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SOME FUNDAMENTAL ASPECTS OF CONTROL OF THE EUROPEAN CORN BORER

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The method of control of the European corn borer by use of insecticides was developed by Batchelder and Questel (Batchelder, Questel and Turner, 1937). Briefly, the method involved application of either sprays or dusts to the whorls, emerging tassels and developing ears of the plants four times at five-day intervals, starting when hatching was first observed. The purpose was maintenance of toxic residues at places where larvae would feed during a large portion of the hatching season. This method of control has been used successfully in both experimental and commercial treatment of sweet corn.

Batchelder and Questel (1931) have pointed out that the rapid growth of the corn plant during the hatching season makes protection of the plant difficult at best. Furthermore, the facts that corn is an annual plant, and that planting dates vary, make it difficult to establish suitable schedules for treatment. The problem was simplified, however, by the work of Beard (Beard and Turner, 1942). He found that moths seldom deposited eggs on plants smaller than the mid-whorl stage, and that few larvae hatching from the eggs deposited before the late-whorl stage became established.

Obviously, then, there was little need for treatment of corn before the late-whorl stage, regardless of the time of first oviposition or the extent of hatching before this stage. Furthermore, since the late-whorl stage is characterized by the appearance of the tassel (Beard and Turner, 1942), this stage is a practical one for use by commercial growers in starting a schedule of treatment.

Having developed a satisfactory and practical method for determining the time to start treatment, the next step was the study of the schedule of applications. According to Vance (1943), eggs of the first generation start hatching the first week in June, and a few hatch as late as July 15. In other words, a schedule of four treatments at five-day intervals would not cover the entire hatching season. Possibly the last 10 or 15 per cent of the eggs would hatch more than five days after the final treatment. The treatment would afford protection from a majority of the larvae, however. Moreover, the schedules would cover the peak of hatching.

Several variations in the interval between treatments and in the number of treatments applied were tested (Beard and Turner, 1942). All variations in timing were made according to days elapsing between treatments. The results showed that this type of change demonstrated no important effect of timing. In fact, the total number of treatments applied had more influence on the degree of control than the time at which they were applied.

The effect of individual treatments and the location and size of the larvae surviving treatment were studied (Beard and Turner, 1942). The results of one experiment indicated that the treatments were about equal in protecting the ears, although there was a slight tendency for later applications to provide better control of larvae in the entire plant.

In the meantime, Beard (1941, 1942) had shown that most of the infestation in the ears was the result of primary infestation by newly-hatched larvae. Earlier in the development of the plant the larvae sought the developing tassel, and most of the migrants from the tassel apparently settled in the stalk. Beard reasoned that direct application to the ears only should protect them from infestation. Therefore, treatment before ear shoots were formed should reduce the total population but might be expected to have little effect on the ear infestation. Treatment of the ear shoots only with three applications, was compared with the standard four-application schedule in 1940 and 1941 (Beard and Turner, 1942). In neither year did ear treatments equal the standard in effectiveness, but in 1940 the results were promising.

It has been shown (Turner, 1941) that, at best, the standard schedule of treatment using fixed nicotine dusts does not provide sufficient control so that the crop can be sold to advantage without sorting. More recently, Questel (1944) has reported sufficient control so that sorting was unnecessary following application of derris sprays. Pepper and Carruth (1945) have reported similar results from experimental applications of *Ryanex*. It has been suggested (Beard and Turner, 1942) that the effectiveness of the standard treatment is influenced strongly by the size of the population. The percentage control decreased as the number of larvae per plant increased. Vance (1943) has recorded fluctuations in population of from 109 to 1,980 larvae in 100 plants in New Haven County. It is obvious, then, that the standard method of treatment must be improved radically in order to meet the goal of a borer-free crop of sweet corn.

Two means of approach may be used to accomplish such a result: (1) the improvement of methods of treatment, and (2) reduction in the amount of infestation by cultural methods or by development of less susceptible strains of corn. Both are being investigated, and this is a report of the experiments that have been completed.

In spite of the large amount of information available, there is still lacking a knowledge of many fundamental facts which must be established in order to control the corn borer successfully. This is especially true of the origin of the larvae infesting the ears, the toxicity of insecticides to these larvae in the field, and the places where insecticides must be deposited in order to prevent infestation.

EFFECT OF INDIVIDUAL TREATMENTS IN THE STANDARD SCHEDULE

No significant difference was found between individual treatments of the four-treatment schedule in the tests conducted in 1941 (Beard and Turner, 1942). A similar type of experiment was carried out in 1942, using corn infested by the first generation of the borer. Dual-fixed nicotine dust (4 per cent nicotine) was applied on June 8, 13, 18 and 23 for the standard schedule, and on each date for individual schedules. In 1943, a similar test was made on late sweet corn with the treatment dates August 2, 7, 12 and 17, using nicotine bentonite dust (4 per cent nicotine). The results of these tests in terms of reduction of larvae at harvest time are summarized in Table 1. The only treatment differing substantially from the others was the August 12 application in 1943, which provided very little or no control. The poor results might have been caused by the heavy rain following treatment. However, a similar amount of rainfall after the June 13, 1942 treatment did not destroy the value of the application. Furthermore, there appeared to be no consistent relation between the time a treatment was made and the control of larvae in the ears.

The degree of control of the standard schedule was relatively low, but this should not invalidate the comparative effects of individual treatments.

TABLE 1. EFFECT OF INDIVIDUAL TREATMENTS OF THE 4-TREATMENT SCHEDULE ON CONTROL OF THE EUROPEAN CORN BORER

Year	Date of treatment	Treatment no.	Rainfall within 5 days after treatment	Per cent reduction in larvae	
				Ears	Entire plant
1942	June 8	I	Trace	10.1	14.8
	" 13	II	.81 in.	18.3	19.7
	" 18	III	.55 "	14.2	14.5
	" 23	IV	Trace	30.1	19.9
	June 8, 13, 18 and 23.	I. II, III, IV		59.4	47.5
1943	August 2	I	Trace	25.7	14.9
	" 7	II	.49 in.	27.5	21.3
	" 12	III	.88 "	2.3	0.0
	" 17	IV	Trace	14.0	27.9
	August 2, 7, 12 and 17.	I, II, III, IV		50.9	48.4

From these three series of tests, it seems evident that no specific time of treatment within the range of four applications at five-day intervals has any special or unusual influence that can be measured at the end of the season. The results support those already obtained (Beard and Turner, 1942) in which number of treatments was found to be more important than timing.

ORIGIN OF LARVAE INFESTING EARS

Beard (1941, and Beard and Turner, 1942) has shown that most of the infestation in the ears was apparently the result of primary infestation by newly-hatched larvae. Earlier in the development of the plant the young larvae were established in the developing tassel, and the migrants from the tassel apparently settled in the stalk for the most part. Therefore, applications directed at the ears only should protect them from infestation. However, three applications of dust or spray directed at the developing ears did not reduce the ear infestation as much as the standard schedule of four treatments, the first of which was applied before ear shoots were present (Beard and Turner, 1942).

In 1942, another test of ear treatment was made on early corn. The standard schedule was applied on June 8, 13, 18 and 23 and the treatment of ears only on June 16, 22 and 27. The results are given in Table 2, and show that the ear treatment approached the standard in effectiveness but did not equal it. In two tests in 1942 and 1943,

TABLE 2. EFFECT OF TREATMENT OF EARS ONLY

Year	Schedule		No. larvae in 100 ears	Per cent reduction in larvae
1942	Standard June	8–13–18–23	127	68.4
	Ears only	16–22–27	165	58.9
	Check		401	
1942	Standard June	10–16–20–25	115	63.1
	Last three	16–20–25	192	38.4
	Check		312	
1943	Standard Aug.	2–7–12–17	168	50.9
	Last three	7–12–17	228	33.3
	Check		342	

schedules of the last three treatments were compared with the standard schedule. The three-treatment schedule fell far short of the standard in both cases. It will be noted, however, that the treatment of ears only when the plants were in the early tassel, early silk and mid-silk stages was relatively more effective than the last three treatments of the standard schedule, which was completed when the plants were in the early silk stage. In other words, the last three treatments of the standard schedule were completed while primary infestation was still in progress, and the later ear-treatment schedule was providing protection over a longer period of time.

However, the fact remains that treatment of ears only has not protected the ears as well as the hypothesis would indicate. In such a case, it is necessary to re-examine all the facts in an attempt to determine what is wrong. There is a possibility that the hypothesis is incorrect, that migration is responsible for at least some of the infestation and that killing these migrants by a treatment before they become established is necessary. A careful study of Beard's methods, data and conclusions shows no obvious flaw in any respect. Moreover, data obtained in various insecticide experiments tend to support his conclusions fully.

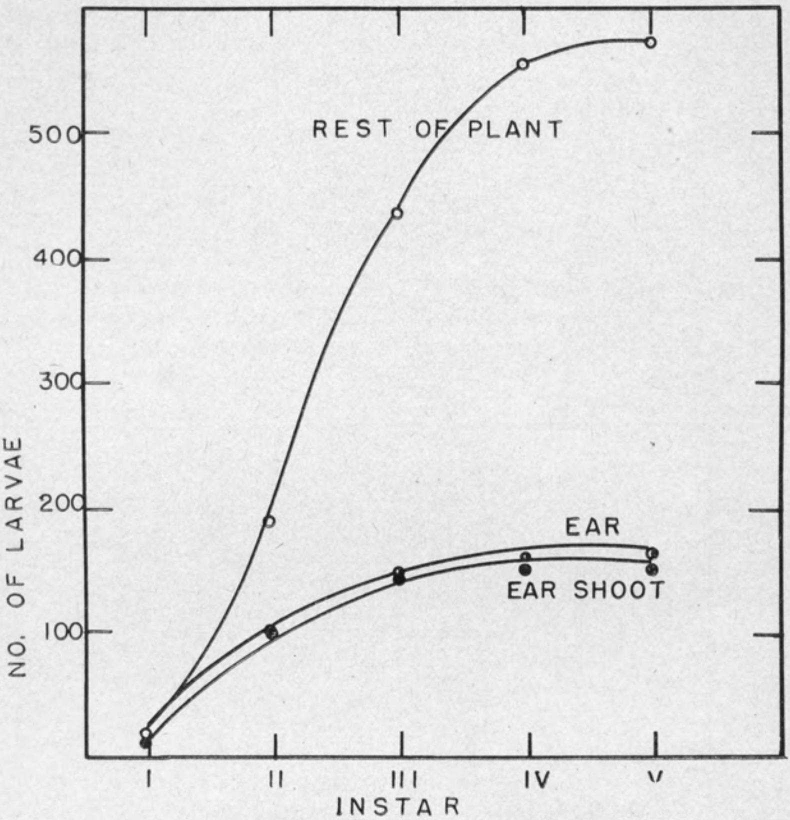

FIGURE 1. Cumulative frequency distribution curves for larval instars in ears, ear shoots and the rest of untreated plants on June 26, 1942.

In 1942, plants were dissected at intervals of five days, starting three days after the first insecticide treatment. Ten stalks were taken at random from each plot, and the position and size of each larva recorded. These data have been summarized in Table 3. For the sake of simplicity, data for tassel infestation include only the period of migration. It will be noted that between June 21 and 26, 182 larvae disappeared from the tassel. In the same period of time ears and ear shoots apparently lost 64 larvae, and the rest of the plant (including the tassel) contained the same number of larvae. The implication is plain that the migrating larvae did not settle in the ears or ear shoots exclusively if at all.

TABLE 3. SIZE AND LOCATION OF LARVAE IN UNTREATED PLANTS, 1942

Date	Location	Instars I	II	III	IV	V	Pupae	Total
June 21	Tassel	126	183	101	11			421
" 26	"	3	82	112	39	3		239
July 8	"	0	4	4	2	6	1	17
June 11	Ear shoots	11						11
" 16	" "	111	17					128
" 21	" "	241	103	19	2			365
" 26	" "	15	83	41	6			145
	Ears	16	83	44	11	2		156
								301
July 8	Ear shoots	2	19	48	41	24	4	138
	Ears	1	18	56	68	75	1	219
								357
	Rest of plant (exclusive of ears and ear shoots)							
June 11		108	8					116
" 16		215	215	87	4			521
" 21		194	221	135	18			568
" 26		10	174	248	118	15		565
July 8		0	17	74	91	218	29	429

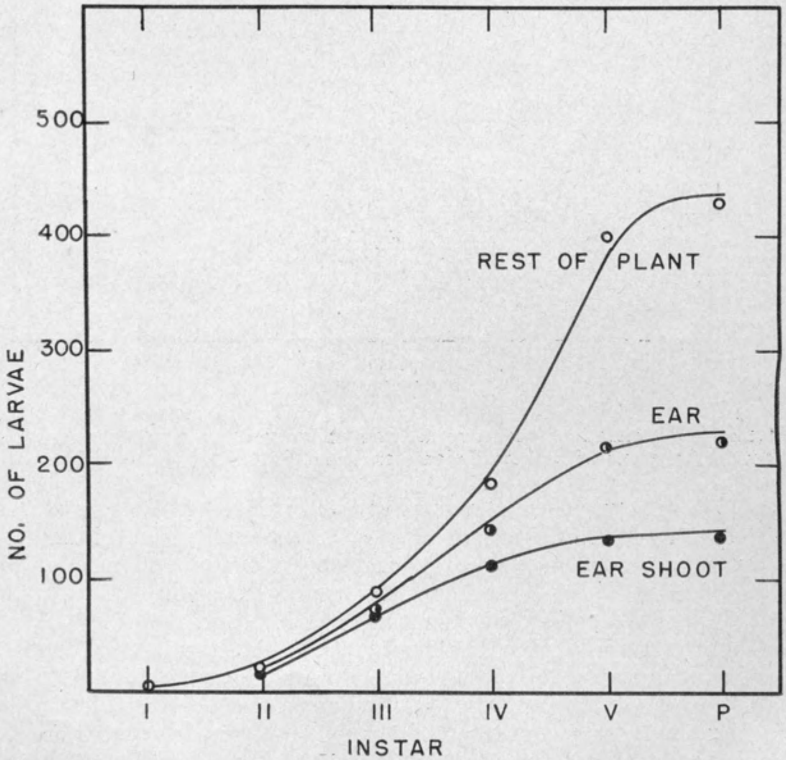

FIGURE 2. Cumulative frequency distribution curves for larval instars in ears, ear shoots and the rest of untreated plants on July 8, 1942.

The data for instars also bears this out. There is no sign of a sudden influx of any instar of larvae in the ears and ear shoots between June 21 and June 26. The cumulative frequency distribution curves (Figures 1 and 2) show that the ears and ear shoots actually contain a smaller proportion of larger instars than the rest of the plant on June 26. By July 8, the large ears have accumulated more advanced instars than the ear shoots, but the curve is not parallel with the distribution curve for the rest of the plant.

A similar experiment on late corn infested by second generation larvae has been summarized in Table 4. Here again, there is no direct evidence that larvae migrating from the tassel entered the ear. Between August 5 and 9 the ear population did not increase, although the tassel population declined. Between August 9 and 14 the increase in ear infestation was mostly in the early instars. In the rest of the plant the increase was mostly in third instar larvae. Frequency distribution curves (Figures 3 and 4) emphasize further the fact that the rest of the plant contained larger proportions of the larger instars. There is no indication of an accumulation of larger larvae in ears at the final dissection as there was in the first generation test (Figure 2).

It must be stated that the figures for the different dates represent samples drawn from a population and not identical plants. It is im-

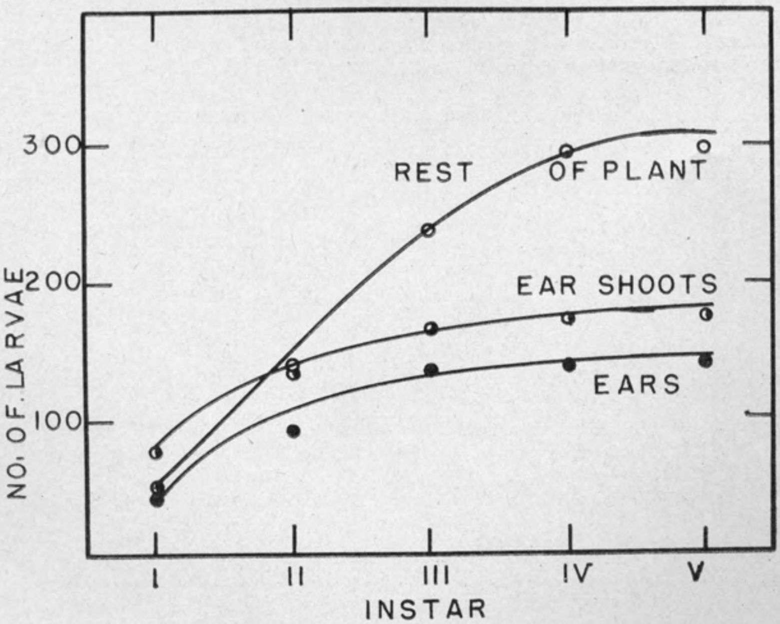

FIGURE 3. Cumulative frequency distribution curves for larval instars in ears, ear shoots and the rest of untreated plants, August 19, 1943.

possible to follow the movements of larvae without destroying the plant. However, there should be some clear indication of establish-

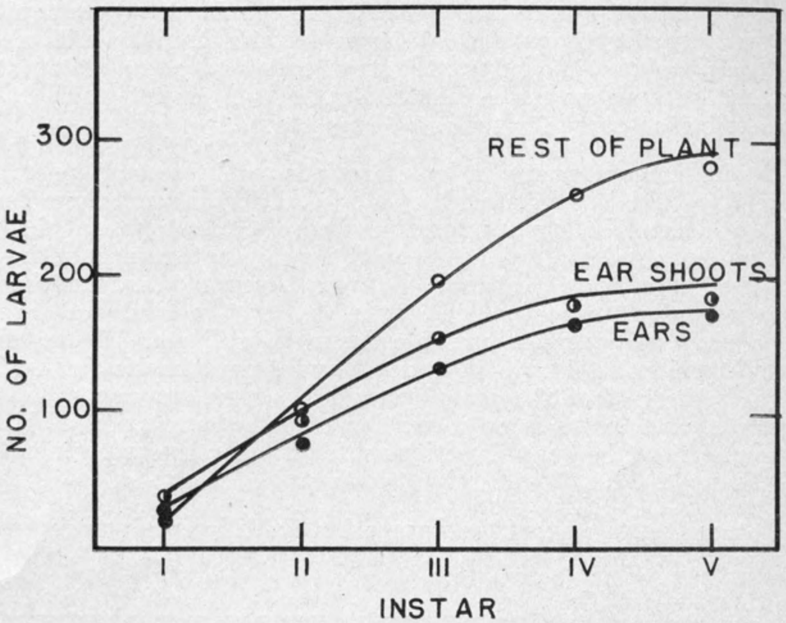

FIGURE 4. Cumulative frequency distribution curves for larval instars in ears, ear shoots and the rest of untreated plants, August 25, 1943.

TABLE 4. LOCATION AND SIZE OF LARVAE, SECOND GENERATION, 1943

Date		I	II	III	IV	V	Total
				Tassel			
August 5		112	54	25			191
9		48	42	30	2		122
14		7	16	41	6		70
19		5	5	12	9	2	33
25		0	0	1	0	0	1
				Ears and ear shoots			
August 5		73	16	2			91
9		58	21	3	1		83
14		96	63	8	0		167
19	Ear shoot	74	60	31	7	1	173
	Ear	41	49	43	4	1	138
25	Ear shoot	37	67	55	23	3	185
	Ear	33	46	57	32	3	171
				Rest of plant			
August 5		151	64	27			242
9		85	69	48	4	3	209
14		40	82	118	29	0	269
19		52	88	96	58	2	296
25		21	73	103	65	20	282

TABLE 5. SIZE OF LARVAE AT HARVEST TIME FOLLOWING EAR TREATMENT

Number larvae — Instar

Treatment	II		III		IV		V		Pupae		Total
	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent	
Standard	44	13.8	83	26.1	84	26.4	95	29.9	12	3.7	318
Ears only	64	15.5	94	22.8	80	19.1	146	35.4	28	6.8	412
None	160	16.0	257	25.6	257	25.6	319	31.8	9	.9	1,002

ment of migrating larvae in ears if this actually occurred. From all the data available, it is evident that ear infestation is primary and not a result of migration.

Having established the validity of the hypothesis, the next step is to examine the other possibilities. The instars of the larvae found in the ears in the 1942 ear treatment experiment are recorded in Table 5, and plotted as cumulative frequency distributions in Figure 5. In general the distribution in the standard treatment follows the pattern in the untreated check. Following the ear treatment, however, there was a distinct shortage of fourth instar larvae. Otherwise, the pattern was very similar to the untreated. The three applications to the ears did not control the borer as well as four treatments to the plant. Just why there should be a shortage of the fourth instar is not at all plain. There are at least three possible explanations. The treatment may have killed a large proportion of young larvae attempting to enter the ear, for a very short time only. This might result in shortage in one instar. However, if such a type of control did result, it should also appear in the standard treatment. The second possibility is that large migrating larvae were killed by the late ear treatment. This also seems unlikely because, if the late treatment was that effective, it should have killed more young larvae than it did. The third possibility is that the shortage is a result of heterogeneity. It is dangerous to write off such variations as heterogeneity, because some important effect may be discarded in the process. However, in this case both the number and percentage of pupae far exceeds those found in the untreated ears. There is no logical reason for believing that treatment could increase either the number or percentage of pupae. The shortage of the fourth instar is only a trifle larger in percentage than the excess of pupae.

There is certainly nothing in the instar data to show why the ear treatment was not as effective as the standard treatment. It seems probable that the three ear applications are simply not as effective as four treatments, even though the first of the four is applied before the ears are formed. Residual effect of insecticide which undoubtedly falls in the axils of the leaves may account for the toxicity of this first treatment.

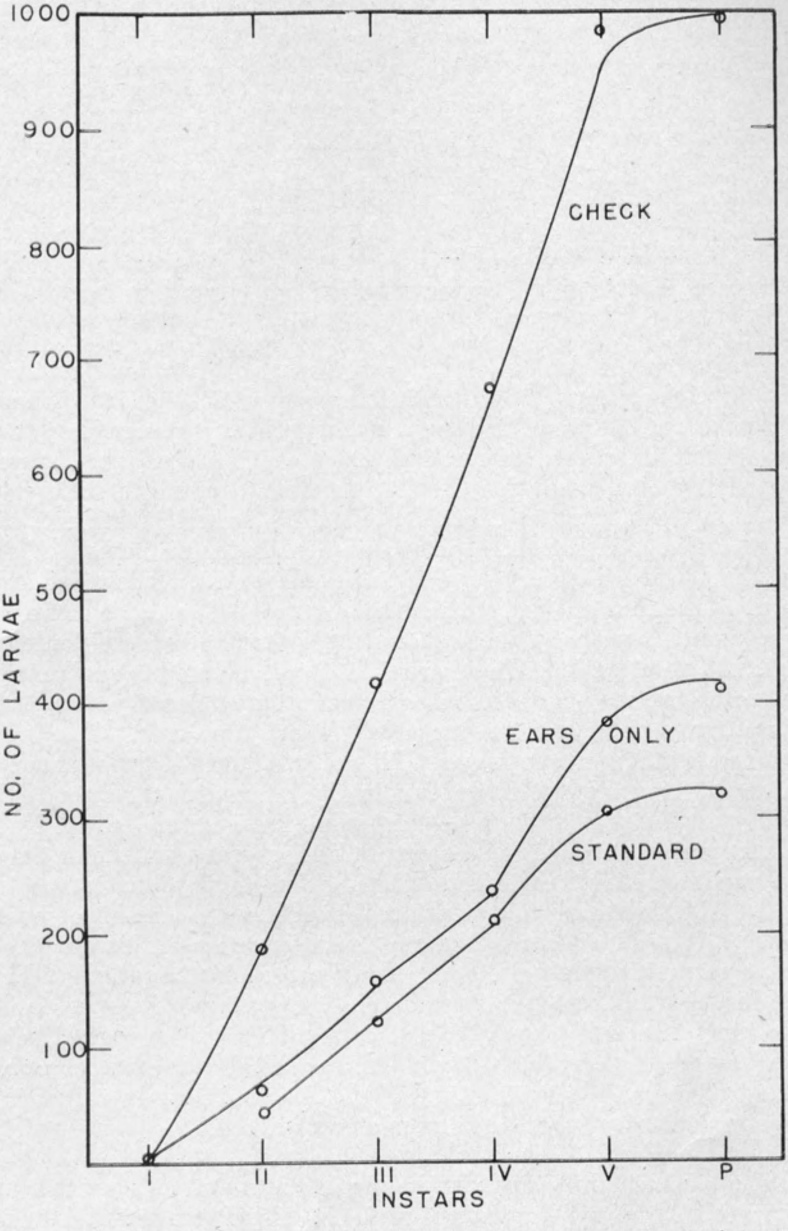

FIGURE 5. Cumulative frequency curves for larvae in untreated plants, those with three applications to ears only, and with the standard treatment of two applications to the stalk and two to ears.

LOCATIONS AT WHICH LARVAE WERE KILLED

The second type of approach to this same problem was made in the attempt to evaluate the effectiveness of the treatment by determining the number and position of the larvae after treatment (Beard and Turner, 1942). Dust applied directly to the ears did reduce the infestation in the ears, but little more so than in other parts of the plant such as the stalk. Obviously, not all of the dust stayed on the ear, but the implication was that newly-hatched larvae wandered over the plant to such an extent that they came in contact with the dust. This experiment was repeated on the first generation in 1942, and on the second generation in 1943, in an attempt to obtain more information. The results were substantially the same as already reported.

Since the data obtained could be interpreted as meaning that larvae were killed as they wandered over the plant, the use of dose-response technique as applied to coverage was indicated. If larvae were killed as they wandered over the plant, covering as much of the surface of the plant as possible uniformly and completely should increase the probability of reaching them with the insecticide. If, on the other hand, the larvae were killed as they tried to enter the tassels or ears, spreading the material over the entire plant would reduce the effectiveness. The method which reached the largest proportion of the larvae should have the steepest dose-response curve. The method which placed the largest amount of toxicant where it was needed (in terms of toxicant used) should show a dosage-response curve displaced to the left. (See Dimond, et al., 1941; Horsfall, 1945.)

Accordingly, a hood was constructed to cover a single row of corn. The wooden framework was five feet high and open at the ends. It was mounted on two bicycle wheels so that it could be pushed down the row. A muslin hood was tacked to the frame, with the front and back panels split to allow the hood to be moved down the row. A rotary hand duster was mounted at one side with the nozzle directed slightly upwards. The dust swirled within the hood, and observation showed that all parts of the corn plant were exposed to the dust. The hood was used to apply nicotine bentonite-pyrophyllite dust, 1, 2, 4 and 8 per cent nicotine, at the rate of 12 pounds per acre, and to a second series of plots at 48 pounds per acre (by increasing opening of the feed slot).

Other series of plots were treated using the same duster without the hood. The dust was directed at the developing tassels for the first treatment, and at the developing ears thereafter.

Plots were randomized in blocks, with three replications. The only restriction in design was that all the hood treatments were placed in the same row of plots to facilitate application. Plots consisted of two rows, 25 feet long for the direct application and 50 feet long for hood treatment. The plots were six feet apart, a missing row being used to prevent migration instead of the usual two buffer rows. Ten plants in each row were segregated from the rest of the plot by removing two plants at each end. These 20 plants per plot were examined at least once every five days for eggs. Records were kept on the basis of the 10 plants in one row. This procedure was adopted for two reasons: (1) to determine the number of larvae actually entering the plant in an effort to reduce the enormous variation in results and (2) to determine the effect of treatment on oviposition.

Spancross corn was planted April 14 and dusted June 7, 12, 17 and 22. The records show that the amount of dust used was approximately that desired. The plans called for dissection of half of the plants after two treatments had been made, but there was not sufficient time for such a dissection. The 10 plants for which egg-deposition records were taken were dissected, and the position of each larva recorded. In addition, 10 stalks were taken at random from the rest of the plot, but the tillers were not included. Results of the final dissection of the 10 entire plants from each of the three replicates are summarized in Table 6, and of the main stalk only for 20 plants from each plot in Table 7.

Table 6 shows the enormous variation in number of eggs hatching on 30 plants. The low number was 2,988 and the high, 4,536. The two checks differed by almost 700 larvae, but the percentage of survival was practically identical. For 10-plant plots, the low was 810 larvae, and the high, 1,872, or more than twice as many. It is obvious that the same insecticide applied to these two plots would not leave the same number of larvae. However, dose-response curves drawn for percentage of survival (Figure 6) are not much more satisfactory

Table 6. Larvae Hatching and Surviving Treatment. Dosage-Response Tests Using Direct and Hood Application

Method	Pounds per acre	Per cent nicotine	Larvae hatched	Larvae surviving	Per cent survival	Per cent control
Hood	12	1	4,086	1,187	29.1	
		2	3,384	1,027	30.3	
		4	3,456	1,030	29.8	
		8	3,564	932	26.2	9.3
	48	1	3,294	1,006	30.5	
		2	3,797	893	23.5	18.7
		4	3,870	958	24.7	14.5
		8	3,420	573	16.8	41.9
Direct	12	1	3,312	1,015	30.6	
		2	2,988	821	27.3	5.5
		4	4,536	910	20.1	30.4
		8	4,158	743	17.9	38.1
	48	1	3,852	801	20.8	28.0
		2	3,618	785	21.7	24.9
		4	2,988	563	18.8	34.9
		8	3,114	364	11.7	59.5
Check	None	None	3,150	908	28.8	
"	"	"	3,834	1,108	28.9	

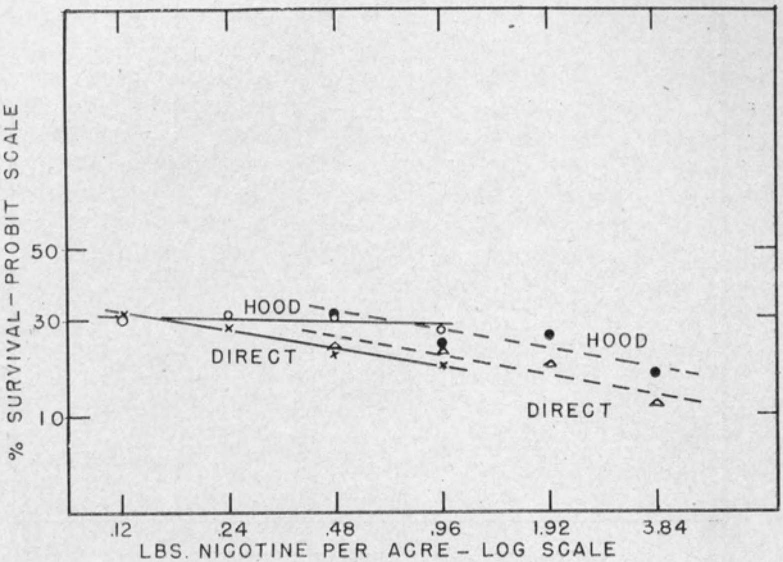

FIGURE 6. Relation between amount of nicotine used, method of application and rate per acre and survival of the European corn borer. Solid lines represent 1, 2, 4, and 8 per cent nicotine in nicotine bentonite dust applied at 12 pounds per acre; broken lines the same concentrations at 48 pounds per acre.

TABLE 7. LARVAE SURVIVING TREATMENT; 20 STALKS ONLY FROM EACH PLOT. DOSAGE-RESPONSE TESTS USING DIRECT AND HOOD APPLICATION

Method	Pounds per acre	Per cent nicotine	Larvae In stalk	Larvae In ears	Larvae Total	Per cent reduction in larvae[1]
Hood	12	1	552	268	820	. . .
		2	492	238	730	6.2
		4	480	219	699	10.2
		8	459	208	667	14.3
	48	1	539	257	796	. . .
		2	461	213	674	13.4
		4	405	205	610	21.6
		8	292	141	433	44.3
Direct	12	1	553	224	777	. . .
		2	402	207	609	21.7
		4	411	182	593	23.8
		8	327	187	514	33.9
	48	1	408	217	625	19.7
		2	296	149	445	42.8
		4	266	146	412	47.0
		8	182	56	238	69.4
Check	None		532	246	778	
			229	462	691	

[1] Calculated on the basis of the largest check.

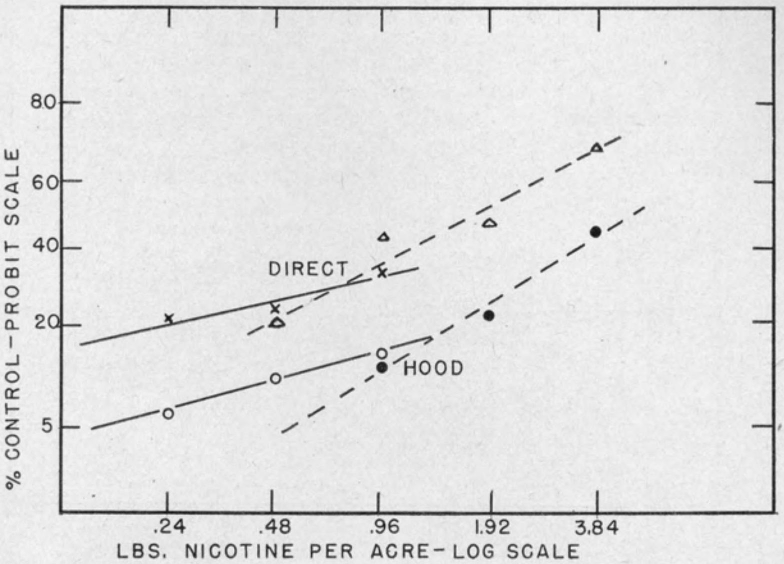

FIGURE 7. Relation between degree of control, method of application and rate per acre and control of the European corn borer. Solid lines represent 1, 2, 4 and 8 per cent nicotine in nicotine bentonite dust applied at 12 pounds per acre; broken lines the same concentrations at 48 pounds per acre.

than those for control on the basis of comparing numbers surviving in treated and untreated plots. Apparently, the use of even three replicates does much to equalize the differences in number of eggs hatching on a plant.

There is no indication in the data that the nicotine bentonite used had any effect on egg deposition or hatching. A careful study of the detailed data failed to show any important effect of position in the field on number of eggs deposited.

The test failed to show any substantial difference in slope of dosage-response curves for the two different methods of application (Figure 7). Both methods apparently reached the same proportion of larvae. On the other hand, the direct method provided much better control in terms of amount of dust used. To control 40 per cent of the larvae, 1.1 pounds of nicotine were used by direct treatment and 3.2 pounds by hood treatment at 48 pounds per acre. Direct treatment was therefore about three times as effective.

The location of the larvae found following treatment has been summarized in Table 8. The larvae in tassels and in leaf sheaths have been omitted from the table, because they form so small a portion of the total larvae. In general, the hood type of treatment apparently gave more uniform control in the different parts of the plant

TABLE 8. PERCENTAGES OF LARVAE PRESENT IN PARTS OF PLANTS FOLLOWING TREATMENT

Method	Pounds per acre	Per cent nicotine	Per cent larvae in: Tiller	Ear shoot	Ear	Stalk
Hood	12	1	49.4	21.0	7.7	15.7
		2	45.8	20.0	9.9	17.4
		4	46.6	19.0	10.8	16.5
		8	47.2	19.6	9.4	16.1
		Average[1]	47.5	20.0	9.4	16.4
	48	1	43.5	15.9	13.4	20.5
		2	45.3	18.5	11.4	19.5
		4	47.5	21.4	10.2	15.8
		8	45.9	21.3	9.8	19.7
		Average[1]	45.5	19.0	11.4	18.8
Direct	12	1	48.9	18.3	9.2	16.7
		2	49.0	19.0	10.0	14.7
		4	52.9	18.3	7.7	15.6
		8	49.5	20.0	10.4	15.2
		Average[1]	50.1	18.8	9.2	15.9
	48	1	47.8	17.2	13.0	18.2
		2	55.7	16.9	11.6	13.4
		4	57.4	17.2	7.8	14.0
		8	49.2	15.6	9.1	22.8
		Average[1]	52.6	16.9	10.8	16.4
None	...	...	40.7	17.3	12.7	24.7
			51.6	16.7	10.2	16.5
		Average[1]	46.7	17.0	11.3	20.2

[1] Calculated from total numbers in each part of the plant.

than direct application of dust. This is noticeable chiefly in the proportion of larvae in the tillers. Although the results are highly variable (see data for the two checks), there is a definite trend towards a larger proportion of larvae in the tillers of the plants receiving direct dusting than in untreated plants and hood-treated plants. This also shows the reason for the greater difference between types of treatment in Figure 7, based on the main plants and excluding tillers, than in Figure 6, where the tiller population was included.

Taking all the results into consideration, it is clear that direct treatment of the main stalk did protect it better than spreading the same amount of dust over the entire plant. The implication is strong that direct treatment of the ears should protect them.

The principal reason for the difference in effectiveness is evident. The hood application evidently did not deposit as much toxicant where it would reach the insect as the direct treatment. In terms of dosage for equal control, 1 per cent nicotine applied directly was as effective as 3 to 4 per cent nicotine applied under the hood (Figures 6 and 7). Furthermore, 12 pounds of 8 per cent dust was more effective than 48 pounds of 2 per cent dust, and 12 pounds of 4 per cent dust gave better results than 48 pounds of 1 per cent dust when applied under the hood. In the direct application, 12 pounds of 8 per cent dust was not as satisfactory as 48 pounds of 2 per cent dust, but 12 pounds of 4 per cent dust exceeded 48 pounds of 1 per cent dust in kill. Thus, the evidence on the coverage effect is not conclusive but, in three of the four comparisons possible, the difference was in favor of a small amount of high concentration dust. This follows the same pattern as coverage tests using dusts for control of other pests (Turner, 1945). However, the slopes of the curves for 48 pounds per acre appear to be definitely steeper than for 12 pounds (Figure 7), indicating better coverage for the larger amount. Certainly, the use of a dust cloud under a hood did not improve coverage as much as application of more pounds per acre.

A second test of the effect of coverage was made in the experiments on tillers described on pages 38-41. In this case the same amount of dust of the same concentration was applied in the same way to plants with and without tillers. All dusts were directed first at the developing tassel and later at the ear shoots, whether tillers were present or not. Obviously, the larvae on plants without tillers were concentrated in a much smaller area than on plants with tillers. Therefore, in this test the *coverage of larvae* was changed in relation to the place the insecticide was applied. On the basis of the theory of coverage (Horsfall, 1945), if concentration of larvae in the main stalk increased the probability of hitting them, steeper dosage-response curves should result.

The data from Table 22 has been plotted in Figure 8 which shows no evidence of any coverage effect as evidenced by a change in slope of the curves. In fact three of the four points of the curves are approximately the same and the same curve can represent both sets of points. The fourth point must be considered aberrant and as having little effect in changing the slope. In other words, the treatment of stalk only killed about the *same percentage of larvae*, whether tillers were present or not.

The two types of coverage tests used, (1) applying the insecticide over a larger part of the plant and (2) applying the insecticide to a small portion of plants with and without tillers, failed to show any important effect of coverage. In fact, it was definitely preferable to treat a small area with the insecticide rather than to scatter it over the entire plant.

In the experiments on locations at which larvae were killed, discussed above, the implication was strong that larvae may move about the plants freely and may be killed at a place relatively distant from their location when the final dissection is made. If the portion of the stalk near the ears were the principal route followed by the migrating larvae, regardless of the presence or absence of tillers, treatment of that area should produce the same relative results whether tillers were present or not.[1] Furthermore, the treatment of the main stalk with 48 pounds of dust should leave a heavier deposit of insecticide in the critical area than application of this same amount of material to the entire plant. The results of experiments seeking information on the locations at which larvae were killed, and the origin of larvae infesting the ears, all tend to support the hypothesis that the stalk is the main avenue for migration. It would be difficult to interpret the results of the tests on coverage by any other theory.

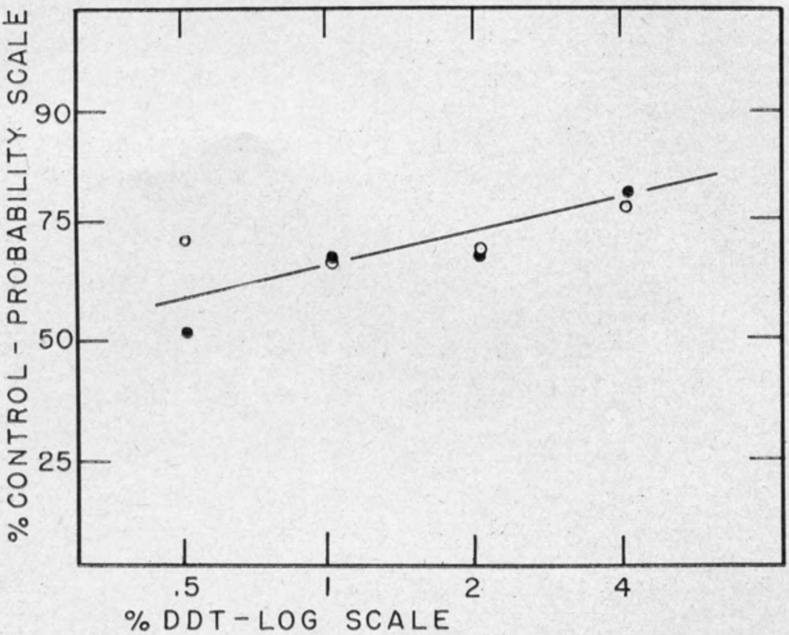

FIGURE 8. Control on plants with tillers (solid) and without tillers (open circles) using a dosage series of DDT dusts.

SIZE OF LARVAE KILLED BY DUSTS

The fundamental importance of the size of larvae killed by dusts is evident. If only first-instar larvae are susceptible, all of the control obtained must be accomplished by killing newly-hatched larvae before they become established in the plant. If, on the other hand, treatment will kill larger larvae that migrate, there may be two or more opportunities to kill each larva. In the tests of individual treatments described above, the instar as well as the position of the larvae was recorded. In general, the first dissection was made three days after treatment; the second, eight days after treatment, and the final examination, when the corn had reached the roasting ear stage.

[1] Hypothesis suggested by A. E. Dimond, Department of Plant Pathology and Botany.

TABLE 9. SIZE OF LARVAE SURVIVING TREATMENT, SCHEDULE TESTS

treated Date	Date dissected	No. larvae in instar I	II	III	IV	V	Pupae	Total
			1942					
June 8	June 11	111	12					123
	June 16	299	107	10	2			418
	July 8	6	81	125	120	298	39	669
June 13	June 16	253	118	39				410
	June 21	231	162	101	11			505
	July 8	2	78	169	170	180	32	631
June 18	June 21	204	276	112	17			609
	June 26	63	225	273	82	16		659
	July 8	8	49	140	149	273	53	672
June 23	June 26	59	198	275	65	11	1	609
	July 8	3	56	126	142	254	38	619
June 8	June 11	111	12					123
June 8, 13	June 16	203	104	24	2			333
June 8, 13, 18	June 21	125	169	79	2			375
June 8, 13, 18, 23	June 26	20	120	140	46	4		330
	July 8	2	41	78	92	150	49	412
None	June 11	119	8					127
	June 16	326	232	87	4			649
	June 21	435	324	154	20			933
	June 26	41	340	333	135	17		866
	July 8	3	54	178	200	317	34	786
			1943					
Aug. 2	Aug. 5	235	81	4	1			321
	Aug. 10	94	119	53	1			267
	Aug. 30	50	129	171	156	37		543
Aug. 7	Aug. 10	173	87	34				294
	Aug. 15	128	111	66	15			320
	Aug. 30	56	121	145	115	37		474
Aug. 12	Aug. 15	115	129	106	26			376
	Aug. 20	116	136	174	69	3		498
	Aug. 30	73	145	204	181	39		642
Aug. 17	Aug. 20	148	153	141	87	6		535
	Aug. 30	26	103	196	197	30		552
Aug. 2	Aug. 5	235	81	4	1			321
Aug. 2, 7	Aug. 10	98	65	14				177
Aug. 2, 7, 12	Aug. 15	50	99	72	15	1		217
Aug. 2, 7, 12, 17	Aug. 20	90	66	58	40	2		256
	Aug. 30	37	64	106	97	25		329
None	Aug. 5	224	80	29				333
	Aug. 10	143	90	51	5	3		292
	Aug. 15	136	145	126	29	0		436
	Aug. 20	167	197	170	69	4		607
	Aug. 30	91	186	215	120	26		638

Three series of experiments were completed, including tests on the first generation in 1941 and 1942, and on the second generation in 1943. A summary for the tests in 1942 and 1943, the years for which complete data were taken, is given in Table 9. These data have been calculated (1) according to the percentage reduction of each instar as compared with the untreated check, (2) according to percentage of each instar found in the treated plots, which was then compared to the percentage in the untreated checks and (3) as frequency distributions of the various instars. Only the last method seemed to present a consistent picture. Unfortunately, the problem is very complex, since the size of the larvae present depends on both the age of the larvae and its nutrition. Furthermore, eggs hatched throughout the time treatments were being made.

Cumulative frequency distribution curves drawn for the different dates following the different treatments in three seasons followed two patterns in general. Eight were roughly parallel, the remaining 34 were divergent. Of those that were parallel, four represented the first dissection only three days after treatment and were results of the

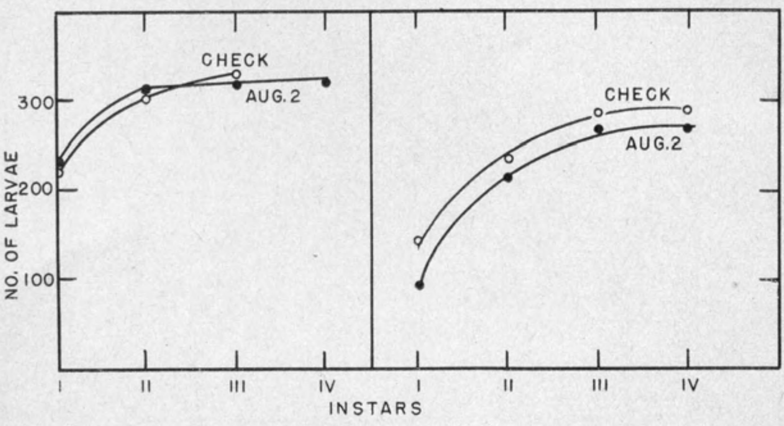

FIGURE 9. Cumulative frequency distribution curves for larval instars in untreated plants and plants dusted August 2, examined August 5 (at left) and August 8 (at right).

first or second treatment when most of the larvae were in the first and second instar. This would indicate that most of the larvae killed were in the first instar. The killing of first instar larvae only in a population of mixed larval sizes would have the effect of subtracting a constant from the number for each instar which would result in a parallel frequency curve for treated plants as compared with untreated plants. As the season progressed, however, the killing of first instar larvae only should result in reducing the number of larger instars. This reduction might or might not be directly proportional to the number killed. In any event, killing the first instar only should result in diverging frequency curves later in the season. This is actually the

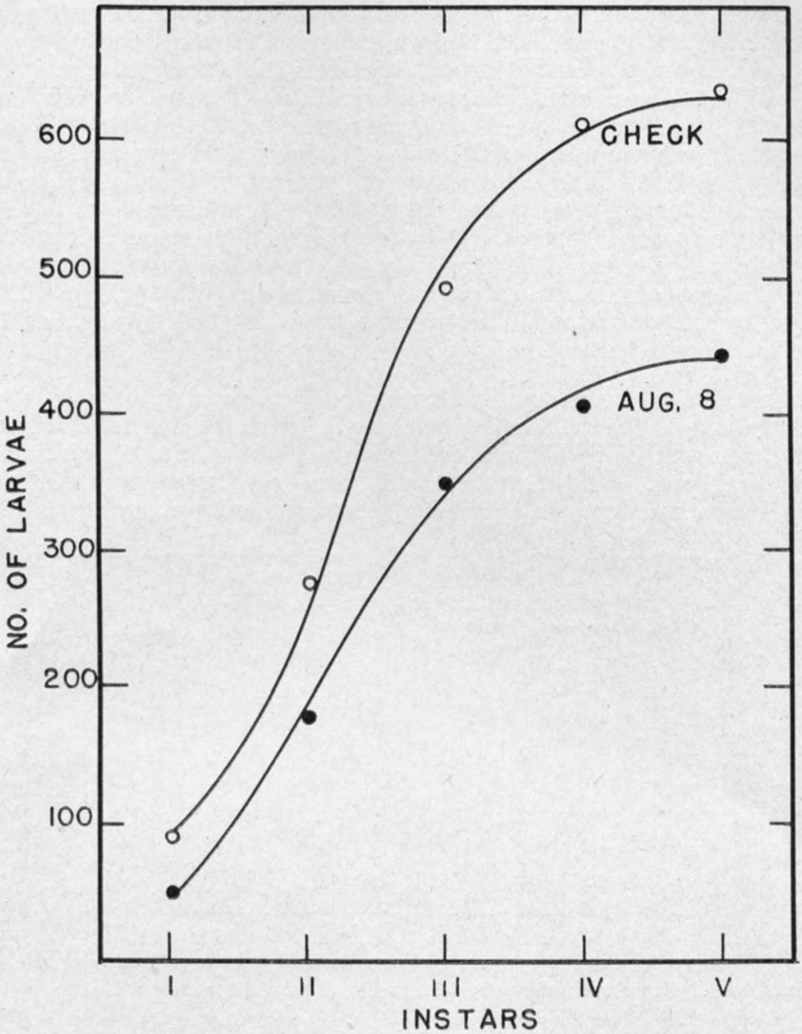

FIGURE 10. Cumulative frequency distribution curves for larval instars in untreated plants and plants dusted August 8, examined at harvest time.

case. In Figures 9 and 10 the curves for three observations following the first treatment in the 1943 test are shown. The count made only three days after treatment showed very little control. Eight days after treatment the curves were roughly parallel. At the end of the season, the curves diverged.

Frequency distribution curves for observations made three days after each treatment in the four-treatment standard schedule in 1943 are shown in Figures 11, 12 and 13. The divergence became much more marked as the season progressed. At no time was there any indication that any other instar than the first was being killed. If any

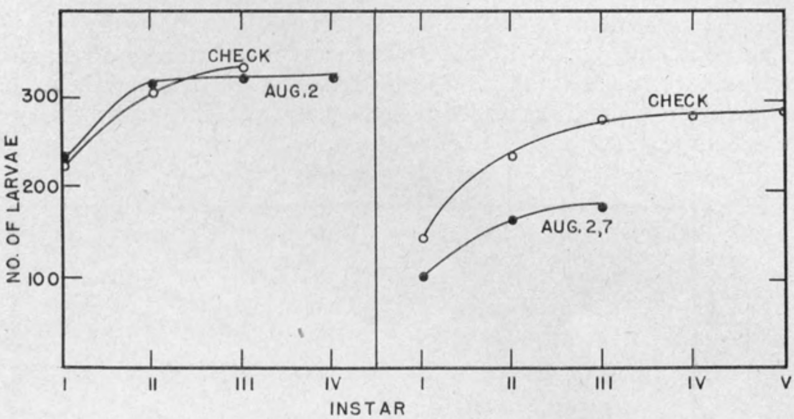

FIGURE 11. Cumulative frequency distribution curves for larval instars in untreated plants and following the standard schedule of treatment. Examined after one treatment (at left) and after two (at right).

substantial proportion of any advanced instar was killed when migration took place, the resulting deficiency in numbers should appear

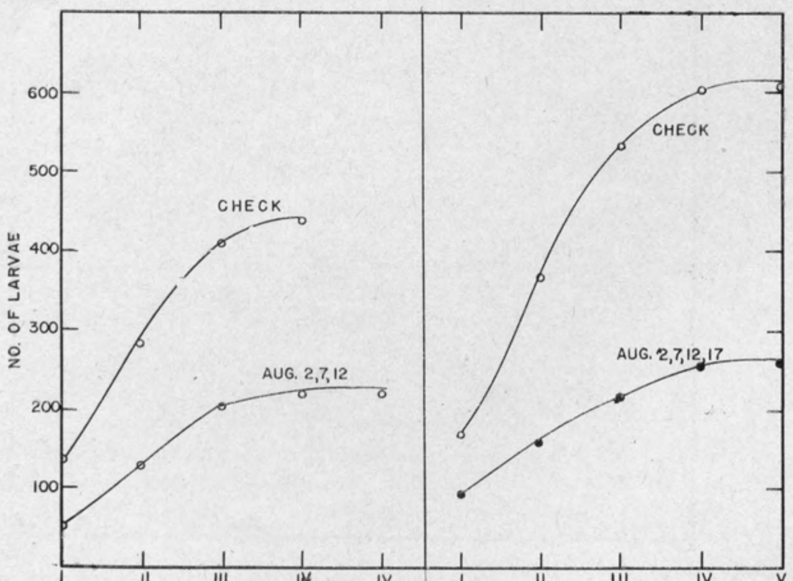

FIGURE 12. Cumulative frequency distribution curves for larval instars in untreated plants and following the standard schedule of treatment. Examined after three treatments (at left) and four (at right).

as an aberration in the frequency curve. In only two of the 42 sets of curves was there any indication of this sort of aberration. The first is a shortage of the second instar in the August 30 dissection of the August 12 treatment in 1943. The shortage is striking but no reason can be advanced for it. The other case is a shortage of third and fourth instars in the final dissection of the complete schedule in 1941. The deviation was slight and did not occur following any other complete schedule.

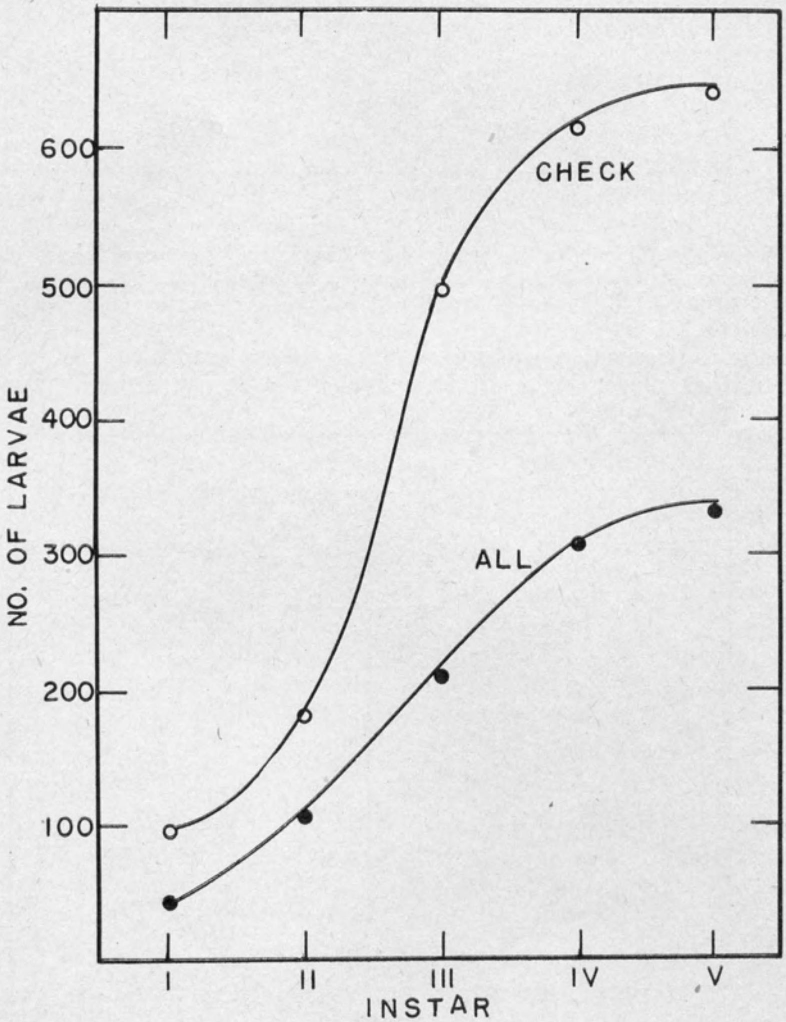

FIGURE 13. Cumulative frequency distribution curves for larval instars in untreated plants and following the standard schedule of treatment. Examined at harvest time.

The one remaining possibility is that all instars might be exposed to the insecticide at some time or another. If this occurred, the earlier instars would be most susceptible and the later instars least susceptible. The result should be converging frequency curves. No such convergence was noted in any of the tests.

These observations do not prove directly that only first instar corn borer larvae were killed by treatment. However, the implication is so strong and the absence of any data indicating other instars are killed is so complete that it is accepted as a working hypothesis at least. This is further evidence that a more effective toxicant is needed for corn borer control.

INSECTICIDES

Dual-fixed nicotine dust, developed by Batchelder (Batchelder, Questel and Turner, 1937) has been the standard material for corn borer control since its introduction. Derris dust was more effective in one series of tests conducted by Baker and Questel (1939). Use of the dosage-response technique by Turner (1943) showed that derris dust and dual-fixed nicotine dust produced crossing dosage-response curves. Moreover, dual-fixed nicotine dust resisted washing much less than derris dust. Differences in rainfall might therefore account for the apparent reversals in order of effectiveness.

Nicotine bentonite dust, a commercial preparation made of nicotine sulfate and bentonite, was less effective than dual-fixed nicotine dust (Beard and Turner, 1942) in a test made in 1941. Carruth (1943) demonstrated a difference in the toxicity of nicotine bentonite depending on the diluent used, walnut shell flour being outstanding in effectiveness. Pepper and Carruth (1945) reported an effect of diluents on the toxicity of *Ryanex* dusts. Fibrous talc was the most effective, followed by talc and sulfur, pyrophyllite and tobacco powder in that order. Turner (1944) measured the dosage required for equal control using pyrophyllite and clay with nicotine bentonite. Approximately 5 per cent nicotine with clay was required to equal the control of 3 per cent nicotine with pyrophyllite.

Questel (1944) has reported that DDT is one of the promising substitutes for derris or cube.

With the few exceptions noted in the introduction, commercial treatment for the European corn borer has not provided sufficient protection to eliminate sorting the corn. This has been true particularly of dusts, which are preferred to sprays by Connecticut farmers. The data presented in the preceding section of this publication may be interpreted as showing that the insecticides used were not toxic enough or the methods used did not deposit the material in the proper places to kill large larvae.

The investigations on insecticides have been conducted (1) to improve the performance of the materials used now and (2) to provide more toxic new materials. The latter phase is still very much in the experimental stage.

The work conducted in 1944 included a comparison of DDT dusts with derris and fixed nicotines, and a comparison of nicotine bentonite with a pyrophyllite diluent and the standard dual-fixed nicotine which was manufactured with a clay diluent.

A midseason hybrid corn was planted June 22, 1944, for insecticide tests for the second generation of the European corn borer. The season was very dry, and the emerging moths of the first generation did not oviposit as freely as expected. Eggs were present, however, when the corn reached the early green tassel stage and treatment was started. It was necessary to irrigate the plants several times during August. An ordinary lawn sprinkler was used for this purpose, and the irrigation was done by blocks as far as possible to avoid differential effect of irrigation on treatments.

The plots were two rows about 20 feet long, separated by a space of six feet between plots to minimize migration. At one end of each plot, 10 plants were segregated from the rest of the plot by removing two plants from the row. These 10 plants were examined at least once every five days for eggs. The masses were tagged and the tags removed after the eggs had hatched. Results were obtained by dissecting the main stalks of these 10 plants and, in addition, dissecting 10 plants taken from the rest of the plot. There were four blocks, with treatments randomized in each block, and two untreated checks used for comparison.

All materials were applied by means of a small hand duster. The first treatment, on August 2, was applied to the young tassels. The remaining applications, August 7, 12 and 17, were directed at the developing ears. The materials compared were (1) dual-fixed nicotine dust (manufactured commercially), (2) nicotine bentonite dust prepared from a commercial concentrate (Black Leaf 155) diluted with pyrophyllite, (3) derris dust diluted with pyrophyllite, and (4) commercially mixed DDT dust with pyrophyllite as the diluent. All materials were applied in dosage series. The purposes of the test were (1) to compare nicotine bentonite dust with pyrophyllite diluent and the dual-fixed nicotine dust which had been a standard material but was no longer available commercially, (2) to compare the performance of DDT with derris and the fixed nicotines and (3) to determine the effect of the various dusts on the infestation of corn borers.

Results of the dissection of the 10 plants for which records of eggs hatching were taken have been summarized in Table 10. The totals for these plants and for the 10 plants taken at random from the plots are summarized in Table 11. Dosage-response curves are plotted in Figures 14 and 15.

TABLE 10. EGGS HATCHING AND LARVAE SURVIVING TREATMENT, INSECTICIDE TESTS, 40 PLANTS

Material	Per cent concentration	No. egg masses hatching	No. ears	Larvae total	Larvae surviving per egg mass	Per cent control[1]
Dual-fixed nicotine	1	80	22	122	1.53	39.0
	2	79	23	98	1.24	50.6
	4	75	21	105	1.40	44.2
	8	74	18	68	.92	63.3
Nicotine bentonite	1	62	25	85	1.37	45.4
	2	73	23	94	1.29	48.6
	4	67	17	99	1.48	41.0
	8	78	13	57	.73	70.9
Derris (rotenone)	0.25	81	21	81	1.00	60.2
	0.5	72	44	119	1.65	34.3
	1.0	97	15	67	.69	72.5
	2.0	106	8	49	.46	81.7
DDT	0.5	72	22	94	1.31	47.8
	1.0	69	17	72	1.04	59.6
	2.0	85	5	61	.72	71.3
	4.0	109	8	53	.49	80.1
None	...	61	42	122	2.0	...
	...	60	59	181	3.02	...

[1] Basis average per cent survival in untreated plots.

TABLE 11. LARVAE SURVIVING TREATMENT, INSECTICIDE TESTS, TOTAL OF 20 PLANTS PER PLOT

Material	Per cent concentration	No. larvae per 100 plants		Per cent reduction in larvae[1]
		ears	total	
Dual-fixed nicotine	1	75	284	22.9
	2	70	284	22.9
	4	52	268	26.4
	8	49	189	48.3
Nicotine bentonite	1	92	292	19.9
	2	76	273	25.3
	4	38	214	41.4
	8	49	174	52.4
Derris	.25	44	212	41.8
	.5	107	320	12.3
	1.0	39	169	53.7
	2.0	41	154	57.9
DDT	.5	55	218	52.7
	1.0	39	161	55.8
	2.0	38	158	56.8
	4.0	20	110	69.9
None	...	100	324	...
	...	131	405	...

[1] Basis of average per cent survival in untreated plots.

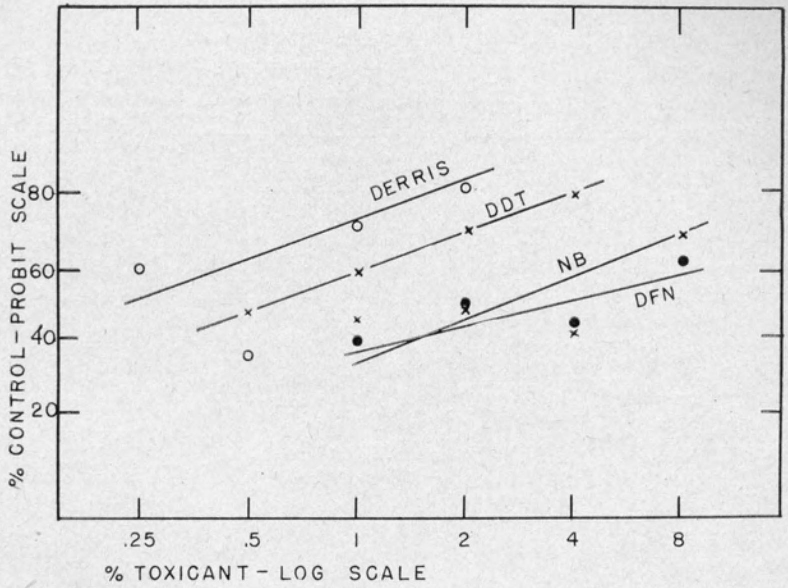

FIGURE 14. Relation between percentage of toxicant and degree of control on the basis of survival of larvae per egg mass. NB = nicotine bentonite. DFN = dual-fixed nicotine.

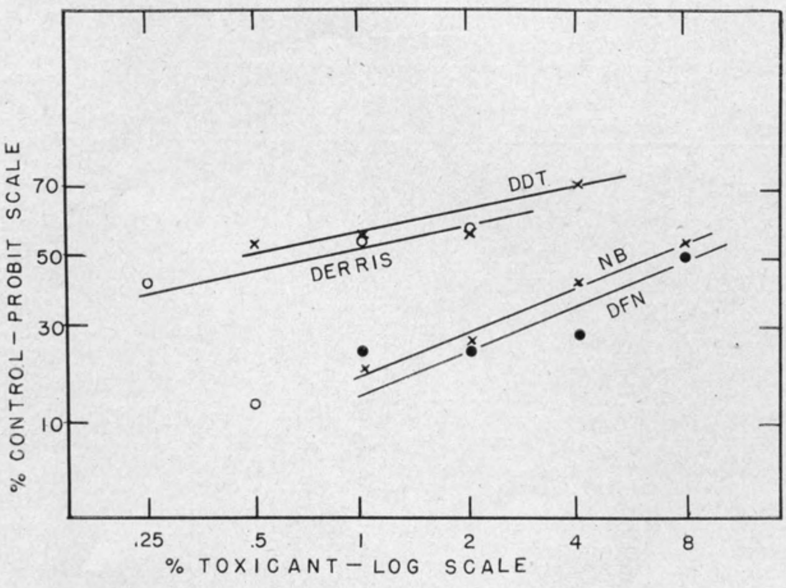

FIGURE 15. Relation between percentage of toxicant and degree of control on the basis of larvae found after treatment. NB = nicotine bentonite. DFN = dual-fixed nicotine.

Nicotine bentonite appeared to be somewhat more effective than dual-fixed nicotine in this test. On the basis of dosage for equal control, 4 per cent nicotine in nicotine bentonite was as effective as about 7 per cent nicotine in dual-fixed nicotine. This is contrary to a previous comparison of similar materials (Beard and Turner, 1942). In the former test, both materials were diluted with a clay. In this test, the dual-fixed nicotine was diluted with clay and the nicotine bentonite with pyrophyllite (Turner, 1944). Apparently the effect of the diluent was great enough to improve the relative performance of nicotine bentonite. In other words, nicotine bentonite with pyrophyllite appeared to be more effective than the dual-fixed nicotine as last manufactured.

The performance of DDT varied somewhat according to the criterion of comparison. On the basis of larvae found after treatment (Figure 15), 0.5 per cent DDT gave the same control as 0.7 per cent rotenone in derris, 5 per cent nicotine in nicotine bentonite and about 8 per cent nicotine in dual-fixed nicotine. When larvae hatching are included in the calculation (Figure 14), 1 per cent DDT provided equal control with about 0.4 per cent derris, 4 per cent nicotine bentonite and 8 per cent dual-fixed nicotine. It will be noted that the 0.5 per cent derris dust was less effective than expected in all cases. This may be caused by an error in diluting the dust. Unfortunately, all of the dust was applied during the test and this cannot be confirmed. Regardless of which of the two sets of data is accepted, DDT was certainly a highly effective material, being much superior to fixed nicotines and, at worst, half as effective as rotenone in derris. The fact that DDT can be used at relatively higher concentrations than derris makes it a very promising material.

It will also be noted that 1 per cent rotenone in derris performed relatively better than 4 per cent nicotine in fixed nicotine, a reversal of results reported previously (Turner, 1943).

The effect of treatment on number of larvae hatching (Table 10) requires comment. In every case, the number of egg masses hatching on treated plants exceeded the number on untreated plants. Unfortunately, no record was made of number of eggs actually deposited. It is evident that in no case did the treatments reduce the number hatching. Furthermore, the fixed nicotines had much less effect than either derris or DDT. With the latter materials, there is a strong indication that more eggs hatched as the concentration of the rotenone or DDT was increased. Dr. George W. Barber, of the U. S. Department of Agriculture Bureau of Entomology and Plant Quarantine, has suggested that these toxicants may destroy predators which normally consume egg masses of the corn borer.

It is noteworthy that most treatments were required to control a larger population than was indicated by examination of untreated plants. Both 4 per cent DDT and 2 per cent rotenone in derris were applied to plants infested by at least one egg mass per plant more than the untreated, or about 20 larvae per plant more. In spite of this higher infesting population, these materials performed relatively well.

The figures also emphasize the fact that insecticides must control the 2 to 3 per cent of larvae surviving naturally, rather than the 70 or 90 per cent of larvae which never reach maturity in the absence of treatment.

In 1945 *Ryanex* and DDT were compared in a dosage series on the second generation infesting Golden Cross Bantam corn. Dusts were applied by hand on August 6 to developing tassels and on August 10, 15 and 20 to ear shoots. There were three replicates with randomized plots of about 25 plants each. Egg masses were tagged on 10 plants in each plot and showed a remarkably uniform infestation. The main stalks were dissected between August 29 and September 4 by blocks. The results are summarized in Table 12 and shown graphically in Figure 16. The pure *Ryania* was less effective

TABLE 12. DOSAGE TESTS OF RYANEX AND DDT DUSTS, SECOND GENERATION, 1945

Material	Concentration	No. larvae 60 plants	Per cent reduction in larvae
Ryanex	12½%[1]	104	72.9
(fibrous talc diluent)	25	102	73.5
	50	49	79.7
	100	95	75.3
DDT	.5%	94	75.5
(diluent unknown)	1.0	95	75.3
	2.0	58	84.9
	4.0	45	88.3
No treatment	...	390	...
	...	380	...

[1] Per cent ground *Ryania*

TABLE 13. NEW ORGANIC INSECTICIDES APPLIED IN DUSTS TO CONTROL THE CORN BORER

Material	Concentration	No. larvae 60 plants	Per cent reduction in larvae
Rhothane[1]	4%	33	45.9
761[2]	10	13	78.7
DDT	4	2	96.7
None	..	61	...
Methoxy DDT[3]	4%	331	14.0
CS431[4]	5	261	32.2
DDT	4	45	88.3
None	..	385	...

[1] Dichlorodiphenyldichloroethane.
[2] Rohm & Haas Laboratory product, chemistry unknown. (Burned corn).
[3] Dimethoxy diphenyl trichloroethane.
[4] Chlorinated cyclic compound from Commercial Solvents Corp.

than the diluted dust. This was caused by the poor dusting properties of the pure material. On the basis of this test, 50 per cent *Ryanex* was about as effective as 1 per cent DDT, and 25 per cent *Ryanex* as .5 per cent DDT.

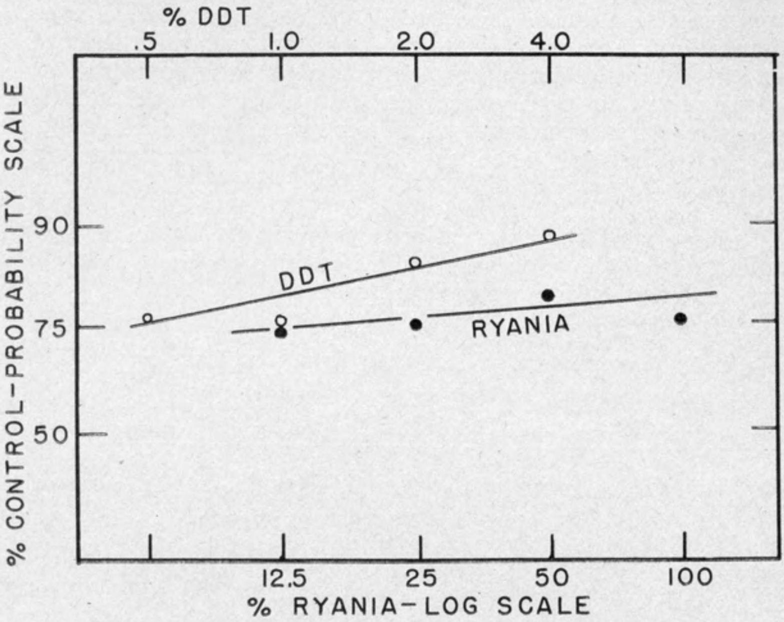

FIGURE 16. Relation between control using DDT and *Ryania* on the European corn borer.

Preliminary tests were made using several new materials. Results are summarized in Table 13. None of the four new materials tested was as effective as DDT.

EFFECT OF ABNORMAL TASSELS AND EARS ON LARVAL SURVIVAL

A special study of the effect of abnormalities on survival of the European corn borer was conducted with genetic stocks of corn supplied by the Genetics Department. Since tassels and ears are by far the most important structures in which larvae become established, the study was confined to these parts of the plant. Three stocks of field corn seed were used in the tassel study. Approximately half of the plants from one stock produced tassels bearing no pollen. The second was segregating as normal tassels and tassels bearing both pollen and silks. The third segregated as normal and "wild" plants which stayed in the whorl stage the entire season and produced neither tassels nor silks.

Three lines were available for abnormal ear production. The corn segregating for tassel seeds also produced plants having no silks.

The "wild" corn produced no ears. In addition, a line was available which was segregating as normal plants and as plants producing no ear shoots nor ears.

Each of these lines was planted in four randomized blocks, with two plantings, on June 6 and June 17. The plots were two rows, each 10 plants long, separated from the other plots by six feet of bare ground to minimize migration. Each plant was examined at least once every five days for egg masses, and a record kept of the date the eggs hatched and the number of masses hatching on each plant. The plants were dissected when the kernels were approximately in the milk stage.

The results of the observations are given in Table 14, including two plantings of the midseason hybrid sweet corn Lee which was used as a normal variety for comparison.

TABLE 14. INFESTATION AND SURVIVAL, ABNORMAL TYPES OF CORN, 1944

Date planted	No. plants	No. egg masses	No. larvae surviving	No. egg masses per plant	No. larvae per plant	Larvae per egg mass
June 6						
Normal	40	112	172	2.8	4.3	1.54
Sterile Tassel	40	103	203	2.58	5.8	2.24
June 17						
Normal	29	78	128	2.7	4.4	1.63
Sterile Tassel	28	69	112	2.46	4.0	1.62
June 6						
Normal	14	35	57	2.5	4.07	1.63
Silkless	21	65	82	3.1	3.9	1.26
Tassel Seed	48	167	150	3.48	3.13	.90
June 17						
Normal	21	59	72	2.81	3.43	1.22
Silkless	25	53	99	2.12	3.96	1.87
Tassel Seed	37	120	146	3.24	3.95	1.22
June 6						
Normal	42	150	409	3.57	9.71	2.7
Barren	24	55	119	2.29	4.96	2.2
June 17						
Normal	13	47	154	3.61	11.08	3.1
Barren	10	13	30	1.3	3.0	2.3
June 6						
Normal	52	78	342	1.5	6.58	4.4
Wild	20	31	55	1.55	2.75	1.8
June 17						
Normal	37	41	180	1.11	4.88	4.4
Wild	12	10	17	.83	1.42	1.7

The tassel abnormalities had little effect on the survival of larvae. This was to be expected because eggs did not hatch in numbers until the tassels had appeared. The delay in oviposition caused by the extreme drought was responsible for this difficulty. The "wild" plants showed substantially less survival than normal plants of the same stock. However, these "wild" plants had neither tassels nor ears. The sterile tassels had no effect on survival. Since these plants were in rows with plants producing pollen, this is no proof that pollen has nothing to do with survival.

The ear abnormalities apparently had some effect on survival. Silkless ears had about the same number of larvae per ear as those plants with normal silks (Table 15). Survival in the barren plants was substantially less in both plantings than in normal plants. However, when the larvae in ears and ear shoots were eliminated (Table 16), the survival of larvae per plant was much greater for normal than for barren, and for normal than for "wild". The normal plants of three of the four pairs also received many more larvae per plant. If the larvae in ears and ear shoots are disregarded, the number of larvae per egg mass does not differ in the barren and wild series, but does in the normal and wild comparison. If the ear were necessary for *establishment* of larvae, the survival ratio should be higher when ears were present. It is possible that the amount of migration was sufficient to obscure this effect in the barren plants. The test did show conclusively that the "wild" plants remaining in the whorl stage throughout the season were not as heavily infested as normal plants.

TABLE 15. LARVAE SURVIVING IN EARS WITH AND WITHOUT SILK

Date planted	Character	No. plants	Larvae in ears	Larvae per ear
June 6	Silks	69	30	.43
	No silks	21	9	.43
June 17	Silks	56	27	.48
	No silks	28	15	.53

TABLE 16. LARVAE SURVIVING IN PLANTS WITH AND WITHOUT EARS, EXCLUSIVE OF EARS AND EAR SHOOTS

Date planted	Type	No. plants	No. egg masses	No. larvae	No. larvae per plant	No. larvae per egg mass
June 6	Normal	42	150	238	5.67	1.59
	Barren	24	55	119	2.29	2.2
June 17	Normal	13	47	107	8.23	2.28
	Barren	10	13	30	1.3	2.3
June 6	Normal	52	78	258	4.96	3.37
	Wild	20	31	55	2.75	1.8
June 17	Normal	37	41	149	4.0	3.6
	Wild	12	10	17	1.42	1.7

This is still another confirmation of Beard's (1942) observation based on growth stages of normal plants.

The number of egg masses hatching per plant is given in Table 14. No record of the number deposited was kept; therefore, it is impossible to determine whether the figures represent comparative mortality in the egg stage or a selection of certain types of plants for oviposition. There seems to be comparatively little difference between segregation in the same planting except for normal and barren. Here, the normal plants showed more eggs hatching than the barren. The tassel-seeded segregate also had more eggs hatching than the normal, but the difference was not large.

It will be noted that all but one of the genetic stocks used received as many or more egg masses per plant as the sweet corn hybrid Lee. The normal plants in the normal and barren series were highest. The leaves of these plants had conspicuous longitudinal wrinkles at frequent intervals. Many egg masses were placed in these wrinkles. During the drouth, eggs dropped from the smooth-leaved varieties much more readily than from the wrinkled leaves. Therefore, the wrinkled leaf may be classed as aiding establishment of the corn borer and contributing to susceptibility.

On the whole, this study showed clearly the importance of the ears in establishment and survival of the corn borer. Obviously, corn plants without ears are of little commercial value. However, the results imply that direct application of insecticides to the ears is necessary for proper protection.

The effect of tassels on survival was studied further in 1945. Comparisons were made between sparse (C103 x Ohio 40B) and bushy (WF x Lbe–12–7) tassels. These stocks were used to measure the effect of tassel size and amount of pollen on survival. In another test two lines of Conn. 20 x R were used. One of these had only 35 per cent fertile pollen and the other 95 per cent. With the exception of the cytological difference in pollen, the lines were identical in size, growth rate and maturity. Unfortunately, the corn was planted too late for the tassels to emerge during the peak of hatching of the corn borer.

The corn was planted in 20-plant plots, randomized in three replicates. A record was made of the eggs hatching, and the plants were dissected in September to determine the number of larvae. The results have been summarized in Table 17. There seems to be no consistent difference in the survival rate within pairs. The 20 x R lines used in the pollen comparison did, however, have a substantially lower oviposition and a substantially higher survival rate than the crosses used to study tassel size.

SURVIVAL IN HIGH AND LOW BREAKAGE LINES

Two lines were grown in 1945 to determine the infestation and survival in lines having a previous record of a high and a low amount of breakage when infested by corn borers. Inbred Ind. 38-11 showed a large amount of breakage following heavy corn borer infestation. Inbred C103 grown in the same plots did not break so extensively. The design of the experiment was as described above, and the results are summarized in Table 18.

No breakage occurred so that no direct comparison between infestation and breakage could be made. However, the low breakage line received fewer egg masses and had fewer surviving larvae than the high breakage inbred. The survival ratio was higher in the low breakage inbred. It seems evident that at least part of the resistance to breakage noted previously could have been caused by a relatively lower infestation.

TABLE 17. EFFECT OF TASSEL SIZE AND STERILE POLLEN ON CORN BORER SURVIVAL

Type	No. egg masses	No. larvae 60 plants	Survival larvae per egg mass
	Planted June 19		
Sparse Tassel	99	257	2.59
Bushy Tassel	202	275	1.36
Fertile Pollen	57	255	4.47
Sterile Pollen	30	133	4.43
	Planted June 25		
Sparse Tassel	129	211	1.63
Bushy Tassel	158	260	1.64
Fertile Pollen	47	101	2.15
Sterile Pollen	46	140	3.12

TABLE 18. INFESTATION AND SURVIVAL IN HIGH AND LOW BREAKAGE LINES

Type	No. egg masses	No. larvae 60 plants	Survival larvae per egg mass
	Planted June 19		
Low Breakage	79	195	2.47
High Breakage	147	217	1.41
	Planted June 25		
Low Breakage	64	144	2.26
High Breakage	138	169	1.22

RELATION BETWEEN TILLER AND STALK INFESTATION

Beard (1941) has shown that larvae hatched from eggs deposited on tillers tend to distribute themselves over the whole plant, but that there appears to be a greater tendency for the borers borne on the main plant to remain there than for tiller-borne borers to remain on the tillers. Tillers appear to be more attractive for oviposition. The 1944 test of methods of application of nicotine bentonite dust afforded an opportunity to study the effect of tillers on the infestation.

In this study, the number of tillers per plant was recorded, and the larvae occurring in the tillers as well as other parts of the plant determined by dissection. It has been shown in Table 8 that the hood method of dusting affected the distribution of larvae less, especially in the tillers, than direct application. For this reason, the hood treatments were used to determine the relation between infestation in tillers and the rest of the plant, in addition to the untreated checks.

The plants were classified according to the number of tillers, and the larvae in the whole plant, main stalk, No. 1 ear and all ears and ear shoots recorded. A summary of the results is given in Table 19. The total number of larvae per plant increased as the number of tillers increased. The number of larvae in the main stalk decreased as the number of tillers increased. The number of larvae in the ears tended to decrease with increase in the number of tillers, especially when ears and ear shoots were considered as a whole. The percentage of larvae in the tillers increased with the number of tillers. It is striking that the number of larvae per plant increases so rapidly with increased tillers, but that the number in the main stalk and in the ears is actually reduced.

TABLE 19. AVERAGE DISTRIBUTION OF LARVAE IN PLANTS WITH DIFFERENT NUMBERS OF TILLERS

No. tillers	No. plants	Number of Larvae				
		Per plant	Per stalk	Per ear	In ears and ear shoots	Per cent in tillers
			Untreated			
2	19	29.8	19.2	4.21	10.5	35.5
3	41	35.6	17.7	3.68	9.4	50.2
4	9	36.8	17.4	5.1	8.9	52.6
			Dusted			
2	74	29.9	18.4	3.4	10.4	36.2
3	183	32.4	16.4	3.0	8.9	49.5
4	22	33.3	15.8	3.2	8.5	52.7

These relationships have an important bearing on the resistance or susceptibility of corn to corn borers. If the same number of eggs are deposited per plant regardless of the number of tillers, a large number of tillers would be desirable. If, however, the presence of tillers increases the oviposition per plant, the desirability would depend on whether the increased oviposition raised the ear infestation as much as the presence of tillers lowered it. Carruth and Pepper (1945) reported that removal of tillers resulted in a substantial increase in number of larvae per 100 plants in their insecticide tests.

In 1945 the effect of the tillers was measured in field plots. Spancross corn was planted early in April. In one series of plots the tillers were removed before eggs were laid, and all new tillers destroyed as they formed. One set of plots was left as a check, and four others treated using a dosage series of DDT dusts. A second set of plots was left with one tiller per plant and not treated. In the third series, all tillers were allowed to grow, and a dosage series of DDT dusts applied, with a suitable check. Notation was made of the number of eggs and whether they were deposited on main stalk or tiller.

Treatment was made June 22 and 28 and July 1 and 7, and covered the growth period from late whorl to mid-silk. Infestation was determined by dissection of the 10 plants in each plot of the four randomized replicates. The data have been summarized in Table 20. The infestation was very light and the differences were not large. There was a tendency for fewer eggs to be deposited on stalks of plants with tillers. Ear infestation on untreated plants was the same

TABLE 20. OVIPOSITION AND SURVIVAL AS AFFECTED BY TILLERS, FIRST GENERATION, 1945

Average no. tillers per plant	Treatment	No. egg masses		No. larvae				Per cent reduction in larvae
		Stalk	Tiller	Stalk	Tiller	Ear	Total	
0	.5% DDT	28	..	10	..	0	11	79.1
	1.0	36	..	6	..	0	7	86.6
	2.0	42	..	11	...	0	12	77.3
	4.0	22	..	1	..	1	2	96.4
	None	30	..	36	..	11	53	...
1	None	28	10	36	7	9	56	...
2.0	.5% DDT	32	13	12	1	2	17	74.8
2.2	1.0	17	15	10	10	0	20	70.5
2.2	2.0	19	13	5	2	7	7	89.8
2.2	4.0	27	25	2	3	5	5	92.6
2.2	None	22	11	36	17	11	68	...

TABLE 21. OVIPOSITION AND SURVIVAL AS AFFECTED BY TILLERS, SECOND GENERATION, 1945

Average no. tillers per plant	Treatment	No. egg masses		No. larvae			
		Stalk	Tiller	Stalk	Tiller	Ear	Total
0	.5% DDT	63	..	39	..	7	127
	1.0	45	..	48	..	16	145
	2.0	86	..	36	..	18	137
	4.0	85	..	31	..	11	101
	None	92	..	134	..	59	433
1	None	41	37	112	149	45	480
4	.5% DDT	20	152	29	213	24	383
3.8	1.0	16	111	34	141	11	260
4	2.0	26	89	27	138	12	256
3.8	4.0	21	92	20	95	5	167
3.9	None	27	106	89	465	39	794

whether tillers were present or not. Control on plants without tillers was slightly more effective than on plants with tillers.

The same experiment was repeated on Golden Cross Bantam corn planted about June 20 and treated August 10, 15, 20 and 26. The results have been summarized in Table 21. The infestation was much greater than in the first generation. Plants with one tiller received about the same number of egg masses as plants with no tillers. Plants with four tillers had a substantially larger number of egg masses, but many less on the main plant. The number of larvae surviving in untreated plants increased with the number of tillers, while the stalk and ear infestation decreased as the number of tillers increased.

TABLE 22. OVIPOSITION, SURVIVAL AND CONTROL AS AFFECTED BY TILLERS, SECOND GENERATION, 1945

No. tillers per plant	Treatment	No. egg masses	Larvae surviving	Per cent reduction in larvae[1]	Larvae per egg mass	Per cent reduction in survival[2]
0	.5% DDT	63	127	70.7	2.01	57.2
	1.0	45	145	66.5	3.22	31.5
	2.0	86	137	68.4	1.59	66.2
	4.0	85	101	76.7	1.18	74.9
	None	92	433	...	4.70	...
1	None	78	480	...	6.15	...
4	.5% DDT	172	383	51.7	2.23	62.6
	1.0	127	260	67.3	2.04	65.8
	2.0	115	256	67.8	2.22	62.8
	4.0	113	167	79.0	1.47	75.4
	None	133	794	...	5.97	...

[1] Basis larvae surviving in untreated check.
[2] Basis larvae survival rate in untreated check.

Data on the larvae surviving per egg mass are summarized in Table 22. In the untreated plants the survival increased when tillers were present. Likewise, in the treated series survival was greater with tillers than without in three of the four comparisons. This is not unexpected because tillers furnish suitable points of entry and food for young larvae.

Effect of tillers on control by insecticides. The dusts were applied to the developing tassels and ears and ear shoots of the main stalks only. The tests reported on pages 15-20 showed that this type of treatment had less effect on the larvae in tillers than in the rest of the plant. The percentage reduction in larvae based on the total surviving in all portions of the plant and on the larvae surviving per egg mass (Table 22) shows little consistent difference whether tillers were present or not. With the exception of one series (.5% DDT on plants with tillers), the number of larvae in the ears was substantially smaller when tillers were present. Pepper and Carruth (1945) found that there were more larvae on plants with the tillers removed in three of four comparisons. Their work was done at a lower infestation level than the second-generation test, but much higher than the first-generation. The data available offer no reason for this reversal.

SUMMARY

Two methods may be used to improve the effectiveness of insecticides for control of the European corn borer: (1) improvement of methods of treatment and (2) reduction in the amount of infestation by cultural methods or by development of less susceptible strains of corn.

Dissection of plants following individual treatments failed to show that any specific time of treatment had any special or unusual influence that could be measured at the end of the season.

Cumulative frequency distribution curves show no evidence of any substantial migration of any later instar of larvae from the plant to the ear.

Three applications of insecticide on the ears only were less effective than four treatments to the entire plant.

Use of a hood which provided distribution of dust to the entire plant resulted in more uniform control in different parts of the plant than direct application of the same amount of toxicant to tassels and ear shoots. Direct application to tassels and ear shoots provided substantially better control than the hood application. One per cent nicotine applied directly was as effective as 3 to 4 per cent applied under the hood.

In four comparisons of concentration of dust and amount applied, smaller amounts per acre of more concentrated dusts were more effective than larger amounts of more dilute dusts.

More effective insecticides may be required to demonstrate the effectiveness of treatment of ears only to prevent infestation.

Treatment of plants with no tillers, in which a relatively large population of larvae was concentrated in the main stalk, produced no better results either in percentage control or in coverage than treatment of similar plants with tillers.

Plants with tillers had a smaller number of larvae surviving treatment in the ears than plants with no tillers.

Cumulative frequency distribution curves for larval instars surviving treatment suggest that only first instar larvae were killed by the treatment made.

Tests of coverage, places at which larvae were killed and size of larvae killed indicated that only first instar larvae were killed at points remote from the places in which larvae survived, and that treat-

ment of the main stalk killed more larvae than application of the same amount of dust to the entire plant. This supports the hypothesis that the main stalk is the principal avenue of migration, and its treatment is especially necessary for control.

Nicotine bentonite diluted with pyrophyllite was as effective with 4 per cent nicotine as 7 per cent dual-fixed nicotine diluted with clay.

On the basis of comparison of larvae found following treatment with larvae in untreated plants, .5 per cent DDT dust was as effective as .7 per cent rotenone in derris dust, 5 per cent nicotine in nicotine bentonite dust and about 8 per cent nicotine in dual-fixed nicotine dust (clay diluent).

Both DDT and rotenone caused a substantial increase in the number of eggs hatching.

About 50 per cent *Ryanex* (dust made from *Ryania speciosa*) was required to kill the same percentage of larvae as 1 per cent DDT.

Several new organic insecticides were found to be less effective than DDT.

Use of genetic stocks with abnormal tassel and ear growth showed that the ears were more important than tassels in establishment and survival of the corn borer. Abnormal tassels had little effect in the tests because of the infestation relatively late in the growth of the plant.

A comparison of the effect of sparse and bushy tassels and of fertile and sterile pollen on survival failed to show any differences. Tassels emerged relatively late in the oviposition period, however.

A strain of corn which had shown low breakage after infestation by the corn borer had fewer eggs and fewer larvae than a high-breakage line. However, survival ratio was higher on the low-breakage plants.

The total number of larvae per plant increased as the number of tillers was increased. The number of larvae in the main stalk decreased as the number of tillers was increased. There was also a tendency for smaller ear infestation as the number of tillers was increased.

The number of eggs deposited increased as the number of tillers was increased. However, the number on the main stalk decreased as tillers were increased.

The percentage of control of larvae was about the same following application of dusts to the main stalk whether tillers were present or not. However, fewer larvae survived treatment in ears of plants with tillers.

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