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THE EFFECTIVENESS OF CULTIVATION AS A CONTROL FOR THE CORN EARWORM[1]

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INTRODUCTION

For many years plowing has been generally recommended as an aid to the control of the corn earworm (*Heliothis obsoleta* F.). During this time the recommendation has been largely supported by the plausibility of the belief that the operation would be effective, taking into consideration the hibernating habits of the insect and the probable effect of the disturbance caused by plowing. In the fall of 1928 a study was undertaken for the purpose of obtaining definite information on this subject. This work continued for 5 years at Charlottesville, Va., ending in the summer of 1933, and for a shorter period at Savannah, Ga. The information thus obtained points definitely to certain conclusions which are presented in this bulletin.

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[2] The writers wish to express their indebtedness to W. J. Phillips, in charge of the field laboratory of the Bureau at Charlottesville, Va., during the years when the work described herein was performed. Through encouragement, generous advice, and help in the field, he aided in making the work possible. Credit is also due A. H. Madden for aiding in the details of the work during 1931, 1932, and 1933.

EXPERIMENTAL METHODS

The corn earworm is peculiarly difficult to handle experimentally in large numbers, owing to the cannibalistic habits of the larva. Each larva must be handled individually, and this factor definitely limits the number that one person can handle in a short time.

In this work it was desired to have larvae enter the soil for pupation as late in the season as possible for ideal hibernation to reduce fall moth emergence to a minimum. By previous experiments it was found that such a period occurred during the second and third weeks of September at Charlottesville, Va., and during the first week of September at Savannah, Ga. During these periods the latest corn of the season was in the roasting-ear stage and the larvae were usually abundant in this corn. When the condition of the latest corn made it necessary to collect larvae a few days earlier than the dates mentioned, considerable fall emergence occurred (see 1930 and 1931 in table 7). Thus at Charlottesville a critical period occurred about the middle of September, after which there was little or no fall emergence of moths. At Savannah corn suitable for collecting corn earworm larvae usually disappeared from the field about 2 weeks earlier than in Virginia. Consequently the collections had to be made earlier, resulting in a much greater fall emergence of moths. While the salubrity of the climate might suggest that corn could be grown until late in the fall at Savannah, the hot weather and periods of drought that occur there during June and July make it difficult to obtain stands during these periods and therefore most of the corn is planted during March and April.

Larvae were collected from field corn and were isolated in 2-ounce tin salve boxes. These larvae were the largest obtainable, usually in the fifth or sixth instar. They were given corn in its dough stage as food for completing development, and a day or so before they became full-grown, as determined by daily examinations, the boxes, supplied with fresh food and with covers removed, were inverted on the soil over the larvae and food. This procedure permitted the larvae to enter the ground under as nearly natural conditions as possible. They dug into the soil and made emergence burrows normally.

In order that the experiments might be controlled, it was necessary that the insects be protected against enemies inhabiting the soil and that the moths be trapped as they emerged. At the same time it was desirable that the hibernating individuals be kept under conditions as nearly like those in the field as possible.

The cages used were of two types. The first type consisted of a board frame 30 inches square and 10 inches deep. To this was hinged a frame cover 4 inches deep covered with 14-mesh screen. The cages were open at the bottom. Hardware cloth, set in the soil about the area in which the cages were set, excluded moles. The second type of cage was a screen-covered area, 10 by 20 feet, and served as a check on the results obtained in the smaller standard cages. These cages are shown in position in figure 1.

In the smaller cages 100 earworm individuals were invariably placed; in the larger cages 1,000 were enclosed. Larvae dying on the surface of the soil were replaced. Previous hibernation studies, in the smaller cages, had shown that there was little, if any, interference among the digging larvae that could be laid to an overpopulation. During the course of the experiments examinations of scores of cages at various periods after the larvae entered the soil showed no evidence that the insect had acted unnaturally under the conditions stated.

Plowing was simulated by spading to a depth of approximately 8 inches in the small cages on designated dates. The soil in the large cages was actually plowed with an 8-inch-bottom plow, after the ends of the cages had been removed. The large cages, therefore, served as a check on the simulated plowing in the small cages. Subsequent treatment consisted only of keeping vegetation in the cages at a minimum. A comparison of the results obtained in these two series of cages, shown in tables 7 and 8, indicates that the effect of spading was practically identical with that of actual plowing.

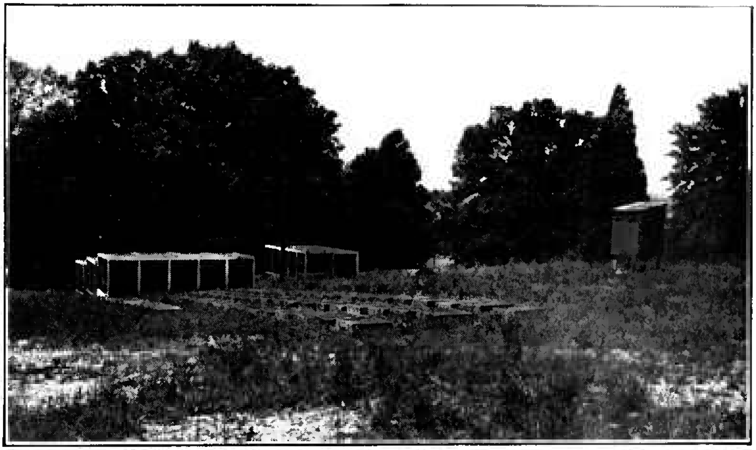

FIGURE 1.—Cages used for testing the effects of seasonal cultivation upon hibernating corn earworm pupae.

Moths could not escape from these cages because they were covered as described, and records of moth emergence were taken by daily examination of the cages during the emergence period. The soil in the cages was examined by carefully shaving away the earth vertically from the surface to a depth of approximately 10 inches.

TYPES OF SOIL USED IN THE EXPERIMENTS

Four types of soil were used in the experimental work. Analyses of these soils are given in table 1. The soils used at Charlottesville consisted of three rather extreme types: (1) Piedmont red clay which became hard when dry and sticky when wet; (2) a sandy loam found in some locations in the vicinity; and (3) a high-humus-content soil made by compounding approximately equal quantities of Piedmont red clay, sandy loam, and cow manure. The soil at Savannah was Norfolk fine sand, 6 to 8 inches deep, with a subsoil of pale-yellow, compact, fine to coarse sand. This soil did not become hard when dry and could be plowed a few hours after a heavy rain.

TABLE 1.—*Analyses of soils used in hibernation experiments with the corn earworm at Charlottesville, Va., in 1932 and 1933 and at Savannah, Ga., in 1931 to 1933*

Item	Charlottesville, Va.[1]			Savannah, Ga.[2]
	Red clay	Sandy loam	Red clay, sandy loam, and humus	Fine sand
	Percent	*Percent*	*Percent*	*Percent*
Potash	2.07	1.24	1.24	0.41
Phosphoric acid (P_2O_5)	.13	.10	.20	.17
Nitrogen	.07	.08	.15	.07
Ignition loss	5.45	3.62	5.76	2.44
Organic matter (by H_2O_2)	1.10	1.78	2.65	2.10

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NATURE OF THE HIBERNATING QUARTERS OF CORN EARWORM PUPAE

The full-grown larva burrows into the soil and prepares a chamber for the pupa and a tunnel for moth emergence. Pupation occurs about 3 or 4 days after the larva has entered the soil, depending largely on the soil temperature. The depth at which the pupae lie ranges from 1 to 10 inches, depending on the type and condition of the soil and the time of year. The usual depth is from 2 to 5 inches below the surface. After reaching the desired depth, the earworm larva constructs the tunnel through which the moth is to escape and which ends from a quarter to a half inch below the surface. Such tunnels, if not interfered with by cultivation, plant roots, or soil-inhabiting animals, have often been found in good condition more than a year after their construction. The base of the emergence burrow, in which the pupa rests during hibernation, is often slightly larger in diameter than the remainder of the burrow. The pupa usually rests in a plane somewhat declining from the vertical, scarcely ever horizontal. It is always found head up, and only one side is in direct contact with the earth, the space between it and the walls being sufficient for circulation of air. Probably the pupa turns occasionally, so that the same side does not always rest in contact with the earth.

NATURAL MORTALITY OF INDIVIDUALS AFTER ENTERING THE SOIL

In no case did moths emerge from all the earworm larvae that entered the soil. Mortality was found to vary with the season and the many natural hazards of a soil environment. Such mortality was observed to be more or less continuous from the time larvae entered the soil in the fall until the period of emergence ended during the following summer. A considerable number of larvae died in the soil before pupating. Some of these individuals possibly had been infected with disease organisms while on the host, where diseased larvae are occasionally found, or became infected while working in the soil.

In 1930 rains occurred at Charlottesville while the larvae were entering the soil and during the early part of the pupal period, but exceedingly dry weather prevailed throughout the fall and the following winter. The conditions, both as to soil and weather, under which the larvae entered hibernation in 1931 and 1932 were similar and continued so for approximately 1 month. The fall of 1931 was dry, as was the following midwinter; but in 1932 dry weather prevailed only until the middle of October, after which continued rains kept the ground very wet throughout the winter. The winter of 1932–33 was accompanied by a number of hard freezes, which penetrated below the hibernation level over a period of a few weeks. Under the conditions that existed in 1930 the average mortality, in clay and sandy soil, before the advent of winter was higher than when the larvae entered a dry soil, as in 1931 and 1932. These data indicate that there is a higher mortality when larvae entering the ground and newly formed pupae are subjected to a wet soil, whereas a soil saturated with water over a considerable period of time does not materially increase mortality after the pupae have hardened, as in 1931 and 1932.

TABLE 2.—*Rates of survival of hibernating corn earworm pupae at Charlottesville, Va., in 3 types of soil at various dates during the 5-year period, 1928–33*

Soil type and season	Examined Nov. 15			Examined Apr. 15			Examined May 15		
	Larvae entered soil in fall	Living pupae found	Rate of survival	Larvae entered soil in fall	Living pupae found	Rate of survival	Larvae entered soil in fall	Living pupae found	Rate of survival
Red clay:	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*
1928–29	200	101	50.5	300	63	21.0	300	32	10.7
1929–30	300	135	45.0	300	58	19.3	300	31	10.3
1930–31	300	60	20.0	300	16	5.3	300	16	5.3
1931–32	300	85	28.3	300	42	14.0	300	68	22.7
1932–33	300	46	15.3	300	34	11.3	300	25	8.3
Total	1,400	427		1,500	213		1,500	172	
Average [2]			30.5			14.2			11.5
Sandy loam:									
1928–29	200	67	33.5	300	12	4.0	300	9	3.0
1929–30	300	128	42.7	300	25	8.3	300	13	4.3
1930–31	300	72	24.0	300	11	3.7	300	10	3.3
1931–32	300	129	43.0	300	53	17.7	300	62	20.7
1932–33	300	199	66.3	300	83	27.7	300	66	22.0
Total	1,400	595		1,500	184		1,500	160	
Average [2]			42.5			12.3			10.7
Sand, clay, and humus:									
1928–29	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
1929–30	200	77	38.5	300	17	5.7	300	3	1.0
1930–31	300	27	9.0	300	1	.3	300	0	0
1931–32	300	18	6.0	300	16	5.3	300	8	2.7
1932–33	300	14	4.7	300	0	0	300	2	.7
Total	1,100	136		1,200	34		1,200	13	
Average [2]			12.4			2.8			1.1

[1] Series of cages destroyed by moles. [2] Based on totals.

The greatest mortality of pupae occurred in the fall (table 2), following which the mortality, at a lower rate, was continuous. In each series of cages at Charlottesville each year, cages representing each soil type were examined at regular intervals to determine survival. The first examination was made on or about November 15, about 2 months after the larvae had entered the soil for pupation. At this time an average of 30.5 percent of live pupae were recovered in red clay, an average of 42.5 percent in sandy loam, and an average of 12.4 percent in the high-humus-content soil. The second regular examination of cages was made about April 15, or 7 months after the larvae had entered the soil, and when the full force of the winter had been experienced. At this time an average survival of 14.2 percent was found in red clay, 12.3 percent in sandy loam, and 2.8 percent in high-humus-content soil. The third examination of cages was made about May 15, 8 months after the larvae had entered the soil and near the time when moths begin to emerge. At this time an average survival of 11.5 percent was found in red clay, 10.7 percent in sandy loam, and 1.1 percent in high-humus-content soil. Furthermore, the number of moths that eventually emerged from these soils indicated that mortality continued subsequent to the last series of soil examinations on May 15.

At Savannah the mortality was much less than at Charlottesville, probably owing to warmer conditions during the hibernation period.

EMERGENCE OF MOTHS FROM HIBERNATION

AT CHARLOTTESVILLE, VA.

At Charlottesville the moths usually began to emerge from hibernation cages during the last week in May, but this was variable with the season. In table 3 a summary of emergence is given. The earliest record of a first moth was on May 25, in 1933, 255 days after larvae began to enter the soil in the fall. The latest record of a first moth was on June 19, in 1929, 277 days after larvae began to enter the soil. The last recorded moths emerged from July 18, in 1930, to August 5, in 1929. The period during which moths emerged ranged from 47 days in 1929 to 63 days in 1932. Most of the moths emerged during the latter part of June and early in July.

AT SAVANNAH, GA.

At Savannah the moths began to emerge from hibernation during the last week of March and continued to emerge over a period of 89 days in 1932 and 124 days in 1933. The majority emerged during May and June in this locality. The longest period of hibernation—from the time larvae began to enter the soil until the last moth emerged—was 333 days in 1932–33, or a period of practically 11 months. The shortest recorded hibernation period was also in 1932–33, and was 209 days, or approximately 7 months. During this year, in this locality, moths emerged from hibernation over a period of 124 days, or practically 4 months.

TABLE 3.—*Emergence of corn earworm moths from hibernation cages at Charlottesville, Va., 1928–33, and at Savannah, Ga., 1931–33*

Location and season	Dates larvae entered soil for pupation	Dates of moth emergence		Period of hibernation		Total moths	Moths emerged during—											
		Earliest	Latest	Minimum	Maximum		March		April		May		June		July		August	
				Days	*Days*	*Number*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Charlottesville:																		
1928–29	Sept. 15–21	June 19	Aug. 5	277	324	80	------	------	------	------	------	------	19	23.8	58	72.5	3	3.7
1929–30	Sept. 12–16	May 27	July 18	257	309	69	------	------	------	------	4	5.8	24	34.8	41	59.4	------	------
1930–31	Sept. 8–15	June 8	July 28	273	323	23	------	------	------	------	------	------	13	56.5	10	43.5	------	------
1931–32	do	May 28	July 30	263	326	258	------	------	------	------	14	5.4	110	42.6	134	51.9	------	------
1932–33	Sept. 12–17	May 25	July 24	255	315	285	------	------	------	------	8	2.8	168	58.9	109	38.2	------	------
Savannah:																		
1931–32	Sept. 1–6	Mar. 30	June 27	211	300	162	2	1.2	28	17.3	85	52.5	47	29.0	------	------	------	------
1932–33	Aug. 28–Sept. 3	Mar. 25	July 27	209	333	259	1	.4	45	17.4	105	40.5	100	38.6	8	3.1	------	------

SURVIVAL AND MOTH EMERGENCE FROM PUPAE EMBEDDED IN THE SOIL

The effect of plowing to a depth of about 6 inches is to dislodge the majority of the pupae from their normal position and, with subsequent cultivation, results in the breaking down of practically all of the moth emergence tunnels. Provided the pupae are not crushed, there is a possibility of moth emergence from pupae embedded in the soil after the process of cultivation. To determine the extent of moth emergence from such pupae, burials in soil were made in divers positions, at various depths, and under various soil treatments at Savannah during 1931 and 1932. The pupae used were exhumed from cages similar to those in which plowing was simulated, the larvae having entered the soil naturally as heretofore described. Pupae were artificially placed in three positions in these experiments, simulating the extreme possible positions from which moths might emerge when dislodged; (1) pupae vertical with head down, (2) vertical with head up, and (3) horizontal. The depth in each case was measured from that point of the pupa resting highest in the soil.

IN SOIL RECEIVING NO MOISTURE

A series of 944 pupae were placed in moist sandy loam soil, gently tamped down, but received no moisture thereafter. Moths showed a surprising ability to make their escape from such buried pupae and to reach the surface of the soil. The data derived from this work are summarized in table 4. No moths emerged from pupae in a vertical position, head down, at a greater depth than 2 inches. Moths successfully emerged from pupae placed in a vertical position, head up, at various depths down to 10 inches below the surface. From this depth 25 of the 35 individuals were successful in escaping to the surface; of this number, however, 3 were unable to spread their wings normally. Moths emerged successfully from pupae placed in a horizontal plane 8 inches below the surface, but failed to emerge from pupae located 10 inches below the surface. Seemingly, therefore, moths would usually be quite successful in developing from pupae embedded in moist sandy loam soil which received no rain before the period of emergence, and some of the moths would reach the surface.

IN SOIL WITH RAIN SIMULATED

The experiments of this series were similar to those described in the preceding paragraph, except that the soil received moisture immediately after the pupae were placed in it. The surface was somewhat puddled, simulating a single rain, after which the soil was allowed to dry naturally. A summary of these experiments is given in table 5. From pupae buried in a vertical position, head up, moths emerged from a depth of 6 inches; and from horizontal pupae they emerged from a depth of 5 inches. In this "rained-on" soil many moths died while trying to force their way from the pupae and were recovered dead, partly emerged, when the soil was examined. These experiments indicated that the effect of rain was to pack the earth about the pupae so that, to depths of 5 or 6 inches, the moths were often unable to exuviate or to make their way through the soil to freedom. The rain, in changing the physical condition of the soil, was an important factor in limiting moth emergence from such embedded pupae.

TABLE 4.—*Effect of embedding pupae of the corn earworm in slightly moist, gently tamped, sandy loam soil, receiving no rain, on the survival of pupae and the emergence of the moths; experiments in cages in insectary, Savannah, Ga., 1932*

Position of pupae in the soil	Depth of pupae in the soil	Total pupae	Moths issuing		Recovery on examination of the soil		
			Perfect	Imperfect	Dead moths	Dead pupae	Live resting pupae
	Inches	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Vertical, head down	½	25	9	0	9	2	5
	1	60	12	3	38	4	3
	2	60	6	0	48	3	3
	3	25	0	0	18	0	7
	4	25	0	0	21	0	4
Vertical, head up	1	49	43	0	0	3	3
	2	60	50	0	2	4	4
	3	60	48	0	2	1	9
	4	60	50	0	2	1	7
	5	35	33	0	0	0	2
	6	35	29	0	2	1	3
	8	35	21	0	4	2	8
	10	35	22	3	9	1	0
Horizontal	1	60	57	0	0	0	3
	2	60	52	0	0	2	6
	3	60	49	0	3	2	6
	4	60	54	1	2	2	1
	5	35	30	0	1	1	3
	6	35	23	1	7	1	3
	8	35	28	0	6	1	0
	10	35	0	0	17	18	0

TABLE 5.—*Effect of embedding pupae of the corn earworm in wet sandy loam soil, somewhat puddled from simulated rain, on the survival of pupae and the emergence of moths; experiments in cages in insectary, Savannah, Ga., 1932*

Position of pupae in the soil [1]	Depth of pupae in the soil	Moths issued		Recovery on examination of the soil		
		Perfect	Imperfect	Dead moths	Dead pupae	Living resting pupae
	Inches	*Number*	*Number*	*Number*	*Number*	*Number*
Vertical, head up	1	26	2	2	2	3
	2	29	1	3	1	1
	3	12	8	[2] 9	3	3
	4	5	12	[2] 16	1	1
	5	0	0	[2] 35	0	0
	6	6	1	[2] 24	4	0
Horizontal	1	20	0	[2] 9	2	4
	2	6	0	[2] 27	1	1
	3	23	3	[2] 7	0	2
	4	24	3	[2] 7	0	1
	5	5	0	[2] 27	3	0
	6	0	0	[2] 30	5	0

[1] 35 pupae were buried at each position and depth.
[2] Moths partly emerged from pupal cases and died.

OUT OF DOORS OVER WINTER

On December 10, 1931, experiments similar to those described in the two preceding sections were conducted out of doors in standard 30- by 30-inch hibernation cages, previously described. These experiments were for the purpose of checking the experimental work done under controlled conditions in the insectary, summarized in tables 4 and 5. After the winter hibernation period, moths emerged from pupae placed horizontally 1 inch deep in the soil; from pupae placed vertically, head up, as deep as 4 inches; and from pupae placed vertically, head down, as deep as 3 inches. This work is summarized in table 6. A much smaller percentage of emergence occurred in these field experiments than in the controlled experiments in the insectary, probably because the pupae were subjected to intermittent rains and extremes of heat and cold. The results obtained compared favorably with the emergence from the cages in which plowing was simulated or actually performed (described in succeeding paragraphs). These experiments suggested that contact with the earth on all sides during hibernation, in which condition circulation of air about the pupae was prevented, was unfavorable to pupal survival, and that the natural packing of the soil during the hibernation period was unfavorable for moth emergence.

TABLE 6.—*Effect of embedding pupae of the corn earworm in sandy loam soil, out of doors, on the survival of pupae and the emergence of moths; pupae embedded Dec. 10, 1931, Savannah, Ga.*

Position of pupae in the soil [1]	Depth of pupae in the soil [2]	Moths emerged		Position of pupae in the soil [1]	Depth of pupae in the soil [2]	Moths emerged	
		Number	Percent			Number	Percent
	Inches				*Inches*		
Vertical, head down	1	1	2.1	Vertical, head up	3	4	8.5
	2	1	2.1		4	2	4.3
	3	1	2.1	Horizontal	1	1	2.1
	4	0	.0		2	0	.0
Vertical, head up	1	7	14.9		3	0	.0
	2	4	8.5		4	0	.0

[1] 47 pupae were buried at each position and depth.
[2] By the time of moth emergence the pupae lay somewhat less deep than originally placed in the soil owing to settling of the soil by frequent rains.

EFFECT OF FALL PLOWING ON SURVIVAL OF PUPAE AND EMERGENCE OF MOTHS

IN RED CLAY SOIL AT CHARLOTTESVILLE, VA.

Over a 5-year period the number of moths that emerged from 15 small fall-spaded cages was 17 out of 1,500 larvae that entered the soil in the fall, or an emergence of 1.13 percent. From the check cages 136 moths emerged, or 9.1 percent of the 1,500 larvae entering the soil in the fall. Data obtained in this work are summarized in table 7. In each year much smaller numbers of moths emerged from hibernation in spaded cages than from the control cages. Out of 153 moths that emerged over a 5-year period from the small fall-spaded and check cages in this soil, 11.1 percent were from spaded cages and 88.9 percent were from control cages.

IN SANDY LOAM SOIL AT CHARLOTTESVILLE, VA.

In small cages containing sandy loam soil, fall-spaded, a total of 5 moths emerged out of 1,500 larvae that entered the soil in the fall, or 0.3 percent. From the control cages 152 moths emerged out of 1,500 larvae that entered the soil in the fall, or 10.1 percent. The data taken from this work are summarized in table 7.

The results obtained in the large cages that contained similar soil, summarized in table 8, were similar to those obtained in the small

TABLE 7.—*Effect of spading red clay, sandy loam, and fine sand soils in fall and in spring on the emergence of moths of the corn earworm from hibernation at Charlottesville, Va., and Savannah, Ga.*

Season of experiment	Dates larvae entered soil in fall	Soil fall-spaded					Soil spring-spaded					Soil uncultivated			
		Total larvae entering soil	Moths emerging in fall	Date of fall spading	Emergence from hibernation		Total larvae entering soil	Moths emerging in fall	Date of spring spading	Emergence from hibernation		Total larvae entering soil	Moths emerging in fall	Emergence from hibernation	
					Total moths	Moths per 100 larvae				Total moths	Moths per 100 larvae			Total moths	Moths per 100 larvae
RED CLAY, CHARLOTTESVILLE, 1928–33															
		Number	*Number*		*Number*	*Number*	*Number*	*Number*		*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1928–29	Sept. 15–21	300	0	Nov. 15	10	3.3	300	0	Apr. 15	6	2.0	300	0	44	14.7
1929–30	Sept. 12–16	300	0	do	1	.3	300	0	do	5	1.7	300	0	57	19.0
1930–31	Sept. 8–15	300	23	do	0	.0	300	20	Apr. 14	1	.3	300	20	5	1.7
1931–32	do	300	15	Nov. 16	5	1.7	300	21	do	8	2.7	300	1	13	4.3
1932–33	Sept. 12–17	300	1	Nov. 25	1	.3	300	2	Apr. 15	4	1.3	300	3	17	5.7
Total		1,500	39		17		1,500	43		24		1,500	24	136	
Average [1]						1.13					1.6				9.1
SANDY LOAM, CHARLOTTESVILLE, 1928–33															
1928–29	Sept. 15–21	300	0	Nov. 15	0	0.0	300	0	Apr. 15	1	0.3	300	0	3	1.0
1929–30	Sept. 12–16	300	0	do	0	.0	300	0	do	1	.3	300	0	13	4.3
1930–31	Sept. 8–15	300	19	do	0	.0	300	36	Apr. 14	1	.3	300	29	5	1.7
1931–32	do	300	21	Nov. 16	1	.3	300	36	do	4	1.3	300	24	73	24.3
1932–33	Sept. 12–17	300	2	Nov. 25	4	1.3	300	1	Apr. 15	3	1.0	300	2	58	19.3
Total		1,500	42		5		1,500	73		10		1,500	55	152	
Average [1]						.3					.7				10.1
FINE SAND, SAVANNAH, 1931–33															
1931–32	Sept. 1–6	400	49	Dec. 10	19	4.8	400	57	Mar. 25	48	12.0	400	44	95	23.8
1932–33	Aug. 28–Sept. 3	400	104	do	43	10.8	400	104	Mar. 13	60	15.0	400	109	156	39.0
Total		800	153		62		800	161		108		800	153	251	
Average [1]						7.8					13.5				31.4

[1] Based on totals.

TABLE 8.—*Effect of fall plowing, spring plowing, and fall disking of sandy loam, in large cages, on the emergence of moths of the corn earworm from hibernation at Charlottesville, Va., 1930–33*

Season of experiment	Dates larvae entered soil in fall	Soil fall-plowed					Soil spring-plowed				
		Total larvae entering soil	Moths emerging in fall	Date of fall plowing	Emergence from hibernation		Total larvae entering soil	Moths emerging in fall	Date of spring plowing	Emergence from hibernation	
					Total moths	Moths per 100 larvae				Total moths	Moths per 100 larvae
		Number	*Number*		*Number*	*Number*	*Number*	*Number*		*Number*	*Number*
1930–31	Sept. 8–15	1,000	21	Nov. 15	0	0.0	1,000	33	Apr. 14	0	0.0
1931–32	do	1,000	169	Nov. 16	3	.3	1,000	260	do	19	1.9
1932–33	Sept. 12–17	1,000	1	Nov. 25	3	.3	1,000	3	Apr. 15	4	.4
Total		3,000	191		6		3,000	296		23	
Average [1]						.2					.8

Season of experiment	Dates larvae entered soil in fall	Soil fall-disked					Soil uncultivated			
		Total larvae entering soil	Moths emerging in fall	Date of fall disking	Emergence from hibernation		Total larvae entering soil	Moths emerging in fall	Emergence from hibernation	
					Total moths	Moths per 100 larvae			Total moths	Moths per 100 larvae
		Number	*Number*		*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1930–31	Sept. 8–15						1,000	39	11	1.1
1931–32	do	1,000	57	Nov. 16	17	1.7	1,000	86	111	11.1
1932–33	Sept. 12–17	1,000	6	Nov. 25	18	1.8	1,000	4	173	17.3
Total		2,000	63		35		3,000	129	295	
Average [1]						1.75				9.8

[1] Based of totals.

cages. In the large fall-plowed cages 6 moths emerged from hibernation out of 3,000 larvae that entered the soil in the fall, or 0.2 percent; whereas 295 moths emerged from the control cages out of 3,000 larvae that entered the soil in the fall, or 9.8 percent.

Over a 5-year period, out of 157 moths emerging from fall-spaded and control experiments in this soil in small cages, 3.2 percent were individuals that emerged from fall-spaded soil and 96.8 percent were from uncultivated soil (table 7). Over a 3-year period, out of 301 moths emerging from large cages, 2 percent emerged from fall-plowed soil and 98 percent from uncultivated soil (table 8). The similarity of results in these two types of cages shows that the size of the cage had little effect on the efficiency of the experiment and that the effect of simulated plowing or spading was apparently about the same as that of actual plowing. The results indicate that fall plowing is somewhat more effective as a control measure in sandy loam soil than in red clay soil.

IN FINE SAND SOIL AT SAVANNAH, GA.

While much greater emergence of moths occurred during the fall in the experiments at Savannah, for the reasons previously stated, such loss of population from the cages was reasonably similar in all series of cages during a season, and the effectiveness of the experiments was not unduly affected thereby. Thus, over a 2-year period, 62 moths emerged from hibernation from fall-spaded cages out of 800 larvae that entered the soil in the fall, or 7.8 percent. In the control cages, 251 moths emerged from hibernation out of 800 larvae that entered the soil in the fall, or 31.4 percent. A summary of the data obtained in this work is given in table 7. Out of 313 moths emerging from hibernation from fall-spaded and control experiments in this soil and locality, 19.8 percent were from fall-spaded cages and 80.2 percent were from control cages in which the soil was uncultivated. Under these conditions, owing probably to the fact that a milder climate made possible a much greater survival of pupae through the hibernation period, the effectiveness of fall spading was not so great as in Virginia, where a much smaller number of individuals survive the winter. Thus, while there was an average emergence of 31.4 percent from larvae entering the soil in control cages at Savannah (table 7), the emergence from 6,000 larvae that entered red clay and sandy loam soil in control cages at Charlottesville was 583, or 9.7 percent (tables 7 and 8). But while fall plowing seemed less effective in limiting spring emergence of moths from hibernation at Savannah, it was nevertheless an important control measure.

EFFECT OF SPRING PLOWING ON SURVIVAL OF PUPAE AND EMERGENCE OF MOTHS

IN RED CLAY SOIL AT CHARLOTTESVILLE, VA.

In small cages at Charlottesville, containing red clay soil, a total of 24 moths emerged from spring-spaded cages, over a 5-year period, out of 1,500 larvae that entered the soil in the fall, or 1.6 percent. From uncultivated cages 136 moths emerged, or 9.1 percent. The data taken from this work are given in table 7. Thus, of a total emergence of 160 moths from spring-spaded and uncultivated cages, 15 percent emerged from the spring-spaded cages and 85 percent from the control or uncultivated cages. As was the case in fall-spaded experiments in this soil, survival and emergence were greater than in sandy loam soil.

IN SANDY LOAM SOIL AT CHARLOTTESVILLE, VA.

In small cages containing sandy loam soil a total of 10 moths emerged from spring-spaded cages, over a 5-year period, or 0.7 percent of the 1,500 larvae that entered the soil in the fall; whereas from the control cages which were uncultivated a total of 152 moths emerged from hibernation, or 10.1 percent of the 1,500 larvae that entered the soil in these cages during fall. The data concerning this work are summarized in table 7. In the large cages in similar soil, the data from which are summarized in table 8, the results were very similar. In the large spring-plowed cages a total of 23 moths emerged from hibernation over a 3-year period, or 0.8 percent of the 3,000 larvae that entered the soil in the fall; whereas in the uncultivated cages 295 moths emerged from hibernation, or 9.8 percent of the 3,000 larvae that entered the soil in the fall. Thus in the small cages, of 162 moths emerging from hibernation from spring-spaded and uncultivated cages, 6.2 percent were from spring-spaded cages and 93.8 percent were from uncultivated cages. Similarly, in the large cages, of 318 moths emerging from hibernation from spring-plowed and uncultivated cages, 7.2 percent were from spring-plowed cages and 92.8 percent were from uncultivated cages.

IN FINE SAND SOIL AT SAVANNAH, GA.

In fine sand soil, at Savannah, spring spading was not nearly so effective as fall spading in limiting emergence of moths from hibernation. The data from this work are summarized in table 7. From spring-plowed cages 108 moths emerged over a 2-year period out of 800 larvae that entered the soil in the fall, or 13.5 percent; while from uncultivated cages 251 moths emerged from hibernation out of 800 larvae that entered the soil in the fall, or 31.4 percent. Of 359 moths that emerged from hibernation in spring-spaded and uncultivated cages, 30.1 percent emerged from spring-spaded cages and 69.9 percent emerged from uncultivated cages. These results indicate that, in this locality, fall plowing was much to be preferred to spring plowing as a control measure against the corn earworm.

EFFECT OF FALL DISKING ON EMERGENCE OF MOTHS FROM HIBERNATION

During 2 years sandy loam soil in large cages at Charlottesville was disked in the fall for the purpose of comparing the effectiveness of this treatment with that of plowing in limiting the emergence of moths from hibernation. From soil so treated 35 moths emerged out of 2,000 larvae that entered the soil in the fall, or 1.75 percent; while from uncultivated cages 295 moths emerged from 3,000 larvae that entered the soil in the fall, or 9.8 percent. Data from these experiments are given in table 8. While these experiments show a somewhat higher percentage of moth emergence from fall-disked ground, the merits of this operation should not be underestimated. Disking is a widely used treatment in preparing corn land, in fall as well as in spring, for the seeding of small-grain crops, where it has been found to be a good practice from the standpoint of yield and economy.

SURVIVAL OF PUPAE IN HIGH-HUMUS-CONTENT SOIL AT CHARLOTTESVILLE, VA.

Although experiments similar to those with red clay and sandy loam soils at Charlottesville, previously described, were conducted with high-humus-content soil over a 5-year period, no moths emerged from hibernation during spring. Examinations of the cages at regular intervals (table 2) showed that the mortality of pupae during the fall was unusually high and that by November 15, about 2 months after larvae entered the soil, an average of only 12.4 percent remained alive. By April 15 the average recovery of live pupae was only 2.8 percent, and by May 15 an average of only 1.1 percent survived. Examination of the high-humus-content soil, about 30 and 45 days after the larvae had entered the soil in 1932, showed a survival of 1.5 percent, as compared with 62 percent in sandy loam soil, and revealed that the pupae died very soon after they had formed in the soil.

It became evident during these experiments that an unusual phenomenon was occurring in the cages containing this soil, one that took place only to a negligible degree in the other soils studied. Owing to the necessity of once moving the series of cages and once augmenting their number, this soil was artificially prepared three times during the course of the studies. It was first prepared in the summer of 1928 and served for experiments during the seasons 1928–29 and 1929–30. In 1930 this soil was removed from these cages, as were also the red clay and sandy loam. During the period 1928–30 the organic matter had largely decayed, and additional soil was required to fill the new cages. Approximately equal quantities of red clay, sandy loam, and cow manure were added, as was also done in 1932 when 10 cages were added to this series, so the original soil was used in all of the cages during the 5-year period.

In order to obtain information concerning the reasons for the negative results obtained with this soil, a study of the micro fauna and flora of the soil was undertaken. It was finally established that a parasitic fungus, *Sorosporella uvella* (Krass.) Giard, was killing the pupae of *Heliothis obsoleta* in this soil. This organism, which was determined by Vera K. Charles, of the Bureau of Plant Industry, had not previously been recorded from this host, although earworm larvae have been artificially inoculated by Speare [3] and found susceptible to this fungus. Seemingly the particular nature of the high-humus-content soil created an environment favorable to the development of this disease organism.

BENEFICIAL EFFECT OF PLOWING AND DISKING IN LIMITING MOTH EMERGENCE

The conclusion to be drawn from figure 2 (based on data in the tables) is that plowing, in the fall or in the spring, or fall disking are useful control practices in the localities and soil types in which experiments were performed. While with each type of treatment, in each type of soil, and in each locality, moths emerged from the plowed or disked soil, the number in each case was much less than the number that emerged from soil left uncultivated. Therefore each type of treatment markedly limited the emergence of moths from hibernation.

[3] SPEARE, A. T. FURTHER STUDIES OF SOROSPORELLA UVELLA, A FUNGOUS PARASITE OF NOCTUID LARVÆ. Jour. Agr. Research 18: 399–440, illus. 1920.

Although none of these treatments gives complete control of the earworm, all are sufficiently effective to be recommended in control programs in areas where the earworm is known to hibernate and where such practices meet cultural and economic conditions to best advantage.

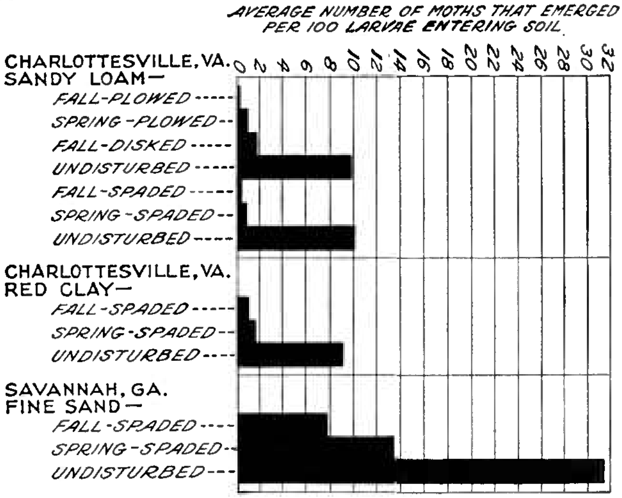

FIGURE 2.—Emergence of corn earworm moths from hibernation cages containing different types of cultivated soil at Charlottesville, Va., and Savannah, Ga.

SUMMARY

Descriptions are given of experiments with simulated and actual plowing of three types of soil at Charlottesville, Va., and one type of soil at Savannah, Ga., during the period 1928 to 1933, for the purpose of determining their effect on the control of the corn earworm (*Heliothis obsoleta*).

Piedmont red clay, sandy loam, and an artificially made high-humus-content soil were used at Charlottesville, and a fine sand soil was used at Savannah.

Cages containing these soils were fall plowed and spaded, spring plowed and spaded, and fall disked, respectively; control cages in which the soil was uncultivated accompanied each series of treated soils.

It was found that each kind of treatment was an important factor in reducing the number of moths of the corn earworm emerging from hibernation. Fall plowing reduced moth emergence most, fall disking least, and the effectiveness of spring plowing lay between these two treatments. Each operation is a material aid in the control of the insect and can be employed where its practice meets cultural and economic conditions to best advantage.

The high-humus-content soil (a mixture of cow manure, sandy loam, and red clay) appeared to be very favorable to the development of the parasitic fungus *Sorosporella uvella*, which killed the pupae, so that during a 5-year period in which experiments were carried on no moths emerged from hibernation from this soil.

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