and cavities	223	0.763 **
	cavities (m) and borers (f)	223	0.410 **
Late planting	borers and yield	448	–0.158 **
	cavities and yield	448	–0.040
	borers and cavities	448	0.753 **
	cavities (m) and borers (f)	448	0.273 **
Late susceptible	borers and yield	223	–0.296 **
	cavities and yield	223	–0.164 *
	borers and cavities	223	0.744 **
	cavities (m) and borers (f)	223	0.272 **
Late resistant	borers and yield	223	–0.189 **
	cavities and yield	223	–0.066
	borers and cavities	223	0.694 **
	cavities (m) and borers (f)	223	0.139 *
All plots	borers and yield	898	–0.147 **
	cavities and yield	898	–0.056
	borers and cavities	898	0.820 **
	cavities (m) and borers (f)	898	0.320 **

[a] (m) = midseason, (f) = fall

* Significant at 5-percent level

** Significant at 1-percent level

Table 26. Correlations among borers, cavities, and yield. Data collected during fall at all locations. 1958-1962.

Planting	variables correlated	df	r value and significance
Early planting	borers and yield	1348	–0.064 *
	cavities and yield	1348	–0.032
	borers and cavities	1348	0.870 **
Early susceptible	borers and yield	673	–0.134 **
	cavities and yield	673	–0.154 **
	borers and cavities	673	0.853 **
Early resistant	borers and yield	673	–0.071
	cavities and yield	673	–0.096 *
	borers and cavities	673	0.903 **
Late planting	borers and yield	1348	–0.049
	cavities and yield	1348	–0.020
	borers and cavities	1348	0.886 **
Late susceptible	borers and yield	673	–0.154 **
	cavities and yield	673	–0.158 **
	borers and cavities	673	0.873 **
Late resistant	borers and yield	673	0.008
	cavities and yield	673	0.038
	borers and cavities	673	0.908 **
All Plots	borers and yield	2698	–0.063
	cavities and yield	2698	–0.022
	borers and cavities	2698	0.876 **

* Significant at 5-percent level

** Significant at 1-percent level

$$100 - 100 \frac{\text{(Yield from plots other than treatment 1)}}{\text{(Yield from treatment 1 plots)}}$$

Nonlinearity of response was assumed; therefore, a quadratic of the following form was used:

$$\hat{\gamma} = \alpha + \beta_1 X_1 + \beta_2 X_1^2 + \beta_3 X_2 + \beta_4 X_2^2 + \epsilon$$

where $\hat{\gamma}$ = predicted percentage loss in yield

X_1 = average number of borers at midseason

X_2 = average number of borers in the fall

α and β = parameters to be estimated

ϵ is $N(0,\sigma)$

A total of five regression equations were computed, one for each planting date-hybrid classification and one for the combined data. These equations are listed:

Early susceptible:

$$\hat{\gamma} = -1.9995 + 1.6158 X_1 - 0.04638 X_1^2 + 0.02077 X_2 - 0.00003709 X_2^2$$

$R^2 = 0.4511$

Early resistant:

$$\hat{\gamma} = -0.5614 + 1.3206 X_1 + 0.1077 X_1^2 + 0.003029 X_2 + 0.00002370 X_2^2$$

$R^2 = 0.1833$

Late susceptible:

$$\hat{\gamma} = 0.1301 + 2.0071 X_1 - 0.05737 X_1^2 + 0.02075 X_2 - 0.00002959 X_2^2$$

$R^2 = 0.3693$

Late resistant:

$$\hat{\gamma} = -0.3610 + 2.4531 X_1 - 0.4330 X_1^2 + 0.03908 X_2 - 0.00007416 X_2^2$$

$R^2 = 0.1147$

Data combined:

$$\hat{\gamma} = -0.7276 + 1.5982 X_1 - 0.04863 X_1^2 + 0.02323 X_2 - 0.00003453 X_2^2$$

$R^2 = 0.2721$

These equations are not very satisfactory for two reasons: (1) The R^2 (coefficient of determination) values are low and (2) there are reversals in signs for the early resistant quadratic equation.

After due deliberation, a bias due to the large number of zeros in the data was suggested. With this in mind, the data were transformed thusly, $X' = \log(X + 0.5)$. Since logs are curvilinear functions, the new equations should have been linear; i.e., $\hat{\gamma} = \alpha + \beta_1 \log(X_1 = 0.5) + \beta_2 \log(X_2 + 0.5)$. The regressions were rerun; however, the results were not improved.

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APPENDIX A

Appendix A-1. Summary of individual analyses of variance by years and locations.

		Borers midseason			Cavities midseason			Borers fall			Cavities fall			Yield		
Year	Source	Iowa	Minn.	Ohio	Iowa	Minn.	Ohio	Iowa	Minn.	Ohio	Iowa	Minn.	Ohio	Iowa	Minn.	Ohio
1958	Dates	**		**	**		**	**					**	**	*	**
	Hybrids	**	**	**	**	**	**		**		**	**	**	**	**	**
	DH													**		*
	Treatments	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
	TD	**			**	*				*	**			**		**
	TH	**			**	**	*			**	**	**	*	**		**
	TDH									*				**		
1959	Dates	**		*	**		**			*	**		*	**	**	**
	Hybrids	*		**	*		**	**		**	**	**	**	**		
	DH								*					*		
	Treatments	**	**	**	**	**	**	**	**	**	**	**	**	**	*	**
	TD	*			**		**			**	**	**	**	*		
	TH	*		**	*		**	**			**	**	*			
	TDH											*	**			
1960	Dates			*		**	**								*	**
	Hybrids		*	*		*	**	*	**	**	**	**	**	**	**	**
	DH													**		**
	Treatments	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
	TD						**	**			**	**	**	*		*
	TH			**		*	**		*	*	**	**	**	**	**	
	TDH									**		**			*	
1961	Dates			**	**		**	**					**	*	*	**
	Hybrids	**	**	*	**	**			**	**	**	**	**	**	**	**
	DH		*											**		*
	Treatments	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
	TD			**	*		**	**		*	**		**			
	TH	**	**	**	**	**					**	**	**	**	**	
	TDH											*				
1962	Dates	**			**	**	*	**		*				*	**	**
	Hybrids	**	**	**	**	**	**	**		**	**	**	**	**	**	*
	DH	**												**		
	Treatments	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
	TD	**		*	*			**		**	**	**	**		*	
	TH	**	**	**	**	**	**	*		**	**	**	**	**		
	TDH									*		*				

* Significant at 5-percent level
** Significant at 1-percent level

Appendix A-2. Summary of analyses of variance for five variables. Data combined over years and locations. Iowa, Minnesota and Ohio, 1958-1962.

Source	df	Midseason Borers	Midseason Cavities	Fall Borers	Fall Cavities	Yield
Locations ..	2	NS	NS	*	*	*
Years	4	*	NS	*	*	*
LY	8	NS	**	**	**	**
Dates	1	**	**	NS	NS	**
DY	4	NS	NS	NS	NS	NS
DL	2	NS	*	NS	NS	*
DYL	8	NS	NS	NS	NS	NS
Hybrid	1	**	**	**	**	**
HD	1	NS	NS	**	NS	*
HY	4	NS	NS	NS	NS	**
HL	2	NS	NS	NS	NS	**
HDY	4	NS	NS	NS	NS	NS
HDL	2	*	NS	NS	*	NS
HYL	8	NS	NS	NS	NS	NS
HDYL	8	NS	NS	NS	NS	NS
Treatments .	8 (2)[a]	**	**	**	**	**
TH	8 (2)	**	**	**	**	**
TD	8 (2)	*	**	**	**	NS
TY	32 (8)	NS	NS	**	**	NS
TL	16 (4)	**	NS	**	**	NS
THD	8 (2)	NS	NS	NS	NS	NS
THY	32 (8)	NS	NS	NS	NS	NS
THL	16 (4)	NS	NS	NS	NS	NS
TDY	32 (8)	NS	NS	NS	NS	NS
TDL	16 (4)	NS	*	**	**	*
TYL	64 (16)	NS	NS	**	**	NS
THDY	32 (8)	NS	NS	NS	NS	NS
THDL	16 (4)	NS	NS	NS	NS	NS
THYL	64 (16)	NS	NS	NS	NS	NS
TDYL	64 (16)	NS	NS	NS	NS	NS
THDYL	64 (16)	NS	NS	NS	NS	NS

* Significant at 5-percent level

** Significant at 1-percent level

NS nonsignificant

[a] For midseason analysis

Appendix A-3. Yield in bushels per acre at 15.5 percent moisture, Iowa.

Year	Hybrid	Treatment 1	2	3	4	5	6	7	8	9
1958	ES ..	128.6	128.4	126.8	123.2	122.3	121.2	110.9	114.0	111.8
	ER ..	103.5	100.1	101.3	101.7	102.0	99.3	97.9	99.7	98.5
	LS ..	120.6	111.8	107.0	117.0	117.6	111.6	104.1	99.7	95.7
	LR ..	99.7	101.9	100.6	103.0	100.5	102.9	101.4	100.0	100.2
1959	ES ..	110.6	107.9	108.2	112.7	107.7	101.8	106.6	101.9	100.7
	ER ..	99.8	100.1	98.3	98.4	98.1	99.1	98.8	98.8	96.4
	LS ..	107.6	108.1	100.9	109.3	108.4	101.8	103.5	102.8	93.9
	LR ..	96.3	96.5	92.6	97.5	94.1	87.8	95.8	93.3	85.5
1960	ES ..	113.2	114.9	108.2	109.9	109.1	108.7	104.8	103.8	99.9
	ER ..	117.2	111.4	107.3	113.2	112.2	108.0	109.1	101.0	99.0
	LS ..	93.2	93.5	90.0	93.6	91.8	87.7	90.0	90.6	87.5
	LR ..	91.2	89.8	84.4	93.5	88.4	86.6	89.0	87.2	80.5
1961	ES ..	105.9	108.0	107.8	107.3	108.6	104.3	95.0	97.3	90.5
	ER ..	91.4	87.9	89.2	92.6	91.5	88.8	87.4	87.1	87.8
	LS ..	103.8	102.6	100.5	108.5	104.3	98.1	92.2	88.4	90.2
	LR ..	101.4	95.1	94.6	101.2	97.1	92.4	96.3	92.2	90.2
1962	ES ..	113.2	122.7	119.0	118.7	122.1	119.5	102.8	104.8	104.9
	ER ..	100.8	102.5	102.4	99.2	104.9	101.0	104.0	107.4	105.5
	LS ..	117.0	129.5	123.7	125.8	130.2	125.1	111.9	105.8	100.3
	LR ..	104.9	109.4	95.6	100.4	98.0	94.5	97.0	95.3	91.7

Appendix A-4. Yield in bushels per acre at 15.5 percent moisture, Minnesota.

Year	Hybrid	Treatment 1	2	3	4	5	6	7	8	9
1958	ES ..	93.2	89.1	95.3	95.7	91.4	85.0	85.8	86.8	78.8
	ER ..	81.9	82.6	77.7	81.7	81.5	79.2	73.5	78.7	74.7
	LS ..	84.3	88.2	79.3	88.2	80.9	80.3	80.4	79.3	77.7
	LR ..	74.0	75.2	69.4	75.1	73.7	71.5	73.0	72.7	70.7
1959	ES ..	105.8	100.4	103.4	101.5	103.7	96.6	105.3	103.2	98.1
	ER ..	92.8	91.0	91.7	94.9	92.2	90.9	93.0	87.0	90.4
	LS ..	98.0	94.0	96.3	95.8	94.7	92.9	94.5	94.3	88.1
	LR ..	83.2	82.5	82.5	91.6	86.7	84.1	84.2	81.3	85.5
1960	ES ..	126.2	116.3	118.2	125.5	123.3	116.7	116.0	106.4	109.0
	ER ..	94.4	99.0	87.3	95.3	91.0	93.4	89.3	88.5	78.9
	LS ..	121.9	118.6	112.4	124.9	117.1	106.8	105.6	111.9	101.5
	LR ..	93.9	89.4	81.1	91.2	87.0	90.2	86.6	84.3	86.5
1961	ES ..	121.7	118.1	114.4	121.0	125.1	117.1	105.5	106.8	104.0
	ER ..	101.7	105.3	96.3	101.1	98.3	95.4	98.3	98.7	90.3
	LS ..	117.9	121.8	112.7	117.5	117.4	109.4	107.5	107.8	112.3
	LR ..	89.9	93.4	87.4	90.7	91.3	88.6	90.7	88.9	90.3
1962	ES ..	116.4	108.6	106.5	110.9	109.2	108.7	102.9	104.7	100.9
	ER ..	101.7	105.3	96.3	101.1	98.3	95.4	98.3	98.7	90.3
	LS ..	105.1	104.3	101.5	101.0	104.6	95.7	106.0	95.2	95.3
	LR ..	87.8	88.2	83.6	89.6	87.5	86.1	86.7	85.7	84.5

Appendix A-5. Yield in bushels per acre at 15.5 percent moisture, Ohio.

Year	Hybrid	. . Treatment . . 1	2	3	4	5	6	7	8	9
1958	ES ..	93.0	90.0	90.4	94.9	95.5	89.7	81.6	77.8	81.6
	ER ..	83.6	81.6	80.0	79.7	78.4	73.3	73.5	74.8	74.7
	LS ..	82.6	81.5	83.4	80.3	82.3	82.5	74.1	76.4	73.7
	LR ..	72.6	79.3	72.9	72.3	74.2	76.8	73.7	77.6	71.3
1959	ES ..	98.1	105.5	97.5	92.9	94.7	87.9	93.0	94.5	87.0
	ER ..	93.4	92.0	90.6	90.4	87.9	86.7	85.3	84.4	83.3
	LS ..	94.0	89.7	84.1	88.7	94.9	77.8	83.2	78.3	72.5
	LR ..	91.4	86.2	85.8	87.4	86.8	83.0	82.9	82.9	81.4
1960	ES ..	121.7	121.3	117.8	114.9	116.5	113.8	115.4	115.7	107.5
	ER ..	104.8	99.9	102.4	98.8	100.7	95.4	96.0	95.6	95.2
	LS ..	101.3	95.4	93.3	99.9	101.9	94.8	92.1	92.3	86.3
	LR ..	94.1	91.5	90.0	93.2	94.5	88.4	90.6	89.3	86.4
1961	ES ..	84.4	89.2	87.7	86.5	84.2	78.5	76.2	75.3	71.2
	ER ..	78.2	81.5	72.7	70.1	77.3	73.0	70.2	64.8	62.7
	LS ..	72.9	79.4	73.4	71.5	66.2	68.0	65.3	69.3	64.8
	LR ..	67.5	73.2	69.9	69.5	76.6	65.7	68.1	63.4	66.8
1962	ES ..	98.9	104.0	94.6	88.2	91.5	83.3	85.4	88.7	76.0
	ER ..	87.1	85.6	85.2	86.2	87.8	83.9	79.2	85.6	80.4
	LS ..	81.1	80.0	79.3	84.9	80.9	76.3	74.9	81.2	67.7
	LR ..	82.0	81.0	71.4	74.7	77.3	72.4	82.0	81.1	69.4

Appendix A-6. **Number of first-brood European corn borer larvae per 100 plants by planting date, hybrid and location (summary of data from table 10, midsummer dissection) 1958-1962.**

Item	Iowa	Minnesota	Ohio	Average over locations
Early planting[a]	68.0	30.5	98.8	65.8
Late planting	33.6	29.6	62.0	41.7
Difference	34.4	0.9	36.8	24.1
WF9 x M14[b]	73.8	43.8	106.9	74.8
Oh43 x Oh51A	27.9	16.3	53.9	37.7
Difference	45.9	27.5	53.0	37.1
Early susceptible[c]	94.7	43.8	120.9	86.4
Early resistant	41.3	17.3	76.7	45.1
Difference	53.4	26.5	44.2	41.3
Late susceptible	52.9	43.9	92.9	63.2
Late resistant	14.4	15.3	31.1	20.3
Difference	38.5	28.6	61.8	42.9

[a] Averaged over both hybrids, all treatments, and 5 years.
[b] Averaged over both planting dates, all treatments, and 5 years.
[c] Averaged over all treatments, and 5 years.

Appendix A-8. **Number of larvae per 100 plants by planting date, hybrid and location (summary of data from table 14, fall dissection, first and second brood) 1958-1962.**

Item	Iowa	Minnesota	Ohio	average over locations
Early planting[a]	108.7	50.3	152.2	103.8
Late planting	134.1	51.6	155.7	113.8
Difference	25.4	1.3	3.5	10.0
WF9 x M14[b]	131.6	58.4	181.6	123.9
Oh43 x Oh51A	111.2	43.6	126.3	93.7
Difference	20.4	14.8	55.3	30.2
Early susceptible[c]	117.4	55.6	170.5	114.5
Early resistant	100.0	45.1	133.9	93.0
Difference	17.4	10.5	36.6	21.5
Late susceptible	145.8	61.2	192.8	133.3
Late resistant	122.4	42.0	118.7	94.4
Difference	23.4	19.2	74.1	38.9

[a] Averaged over both hybrids, all treatments, and 5 years.
[b] Averaged over both planting dates, all treatments, and 5 years.
[c] Averaged over all treatments, and 5 years.

Appendix A-7. **Number of larvae per 100 plants from an infestation by a natural + 3 first-brood egg masses vs. a natural + 3 second-brood egg masses (by planting date, hybrid and location; summary of data for treatment 7 from table 10 and treatment 3 from table 14) 1958-1962.**

Item	Iowa		Minnesota		Ohio		Averaged over location	
	7	3	7	3	7	3	7	3
	Nat. + 3		Nat. + 3		Nat. + 3		Nat. + 3	
	First brood	Second brood	First brood	Second brood	First brood	Second brood	First brood	Second brood
Early planting[a]	145.5	252.6	94.0	106.3	264.5	273.4	252.0	210.8
Late planting	91.0	252.8	72.5	116.7	175.0	304.6	169.3	224.7
Difference	54.5	0.2	21.5	10.4	89.5	31.2	87.7	13.9
WF9 x M14[b]	177.5	276.4	124.0	125.9	296.5	347.8	199.3	250.0
Oh43 x Oh51A	59.0	229.0	42.5	97.1	143.0	230.2	81.5	185.4
Difference	118.5	47.4	81.5	28.8	153.5	117.6	117.8	64.6
Percentage reduction due to resistant hybrid							59.1	25.9
Early susceptible[c]	210.0	275.2	142.0	117.0	332.0	314.0	228.0	235.4
Early resistant	81.0	230.0	46.0	95.6	197.0	232.8	108.0	186.1
Difference	129.0	45.2	96.0	21.4	35.0	81.2	120.0	49.3
Late susceptible	145.0	277.6	106.0	134.8	261.0	381.6	170.7	264.7
Late resistant	37.0	228.0	39.0	98.6	89.0	227.6	55.0	184.7
Difference	108.0	49.6	67.0	36.2	172.0	154.0	115.7	80.0

[a] Averaged over both hybrids and 5 years.
[b] Averaged over both planting dates and 5 years.
[c] Averaged over 5 years.

Appendix A-9. Average yield in bushels per acre compared by planting date, hybrid and location (summary of data from table 16) 1958-1962.

Item	Iowa	Minnesota	Ohio	Average over locations
Early planting[a]	105.2	98.9	89.1	97.8
Late planting	99.8	92.6	80.5	91.0
Difference	5.4	6.3	8.6	6.8
WF9 x M14[b]	107.4	103.6	87.8	99.6
Oh43 x Oh51A	97.6	88.0	81.8	89.2
Difference	9.8	15.6	6.0	10.4
Early susceptible[c]	110.5	106.2	94.0	103.6
Early resistant	100.0	91.6	84.3	92.0
Difference	10.5	14.6	9.7	11.6
Late susceptible	104.4	100.9	81.7	95.6
Late resistant	95.3	84.4	79.3	86.3
Difference	9.1	16.5	2.4	9.3

[a] Averaged over both hybrids, all treatments, and 5 years.
[b] Averaged over both planting dates, all treatments, and 5 years.
[c] Averaged over all treatments and 5 years.

Appendix A-10. Average number of lesions per 100 plants by planting date, hybrid and location. (Summary of data from table 20; midsummer dissection, first brood). 1958-1962.

Item	Iowa	Minnesota	Ohio	Average over locations
Early planting[a]	187.1	245.5	76.1	169.5
Late planting	109.4	253.7	57.5	140.2
Difference	77.7	8.2	18.6	29.3
WF9 x M14[b]	200.3	415.5	87.0	234.3
Oh43 x Oh51A	96.2	83.7	46.5	75.4
Difference	104.1	331.8	40.5	158.9
Early susceptible[c]	238.7	402.4	90.6	243.9
Early resistant	135.5	88.5	61.5	95.2
Difference	103.2	313.9	29.1	148.7
Late susceptible	161.9	428.5	83.5	224.6
Late resistant	56.9	78.8	31.5	55.7
Difference	105.0	349.7	52.0	168.9

[a] Averaged over both hybrids, all treatments, and 5 years.
[b] Averaged over both planting dates, all treatments, and 5 years.
[c] Averaged over all treatments and 5 years.

Appendix A-11. Number of lesions per 100 plants from an infestation by a natural + 3 first-brood egg masses (by planting date, hybrid and location; summary of data for treatment 7 from table 20). 1958-62.

Item	Iowa	Minnesota	Ohio	Averaged over locations
Early planting[a]	380.0	662.1	172.7	404.9
Late planting	297.2	686.1	158.3	380.5
Difference	82.8	24.0	14.4	24.4
WF9 x M14[b]	488.0	1128.9	225.5	614.1
Oh43 x Oh51A	189.3	219.3	105.5	171.4
Difference	298.7	909.6	120.0	442.7
Early susceptible[c]	518.0	1094.6	215.2	609.3
Early resistant	242.0	229.6	130.2	200.6
Difference	276.0	865.0	85.0	408.7
Late susceptible	457.8	1163.2	235.8	618.9
Late resistant	136.6	209.0	80.8	142.1
Difference	321.2	954.2	155.0	476.8

[a] Averaged over both hybrids and 5 years.
[b] Averaged over both planting dates and 5 years.
[c] Averaged over 5 years.

Appendix A-12. Number of cavities per 100 plants by planting date, hybrid and location. (Summary of data from table 21, midsummer dissection, first brood.) 1958-1962.

Item	Iowa	Minnesota	Ohio	Average over locations
Early planting[a]	132.5	67.3	136.0	111.9
Late planting	64.3	55.4	63.4	61.0
Difference	68.2	11.9	72.6	50.9
WF9 x M14[b]	135.2	85.2	132.4	117.6
Oh43 x Oh51A	61.6	37.4	67.0	55.3
Difference	73.6	47.8	65.4	62.3
Early susceptible[c]	176.5	91.5	169.9	146.0
Early resistant	88.5	43.0	102.2	77.9
Difference	88.0	48.5	67.7	68.1
Late susceptible	93.9	78.9	94.9	89.3
Late resistant	34.6	31.9	31.8	32.8
Difference	59.3	47.0	63.1	56.5

[a] Averaged over both hybrids, all treatments, and 5 years.
[b] Averaged over both planting dates, all treatments, and 5 years.
[c] Averaged over all treatments and 5 years.

Appendix A-13. Number of cavities per 100 plants by planting date, hybrid and location. (Summary of data from table 22, fall dissection, first and second brood). 1958-1962.

Item	Iowa	Minnesota	Ohio	Average over locations
Early planting[a]	374.5	154.4	379.1	302.7
Late planting	374.4	146.9	363.3	294.9
Difference	0.1	7.5	15.8	7.8
WF9 x M14[b]	438.8	185.3	450.1	358.1
Oh43 x Oh51A	310.0	116.0	292.3	239.4
Difference	128.8	69.3	157.8	118.7
Early susceptible[c]	443.1	188.3	447.1	359.5
Early resistant	305.9	120.5	311.1	245.8
Difference	137.2	67.8	136.0	113.7
Late susceptible	434.6	182.3	453.1	356.7
Late resistant	314.2	111.5	273.6	233.1
Difference	120.4	70.8	179.5	123.6

[a] Averaged over both hybrids, all treatments, and 5 years.
[b] Averaged over both planting dates, all treatments, and 5 years.
[c] Averaged over all treatments and 5 years.

Appendix A-14. Number of cavities per 100 plants from an infestation by a natural + 3 first-brood egg masses vs. a natural + 3 second-brood egg masses (by planting date, hybrid and location; summary of data for treatment 7 from table 21 and treatment 3 from table 22) 1958-62.

	Iowa		Minnesota		Ohio		Averaged over locations	
	7	3	7	3	7	3	7	3
	Nat. + 3		Nat. + 3		Nat. + 3		Nat. + 3	
Item	First brood	Second brood	First brood	Second brood	First brood	Second brood	First brood	Second brood
Early planting[a]	290.6	649.2	173.2	235.2	336.7	575.0	266.8	486.5
Late planting	177.7	661.0	144.9	244.3	175.8	621.8	166.1	509.0
Difference	112.9	11.8	28.3	9.1	160.9	46.8	100.7	22.5
WF9 x M14[b]	333.0	745.4	224.2	284.2	345.9	714.0	301.0	581.2
Oh43 x Oh51A	135.3	564.8	93.9	195.3	166.6	482.8	131.9	414.3
Difference	197.7	180.6	130.3	88.9	179.3	231.2	169.1	166.9
Early susceptible[c]	402.6	736.8	236.8	266.2	430.2	665.6	356.5	556.2
Early resistant	178.6	561.6	109.6	204.2	243.2	484.4	177.1	416.7
Difference	224.0	175.2	127.2	62.0	187.0	181.2	179.4	139.5
Late susceptible[c]	263.4	754.0	211.6	302.2	261.6	762.4	245.5	606.2
Late resistant	92.0	568.0	78.2	186.4	90.0	481.2	86.7	411.9
Difference	171.4	186.0	133.4	115.8	171.6	281.2	158.8	194.3

[a] Averaged over both hybrids and 5 years.
[b] Averaged over both planting dates and 5 years.
[c] Averaged over 5 years.