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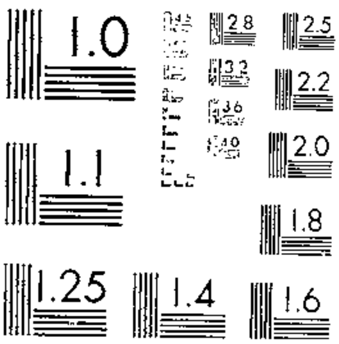

MICROCOPY RESOLUTION TEST CHART
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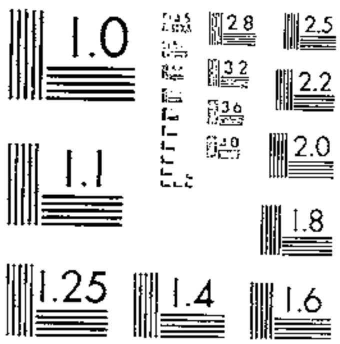

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Hibernation of the Corn Earworm in the Central and Northeastern Parts of the United States[1]

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CONTENTS

INTRODUCTION

The present studies on the hibernation of the corn earworm (*Heliothis armigera* (Hbn.)) were begun in 1935 for the purpose of including in the range of a series of uniformly planned experiments as wide an area as possible. The object was to obtain definite information concerning the northern limits of successful hibernation of this insect, and to learn, if possible, whether the infestation in the North is due to moths emerging locally or to those migrating from more southerly sources.

[1] Received for publication June 15, 1942.

[2] The studies reported herein are largely the results of cooperative cage and field investigations initiated in 1935 by W. H. Larrimer, formerly senior entomologist in the Bureau of Entomology and Plant Quarantine, stationed at Arlington Farm, Va.

The studies were conducted by the Division of Cereal and Forage Insect Investigations, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture, and the State agricultural experiment stations of the several States in which the studies were conducted. The following entomologists and their coworkers located at State experiment stations and Federal offices of the Bureau of Entomology and Plant Quarantine carried out the experiments in their localities: F. F. Dicke, Arlington Farm, Va.; J. S. Pinckney and C. C. Hill, Carlisle, Pa.; I. M. Hawley, C. A. Clark, E. D. Burgess, and F. F. Dicke, Moorestown, N. J.; G. W. Barber, New Haven, Conn.; W. A. Price, P. O. Ritcher, and H. H. Jewett, Lexington, Ky.; J. S. Houser and F. F. Dicke, Marietta, Ohio; W. A. Baker, W. G. Bradley, and L. G. Jones, Toledo, Ohio; E. V. Walter, Lafayette, Ind.; G. E. Marshall, Orleans, Ind.; G. A. Ficht, Auburn, Ind.; A. F. Satterthwait and J. M. Magner, Valley Park, Mo., and Urbana, Ill.; W. P. Flint, Urbana, Ill.; J. R. Horton, Wichita, Kans.; R. T. Cotton and W. T. Emery, Manhattan, Kans.; M. T. Swenk, Lincoln, Nebr.; C. N. Ainslie and W. T. Emery, Sioux City, Iowa; Dwight Isely, Fayetteville, Ark.; F. A. Fenton, Stillwater, Okla., and R. D. Eichmann, Prosser and Walla Walla, Wash.

The writer acknowledges his indebtedness to C. M. Packard and W. R. Walton, of the Bureau of Entomology and Plant Quarantine, for suggestions on arrangements of the manuscript, and to P. N. Annand, Chief of the Bureau, under whose direction the project was initiated.

It was also thought desirable to determine, if possible, the value of the old recommendation for controlling the earworm by cultural operations to kill the hibernating pupae and to investigate further some of the factors affecting hibernation.

In addition to the data obtained from these experiments, free use has been made of the literature on the subject of hibernation of the earworm and factors affecting it.

MATERIALS AND METHODS

Cages for the uniform experiments were all of the type found by Phillips and Barber (*6*)[3] to be the most successful in their earlier work in Virginia. Each cage consisted of a tight wooden frame 30 inches square and 10 inches deep which served as a base, and a frame 30 inches square and 2 to 5 inches high and covered with screen wire which served as a top. The bottom was left open. These cages were set in the ground by placing a cage over the space to be occupied, marking around it, and then digging a narrow trench to sink the cage to a depth of 8 or 9 inches, thereby disturbing the soil within as little as possible. A strip of ¼-inch-mesh hardware cloth was placed around the outside of the bottom edge of the cage and this extended downward and outward at an angle to prevent the entrance of moles and other soil-inhabiting animals.

Last instars collected in the field were used in most of the experiments. The larvae were placed individually in salve boxes as they were collected from the hosts, and supplied with kernels of dough-stage corn for food. They were placed in the hibernation cages as soon after collection as they appeared to be full fed, by removing the covers, inverting the tins, and pressing them into the soil so as to confine the larvae. A few fresh grains of corn were placed under each salve box to provide food in case further feeding was necessary. In general 100 larvae were placed in each cage, but in some instances it was not possible to include that many. Larvae that died before going into the soil were recorded, and replaced in most instances. The screen tops were fastened on the cages as soon as the larvae were introduced. The tin boxes were removed after the larvae had entered the soil.

When temperatures were low enough in the fall to preclude the possibility of further emergence of adults, the cage tops were removed so that the pupae were exposed as nearly as possible to natural conditions throughout the winter. Eight cages were used in most of the uniform experiments. With some exceptions, two cages were examined between November 1 and 15 for fall survival of pupae, two the following spring between March 15 and May 1, to determine winter survival, and four cages had their tops replaced and were observed during May to July for emergence of moths. In most instances soil in the cages left for moth emergence was examined in late July or August. The depths of the pupae below the soil surface were measured in sufficient numbers to give an adequate record.

The dates of beginning the experiments varied somewhat, as in each locality an attempt was made to begin the experiments at what appeared to be the normal time for most of the larvae to enter hiber-

[3] Italic numbers in parentheses refer to Literature Cited, p. 13.

nation. At seven different locations extra cages were installed earlier or later than those of the uniform experiments so that the most favorable time for larvae to enter hibernation might be determined.

Several types of habitat were selected for the hibernation studies. Usually the cages were put down in exposed soil where corn had been grown the same year. In some cases where this was not done the soil in the cages was spaded up and allowed to settle before larvae were introduced, so that the soil would be in a physical condition comparable to that in nearby cornfields. In several localities the cages were placed in alfalfa fields or grass sod, or were covered by corn shocks after the larvae had been introduced. Cages were placed by two cooperators in very sandy soils during all or part of the period from 1935 to 1938, inclusive. During the winter of

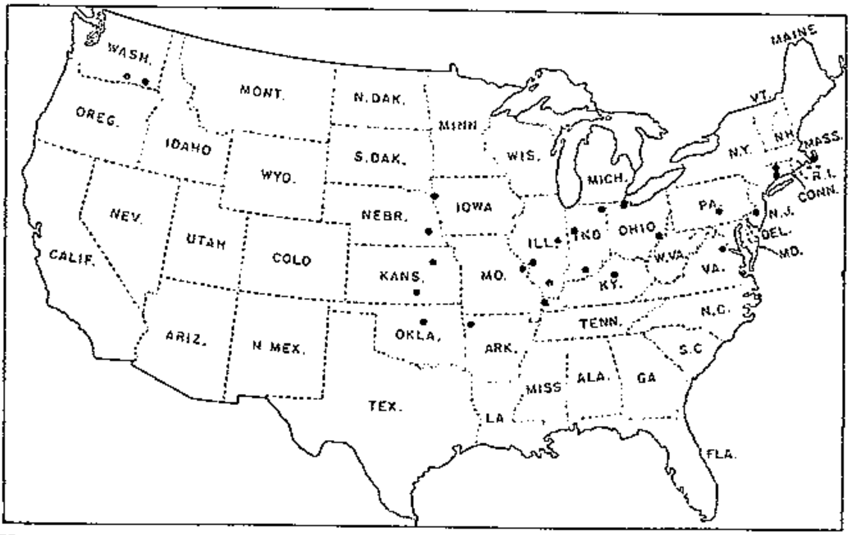

Figure 1.—Locations where uniform or special studies on the hibernation of the corn earworm were conducted.

1938–39 four of the cages in a number of locations were placed in well-drained soil having a high sand content and four were placed in heavier soil having greater water-holding capacity. Cages of other special types were used to confine pupae on wet or dry soil or in special environments such as in holes of various depths.

Besides the cage experiments soil examinations were made in several localities in fields observed to be heavily infested late in the fall. Soil examinations were also made under and around corn cannery buildings at Brookston and Fowler, Ind., during the springs of 1937, 1938, and 1939 and at Hoopeston, Ill., in 1937 and 1938. Figure 1 shows the locations where the studies were conducted.

RESULTS OF CAGE STUDIES

So far as known, or as found in these experiments, the corn earworm hibernates only as a pupa in the soil. Data obtained from cages stocked with larvae between July 30 and September 5 are summarized in table 1.

TABLE 1.—*Results of hibernation studies of the corn earworm in cages established before the peak of normal hibernation under field conditions*

Seasons and localities	Period larvae entered soil	Soil type	Fall emergence [1]	Pupal survival	
				Fall	Spring
			Percent	*Percent*	*Percent*
1935–36:					
Mount Carmel, Conn	July 30–Aug. 3	Loam	94.0		
Milford, Conn	do	do	70.0		
Toledo, Ohio	Aug. 26–31	Clay	42.5		
Valley Park, Mo	Aug. 24–28	Clay loam	31.0		
Manhattan, Kans	Aug. 25–29	do	[2] 33.0		
1936–37:					
Mount Carmel, Conn	Aug. 27–Sept. 2	Loam	37.4		
Milford, Conn	do	do	18.3		
Toledo, Ohio	Aug. 25–Sept. 1		31.0		0
Valley Park, Mo	Aug. 28–29	Clay loam	70.5	9.0	0
Urbana, Ill	Sept. 1–5	Prairie loam	31.5	23.0	0
1937–38:					
Valley Park, Mo	Aug. 29–30	Clay loam	50.5	11.0	0
Urbana, Ill	Aug. 28	Prairie loam	44.0	14.0	0
Average			46.1	14.2	0

[1] There was no summer emergence in any of these cages.
[2] No cage was used, but wire covering was placed to catch moths.

Table 2 gives a summary of the data for the years from 1935–36 to 1938–39 from cages in which larvae were introduced from the middle of September to early in October, or during the period when most of the larvae entering the soil normally remain to hibernate.

TABLE 2.—*Results of hibernation studies of the corn earworm in cages established during supposed peak of normal hibernation under field conditions* [1]

Seasons and localities	Soil type	Average depth of pupae	Fall moth emergence	Pupal survival		Summer moth emergence
				Fall	Spring	
		Inches	*Percent* [2]	*Percent* [2]	*Percent* [2]	*Percent* [2]
1935–36:						
Arlington, Va	Alluvial	3.4	18.0	51.3	0.5	0
Carlisle, Pa	Clay loam	3.0	.12	66.5	0	0
Moorestown, N. J	Sandy loam	3.4	0	74.0	.5	0
Mount Carmel, Conn	Loam	2.8	0	81.0	0	0
Milford, Conn	do					0
New Haven, Conn	do					0
Lexington, Ky			0	16.9	3.8	.5
Marietta, Ohio	Gravelly loam	2.8	1	34.5	0	0
Toledo, Ohio	Sandy loam	2.6	0	65.5	0	0
Orleans, Ind		3.0	0		0	0
Auburn, Ind						0
La Fayette, Ind	Sandy loam	2.2	0	74.0	0	0
Valley Park, Mo	Clay loam	2.7	6.25	62.0	0	0
Wichita, Kans	Black clay loam	2.5	1.0	38.0	0	0
Manhattan, Kans	do	2.9	12.25	20.5	0	0
Lincoln, Nebr	do	3.5			0	0
Sioux City, Iowa	do	3.3			0	0
1936–37:						
Arlington, Va	Alluvial	3.5	4.4	64.5	21.5	2.3
Carlisle, Pa	Clay loam	2.8	.25	53.5	13.5	0
Moorestown, N. J	Sandy loam	3.5	7.6	58.0	20.5	2.0
Mount Carmel, Conn	Loam	3.8	0	73.0	0	0
Milford, Conn	do	3.2	0	87.0	0	0
New Haven, Conn	do					0
West Dennis, Mass	Cultivated sand	3.6			39.0	6.0
Lexington, Ky		3.0	.25	70.0	6.0	.5
Marietta, Ohio	Gravelly loam	3.5	8.4	62.5	9.0	5.3
Toledo, Ohio	Sandy loam	2.4	0	76.5	0	0
Orleans, Ind	Clay	2.5	0			0
La Fayette, Ind	Sandy loam	2.5	0	68.0	0	0
Auburn, Ind			0			0
Charleston, Mo	Light alluvial	2.2	1.0	30.0	15.0	.5
Ewing, Ill	Clay	2.3	.5	50.0	1.5	0

[1] Cages were established September 15-30 in most cases.
[2] The percentages given are based on the number of larvae that entered the soil.

TABLE 2.—*Results of hibernation studies of the corn earworm in cages established during supposed peak of normal hibernation under field conditions*—Continued

Seasons and localities	Soil type	Average depth of pupae	Fall moth emergence	Pupal survival		Summer moth emergence
				Fall	Spring	
1936-37—Continued.		*Inches*	*Percent*	*Percent*	*Percent*	*Percent*
Valley Park, Mo	Clay loam		5.6	49.0	1.0	0
Urbana, Ill	Prairie loam	2.5	0	66.5	1.0	0
Fayetteville, Ark	Fine sandy loam	3.0	0	25.0	19.4	0
Wichita, Kans	Black clay loam	2.0	0		0	0
Manhattan, Kans	do	2.0	0	36.0		0
Do	Silty sand					0
Lincoln, Nebr	Black clay loam	2.5	0	24.0		0
Sioux City, Iowa	do		0			0
1937-38:						
Arlington, Va	Alluvial silt		0	68.0	29.5	.75
Do	Clay		0	67.5	1.0	0
Carlisle, Pa	Clay loam		0	84.0	22.5	0
Moorestown, N. J	Sandy loam		0	70.5	26.5	2.3
Mount Carmel, Conn	Loam	3.1	0	78.0	0	
Milford, Conn	do	2.9	0	61.5	0	
West Dennis, Mass	Sand	3.9	0		3.0	
Lexington, Ky	Well drained		0	67.0	22.5	2.75
Marietta, Ohio	Gravelly loam	2.5	0	70.5	10.5	4.8
Toledo, Ohio	Sandy loam		0	63.0	0	0
Orleans, Ind	Clay					2.0
La Fayette, Ind	Sandy loam	2.7	0	75.5	1.0	0
Auburn, Ind						0
Charleston, Mo	Dark silt loam		0	67.2	30.0	3.1
Ewing, Ill	Clay		0	31.4	.5	0
Valley Park, Mo	do		0	55.5	0	0
Urbana, Ill	Prairie loam		0		0	0
Fayetteville, Ark	Sandy loam				0	0
Stillwater, Okla	Fine sandy loam	2.6	0	54.2	43.0	5.2
Wichita, Kans	Black clay loam		0	52.0	6.0	6.5
Manhattan, Kans	Clay loam		6.1	43.5	0	0
Lincoln, Nebr	do		0	16.0	0	0
Sioux City, Iowa	do		0	45.0	0	0
1938-39:						
Arlington, Va	Sandy loam	3.6		83.1	41.5	[3] 1.0
Do	Sandy				75.1	
Carlisle, Pa	Well drained	2.7	3.0	85.9	24.0	0
Do	Poorly drained		0	88.0	24.0	0
Marietta, Ohio	Gravel loam	2.7	0	69.5	8.0	
Toledo, Ohio	Sandy loam	3.5	0		0	0
Do	Pure sand	3.9	0		0	
Orleans, Ind	Clay					3.5
La Fayette, Ind	Sandy loam	3.2	.5	81.0	0	0
Valley Park, Mo	Clay	2.5	.3	57.0	3.0	0
Do	Sandy loam		13.8	40.0	25.0	2.0
Urbana, Ill	do	2.5	.3	73.0	0	0
Do	Prairie loam	2.2	.3	64.0	0	0
Stillwater, Okla	Tight clay	2.5	0	32.0	13.0	1.5
Do	Sandy soil	3.7	0	12.0	0	1.5
Wichita, Kans	Black clay loam		4.0	52.0	9.0	
Manhattan, Kans	do		0	44.0	2.0	0
Do	Sandy silt		0	25.0	2.0	6.0
Prosser, Wash			0	24.0	9.0	2.4
Walla Walla, Wash			0	47.0	3.0	0

[3] Approximate.

In general, in cages established late in September or early in October the percentages of individuals entering hibernation were much higher, and the percentages changing to moths and emerging before winter were much lower than in the cages into which the larvae were introduced in August. From 21 to 100 percent of the larvae entering the soil the latter part of August changed to adults before winter, whereas only 0 to 18 percent of the larvae placed in cages during the period from the middle of September to early in October produced adults in the fall,[4] this latter period apparently being the optimum time for larvae to enter the soil, pupate, and

[4] Adults were known to emerge as late as November 6 in the Valley Park, Mo., area and some were still living November 19.

hibernate successfully. Individuals entering the soil in the middle of October or later apparently stand a much poorer chance of pupating and hibernating successfully. Examination of cages established at La Fayette, Ind., and Toledo, Ohio, between October 11 and November 4, 1935, showed that only 2 percent and 1 percent, respectively, formed pupae. At La Fayette 49 percent of the living forms observed in these cages in December 1935 were still prepupae, 30 percent were dead larvae, and 19 percent could not be found. At Toledo 35.8 percent of the larvae placed in a cage between October 11 and 31 died without entering the soil.

In general, from 0 to 79 percent of the larvae entering the soil the latter part of August remained to begin hibernation as pupae in the cages conducted in the different localities, with considerable variation from year to year in all localities. None of the pupae in any of the early cages produced adults the following summer at any of the locations. Barber (*1, p. 9*) states that of the individuals entering the soil during the first week of August, in southern Connecticut in 1935, from 6 to 30 percent of the possible maximum entered hibernation, and that of those entering the soil the last week in August, 80 percent of the possible maximum entered hibernation.

It is likely that the type of food available to the larvae has an important effect on the time they enter hibernation, as well as on their chances of surviving the winter. It has been found (*8, p. 516*) that insects prepare themselves for hibernation by reducing the amount of free, easily freezable, water in the tissues. The amount of free water in the tissues of such larvae as the corn earworm may be regulated by the amount in their food (*7, p. 899*). Ditman (*3, pp. 204–205*) states that prepupae and pupae of earworm larvae maturing on milk-stage corn contain a higher percentage of water and a lower percentage of fat than do most of those maturing on dough-stage corn. Ditman et al. (*4, p. 204*) also state that the drop in average temperature to about 66° F., which usually occurs in most of the areas by early September, causes pupae forming after that time to enter the diapause. Other more obscure factors may also be involved. Nevertheless, the larvae used in the experiments summarized in table 2, as well as larvae maturing in the field from the middle of September to early October, would probably be in a suitable physiological condition for successful hibernation, because of their having fed on corn with reduced water content and being subjected to other conditions likely to cause diapause.

To sum up the results from field cages following the severe winter of 1935–36, pupal survival occurred only at Arlington Farm, Va., Moorestown, N. J., and Lexington, Ky., of the 14 locations at which determinations of pupal survival were made. Pupal survival occurred in cages at a much higher percentage of the locations after the milder winter temperatures in the other 3 years of these experiments. In 1936–37 cages were placed in 22 locations and pupae survived at 11 where records were made. In 1937–38 cages were placed in 22 locations and pupal survival was recorded in 11 of them, including all the above areas with the exception of Valley Park and Urbana, but, in addition, pupae survived at La Fayette, Ind., and in large numbers in cages run for the first time at Stillwater, Okla. In 1938–39 the number of localities in which cages were stocked with larvae was reduced to 13, including two new locations, Prosser and Walla Walla, Wash. Pupal survival occurred at 9 points. Cages installed at Orleans, Ind., during 3 seasons were not examined for pupal survival.

Moth emergence in the cages extended from the second week in May to the last week in June. The earliest record of emergence was between May 8 and 10 at Charleston, Mo. Observations as to the time of first appearance of eggs, larvae, or adults in the field indicate that adults emerge at approximately the same time under either field or cage conditions.

It would appear from a study of soil temperatures at the various stations that lethal temperatures alone do not explain the mortality at the more northern stations, although longer duration of the low temperatures at those stations may aid in bringing about the mortality. Factors which, taken in conjunction with low temperatures, increase the mortality rate are the moisture content of the soil and heaving through action of frost.

CLIMATIC AND SOIL FACTORS

As is shown in tables 1 and 2 a wide range in climatic and soil factors known to affect hibernation is represented. The data can, perhaps, best be interpreted by making some comparisons of these factors. For this purpose the soil temperatures and precipitation data for five key localities were studied. The important figures from this study are given in table 3.

TABLE 3.—*Summary of soil temperatures, rainfall, and survival of the corn earworm at five key locations, 1935–36 to 1938–39, inclusive*

Period	Locality	Depth below surface	Minimum temperature	Periods of freezing or below	Total rainfall Nov.–Apr.	Spring survival	Moth emergence
		Inches	*° F.*	*Days*	*Inches*	*Percent*	*Percent*
1935–1936	Arlington, Va.	4	22.5	35	22.2	0.5	0
	Carlisle, Pa.	4	28	53	22.5	0	0
	Toledo, Ohio	4	20	------	12.0	0	0
	Urbana, Ill.	------	------	------	------	------	------
	Manhattan, Kans.	4	16	58	6.1	0	0
1936–1937	Arlington, Va.	3	20	8	25.5	21.5	2.3
	Carlisle, Pa.	4	20	51	24.7	13.5	0
	Toledo, Ohio	4	18	155	17.0	0	0
	Urbana, Ill.	4	22	79	21.4	0	0
	Manhattan, Kans.	[1] 2½	16	73	6.2	0	0
1937–1938	Arlington, Va.	3	32	1	13.5	20.5	.75
	Carlisle, Pa.	4	29	26	14.9	22.5	0
	Toledo, Ohio	4	17	145	14.4	0	0
	Urbana, Ill.	4	22	92	18.0	0	0
	Manhattan, Kans.	[1] 4	26	44	5.5	0	0
1938–1939	Arlington, Va.	3	32	1	17.3	41.5	[3] 1.0
	Carlisle, Pa.	4	42	0	18.8	24.0	0
	Toledo, Ohio	[2] 6	36	0–136	13.2	0	0
	Urbana, Ill.	4	26	52	15.8	0	0
	Manhattan, Kans.	2½	18	73	6.5	2.0	6.0

[1] Minimum temperature at 4-inch level was 2° higher than at the 2½-inch level during 1935–36 and 10° higher during 1937–38.

[2] Sand covered by corn shock had 2 days of freezing temperature or below; sand, uncovered, had none, and sandy loam, covered, had 136 days with temperature at or below freezing.

[3] Approximate.

Manhattan, Kans., Urbana, Ill., Toledo, Ohio, Carlisle, Pa., and Arlington Farm, Va., were selected for this study since those localities represent the extremes in climatic conditions as well as in pupal survival and adult emergence. As is shown in tables 2 and 3, pupae survived the winter at Arlington Farm during the entire period, at Carlisle in the winters of 1936–37 to 1938–39, inclusive, and at Manhattan in the winter of 1938–39, whereas there was no survival at Urbana or Toledo in any season. No adults emerged in the cages at Arlington Farm in 1936, but from 0.75 to 2.3 percent of the larvae entering the soil to pupate produced adults the following spring during the years 1937 to 1939, inclusive. No adults emerged in the spring in cages at any of the other localities during any of the years included in this study.

Since it has been shown that under dry cage conditions earworm pupae can survive exposure for several days to temperatures as low as 10° to 14° F.,[5] it would appear that lethal temperatures were not reached at any of the places shown in table 3. Salt (*9, p. 31*) states, as has also been shown by other investigators, that—

> Excluding contact moisture as a factor, there are certain types of insects which are killed by low temperatures without being frozen, provided the time of exposure is of sufficient length. The lower the temperature, the shorter is the exposure necessary to kill them, and vice versa.

Length of time the pupae were exposed to low temperatures would seem to explain lack of survival in areas like Manhattan, where winter rainfall does not appear to be an important factor in causing death of the pupae. During 1938–39, however, 2 percent of the pupae survived the winter at Manhattan both in the clay loam and sandy silt soils. Six percent of the pupae in the sandy silt soil produced adults, whereas no adult emergence occurred in the clay loam soil. The temperature in the clay loam soil reached a minimum of 18° F. 2½ inches below the surface and was 32° or lower for a total of 73 days. In 1936–37 at the same location no pupal survival or adult emergence occurred in the clay loam soil. The temperature that winter reached a minimum of 16° 2½ inches below the soil and was 32° or lower for 73 days. At Toledo in 1938–39 the minimum temperature at the 6-inch level in uncovered sand was 36°, and yet no pupal survival occurred. These facts suggest that there are differences in the physiological condition of the pupae in different years or localities and perhaps even in different lots of pupae collected in any single year.

Moisture content of the soil is no doubt an important factor. Barber and Dicke (*2*) have shown that more pupae survive in cages on dry soil or sand than on moist soil or sand. The fact that the soil is frozen to a depth below the pupal cells in the more northern areas tends to maintain the soil surrounding the pupae in a much moister condition as spring thawing takes place in those areas than in areas farther south where soil is not frozen so deeply or for so long a period. This may be an important reason for the difference in survival. Salt (*9, p. 14*), in his studies on the freezing process in insects, states:

> * * * This [moisture] is obviously of importance also in nature, since hibernacula of insects are frequently wet or icy, and the contact of such moisture with the insect body produces a center of ice formation which may inoculate or seed the body fluids. * * * If the insect were dry, or if inoculation failed to occur, freezing would not take place until the temperature dropped to the

[5] Unpublished data supplied by Dwight Isely of the Arkansas Agricultural Experiment Station and F. F. Dicke of the Arlington, Va., laboratory of the Bureau of Entomology and Plant Quarantine.

undercooling point, thus providing a margin of safety equal to the difference between the undercooling and freezing points. This difference ranges from a very few to 30° or 40° C., depending on the species, stage, and physiological condition.

The foregoing statement taken in connection with the earlier quotation concerning length of exposure to low temperatures would appear directly applicable in explaining the results of the studies on earworm hibernation, since both length of exposure to low temperatures and direct contact with soil moisture in general are prolonged in more northern latitudes.

Soil type is also undoubtedly an important factor in survival, hibernation in the sandier, more pervious soils resulting in somewhat higher survival in most cases than in clay and other soils where percolation is not so rapid. In fact, at several stations in the more northern areas moth emergence occurred only in sandy soil types (table 2). The larvae burrowed somewhat deeper into sandy soils before pupation than in the heavier soils. Heaving of the soil is another factor that has been shown to cause mortality by the breaking up and filling of the burrows. Obviously, more heaving occurs in soils with higher surface-moisture content and subject to more freezing and thawing.

In cages covered by corn shocks, or located in alfalfa or grass sod, none of these types of cover appears to have increased winter survival where no pupae survived in adjacent cages in exposed soil. In the case of alfalfa and grass sod the larvae did not burrow so deeply into the soil before pupating as in exposed soil. Roots of the growing plants also filled the burrows, thereby preventing escape of the moths.

MISCELLANEOUS OBSERVATIONS

The establishment of cages in protected areas under storage sheds and soil examinations under and around corn canneries have revealed some facts not obtainable from the standard cage studies. Examinations of soil in corn and alfalfa fields have also supplied pertinent auxiliary information. Barber (*1, p. 24*) has shown that in southern Connecticut a small percentage of pupae in soil under an open shed survived the mild winter of 1936–37.

Examinations under and around cannery buildings in Indiana and Illinois showed the mortality in such locations to be very high. Fungous and bacterial diseases appeared to be the most important factors in this mortality. The larvae falling through the cracks in the floors of the cannery buildings would usually crawl to the outer edges of the buildings before digging into the soil. Here the moist soil, and the fact that large populations were sometimes crowded into small areas, enhanced the development and spread of diseases. An occasional living pupa was found along a stone wall surrounding a cannery building at Hoopeston, Ill., following the mild winter of 1936–37, but less than 1 percent of the total pupae observed were alive.

Field examinations also revealed an occasional living pupa in central Illinois following the mild winters of 1936–37 and 1937–38. In every case such pupae were in well-drained soil with a layer of unrotted, plowed-under, plant debris just below the pupa. The better drainage seemed to favor survival. Soil examinations made in an area of very sandy soil in central Illinois showed a very small percentage of survival in the spring of 1939. It appeared that most of the pupae produced adults late in the fall in this sandy soil. Examinations made in this same area in heavily infested fields that had been cultivated late in the season did not produce any living forms in the fall of 1937 or the spring of 1938. Soil examinations in southern Illinois have, to date, failed to reveal any survival under field conditions, although large numbers of larvae entered the soil in alfalfa and soybean fields in that area during the fall of 1936, and the mild winter that followed seemed to provide temperature conditions favorable to some successful hibernation. Pupae from larvae completing their development on alfalfa were very small, however, and perhaps were in a poor physiological condition to withstand even moderately low temperatures. Small size is characteristic of pupae from larvae fed on alfalfa (*5, p. 20*). Where adults are forced to select alfalfa for oviposition owing to the scarcity of other succulent hosts, the chances for successful hibernation of their progeny are apparently reduced. Soybean appears to be a better food for the earworm than alfalfa.

In several instances in 1936 heavily infested corn was observed to be shocked in fields in southern Illinois late in the fall with larvae still feeding on the grain. Examinations of soil under and around such shocks were made early in the winter. No pupae or pupal burrows were found directly under the shocks, but living pupae were found from the edges outward for a distance of several feet. Only dead pupae were found in these fields in the spring of 1937. These records, together with observations made under and around cannery buildings in Indiana and Illinois, show that earworm larvae tend to seek unprotected soil in which to hibernate. The fact that pupae entered for hibernation in greatest numbers the wet clay types of soil seems to explain lack of survival in corn and soybean fields during mild winters like that of 1936–37.[9]

BIOTIC FACTORS

Biotic factors played an important part in the more southern localities. For instance, fungous and bacterial diseases appeared to cause greater mortality at such places as Fayetteville, Ark., Charleston, Mo., and Arlington, Va., than in other areas with a longer winter season. Earthworms caused considerable mortality by destroying the earworm emergence tunnels and embedding the pupae in their castings. Earthworm activity occurred over a longer period at Arlington than in areas having a colder climate. Soils of high humus content contained larger earthworm populations than those, such as most sandy soils, having lower humus content. Nematodes and ants apparently caused some mortality of hibernating pupae. Carabid beetle larvae destroyed some pupae in the cages. Field mice and other rodents, as well as moles, destroyed a large percentage of pupae under field conditions. Their period of activity is longer in southern areas than farther north.

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[9] Pupal survival was observed in the spring of 1941 in southwestern Illinois in a field with heavy clay soil. The winter of 1940–41 was very mild, and very little precipitation occurred in the area.

FACTORS INDIRECTLY AFFECTING HIBERNATION

The number of larvae that enter hibernation successfully in the field and the likelihood of pupal survival are affected indirectly by a number of factors. Among these are time of corn planting, rapidity of drying of the corn, and the time of first frost in the fall.

Time of planting of the corn is dependent to a considerable extent on the amount of rainfall in the spring as well as the soil type. A dry spring allows corn to be planted at an early date, especially in well-drained, sandy soils. Such soils warm up and dry to a good tillable condition earlier than do the heavier soils. Also farmers as a rule plant corn in sandy soils as early as possible to take advantage of the moisture that has accumulated during the winter and early spring, as such soils tend to dry out too rapidly during the late summer months to produce a good crop. It has been observed, therefore, that in general the late-maturing corn is found on the heavier, less drained clay or river-bottom soils. It is here that earworm larvae enter hibernation in greatest numbers, and yet such locations offer the poorest chances for survival owing to excess moisture, heaving of soil, and accumulation of weed growth before the land can be plowed for a crop. In some market-corn areas late crops of corn are planted on the sandier soils, thereby affording suitable food for larvae to hibernate under optimum conditions, but taken over a large area this is not the general situation.

The rate of maturing or drying of corn is the result of several factors, among which are variety, time of planting, amount of rainfall late in the summer, and time of first frosts. Long-season, slow-maturing varieties, which remain in the dough stage a considerable length of time, provide the best foods for larvae that are to enter hibernation. Ample rainfall in the late summer and early fall also increases the time the corn remains in the dough stage, thereby allowing larvae to enter hibernation in good condition in large numbers. Dry, warm weather in the fall, on the other hand, results in earlier drying of the corn, which in turn has been observed to result in desiccation of a large percentage of the larvae that are attempting to feed on it.

Frost not only hastens the drying of late-planted corn but has been observed to kill many of the larvae that were feeding on the ears. This occured in central Illinois in the fall of 1937 and in northern Illinois in 1938. Even where mild weather in northern latitudes allows larvae to develop late in the fall, the chances of their being able to pupate normally are reduced. This was mentioned previously in discussing cages established at La Fayette, Ind., and Toledo, Ohio, between October 11 and November 4, 1935, in which only a very small percentage of the larvae placed in them were able to form pupae.

CONCLUSIONS

The limits of successful hibernation reach much farther north after dry, mild winters than after those during which the weather is more severe. Likewise, the chances for successful hibernation are much greater in well-drained, sandy soil than in heavier soils. Certain protected locations, such as those around cannery buildings, were observed to allow a small percentage of successful hibernation farther north than occurred in cages unprotected from the weather. As far as can be determined from observations made in Indiana and Illinois, however, only a very light infestation can be traced to such a source.

Cultural operations, such as plowing and disking, are normally carried out before the time adults were observed to have emerged in the spring. Therefore, any infestation that develops from pupae hibernating in any of the localities covered by these experiments does so in spite of the cultural practices common to the growing of farm crops. Although a high degree of control may result from cultural practices, these practices need not be especially recommended except in cases of abandoned cornfields.

Conclusive data on the subject have not been obtained and may be impossible to obtain, but circumstantial evidence suggests that large-scale migrations from the South into the North Central States occur during years like 1936 when crops in the South attractive to the earworm moths are dried up as a result of drought. Lack of successful hibernation in cages located in the more northern parts of the Central States seems to indicate that the small populations that occur there yearly, as well as the relatively severe infestations that occur during occasional years, must be the result of immigrations the size of which is governed by conditions in corn and other crops to the southward.

SUMMARY

Cage experiments supplemented by field studies extending over the Central and Northeastern States were begun in 1935 in an attempt to determine the northern limits of successful hibernation of the corn earworm and to learn more about the factors involved. Cages of identical type were established in exposed soil of a number of different types, in alfalfa and grass sod, under corn shocks, and under an open shed. Field studies included soil examination in exposed soil in cornfields, in alfalfa and soybean fields, under and around corn shocks, and under cannery buildings where large numbers of larvae entered hibernation. A wide range of soil types were also included in the field studies.

From 21 to 100 percent of the estimated total possible adult emergence occurred in the fall in cages established late in August. Apparently the period from the middle of September to early in October is the optimum time for larvae to enter the soil, pupate, and hibernate successfully. Larvae that mature after the middle of October are unable to enter hibernation in the Central and Northern States.

Moth emergence in cages extended, for the whole area, from the second week in May to the last week in June. Adults emerged at approximately the same time under either field or cage conditions.

Lethal low temperatures were not reached at any of the locations under study. Length of exposure would seem to explain the lack of survival at many of the points of observation.

Biotic factors that have been observed to cause mortality in hibernating forms are fungous and bacterial diseases, earthworms, ants, nematodes, carabid beetle larvae, moles, rodents, and roots of growing plants. Biotic factors appeared to be of more importance in areas

having a mild winter climate than in those where temperatures were lower.

Factors observed to affect hibernation indirectly under field conditions were time of planting, rate of maturity of the corn, and time of first frost in the fall. Late corn, which provided food for hibernating larvae in largest numbers, was planted largely in heavier, poorly drained soils and thereby offered the poorest chances for survival of the pupae because of excess moisture. Dry fall weather and rapid maturity of the corn, sometimes hastened by frost, resulted in considerable fall mortality of larvae that would otherwise have hibernated. Large numbers of late-maturing larvae are destroyed directly by frost or, if they enter the soil, fail to pupate because of low temperatures.

During the spring of 1937 an occasional living pupa was found in protected soil around a cannery building at Hoopeston, in central Illinois. Occasional living pupae were found in cornfields in central Illinois following the mild winters of 1936–37 and 1937–38. In every case the pupae were located in sandy soil or in well-drained soil having unrotted plant debris below the pupae, thereby allowing better than ordinary drainage. Field examinations of soil to date have failed to reveal any survival under field conditions in southern Illinois. The fact that the soils where pupae went into hibernation in greatest numbers were wet clay types seems to explain this. Larvae feeding on ears of corn in shocks, as well as those that had opportunity to dig into the soil under cannery buildings, tended to leave the cover before digging into the soil.

Cultural operations to destroy hibernating earworms are recommended only for abandoned cornfields.

Circumstantial evidence points to migrations from the South as the source of infestations that are found in the northern parts of the United States.

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