DIFFERENTIAL DAMAGE TO THE FEMALE INFLORESCENCE OF CORN, *ZEA MAYS* L., BY THE CORN ROOTWORMS *DIABROTICA VIRGIFERA* LECONTE, *DIABROTICA LONGICORNIS* (SAY) AND *DIABROTICA UNDECIMPUNCTATA HOWARDI* BARBER. CHRYSOMELIDAE: COLEOPTERA

by

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INTRODUCTION

Many writers consider that some of the most important pests of corn are the corn rootworms of the genus *Diabrotica*. In the corn belt the western corn rootworm, *Diabrotica virgifera* Lec., and the northern corn rootworm, *Diabrotica longicornis* (Say), are the most important. On the other hand, the southern corn rootworm, *Diabrotica undecimpunctata howardi* Barber, is frequent in the greater part of the United States east of the Rocky Mountains, in southern Canada and in Mexico, but is more abundant and destructive in the southern part of its range.

It is considered that the larval stages of the three species are the most harmful to corn because the larvae feed in and on the roots, and when the infestation is heavy, the corn plants will lodge resulting in poorly filled kernels and rotten ears. Lodging makes it more difficult to harvest mechanically. However, the adults of the three species feed on all parts of the corn plant above the ground and their damage to the silks is thought to interfere with pollination and hence with fecundation.

The corn rootworm problem was sizably reduced with the discovery and use of organic synthetic insecticides. However, the large scale soil treatments for the control of the larvae, using exclusively chlorinated hydrocarbons, have resulted in recent years in the development of resistance to these insecticides by the northern and western species. Due to this new problem, more time and effort is being devoted to obtaining varieties of corn resistant to the root damage.

So far tolerance, which is an ability to regenerate roots, has been the only component of resistance found in the promising varieties. The only exception is the inbred Indiana 38-11, which is believed to have an antibiotic effect on the larvae of southern corn rootworm.

One of the effects of the resistant varieties upon insect population, when the variety has an antibiotic effect on the insect and when it is planted in a large area, is an overall reduction of the population throughout the years. This hardly will be reached with the use of tolerant varieties. Hence the number of adults emerging from a plot with resistant (tolerant) varieties and a plot with susceptible varieties would be expected to be about the same under similar levels of infestation.

Since the adults feed on the tassel, on the leaves, on the silks and developing kernels, the search for resistant varieties to corn rootworm should include silk and kernel damage as well as root damage.

Very little is known of the relation of damage to the silks with possible interference with the normal pollination. This work was organized to obtain information about the extent and differential damage to the silks by the adults of corn rootworm.

LITERATURE REVIEW

Biology of Northern and Western Corn Rootworm

Generally speaking, both species have a similar biology. The eggs overwinter in the soil where they are laid near the base of the corn plant in the middle of the summer (Metcalf, Flint and Metcalf, 1962). Ball (1957) determined that "23% of the eggs are laid in the upper two inches of the soil, 58% in the upper four inches, 80% in the upper six inches and that the remaining 20% of the eggs are probably laid below the six inch level."

The eggs do not hatch until the following spring, however the diapause can be broken artifically by chilling the eggs for prescribed periods at various temperatures (Cunningham and Peters, 1964). Work done by Chiang (1965) with diapausing eggs of northern corn rootworm, proves that some eggs will naturally remain in diapause for two years.

Eiche (1953) in Kansas, Ball (1957) and Tate and Bare (1946) in Nebraska dealing with western corn rootworm biology, and Smith (1961) in Wisconsin dealing with the northern species, agree that the eggs will hatch late in the spring and the larvae will work through the ground until they encounter the roots of corn upon which they feed. After three moults, which will occur during a period from 25 to 45 days, the larvae will go into the pupal stage which lasts approximately two weeks. Beetles emerge and are present in the corn field feeding on leaves, pollen, silks and developing kernels, from mid July to September, with the peak population in mid August. Eggs are ready to be laid by a week to 10 days after appearance of the adults of the single generation each year. The larvae, as far as is known (Metcalf, Flint and Metcalf, 1962) feed exclusively in corn roots, but the adults of both species (Hamilton, 1965), have been found on common sunflower, *Heliantus annuus* L., Maximilian sunflower, *H. maximilinai* Schad, Ashy sunflower, *H. mollis*, Goldenrod *Solidago missouriensis* Nutt., etc. He also pointed out that only the northern species is found in alfalfa, however Kaufmann (1965) reports the presence of adults of the western species in alfalfa.

Biology of Southern Corn Rootworm

Contrasting with the biology of the northern and western species, the eggs of the southern corn rootworm do not remain in the soil during the winter in Kansas, but the adults which migrate from the south (Metcalf, Flint and Metcalf, 1962), (Smith and Allen, 1932), appear at the latitude of Iowa in early June (Sweetman, 1926) and begin oviposition immediately. The larval stage lasts approximately 21 days and the pupal stage 2 weeks. The larvae of this species are general feeders developing on roots of corn, beans, small grains, alfalfa and many wild grasses (Metcalf, Flint and Metcalf, 1962). The damage done to corn by the larvae of this species is similar to the damage done by the other two species and consists mainly (Bigger, 1941) of root pruning and tunneling. The adults of southern corn rootworm are general feeders, and besides corn, they feed on more than 200 common weeds, grasses, cucurbits, and cultivated crops. According to Smith (1932) the adults migrate northward in the spring and the offspring migrate back to the south during the fall, with none surviving the winter north of central Missouri. He reported two generations per year in the corn belt states.

Damage to Corn

Larvae. The larvae of the three species, generally speaking, do the same kind of damage to the corn roots. Bryson (1953) gave an accurate description of the damage done by the western species to the corn roots. According to his description "The larval feeding period usually coincides with the time at which field corn normally makes its most rapid growth. Where larval concentrations are high all the main roots and rootlets are tunneled or cut off. Often the roots and bases of the stalks are so badly damaged that decay organisms gain entrance and completely destroy the roots. Plants damaged to this extent offer no resistance when an attempt is made to pull them from the soil, and lodge during a wind or rain storm."

This lodging results in some cases in failure to produce ears, and the ears produced have a considerable variation in size and weight. There also may be further loss due to attack by birds, rodents and decay organisms. Peters (1961), reported that in a survey made in the main corn producing counties in Kansas, it was possible to detect reduction of yield between plants lodged because of corn rootworm damage to the roots, and normal ones, by means of actual count of kernels. Hill (1948) reported that in an experiment performed in Nebraska, a highly significant correlation was found between lodging and loss of yield. He also pointed out that an extra factor of loss in yield is the fact that when harvest is done with mechanical pickers part of the crop remains in the field because the plants lodged severely, 60° or more, cannot be harvested.

Luginbill (1922) reported a different damage done by the larvae of the southern species. The damage is done by the larvae boring in the seedling stem, above the first circle of roots, boring out the crown and killing the bud. This damage kills the plant and under severe infestations no stand of corn can be secured. This kind of damage has not been reported in literature from the corn belt.

Loss due to corn rootworm larvae injury. Burkhardt (1961) in Kansas, estimated that the total loss in the 1953 corn crop due to the damage done by the *D. virgifera* and *D. longicornis* larvae was about 2.5 million dollars, and considered that in 1960 a total of $1,807,911.00, which was the 2.1% of the value of the corn crop, was lost for the same reason. When considering the north central counties alone, the actual yield loss increased to 9.82% of the total. According to Anderson (1953) in Iowa, heavily infested plots could lose up to 50 bushels per acre if no larval control was practiced.

Cutkomp (1954) estimated that at least 7% of the farmers planting corn in the southern part of Minnesota had some evidence of damage done by northern corn rootworm in 1953.

Adult. The beetles of the three species feed upon every part of the growing corn plant above the ground. Sifuentes and Painter (1964) reported that under field conditions the adults of D. virgifera caused severe damage to foliage of 37 day old corn plants. However, Ball (1952) and Bryson et al. (1953) also reported this kind of damage, but considered it of minor importance.

Attempts to correlate leaf feeding with root damage have failed (Ortman, personal communication). However, preference for extracts of different parts of the corn plant by beetles of northern and western species (Derr et al., 1964) is known to exist. According to Derr's work, beetle of both species prefer kernel, pistilate branches, silks, leaves and root extracts in that order.

Damage done to the corn silks by the western and northern species is considered by most authors most important. Bryson et al. (1953) stated this and emphasized that when the clipping of the silks is done as the ears begin to silk, incomplete fertilization of the ovules occurs and this results in ears sparsely covered with kernels. Ball (1952) and Peters (1961) agree with these observations, and Burkhardt (1954) reported that in 1953 in the north central counties of Kansas, mainly in Jewell and Republic counties, there were corn fields in which many plants harbored more than 100 western corn rootworm adults each and that damage to the silks was severe, making necessary the application of insecticides to control adults. He pointed out that in plants free of adults, the pollination was normal, but where beetles were present a severe injury was observed and just a few kernels developed on the ears. Bradley (1954) also reported damage to the silks by western corn rootworm adults.

Damage to the silks done by northern corn rootworm has been reported by Gould (1954) and Smith (1961). On the other hand Richter (1949) performed an experiment in which corn ears were artificially infested and no difference in pollination was observed between infested ears and the checks without infestation. Bryson (1953) reported that western corn rootworm adults fed upon the already formed kernels for a distance of two inches below the tip of the ear.

Range

Western corn rootworm. This insect was first reported injurious to corn in Norton County, Kansas in the summer of 1945 (Bryson et al., 1953). The range of this species increased and Burkhardt and Bryson (1955) reported that in a survey done in 1953, adults were found in 50 counties, covering the northwestern two-thirds of the state of Kansas. No adults were found in the eastern-most counties. However, Burkhardt et al. (1964) after completing that year's survey for corn rootworm in Kansas reported that adults of western corn rootworm had been collected in 69 counties and that the eastern-most counties harbored an infestation, which indicated an eastward migration of these insects.

According with Tate and Bare (1946), western corn rootworm has been known in Nebraska since 1929-30, but it was not until 1941 that it became an important pest of corn in a few counties. He also reported that by 1946 this species had already established itself in the irrigated lands along the

Platte River. Ball (1957) reported that this beetle had moved eastward and that he collected it along the Missouri River from South Dakota to Missouri. He emphasized that no adequate explanation can be provided for this eastward migration. Weekman (1961) reported that western corn rootworm had been found in some counties of Iowa and Missouri.

Northern corn rootworm. According to Ball (1957), Blair et al. (1963), Burkhardt et al. (1964), Chiang (1965), Cunningham and Peters (1964) and Tate and Bare (1946), this species is found in Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio and South Dakota, occasionally causing severe damage to corn. In Kansas, according to Burkhardt et al. (1964) this species was present in 31 counties, 27 of them located in the northeast part of the state and 4 in the south central region.

Southern corn rootworm. According to Metcalf et al. (1962) this species is widely distributed, occurring over the greater part of the United States east of the Rocky Mountains, in southern Canada and in Mexico, but is more abundant and destructive in the southern part of its range.

Corn Rootworm Larvae Control

Chemical control. This type of control has been investigated by several authors and their findings permitted farmers in the corn belt to grow crop after crop of corn, more or less safe from this insect's injury, but recently there have been reports of increasing resistance of both western and northern species to chlorinated hydrocarbon insecticides (Ball and Weekman, 1962; Blair et al., 1963; and Hamilton, 1965).

Cultural control. Gillette (1912) was the first one who pointed out that it should be easy to control *D. virgifera* by means of crop rotation.

Tate and Bare (1946) considered that a "complete" control of northern and western corn rootworm could be achieved by avoiding planting corn after corn. Ball and Hill (1952) pointed out that crop rotation is the cheapest and most effective way to stop this pest. Anderson (1953) reported that in Illinois, in land that had been out of corn for two or more years, usually there were not enough larvae in the ground to cause serious damage. On the other hand, Hill (1948) pointed out that rotation was very effective but occasionally injury had occurred in first year corn. In this respect Bigger (1932) working with crop rotation as a way to prevent rootworm injury, found that in a three year rotation of corn, corn, oats and sweet clover, heavy damage to corn roots occurred, whereas a 4 year rotation of corn, oats, red clover, wheat and sweet clover was effective in reducing rootworm damage. A possible explanation to this situation is the work of Chiang (1965) in which he reported that a small proportion of northern corn rootworm eggs diapaused for two years and remained viable.

In the case of southern corn rootworm, crop rotation has been reported as not effective by Arant (1929), Bigger et al. (1941) and Metcalf et al. (1962). They emphasized the fact that eggs of this species are laid after the corn has come up and that both larvae and adults can feed and complete their development in many crops besides corn.

Resistant varieties. Research toward the development of resistant varieties to root damage by corn rootworms has been carried out, among others, by Bigger et al. (1941), who has searched for resistance to the southern species. He reported Ind. 38-11 as the least damaged (8.6% lodging) and Oh. 02 as the more susceptible (62.6% lodging). He pointed out that Ind. 38-11 transmits its resistance to the hybrids in which it is a parent line. Lonnquist and Kiesselback (1948) reports, without mentioning varieties, that evaluation of single and top crosses in Nebraska, led to the conclusion that resistance to root damage in corn, by corn rootworms is due to two factors, regeneration of roots, and the presence of a repellent to rootworms in the corn roots. Eiben and Peters (1962) working in Iowa, tested seven corn inbred lines against a field population of western and southern corn rootworms, and found that B_2 was the most damaged with 14.04% of the root system destroyed, and that the least damaged was WF_9 with 8.13% root destruction. The population in the field ranged from 19 to 33 larvae per plant and he considers this level as a light infestation.

In the Northern Grain Insect Research Laboratory, Brookings, South Dakota, extensive work toward the development of resistant varieties to root damage, mainly by western and northern corn rootworm is being carried on, however most of the information at the present time is unpublished.

Varieties resistant to silk damage. So far, no extensive work toward the development of varieties resistant to silk damage by adults of corn rootworm has been reported.

MATERIALS AND METHODS

1964 Field Test

Material tested.* In the summer of 1964, a total of 356 different lines of corn were tested to determine their susceptibility to the damage

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*The material tested included selections made from single crosses, double crosses, test crosses, as well as inbred lines. Therefore it was decided to refer to them as lines. It was believed that no other generic name describes them as a group more fully.

done to the silks, by the three corn rootworm adults known to occur in Kansas, the southern corn rootworm, Diabrotica undecimpunctata howardi Barber, the northern corn rootworm, D. longicornis (Say), and the western corn rootworm, D. virgifera LeC. The corn material tested included: 77 Kansas inbred lines; 81 Mexican single and 3 way crosses; 154 lines derived by selfing or open pollination from hybrids brought from Mexico and planted in 1962; 10 special Mexican collections, and 34 lines from the U.S.D.A. corn rootworm uniform nursery. The planting distribution of the corn lines tested is given in Table 1.

The reasons for selecting this particular germplasm for testing was that the 81 Mexican crosses constitute a set of material with tremendous variability since it contains crosses between eleven Mexican races of corn and 3 common testers, as well as a number of crosses between collections from Central America and the West Indies. These common testers were, Colorado Manfredi from Argentina, a U.S.A. single cross, B_{10} x B_{14}, and a U.S.A. single cross WF_9 x B_7.

The 77 Kansas inbred lines were tested to find if one or more, which were adapted to Kansas environmental conditions, were resistant to the damage to the silks by the corn rootworm adults.

The 154 derived lines constitute germplasm similar to the 81 Mexican crosses but they were included in the test because during 1962 and 1963 this material underwent a selection for early maturity and adaptation to Kansas climatic conditions.

Because the susceptibility or resistance of the 34 U.S.D.A. corn rootworm uniform nursery lines is more or less known, as far as root damage is concerned, it was decided to include them and determine their reaction to silk damage.

The 10 special Mexican collections were thought to have a certain degree of resistance to the root damage and for the reasons stated above it was decided to include them.

Location of Plantings. In order to increase the probabilities of having a suitable infestation of corn rootworm adults, at least in part of the material to be tested, it was planted in three different places: the Agronomy Farm, located 2 miles north of K.S.U. campus; the Belleville Experimental field, 2 miles west of Belleville, Kansas, and the Scandia Experimental field, 4 miles west of Scandia, Kansas, the last two located in Republic county, in north central Kansas.

The material was planted in the three locations as indicated in Table 1, in 20 foot rows 40 inches apart and plants spaced one foot apart. The dates of planting were May 20 in Belleville, May 26 in Scandia and June 1st in Manhattan.

During the first week of August, the material at the three localities started flowering, beginning the first of August in Belleville and Scandia and the fourth in Manhattan, the plots were inspected frequently and the rows which had at least 4 plants in the silking stage, were immediately recorded and labelled.

Seven days after the plants started silking, four plants in each row were inspected and data were taken on number of adults feeding in the tassel, on the silks, and the total adults present on the entire plant. In addition the silk feeding was graded according to an arbitrary scale of damage ranging from 0 to 3. Zero corresponded to the plants without apparent damage and the 3 was given to plants with the silks chewed down as far as the husk

Table 1. Planting distribution of the corn lines tested in 1964 in relation to silk damage done by corn rootworm adults.

Kind or origin	Number lines at		
	Belleville	Scanda	Manhattan
U.S.D.A. uniform rootworm nursery	34	34	68*
Mexican special rootworm nursery	10	10	
Mexican crosses 1964, 1st half		41	
Mexican crosses 1964, 2nd half	40		
Kansas Inbreds	26	26	77
Mexican derived lines	30	154	91

*This represented two replications of the 34 U.S.D.A. lines.

level. Plate I shows the scale of damage used.

Five days after the first grading, the same plants were graded again for silk damage. This was done to detect any possible change in silk damage.

Because of the heterogeneity and lack of adaptation of some of the material under this test, the grading had to be done over a long period of time, because some lines started silking in early August and some in early October. A heavy drought in Belleville delayed the flowering of many lines, mainly the ones of Mexican origin.

1965 Field Test

Material tested. A total of 48 lines of corn were tested in 1965 for study of corn rootworm damage to silks. These lines were chosen from the material tested in 1964. Not all the lines that showed a low damage to the silks in 1964 were tested in 1965. The late-maturing lines, which flowered when the population of *Diabrotica* spp. was already at a low level were not tested. The lines tested in 1965 are listed in Table 2.

Location and Planting Distribution. Following the same plan used in the previous year, the material was planted at 3 places: the Agronomy farm near Manhattan, the Belleville Experimental field, and a plot rented from a farmer, located 4 miles north of the town of Riley in Riley County, in northeast Kansas. In each plot the 48 lines were replicated twice, following a random block design. Each line was planted in 20 foot rows 40 inches apart and plants spaced one foot apart.

Because of the long vegetative cycle of some lines, mainly the lines of Mexican origin, these were planted first, and two weeks later the remainder of the material. This was done in an attempt to have most of the material

EXPLANATION OF PLATE I

Scale used to grade the damage done to the corn silks by adults of corn rootworm in the field.


PLATE 1
SILK DAMAGE SCALE
0
1
2
3

Table 2. Lines of corn planted on three localities for studies of corn rootworm adults damage to the silks. Kansas 1965.

Entry	Lines
1	Lancaster x Guadalupe
2	(B10 x B14) x Tehuacan
3	Haiti x Manfredi
4	Comp. Pan. 2 x Manfredi
5	Color. Manfredi x Vandeno
6	Jamaica 15 x Manfredi
7	Veracruz 184 x Manfredi
8	Costa Rica 287 x Manfredi
9	(B10 x B14) x P. 330 x Nar. 330 - 63:1125-1
10	(B10 x B14) x Oloton
11	Criollo de Cotaxtla x (WF9 x B7)
12	Trinidad 31D x (WF9 x B7)
13	Antigua 6-D x C.B.C.
14	(WF9 x B7) x Zapalote Grande
15	Colorado Manfredi x Maiz Dulce
16	Costa Rica x Manfredi
17	San Croix 7D x Manfredi
18	Guadalupe 3D x C.B.C. - 63:1164-1
19	Lancaster x Zapalote Grande - 63:1177-1
20	63:1188-1
21	Guadalupe 3D x C.B.C. - 63:1200-2
22	K166
23	(WF9 x B7) x Maiz Dulce
24	Lancaster x Zapalote Grande - 63:1212-1
25	Lancaster x Zapalote Grande - 63:1178-1
26	SWCB 59:158 (T)
27	63:1192-1
28	Guadalupe 3D x C.B.C. - 63:1195-1
29	K55
30	K66
31	Teozintle
32	A251
33	Jamaica 4J x Manfredi
34	Lancaster x Zapalote Grande
35	H-55
36	B-57
37	San Croix 2D x Manfredi
38	Colorado Manfredi x Maiz Dulce
39	Costa Rica 22 x Manfredi
40	(B10 x B14) x P. 330 x Nar. 330 - 9328 x 234
41	B8
42	Oh. 41
43	B2
44	SD10

Table 2 (Cont.).

Entry	:	Lines
45		F6 x F44
46		CI-187-2
47		K-1859
48		H-51

flowering at the same time. The planting dates are shown in Table 3.

Table 3. Planting dates of the corn lines tested in 1965 for study of corn rootworm damage to silks.

	Farmer's plot Riley County	Agronomy farm Riley County	Belleville Republic County
Later maturing material	May 12th	May 21st	May 17th
Earlier maturing material	May 29th	June 11th	June 4th

The plants were inspected frequently and as soon as the silks started to appear in the different varieties, four plants per row were tagged. Seven days after the silks emerged, the labelled plants were inspected and data taken on number of Diabrotica adults feeding in the tassel, in the silk, and total adults present on the entire plant. The damage done to the corn silks by adults of Diabrotica spp. was graded using an arbitrary scale ranging from zero to three. Plants graded with zero were those in which no damage to the silks was observed at the time of the inspection, the grade 3 was given to plants with the silks eaten down as far as the husk level.

Five days after the first grading, the same plants were graded again, taking the same type of data.

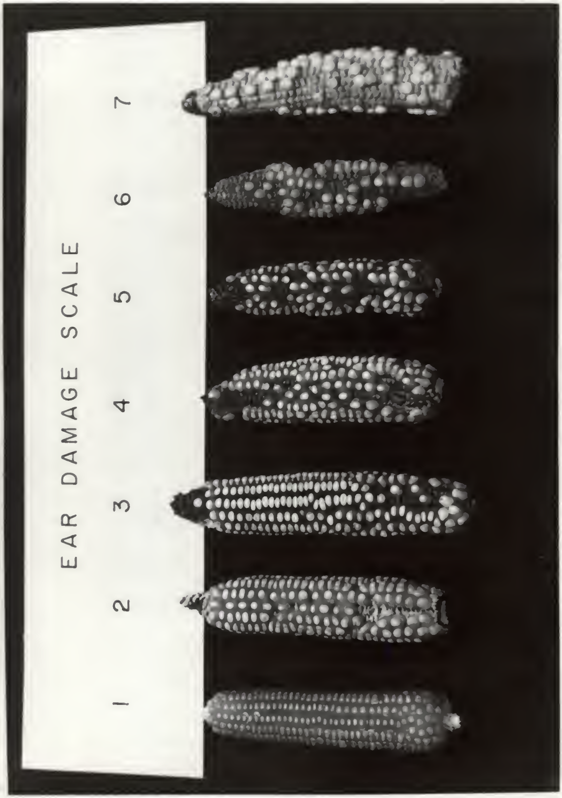
In the first week of September the ears were harvested, brought to the laboratory and graded using a scale of damage according with the relative number of kernels lacking. The scale used to grade the corn ears, which ranged from 1 to 7 is shown on Plate 2.

Data were also taken where possible on the feeding by the corn rootworm adults on the developing kernels.

EXPLANATION OF PLATE 2

Scale used to grade the corn ears in relation to lack of kernels due to faeding on the silks by adults of corn rootworm.

PLATE 2



RESULTS

1964 Field Test

Population of corn rootworm. According to the figure obtained in the actual count of adults in the corn plants, it was found that the population of corn rootworm adults at Belleville, and at the Agronomy farm, were almost exclusively made up of the western species, *D. virgifera*. In Scandia the plot was abandoned because of lack of infestation. In this plot on August 6, the population of corn rootworm beetles averaged 1.3 per plant, whereas at Belleville on the same date, the population was almost at its peak averaging 8.7 adults per plant, and at Manhattan, the 5th of August there was an average of 5.4 adults per plant.

As can be seen in Graph 1, the population of *D. virgifera* in Belleville had at the time of the first count (August 1) an average of 8.9 adults per plant, dropped to 8.7 adults per plant on August 6, and reached its peak on August 20, with an average of 11.5 adults per plant, after which it dropped to 5.3 at the time of the last count, September 1st.

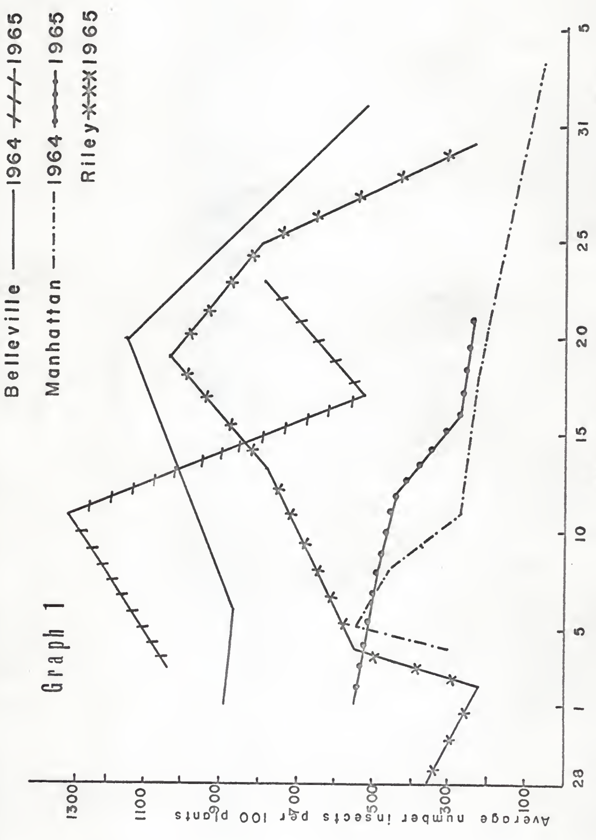
In Manhattan, as can be noticed in Graph 1, the population of beetles was smaller than in Belleville, and the peak population which occurred on August 5th, had an average of 5.4 adults per plant and from that date to September 3rd, it dropped at a steady rate, averaging less than 1 adult per plant in the last reading.

Damage to the silks in the different varieties and varietal preference by corn rootworm adults.

Manhattan. From the 236 rows planted at the Agronomy farm, only 173 were graded. In the remaining 64 rows no stand was obtained because of low

EXPLANATION OF GRAPH 1

Corn rootworm adult populations in the plots where tests were conducted on corn rootworm damage to the silks. Kansas 1964-65.


Graph 1
Belleville —— 1964 -/-/- 1965
Manhattan -·-·-· 1964 -•-•- 1965
Riley -X-X- 1965
Average number insects per 100 plants
1300
1100
900
700
500
300
100
28
July
1
5
10
15
August
20
25
31
Sept.
5

germination. The material that failed to germinate was mainly the Kansas inbred lines.

Among the 173 rows graded, representing 145 different lines, 36 had an average damage to the silks of 1.0 or less, 92 had an average damage that ranged from 1.1 to 2.0 and among the remaining 17 the average silk damage was of 2.1 or higher.

The 36 lines that had an average damage to the silks of 1.0 or less included 6 U.S.D.A. corn rootworm uniform nursery lines, 2 Kansas inbred lines and 28 lines derived from Mexican material. In Table 4 are listed that 36 lines including their average silk damage and average number of corn rootworm beetles per plant.

Belleville. Out of the 144 lines planted in that plot, only 57 were graded. The remaining 87 did not reach the flowering stage, in part because of lack of adaptation and also because of the heavy drought that prevailed in the north central region of Kansas during the months of July and August, 1964.

Among the 57 lines graded, 10 had an average damage to the silks of 1.0 or less, 35 had an average from 1.1 to 2.0 and 12 had an average damage between 2.1 and 3.0. The 10 lines that had an average damage to the silks of 1.0 or less included 3 U.S.D.A. corn rootworm uniform nursery lines, 2 Mexican collections and 4 lines derived from Mexican material received in 1962. In Table 5 are listed the 10 lines, including average silk damage and average number of corn rootworm adults per plant.

1965 Field Test

Population of corn rootworm. The actual count of adults in the corn

Table 4. Lines of corn that showed a low damage to the silks by corn rootworm adults at the Manhattan Agronomy farm. 1964 Field test.

Line	Silk damage: Range	Silk damage: Average*	Average corn rootworm adults per plant
(B10 x B14) x P330 x Ner 330	0-1	0.25	3.75
Antigua 6-D x C.B.C.	0-1	0.25	2.50
B57	0-1	0.37	4.12
H51	0-1	0.37	4.87
N38A	0-1	0.50	3.00
Colorado Manfredi x Vandeno	0-2	0.50	7.00
63:1126-1 op.	0-1	0.50	3.50
(B10 x B14) x Oloton	0-2	0.50	2.00
63:1148-1 op.	0-1	0.50	3.25
63:1159-1 op.	0-2	0.50	0.50
Lancaster x Zapalote Grande	0-2	0.50	0.75
K166	0-1	0.50	4.75
Lancaster x Zapalote Grande	0-1	0.50	1.75
H55	0-1	0.66	2.12
(B10 x B14) x Tehuacan	0-2	0.75	5.25
Haiti x Manfredi	0-2	0.75	5.75
Jamaica 15 x Manfredi	0-2	0.75	3.00
Costa Rica 287 x Manfredi	0-2	0.75	1.25
(WF9 x B7) x Zapalote Grande	0-2	0.75	1.50
Manfredi x Maiz Dulce	0-2	0.75	3.25
Guadalupe 3D x C.B.C.	0-2	0.75	0.75
(WF9 x B7) x Maiz Dulce	0-2	0.75	0.75
K137	0-2	0.75	1.25
A401	0-2	0.87	4.12
Lancaster x Guadalupe	0-2	1.00	8.75
H-D2187	1-1	1.00	0.33
Comp. Pan 2 x Manfredi	0-2	1.00	8.50
Veracruz 184 x Manfredi	0-2	1.00	4.50
Criollo de Cotaxtla x (WF9 x B7)	1-1	1.00	3.00
Trinidad 31-D x (WF9 x B7)	0-2	1.00	4.75
Costa Rica x Manfredi	0-2	1.00	3.25
San Croix 7-D x Manfredi	0-2	1.00	1.50
63:1181-1 op.	1-1	1.00	3.50
63:1188-1	0-2	1.00	3.25
Guadalupe 3-D x C.B.C.	0-2	1.00	1.75

*Scale 0-3; zero = no damage; 3 = heavy damage. Average of 4 ears.

Table 5. Lines that showed a low damage to the silks in the Belleville 1964 field trial.

Line	Silk damage: Range	Silk damage: Average*	Average number of corn rootworm adults per plant
N38A	0-0	0.00	3.00
K66-57:748-1	0-1	0.25	4.00
Leon 61-17J	0-2	0.75	1.00
K159-63:1090-1	0-1	0.75	6.00
Chap 61-2039	1-2	1.00	2.00
K159-63:1115-2 op.	0-2	1.00	3.00
K159-63:1111-1	0-2	1.00	2.00
Oh 07	0-2	1.00	1.00
B2	1-2	1.00	2.00
K148-62:523-1	0-2	1.00	4.00

*Scale 0-3; Zero = no damage; 3 = heavy damage. Average of 4 ears.

plants in 1965 revealed that the population of corn rootworm in the Belleville, Agronomy Farm and Riley plots were almost exclusively constituted by the western species, D. virgifera.

As can be seen in Graph 1, the population of D. virgifera at Belleville had at the moment of the first counting (August 3) an average of 10.4 adults per plant, rose to 13.1 adults per plant by August 11th and dropped to 5.3 in August 17th. At the time of the last counting (August 23rd) there was an average of 7.9 corn rootworm adults per plant.

In Riley when the first record was taken July 28 there was an average of 3.5 adults per plant. The population dropped the 2nd of August to 2.3 adults per plant, but after that date, kept increasing at a steady rate, until the 19th of August when a peak of 10.4 adults per plant was recorded. The population was at its lowest level, 2.4 adults per plant, the 30th of August, which was the last date records were taken.

At the Agronomy Farm the population of corn rootworm adults, the 1st of August was 5.5 beetles per plant and it dropped steadily until the 21st of August when the population was 2.3 adults per plant.

Damage to the silks in the different lines. From the 48 lines planted in the 3 different localities, only 30 of them gave a good germination.

In Table 6, are listed the average silk damage in an increasing array. The figures listed in that table correspond to the average of 2 replications in each of 3 localities. As can be seen from that table the damage to the corn silks by corn rootworm adults ranged from 1.06 in the cross Lancaster x Zapalote Grande, to 2.75 in the inbred line B57. After statistical analysis it was found that there were significant differences between lines, with an $LSD_{0.05} = 0.712$. Therefore, among first 15 lines with the least damage

Table 6. Average damage to the silks in 30 lines of corn, by corn rootworm adults. Kansas 1965.

Line	Silk damage: Range	Silk damage: Average*
Lancaster x Zapalote Grande - 63:1212-1	0.00-2.00	1.06
Lancaster x Zapalote Grande - 711 x 637	0.25-2.25	1.08
San Croix 2-D x Manfredi	0.00-1.50	1.16
Comp. Pan-2 x Manfredi	0.00-2.25	1.25
Haiti x Manfredi	0.25-2.75	1.33
Manfredi x Maiz Dulce	1.00-2.00	1.37
Criollo de Cotaxtla x (WF9 x B7)	0.75-2.00	1.37
K-1859	0.25-2.75	1.50
Lancaster x Guadalupe	0.75-2.25	1.50
Guadalupe 3D x C.B.C. - 63:1200-2	0.75-2.00	1.50
SD10	0.25-2.75	1.58
(WF9 x B7) x Maiz Dulce	1.25-2.25	1.62
Lancaster x Zapalote Grande - 63:1177-1	0.00-3.00	1.66
K166	1.00-3.00	1.71
Lancaster x Zapalote Grande - 63:1178-1	0.25-3.00	1.75
(B10 x B14) x Tehuacan	0.25-2.50	1.75
Antigua 6D x C.B.C.	0.75-2.75	1.79
(B10 x B14) x Pan. 330 x Nar. 330 - 9328-234	1.25-3.00	1.79
(WF9 x B7) x Zapalote Grande	1.75-2.25	1.91
Jamaica 15 x Manfredi	0.75-3.00	1.91
K66	0.50-3.00	1.91
Veracruz 184 x Manfredi	1.50-2.50	1.96
(B10 x B14) x Pan. 330 x Nar. 330 - 63:1125-1	0.25-2.75	1.96
Costa Rica 287 x Manfredi	0.25-3.00	1.96
(B10 x B14) x Oloton	1.75-3.00	2.21
K55	0.75-2.75	2.25
Guadalupe 3D x C.B.C. - 63:1195-1	2.00-3.00	2.41
SWCB 59:158 (T)	1.50-3.00	2.46
63:1192-1	2.00-3.00	2.66
B57	2.25-3.00	2.75

*Scale 0 to 3; Zero = no damage; 3 = heavy damage. Average of 24 ears.

$LSD_{(0.05)} = 0.712$

there were no significant differences and likewise there were no significant differences among last six lines with the most damage.

Line preference by corn rootworm adults. The preference of corn rootworm beetles for the different lines was measured by recording the number of beetles found on the corn plants, eight days after the plants started silking.

When the average number of corn rootworm adults per plant was plotted against the range it was found out that the populations in the three plots had a linear relationship. Therefore the figures obtained in each line were transformed to their square roots in order to make the statistical analysis more accurate and valid.

In Table 7 is given the array of lines in an increasing order from the line least preferred which was (B10 x B14) x Tehuacan with an average of 1.63 adults per plant, to the most preferred which was (B10 x B14) x Oloton with a mean of 7.5 adults per plant.

As can be seen in that table statistical difference was found between lines with a mean of 1.63 adults per plant and lines with a mean of 4.02 adults per plant. Also it should be noticed that statistical difference was found between lines with an average number of adults per plant of 4.02 and lines with an average of 7.39 adults per plant.

Damage to the ears. In Table 8, are given the lines in an increasing order according to their average of lack of pollination due to damage to the silks by corn rootworm adults. As can be seen in that table the average damage ranged from 1.91 in the cross Haiti x Manfredi to 4.50 in the cross (B10 x B14) x Tehuacan. A statistical analysis showed that there were significant differences between lines with a $LSD_{0.05} = 1.106$.

It can be noticed that no statistical difference was found to exist

Table 7. Preference of corn rootworm adults, Diabrotica spp. for the whole plant in 30 lines of corn. Kansas 1965.

Line	Average number adults		
	Range	Original mean*	Square root of original means
(B10 x B14) x Tehuacan	0.50-2.25	1.63	1.28
Lancaster x Zapalote Grande - 63:1178-1	1.00-4.37	2.10	1.45
B57	0.62-5.25	2.31	1.52
SD10	1.25-7.00	2.35	1.56
Lancaster x Guadalupe	1.50-3.75	2.47	1.58
Lancaster x Zapalote Grande - 63:1177-1	0.87-5.12	2.62	1.62
K166	0.87-4.62	2.65	1.63
Lancaster x Zapalote Grande - 63:1212-1	1.15-5.75	2.72	1.65
Guadalupe 3D x C.B.C. - 63:1200-2	1.12-4.50	2.75	1.66
Lancaster x Zapalote Grande - 711 x 637	0.25-8.00	3.16	1.78
K55	1.62-5.62	3.45	1.86
Costa Rica 287 x Manfredi	1.25-7.62	3.76	1.94
Veracruz 184 x Manfredi	1.62-5.12	3.84	1.96
(WF9 x B7) x Maiz Dulce	2.75-6.37	4.02	2.03
K66	1.50-7.00	4.06	2.09
Haiti x Manfredi	3.25-10.62	4.75	2.18
Manfredi x Maiz Dulce	2.50-13.25	4.88	2.21
SWCB 59:158 (T)	1.00-11.37	5.01	2.24
K-1859	1.37-9.12	5.06	2.25
Criollo de Cotaxtla x (WF9 x B7)	2.75-19.00	5.10	2.26
(B10 x B14) x Pan 330 x Nar. 330 - 9328 x 234	4.12-14.75	5.29	2.30
San Croix 2D x Manfredi	2.00-13.50	5.29	2.30
Comp. Pan-2 x Manfredi	3.25-13.12	5.61	2.37
Jamaica 15 x Manfredi	2.00-11.75	5.76	2.40
(WF9 x B7) x Zapalote Grande	2.12-11.62	6.30	2.51
(B10 x B14) x Pan. 330 x Nar. 330 - 63:1125-1	0.67-11.12	6.60	2.57
Antigua 6D x C.B.C.	2.62-16.62	7.29	2.70
63:1192-1	1.75-22.62	7.29	2.70
Guadalupe 3D x C.B.C. - 63:1195-1	3.75-11.50	7.39	2.72
(B10 x B14) x Oloton	4.50-16.12	7.50	2.74

*Average of 24 plants.

$LSD_{0.05} = 0.681$

Table 8. Lack of pollination in 30 lines of corn, apparently due to silk injury by corn rootworm adults, Diabrotica spp. Kansas 1965.

Line	Damage to the ears*	
	Range	Average
Haiti x Manfredi	1.00-3.50	1.91
(WF9 x B7) x Zapalote Grande	1.00-3.50	1.95
Manfredi x Maiz Dulce	1.00-3.75	2.00
SD10	1.25-2.50	2.04
K-1859	1.00-2.75	2.41
Veracruz 184 x Manfredi	1.25-7.00	2.41
Antigua 6D x C.B.C.	1.50-4.00	2.50
Comp. Pan 2 x Manfredi	1.00-4.50	2.54
San Croix 2D x Manfredi	1.25-4.75	2.62
Guadalupe 3D x C.B.C. - 63:1200-2	1.00-6.50	2.62
Lancaster x Zapalote Grande - 63:1212-1	1.75-5.25	2.79
K166	2.00-4.50	3.00
Criollo de Cotaxtla x (WF9 x B7)	2.00-6.00	3.08
SWCB 59:158 (T)	1.25-4.50	3.16
Jamaica 15 x Manfredi	2.00-4.25	3.16
Lancaster x Zapalote Grande - 63:1177-1	1.25-5.75	3.33
Costa Rica 287 x Manfredi	2.25-4.25	3.40
K66	1.75-5.75	3.41
B57	2.50-4.75	3.45
Lancaster x Zapalote Grande 711 x 637	1.25-6.50	3.45
Lancaster x Zapalote Grande - 63:1178-1	2.50-5.00	3.49
(B10 x B14) x Pan. 330 x Nar. 330 - 9328 x 234	2.25-6.00	3.54
63:1192-1	2.00-6.75	3.58
(B10 x B14) x Oloton	2.00-5.25	3.62
Lancaster x Guadalupe	2.25-6.75	3.70
(B10 x B14) x Pan. 330 x Nar. 330 - 63:1125-1	1.25-6.50	3.87
Guadalupe 3D x C.B.C. - 63:1195-1	2.50-5.75	4.00
(WF9 x B7) x Maiz Dulce	1.50-7.00	4.25
K55	2.25-7.00	4.37
(B10 x B14) x Tehuacan	2.50-6.50	4.50

*Scale 1-7; One = no damage, 7 = heavy damage. Average of 24 ears.

$LSD_{0.05} = 1.106$

between lines with an average damage of 1.91 and lines with an average of 3.00. This included 12 lines. No statistical difference was found between lines with an average of damage of 3.40 and hybrid (B10 x B14) x Tehuacan which had an average damage of 4.5.

Corn rootworm adults found actually feeding on the silks of the lines tested. As was pointed out earlier in this paper, the adults of corn rootworm were found on all parts of the corn plant above the ground, feeding on leaves, silks and tassel, and it was considered of great importance to find out if there was a statistical difference between the number of beetles found actually feeding on the silks of the different lines tested. This importance arose from the fact that it is not clear exactly if, for example, the beetles found feeding on the tassel would eventually go down to the silks and feed on them, or if they would abandon that particular plant and search for others in the pollen shedding stage.

In Table 9, the array of the per plant average of beetles found actually feeding on the silks of the different lines is given. As can be seen in that table, the averages ranged from 0.37 adults per inflorescence in the cross (B10 x B14) x Tehuacan, to 1.82 adults in the cross (B10 x B14) x P330 x Nar. 330. The statistical analysis revealed that there were significant differences between lines. It can be noticed in that table that no significant difference between the first 21 lines in the list, that is, lines that had an average of adults feeding in the silks ranging from 0.37 to 1.15 beetles per plant, were not statistically different.

Correlation coefficients. Correlation coefficients between possibly related variables were calculated and the figures obtained were as follows:

Table 9. Average number of corn rootworm adults per plant of corn found feeding in the silks. Kansas 1965.

Line	Average number of adults actually feeding on the silks*
(B10 x B14) x Tehuacan	0.37
Guadalupe 3D x C.B.C. - 63:1200-2	0.40
Manfredi x Maiz Dulce	0.50
Lancaster x Zapalote Grande - 63:1178-1	0.57
Lancaster x Zapalote Grande - 711 x 637	0.62
Lancaster x Zapalote Grande - 63:1212-1	0.70
Lancaster x Guadalupe	0.75
Veracruz 184 x Manfredi	0.75
Comp. Pan. 2 x Manfredi	0.77
Lancaster x Zapalote Grande - 63:1177-1	0.82
SWCB 59:158 (T)	0.87
(WF9 x B7) x Maiz Dulce	0.87
K66	0.90
B57	1.00
Costa Rica 287 x Manfredi	1.00
Guadalupe 3D x C.B.C. - 63:1195-1	1.02
Haiti x Manfredi	1.12
(WF9 x B7) x Zapalote Grande	1.12
San Croix 2-D x Manfredi	1.15
Jamaica 15 x Manfredi	1.15
K55	1.15
SD10	1.27
K166	1.27
K1859	1.32
63:1192-1	1.40
(B10 x B14) x Oloton	1.50
Criollo de Cotaxtla x (WF9 x B7)	1.62
(B10 x B14) x P 330 x Nar. 330 - 9328 x 234	1.77
Antigua 6D x C.B.C.	1.82
(B10 x B14) x P 330 x Nar. 330 - 63:1125-1	1.82

*Average of 24 ears.

$LSD_{0.05} = 0.84$

Correlation coefficients between ear damage and silk damage = $+0.416^*$

Correlation coefficients between number of adults and silk damage = +0.284 ns.

Correlation coefficients between ear damage and number of adults = -0.136 ns.

Correlation coefficients between adults in the silks and adults in the whole plant = $+0.620^*$

*Significant at the 0.05% level.

ns = Non significant at the 0.05% level.

Relationship between flowering date of the different lines tested and ear damage. Thinking of the possibility that the lack of pollination in the different lines could have been caused by other factors (besides damage to the silks by corn rootworm adults) such as high temperature during the pollen shedding period which is known to kill the pollen, or by lack of synchronization between the silking stage of a line and pollen shedding stage of the other lines. A scatter diagram for each locality was made by plotting flowering date on the ordinate axis and ear damage (lack of pollination) on the abscissas axis.

In Graph 2, which corresponds to the Belleville plot, no linear relationship between flowering date and ear damage is suggested by the distribution obtained.

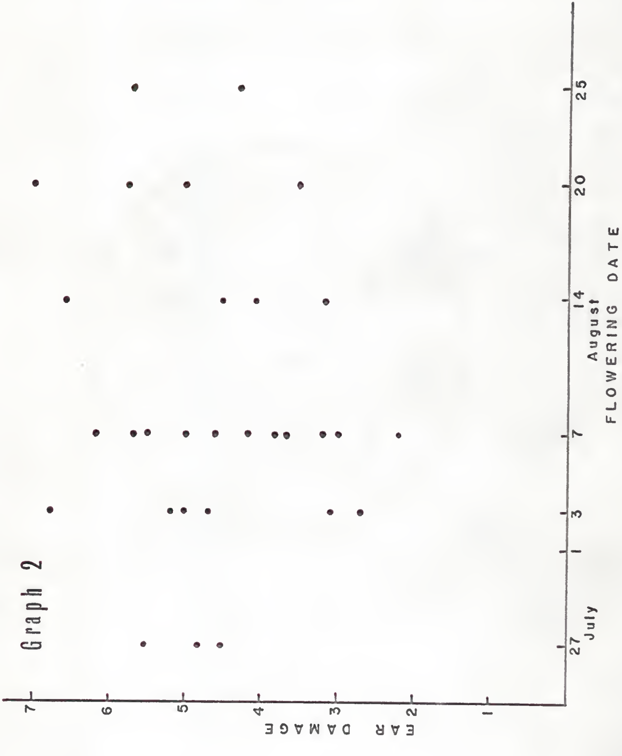
In Graph 3, which represents the distribution obtained by plotting the flowering date and the ear damage of the varieties tested at the Agronomy farm, no linear relationship can be observed.

In Graph 4, which corresponds to the plot in Riley, the distribution obtained suggests a possible linear relationship between flowering date and ear damage.

EXPLANATION OF GRAPH 2

Relation between flowering date and ear damage.

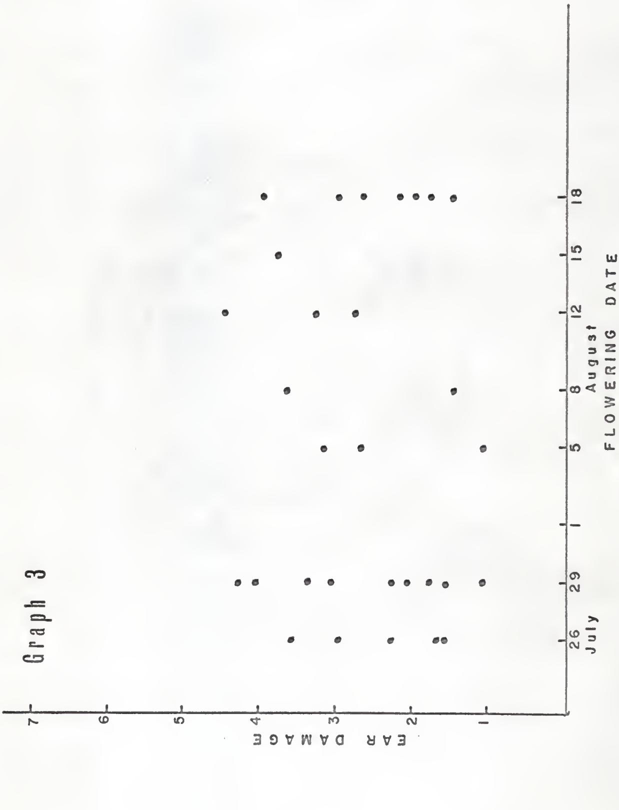
Belleville, Kansas 1965.


Graph 2
EAR DAMAGE
1
2
3
4
5
6
7
27
July
1
3
7
14
August
20
25
FLOWERING DATE

EXPLANATION OF GRAPH 3

Relation between flowering date and ear damage.

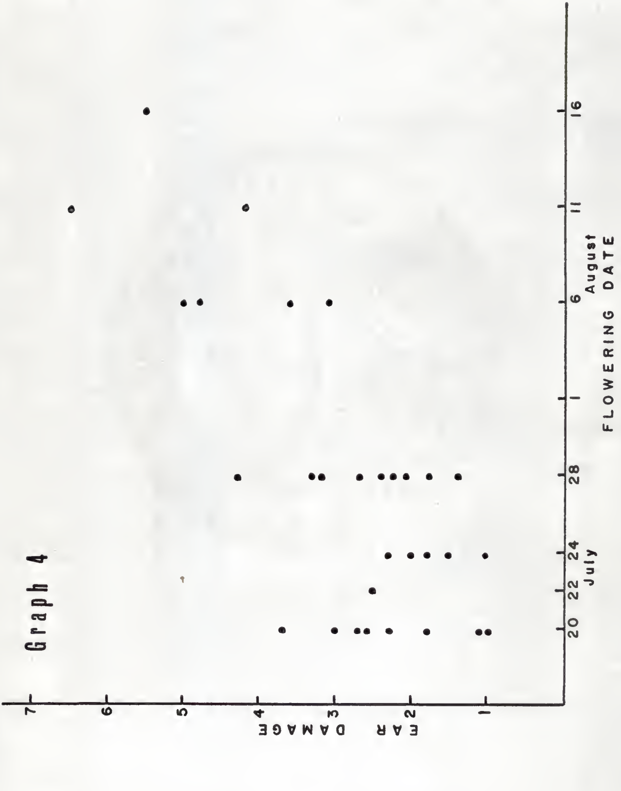
Manhattan, Kansas 1965.


Graph 3
EAR DAMAGE
1
2
3
4
5
6
7
26
July
29
1
5
8
August
12
15
18
FLOWERING DATE

EXPLANATION OF GRAPH 4

Relation between flowering date and ear damage.

Riley, Kansas 1965.


Graph 4
EAR DAMAGE
1
2
3
4
5
6
7
FLOWERING DATE
July
August
20
22
24
28
1
6
11
16

Damage to the female inflorescence 7 and 12 days after its emergence. In the section devoted to materials and methods, it was pointed out that the silk damage done by corn rootworm adults to the varieties tested was recorded seven days after the emergence of the silks and five days later the silks were graded again.

Table 10 shows the data obtained on the two different dates silk damage was graded. It is noticeable in that table that in all the varieties with the exception of three, the observed damage to the silks by corn rootworm adults was higher in the second date of grading. This seems to prove that no capability of recuperation exists in the varieties tested or else that the rate of regrowth of the silks in the varieties tested was smaller than the speed at which the *Diabrotica* adults destroyed them.

DISCUSSION

According to the figures obtained, the population of corn rootworm adults in the different localities during the two years that this study lasted, showed a marked difference among localities and between years. The population of corn rootworm adults in the Belleville Experimental Field and in the Agronomy Farm near Manhattan were higher in 1965 than in 1964. No such comparison is possible as far as the Riley plot is concerned because this plot was planted only in 1965.

Between localities, the population of *Diabrotica* spp. adults, were consistently higher at Belleville throughout 1964 and 1965 than in the other localities but did not reach the levels reported by Burkhardt in 1954.

The synchronization between flowering date of the different lines and the presence of corn rootworm adults in the field was not adequate in the

Table 10. Comparison of observed silk damage done by corn rootworm adults to 30 lines of corn, 7 and 12 days after emergence of the silks. Kansas 1965.

Line	Average silk damage*		
	7 days after silk emergence**	12 days after silk emergence**	Difference
Lancaster x Zapalote Grande - 63:1212-1	0.92	1.06	+ 0.14
Lancaster x Zapalote Grande - 711 x 637	1.28	1.08	- 0.20
San Croix 2-D x Manfredi	1.20	1.16	- 0.04
Comp. Pan. 2 x Manfredi	0.99	1.25	+ 0.26
Haiti x Manfredi	1.29	1.33	+ 0.04
Manfredi x Maiz Dulce	1.16	1.37	+ 0.21
Criollo de Cotaxtla x WF9 x B5	1.33	1.37	+ 0.04
K-1859	1.58	1.50	- 0.08
Lancaster x Guadalupe	1.24	1.50	+ 0.26
Guadalupe 3D x C.B.C. - 63:1200-2	1.20	1.50	+ 0.30
SD10	1.46	1.58	+ 0.12
(WF9 x B7) x Maiz Dulce	1.49	1.62	+ 0.13
Lancaster x Zapalote Grande - 63:1177-1	1.04	1.66	+ 0.62
K166	1.17	1.71	+ 0.54
Lancaster x Zapalote Grande - 63:1178-1	1.70	1.75	+ 0.05
(B10 x B14) x Tehuacan	1.46	1.75	+ 0.29
Antigua 6D x C.B.C.	1.54	1.79	+ 0.25
(B10 x B14) x Pan. 330 x Nar. 330 - 9328 x 234	1.53	1.79	+ 0.26
(WF9 x B7) x Zapalote Grande	1.62	1.91	+ 0.29
Jamaica 15 x Manfredi	1.91	1.91	0.00
K66	1.79	1.91	+ 0.12
Veracruz 184 x Manfredi	1.66	1.96	+ 0.30
(B10 x B14) x Pan. 330 x Nar. 330 - 63:1125-1	1.66	1.96	+ 0.30
Costa Rica 287 x Manfredi	1.66	1.96	+ 0.30
(B10 x B14) x Oloton	1.95	2.21	+ 0.26
K55	1.91	2.25	+ 0.34
Guadalupe 3D x C.B.C. - 63:1195-1	1.96	2.41	+ 0.45
SWCB 59:158 (T)	1.66	2.46	+ 0.80
63:1192-1	2.12	2.66	+ 0.54
B57	2.29	2.75	+ 0.46

*Average of 2 replications in each of 3 localities.

**Scale 0 to 3.

1964 field trials. Most of the material planted in that year started silking in early September when the Diabrotica spp. populations were at the season's lowest. However the 10 lines listed in Table 5 reached the flowering stage in mid August when the population was at its highest level in Belleville with about 11 adults per plant, and the 36 lines listed in Table 4 reached the flowering stage in early August when the corn rootworm population was at its highest level, about five adults per plant, at the Agronomy Farm at Manhattan.

From the 36 lines listed in Table 4, which were the ones that showed a low degree of damage to the silks by corn rootworm adults, 12 of them had a low average of adults, 2.00 or less per plant. According to Painter's (1951) classification of causes of resistance, these lines could be considered as non preferred taking into consideration that the average number of adults present in that field during the time that lines were silking was five per plant. The possible cause of non preference could have been the lack of an attractant to the corn rootworm adults in silks leaves and tassel of those lines.

In the remaining 24 lines listed in Table 4, the average number of adults per plant ranged from 2 to 9.25. However the silk damage was not higher than 1.00. Here it is also believed that the mechanism of resistance involved was non preference in which an attractant in the silks, leaves, or tassels would account for the high number of adults present in the different lines, but the lack of a continuous feeding factor or the presence of a repellent on the silks or both would prevent the corn rootworm adults from feeding extensively on the silks.

The 10 lines listed in Table 5, which were the least damaged of the 140 lines planted in the Belleville Experimental Field plot in 1964 harbored a low number of adults per plant. The population of corn rootworm adults at that location ranged from 0 to 45 adults per plant, with an average of 11 adults per plant when these lines were in the silking stage. Therefore those 10 lines could fit in the non preferred category provided that none of them had more than six adults per plant, which was much less than the average.

The results obtained in the 1964 field trials were helpful primarily in selecting the material to be tested in 1965. They were also useful in helping to decide what the planting date should be in 1965 in order to synchronize the silking date of the lines and the occurrence in the field of the bulk of the corn rootworm adults population.

In the 1965 test, the synchronization of the silking stage of the lines planted on the different plots and the presence of corn rootworm adults was adequate at the Belleville Experimental Field and at the Agronomy Farm at Manhattan, provided that in Belleville the earlier lines reached the silking stage the 27 of July as can be seen in the scatter diagram 1, when the population of corn rootworms was already 10.5 adults per plant the 3rd of August. In the Agronomy Farm at Manhattan the earlier lines started silking the 26 of July and the population of corn rootworms had an average of 5.5 adults per plant the 1st of August. On the other hand, at the Riley plot the material was planted too early and the earlier lines started silking before the corn rootworms had emerged. Probably this is the main reason why the scatter diagram 3 suggests a linear relationship between flowering date and ear damage.

In the 1965 test, as mentioned before, records were taken on the number of adults found on the different lines, and this gives an indication of the preference or non-preference for the different lines by the corn rootworms, provided that the statistical analysis showed that there were significant differences among the lines tested. Table 5 gives the figures corresponding to the total number of corn rootworm adults found on the entire plant and in Table 7 are recorded exclusively the adults found actually feeding on the silks. A close look at both tables permits one to conclude that in both cases the lines followed the same order and therefore it can be assumed that either set of data could give the same information as far as corn rootworm adult varietal preference is concerned. The significative correlation coefficient obtained seems to prove it.

The differential damage done to the silks by corn rootworm adults to the lines tested in 1965, was found to be statistically significant and this fact permits elaboration in this respect following basically the definitions and concepts stated by Painter (1951) in relation to possible mechanisms of insect resistance in crop plants. It can be stated that the differential damage to the silks was either due to the presence of a repellent in the silks of some lines that prevented the feeding of corn rootworm adults on them, or that there was a lack of a chemical that would stimulate the continuous feeding and so the insects did not feed extensively in lines lacking that factor, whereas in the heavily damaged lines the continuous feeding factor might be present. Both little and heavily damaged lines could have an attractant but its effect would only drive the insects to "taste" the silk and the lack of continuous feeding factor would prevent the insects from feeding extensively, or there could even exist in the same plant a combination of both attractants and repellents and this could account for the presence of a large number of adults in plants that showed little damage to the silks. Even though no attempt was made in this research to determine the actual chemicals factors, its existence can be suspected and the fact that the correlation coefficient between number of adults per plant and silk damage was found to be +.248, which is far from a perfect correlation, leads one to suspect that some of the factors previously mentioned may be involved.

The data shown in Table 10 which represent the figures obtained when the silk damage was graded 7 days after the flowering date and the figures obtained 12 days after the flowering date, that is five days after the first grading, indicated that there was an increase in damage to the silks in all the lines but three and even in the three lines the recuperation was so small that it can be said that tolerance, that is, the ability to repair injury, can be ruled out as a mechanism of resistance as far as silk damage by corn rootworm adults is concerned.

It would be logical to expect that the silk damage and the ear damage were directly correlated because fertilization of the egg in corn occurs by means of the growth of the pollen tube from the pollen grains along each individual silk and if the silks are destroyed the fertilization does not occur. The correlation coefficient for these two variables was +.416 which is significant but does not suggest even a near perfect association. A possible reason for this correlation coefficient being so far below the expected one could be the use of a silk damage grading scale that was too narrow. The grading scale used ranged from 0 to 3 and it is thought that if a wider range had been used, differences could have been detected more accurately and the correlation coefficient might have been higher. Another possible factor affecting that relationship is the effect of the high temperatures upon the pollen grains. It is known that high temperatures kill the pollen grains, which could account for part of the lack of seed development observed in some lines. This is known to occur in Kansas some summers.

Observing Tables 6, 7 and 8, it can be noticed that there were lines that had a high damage to the silks and a low number of adults, for example, the inbred K55; lines with low damage to the silks and high number of adults, for example (WF9 x B7) x Zapalote Grande; and lines with a medium silk damage and high number of adults per plant, for example SD10. Because of these differences Table 11 was prepared as a summary of Tables 6, 7 and 8, and there an attempt was made to classify the lines as resistant, susceptible and highly susceptible.

The main factor considered in assigning the lines to a given category was the ear damage because it was the easiest to grade and possibly the most accurate.

As can be seen in Table 11, the average damage to the ears, the number of adults per plant and the silk damage grade, were classified as low, medium and high, using as criteria for this classification the statistical analysis performed and results as given in Tables 6, 7 and 8. In the case of ear damage the lines that had an average damage to the ear ranging from 1.91 to 3.00 were considered as having low damage, these limits were chosen taking in consideration that the statistical analysis (Table 8) indicated that there was no significant difference among lines that had an average damage to the ears included between these limits. Lines that had an average damage to the ears ranging from 3.01 to 4.00 were considered as having a medium damage, the lines which had average damage to the ears between these

Table 11. Summary of the response of 30 varieties of corn, to the damage of corn rootworms *Diabrotica* spp. adults. Kansas 1965.

Line	Average damage to the ears	Average number adults per plant	Average silk damage	Average damage to the ears	Average number adults per plant	Average silk damage	General classification
Haiti x Manfredi	1.91	4.75	1.33	Low	Medium	Low	Resistant
(WF9 x B7) x Zapalote Grande	1.95	6.30	1.91	Low	High	Medium	Resistant
Manfredi x Maiz Dulce	2.00	4.88	1.37	Low	Medium	Low	Resistant
SD10	2.04	2.35	1.58	Low	Low	Low	Resistant
K-1859	2.41	5.06	1.50	Low	Medium	Low	Resistant
Veracruz 184 x Manfredi	2.41	3.84	1.96	Low	Low	Medium	Resistant
Antigua 6D x C.B.C.	2.50	7.29	1.79	Low	High	Medium	Resistant
Comp. Pan-2 x Manfredi	2.54	5.61	1.25	Low	Medium	Low	Resistant
San Croix 2D x Manfredi	2.62	5.29	1.16	Low	Medium	Low	Resistant
Guadalupe 3D x C.B.C. - 63:1200-2	2.62	2.75	1.50	Low	Low	Low	Resistant
Lancaster x Zapalote Grande - 63:1212-1	2.79	2.72	1.06	Low	Low	Low	Resistant
K166	3.00	2.65	1.71	Low	Low	Low	Resistant
Criollo de Cotaxtla x (WF9 x B7)	3.08	5.10	1.37	Medium	Medium	Low	Susceptible
SWCB 59:158 (T)	3.16	5.01	2.46	Medium	Medium	High	Susceptible
Jamaica 15 x Manfredi	3.16	5.76	1.91	Medium	Medium	Medium	Susceptible
Lancaster x Zapalote Grande - 63:1177-1	3.33	2.62	1.66	Medium	Low	Low	Susceptible
Costa Rica 287 x Manfredi	3.40	3.76	1.96	Medium	Low	Medium	Susceptible
K66	3.41	4.06	1.91	Medium	Medium	Medium	Susceptible
B57	3.45	2.31	2.75	Medium	Low	High	Susceptible
Lancaster x Zapalote Grande - 711 x 637	3.45	3.16	1.08	Medium	Low	Low	Susceptible
Lancaster x Zapalote Grande - 63:1178-1	3.49	2.10	1.75	Medium	Low	Medium	Susceptible

Table 11 (Cont.).

Line	Average damage to the ears	Average number adults per plant	Average silk damage	Average damage to the ears	Average number adults per plant	Average silk damage	General classification
(B10 x B14) x Pan. 330 x Nar. 330 - 9328-234	3.54	5.29	1.79	Medium	Medium	Medium	Susceptible
63:1192-1	3.58	7.29	2.66	Medium	High	High	Susceptible
(B10 x B14) x Oloton	3.62	7.50	2.21	Medium	High	High	Susceptible
Lancaster x Guadalupe	3.70	2.47	1.50	Medium	Low	Low	Susceptible
(B10 x B14) x Pan. 330 x Nar. 330 - 63:1125-1	3.87	6.60	1.96	Medium	High	Medium	Susceptible
Guadalupe 3D x C.B.C. - 63:1195-1	4.00	7.39	2.41	Medium	High	High	Susceptible
(WF9 x B7) x Maiz Dulce	4.25	4.02	1.62	High	Medium	Low	Highly Susc.
K55	4.37	3.45	2.25	High	Low	High	Highly Susc.
(B10 x B14) x Tehuacan	4.50	1.63	1.75	High	Low	Medium	Highly Susc.

limits were found not to be statistically different. Lines with a mean damage higher than 4.01 were considered as highly damaged.

As far as silk damage is concerned, the less damaged lines ranged from 1.06 to 1.75, the lines with a medium damage ranged from 1.76 to 1.96 and heavily damaged lines ranged from 1.97 to 2.75.

Lines on which the average number of adults per plant ranged from 1.63 to 3.84 were classified as having a low number of corn rootworms, lines with an average between 4.02 to 6.3 adults per plant were listed in the medium category and lines with more than 6.3 adults per plant were considered as highly infested.

Observing Table 9, it will be seen that 12 lines had a low average damage to the ears; a total of 15 lines had a medium average damage and three lines had a high average damage to the ears. The lines included in those three groups could be arbitrarily classified as resistant, susceptible and highly susceptible. The other two factors considered in this study, that is, the silk damage and the number of adults per plant were used to point out the possible mechanisms of resistance involved as will become evident in the following discussion.

In the group of lines classified as resistant, a total of four had low damage to the ears, low number of adults per plant and low damage to the silks. This suggests that the mechanism of resistance involved was non-preference which could be due to a lack of an attractant or the presence of a repellent in both silks and plant. Four of the lines that had low damage to the ears, had a medium number of adults and low damage to the silks, in which case the resistance exhibited by these lines was also thought to be non-preference where the presence of an attractant would account for the medium number of adults and the lack of a continuous feeding factor or the presence of a repellent could result in low injury to the silks. Two of the lines classified as resistant had high number of adults per plant and medium damage to the silks; this combination could be explained by the presence of an attractant, and also of an arrestant but may be the lack of a proper amount of a continuous feeding factor.

One of the 12 lines considered as resistant, had besides low damage to the ears, a low number of adults per plant, but had a medium damage to the silks, which could be explained by the lack of an attractant. This would account for the low number of adults found in this line because the insects would find the plants just by chance, but the few that did find the plants would feed actively because the presence in those silks of an arrestant and/or a continuous feeding factor.

Some of the lines that appeared to be resistant had a medium damage to the silks, however the ear damage was low. This could be explained if the damage to the silks had occurred after the fertilization had already taken place.

No data were obtained that would support the existence of antibiotic factors in the lines classified as resistant. However it could be present.

Among the 15 lines which had a medium damage to the ears and were classified as susceptible, all the possible combinations of number of adults per plant and silk damage occurred, with the exception of the combination of a high number of adults per plant and low silk damage. Most of the other combinations could be explained by means of the presence or absence of attractants, repellents, arrestants, and continuous feeding factors on leaves and/or silks. However it can be noticed in Table 9, that there were four lines that had a low damage to the silks and nevertheless the ear damage was in the medium classification. An explanation of this may be the fact that these lines showed damage to the developing kernels at the tip of the ears which were not covered by the husks, and because of that the ear damage was higher than it would have been expected when considering the silk damage alone.

Among the 3 lines classified as highly susceptible, one had, besides a high damage to the ears, a medium number of corn rootworm adults per plant and a low damage to the silks. This line, (WF9 x B7) x Maiz Dulce, did not have damage to the developing kernels at the tip of the ears, and therefore in this particular case it cannot be suggested that the high damage to the ears was due to the combination of silk damage and actual feeding on the developing kernels by the corn rootworm adults. It is possible that environmental factors may have had a large influence in the lack of effective pollination in this line.

The other two highly susceptible lines had a low number of adults which could be due to a lack of an attractant to the leaves, and one of them, K55, had a high damage to the silks which suggests the existence of an arrestant and a continuous feeding factor in the silks separate from the leaves. The other line, (B10 x B14) x Tehuacan had a medium damage to the silks, but the developing kernels at the tip of the ears were damaged. This and the medium damage to the silks would account for the high damage to the ears.

The attraction of the corn rootworm adults to the plants in the lines tested could have occurred because of an attractant present in the tassel, in the leaves or in the silks. Each one of those parts of the corn plant could have had a different attractant or it could be the same. This could account for attraction of adults to the tassel but not to the silks, or to the leaves but not to the silks, etc. The same can be said for arrestants for continuous feeding factors and for repellents.

A large variability was observed in some of the material tested for corn rootworm injury. In the four entries of the cross Lancaster x Zapalote Grande, one entry was resistant and the other three entries tested were susceptible. A possible explanation is that the material used in this test was not the original brought from Mexico in 1962, but the different selections made from it, under Kansas climatic conditions largely in the absence of Diabrotica. The four entries even though coming from the same original material, did not have the same genotype. This would account for the observed differences in susceptibility to adult rootworm injury in these tests. The same can be said in the case of two entries of Guadalupe 3D x C.B.C., and also in relation to the two entries of (B10 x B14) x Pan. 330 x Nar. 330 - 63:1125-1 and 9328 x 234.

SUMMARY AND CONCLUSIONS

The larval stages of the western corn rootworm, Diabrotica virgifera LeConte, the northern corn rootworm, Diabrotica longicornis (Say) and the southern corn rootworm Diabrotica undecimpunctata howardi Barber, cause much damage to the roots of corn plants in the corn belt. The adults of the three species are known to feed on most parts of the corn plant above the ground and their damage to the silks is thought to interfere with normal pollination and as a consequence with corn egg fecundation.

The purpose of this study was to obtain information concerning the extent and differential damage to the corn silks by the corn rootworm adults.

A total of 356 different lines of corn were tested under field conditions in the summer of 1964. These lines included 77 Kansas inbred lines, 81 crosses between corn belt material and Mexican races and collections, 151 lines derived from Mexican races cross onto a corn belt hybrid and an Argentine line and brought to Kansas in 1962, 34 U.S.D.A. corn rootworm uniform nursery inbred lines and 10 special Mexican collections. The lines were planted at the Belleville Experimental field and the Scandia Experimental field both at Republic County, Kansas and at the Agronomy Farm near Manhattan, Kansas.

Seven days after the lines started silking, data were taken in relation to number of corn rootworm adults present on the different lines and in relation to silk feeding. The silk feeding by corn rootworm adults was graded according to an arbitrary scale of damage ranging from 0 to 3. Zero corresponded to the plants without apparent damage and the 3 was given to plants with the silks chewed down to a level with the husks.

Peak population of corn rootworm adults in 1964 at Republic County plot was an average of 11.5 adults, per plant. At the Agronomy Farm, near Manhattan, was an average of 5.4 adults per plant.

The information obtained in 1964 was helpful in choosing the material to be tested in 1965, and in setting the planting dates for 1965.

As many as 48 lines, selected from the 1964 test, were planted in the summer of 1965. The 1965 tests were conducted at the Belleville Experimental field in Republic County, Kansas, the Agronomy Farm near Manhattan, Kansas, and a plot located 4 miles north of the town of Riley in Riley County, Kansas. Only 30 of the 48 lines planted germinated satisfactorily.

In the 1965 field test, data were taken on relation to number of corn rootworm adults present on the different corn lines tested. The material was also graded for silk damage using a damage scale ranging from 0 to 3 and for ear damage using a scale ranging from 1 = no damage to 7 = heavy damage. Data were also taken on relation to feeding of the adults on the kernels developing at the tip of the ears and on silk damage five days after the first grading.

Peak populations of corn rootworm adults in 1965 were an average of 13.0 adults per plant at the Belleville Experimental field, an average of 5.4 at the Agronomy Farm, and an average of 10.4 at the Riley plot.

The statistical analysis of the data obtained indicated that there were significant differences among lines as far as silk damage, ear damage and number of corn rootworm adults present on each line is concerned. Taking that into consideration, the lines were classified as resistant, susceptible and highly susceptible. The main factor considered in assigning the lines to a given category was the ear damage because it was the easiest to grade and possibly the most accurate. The other two factors considered in this study, that is, the silk damage and the number of adults present on the different lines were used to point out the possible mechanism of resistance involved.

A total of 12 lines were classified as resistant, 15 lines were classified as susceptible and three as highly susceptible.

The mechanism involved in the resistance or susceptibility of the lines tested was thought to be preference or non-preference, in which, attractants, repellents, arrestants and continuous feeding factors could account for the high or low number of corn rootworm adults present on the different lines and also for the high or low damage to the silks.

No recuperation was observed when the silk damage was graded five days after the first grading. This appears to rule out tolerance as mechanism responsible for resistance.

Lack of tests of differential effect of silks on the corn rootworm adults did not permit detection of the existence of antibiotic factors in the corn silks.

The 12 lines classified as resistant included one Kansas inbred line, K166, a Kansas hybrid, K-1859, a U.S.D.A. corn rootworm uniform nursery inbred line, SD10, and nine lines selected from crosses between Mexican and corn belt lines or Argentine varieties.

Conclusions

The results obtained in this work strongly suggest that the lack of pollination in corn due to feeding on the silks by the corn rootworm adults of the species Diabrotica virgifera LeConte; D. longicornis (Say) and D. undecimpunctata howardi Barber can be of economic importance in Kansas.

A suitable population of corn rootworm adults permitted detection of varietal differences in damage to the silks by these insects in two of the three plots planted in 1964 and in the three plots planted in 1965.

The corn rootworm populations in the two plots where satisfactory tests were conducted in 1964 and in the three plots planted in 1965 were constituted primarily by western corn rootworm Diabrotica virgifera LeConte. The northern species D. longicornis (Say) and the southern species D. undecimpunctata howardi Barber constituted only a small part of the total population.

Corn rootworm adult populations were consistently higher at the

Belleville Experimental field at Republic County than in Riley County in both 1964 and 1965 field tests. Peak populations at Republic County plots were an average of 11.5 adults per plant in 1964 and 13.0 adults per plant in 1965.

The differences in silk damage among the corn lines tested in 1965 were found to be statistically significant at the 0.05% level. The correlation coefficient between silk and ear damage was +.416 and was found to be statistically significant at the 0.05% level.

A wider silk damage grading scale, than the scale used (0 = no damage; 3 = heavy damage) might permit detection more accurately of the silk damage and result in a higher correlation coefficient between silk and ear damage.

The lack of fertilization in the different lines which was measured by an ear damage scale ranging from 1 = no damage to 7 = heavy damage was used to classify the corn lines as, resistant, susceptible and highly susceptible. The ear damage (lack of fertilization) was considered to be the easiest to use and possibly the most accurate. Killing of pollen by high temperatures in 1964 and 1965 and corn earworm damage in either year may have introduced differences in records of the same lines in the two years.

The mechanism of resistance involved in the resistance of the different corn lines to silk damage by Diabrotica spp., appears to be exclusively non-preference. Presence or absence of attractants, repellents and/or continuous feeding factors in the tassels, leaves and silks could account for the different number of adults present on the lines tested and could explain the differential damage to the silks observed. The fact that no recuperation or repair of the silks was detected when the silk damage was graded seven and 12 days after emergence seems to rule out tolerance as the mechanism responsible for resistance among the lines tested. Lack of tests of differential effect of silks on beetles did not permit detection of the existence of antibiotic factors in the corn silks.

A total of 12 lines out of the 30 corn lines tested in 1965 were classified as resistant. These lines had an average ear damage ranging from 1.91 to 3.00. At least 15 lines which had an average ear damage ranging from 3.08 to 4.00 were classified as susceptible. Three lines which were classified as highly susceptible had an average ear damage ranging from 4.25 to 4.50.

The corn material classified as resistant included one Kansas inbred line, K166, a Kansas hybrid, K-1859, a U.S.D.A. corn rootworm uniform nursery inbred line, SD10, and nine lines selected from crosses between Mexican and corn belt lines or Argentine varieties. These nine lines were: Haiti x Manfredi; (WF9 x B7) x Zapalote Grande; Manfredi x Maiz Dulce; Veracruz 184 x Manfredi; Antigua 6D x C.B.C.; Comp. Pan. 2 x Manfredi; San Croix 2D x Manfredi; Guadalupe 3D x C.B.C. - 63:1200-2 and Lancaster x Zapalote Grande - 63:1212-1.

The U.S.D.A. corn rootworm uniform nursery line, SD10, is known also to carry root resistance to the corn rootworm larvae.

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DIFFERENTIAL DAMAGE TO THE FEMALE INFLORESCENCE OF CORN, ZEA MAYS L., BY THE CORN ROOTWORMS DIABROTICA VIRGIFERA LECONTE, DIABROTICA LONGICORNIS (SAY) AND DIABROTICA UNDECIMPUNCTATA HOWARDI BARBER. CHRYSOMELIDAE: COLEOPTERA

by

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AN ABSTRACT OF A MASTER'S THESIS

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The purpose of this study was to obtain information concerning the extent and differential expression of damage to the corn silks by corn rootworm adults of the three species of Diabrotica known to occur in Kansas.

A total of 356 different lines of corn were tested under field conditions in the summer of 1964. These lines included 77 Kansas inbred lines, 81 crosses between corn belt material and Mexican races, 151 lines derived from Mexican material brought to Kansas in 1962, 34 U.S.D.A. corn rootworm uniform nursery inbred lines and 10 special Mexican collections. The material was planted at two localities in Republic County, Kansas, and at one locality at the Agronomy Farm near Manhattan, Kansas.

Data were taken in relation to corn rootworm adult preference for the different lines, and also in relation to damage to the silks caused by the beetles. Silk damage was graded using a damage scale that ranged from 0 to 3 (0 = no damage; 3 = heavy damage).

The peak population of corn rootworm adults in 1964 at the Republic County plot was an average of 11.5 adults per plant. At the Agronomy Farm the average was 5.4 adults per plant.

The information obtained in 1964 helped to choose the material to be tested in 1965, and to set the planting dates for 1965.

Forty-eight lines, selected from the 1964 test were planted in the summer of 1965. The 1965 field tests were conducted at 2 localities in Riley County, Kansas, and at one locality at the Belleville Experimental field in Republic County, Kansas. Only 30 of the 48 lines that were planted germinated satisfactorily.

In the 1965 field test, data were taken in relation to number of corn rootworm adults present on the different lines tested. The material was also graded for silk damage by using a damage scale ranging from 0 to 3 and for ear damage by using a scale ranging from 1 = no damage to 7 = heavy damage. Data were also taken in relation to feeding of the adults on the kernels developing at the tip of the ears and on silk damage five days after the first grading.

Peak populations of corn rootworm adults in 1965 were an average of 13.0 adults per plant at the Belleville Experimental field, an average of 5.4 adults per plant at the Agronomy Farm, and an average of 10.4 adults per plant at the Riley plot.

Statistically significant differences were detected among the lines tested as far as silk damage, ear damage and number of corn rootworm adults present on each line is concerned.

The lines were classified as resistant, susceptible and highly susceptible according to their respective ear damage. Ear damage was considered to be the easiest to grade and was possibly the most accurate rating system.

A total of 12 lines were classified as resistant, 15 lines were classified as susceptible and three as highly susceptible.

The corn material classified as resistant included one Kansas inbred line, K166; a Kansas hybrid, K-1859; a U.S.D.A. corn rootworm uniform nursery inbred line, SD10; and nine lines selected from crosses between Mexican and corn belt lines or Argentine varieties. These lines exhibited an average ear damage ranging from 1.91 to 3.00.

The mechanism involved in the resistance or susceptibility of the lines tested was thought to be preference or non-preference, in which, attractants, repellents, arrestants and continuous feeding factors could account for the high or low number of corn rootworm adults present on the different lines and also for the high or low damage to the silks.

No recovery was observed when the silk damage was graded again five days after the first grading. This seems to rule out tolerance as the mechanism responsible for resistance.

Lack of tests of differential effect of silks on the corn rootworm adults did not permit detection of the existence of antibiotic factors in the corn silks.