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Friday, December 30, 1921, 1.30 p. m.

President Dean presided while four papers were being presented and discussed that were left over from the program of the previous afternoon. At the close of these papers, Mr. Arthur Gibson, President of the Entomological Society of Ontario, presided during the rest of the session.

PRESIDENT GEORGE A. DEAN: The first paper is by P. A. Glenn.

RELATION OF TEMPERATURE TO DEVELOPMENT OF THE CODLING-MOTH

By P. A. GLENN, *Chief Inspector, Division of Plant Industry, State Department of Agriculture, Urbana, Illinois*

The purpose of this paper is to give briefly some of the results of a study recently made of the relation of climatic conditions to the development of the codling-moth and especially to the time of appearance of the several broods of the moth. The study is based upon data collected during a period of three years, 1915, 1916, 1917 at three localities in Illinois.

The purpose of the study was to find some temperature unit so related to development that the sums of these units which accumulate

during the period of any stage of the insect would be the same for all temperatures.¹

The unit of temperature used is the day-degree. It may be defined as a temperature of one degree acting for a period of one day.

Table 1 gives the results of the studies on the incubation period based upon observations on 4175 eggs.

TABLE 1. TEMPERATURE AND THE INCUBATION PERIOD OF THE COOLING-MOTH

MEAN DAILY TEM.	PER-100	DAILY DAY-DEG.				TOTAL D.DEG.	
		+50°	2(48°)	+50°-2(48°)	+50°	+50°-2(48°)	
61.60	14.00	12.30			12.30	172	172
63.11	12.67	13.31			13.31	170	170
64.94	10.66	15.13			15.13	161	161
67.48	9.35	17.47			17.47	163	163
69.01	8.67	19.01			19.01	165	165
71.33	7.72	21.33			21.33	165	165
73.12	7.00	23.12	.01		23.11	162	162
74.86	6.60	24.86	.45		24.41	164	161
77.43	6.12	27.43	.96		26.47	165	159
78.71	5.95	28.71	.96		27.75	171	165
80.14	5.71	30.14	1.93		28.21	172	161
82.86	5.52	32.86	3.74		29.12	181	161
84.00	5.53	34.00	4.66		29.34	188	162
	7.67	21.70			21.33	166	163

age daily day-degrees above 50 deg. and column 6 gives the product of the day-degrees in column 3 by the periods in column 2. These products are fairly uniform for the lower temperatures,² but increase

TABLE 2. TEMPERATURE AND THE LARVAL PERIOD OF THE COOLING-MOTH

MEAN DAILY TEM.	PER-100	DAILY DAY-DEGREES				TOTAL DAY-DEG.	
		+50°	2(48°)	+50°-2(48°)	+50°	+50°-2(48°)	
69.45	35.57	19.45	.34		19.11	692	680
70.88	32.29	20.88	.30		20.58	674	665
73.48	29.20	23.48	.72		22.76	686	665
74.53	28.62	24.53	.74		23.79	702	681
76.74	27.14	26.74	.40		25.34	726	688
79.39	25.93	29.39	3.62		25.77	762	668
80.30	26.33	30.30	4.36		25.94	798	683
74.31	29.07	24.31			22.75	719	675

¹Humidity and evaporation under out-of-door conditions have such a slight effect upon the rate of development that for practical purposes they may be disregarded.

²An exception should be noted in the case of the total day-degrees when the mean daily temperatures averaged 61.6 and 63.11 degrees. The total day-degrees at these temperatures are greater than at other temperatures. This indicates that possibly the threshold of development is greater than 50 deg.

The average mean daily temperatures which prevailed during these observations varied from 61.6 to 84 deg. Fahr. and the periods from 14 to 5.52 days. Development of the egg proceeds only at temperatures above 50 deg. Fahr. The rate of development increases as the temperature rises above 50 deg. until it reaches 88 deg. at which point development is at the maximum rate. The third column gives the average

because during the warmer part of the season the temperature for a part of the time was above 88 deg. and the day-degrees in column 3 contain some day-degrees above 88 deg., which retard development. To make the needed correction in the day-

degrees on account of temperatures above 88 deg. twice the day-degrees above 88 were subtracted from the day-degrees above 50. This gave the effective day-degrees recorded in column 5. Multiplying the day-degrees in column 5 by the periods in column 2, we get the sums of day-degrees, or the total day-degrees, recorded in column 7, which are quite uniform for all temperatures.

Proceeding with the data on the larval period as we did with the data on the incubation period, we find that if twice the number of day-degrees above 85 be subtracted from the day-degrees above 50, we shall have temperature factors in column 5, which when multiplied by the periods in column 2, give products which are fairly uniform in size. The number of larvae observed was comparatively small, being only 344, and the wider variation in the products as compared with the products in the table of data on the incubation period is due to this fact. It is generally true that the greater the number of observations the more nearly does the average of the products approach a constant.

TABLE 3. TEMPERATURE AND THE PUPAL PERIOD OF THE CODLING-MOTH

MEAN DAILY TEM.	PER- IOD	DAILY DAY- DEG. +52°	DAY- DEG. 2(+87)	DAY- DEG. 52° 2(+87)	TOTAL DAY-DEG. +52°	TOTAL DAY-DEG. +52° 2(+87)
52.60	4550	5.19		5.19	236	236
55.70	35.20	6.80		6.80	238	238
56.15	34.01	7.08		7.08	241	241
58.50	27.77	8.69		8.69	241	241
69.28	13.80	17.31		17.31	239	239
70.79	12.70	18.79	.04	18.75	239	239
73.11	11.51	21.11	.24	22.87	243	240
74.92	10.73	22.92	.42	22.50	246	241
76.77	10.02	24.77	.88	23.89	248	239
79.14	9.44	27.13	1.63	25.50	256	241
80.88	9.43	28.88	3.52	25.36	272	239
82.68	9.24	30.68	4.12	26.56	284	245
	14.99	17.38	.77	16.61	252	241

The above table is based upon observations on 3817 pupae. To secure temperature factors for the pupal stage which when multiplied by the periods would give nearly the same results for all temperatures, it was necessary to subtract twice the day-degrees above 87 degrees from the day-degrees above 52 degrees.

We concluded therefore, that the threshold of development for the

egg and larva is approximately 50 deg. Fahr. and for the pupa approximately 52 deg. Fahr., and the degree of the maximum rate of development for the egg is about 88 deg. Fahr., for the larva 85 deg. Fahr., and for the pupa 87 deg. Fahr., that the effective day-degrees for any day may be found by subtracting twice the day-degrees above the degree of the maximum rate of development from the day-degrees above the threshold of development, and that the sum of the daily day-degrees for all the days in the period will be the theoretical thermal constant. This constant in the case of the incubation period is about 163, the larval period 673, and the pupal period 241, (265 if 50 deg.

Fahr. be taken as the threshold of development.³) The sum of the effective day-degrees is not a constant in individual cases, but the average of the sums in a large number of observations approaches a constant.

Variations from the average were comparatively large in individual cases. These were due partly to the use of the day as the unit of time, partly to local conditions by reason of which the temperature of the specimen was not always the same as that of the recording instrument, possibly partly to humidity and evaporation, and in the case of the larva to differences in the character of food.

After all allowances were made for variations caused by factors which were measurable, the variation in the sums of effective day-degrees which must be attributed to other causes were for the incubation period from about 156 to 170, for the larval period from about 527 to 873 and for the pupal period from about 256 to 274. Adding these together we have for the three periods a minimum of 939, an average of 1101 and a maximum of 1317.

From a computation of the sums of effective day-degrees for the entire development period of over 200 individuals kept under observation from the dates when the eggs were laid to the dates when the adults emerged, using 50 deg. as the threshold of development and 86 deg. as the degree of maximum rate of development, the minimum sum was about 950, the average 1120 and the maximum about 1350.

Data on the seasonal history were secured by noting the dates of appearance of the first eggs, larvae and adults of the several generations and computing the total number of effective day-degrees that had accumulated on these dates after January 1. The average accumulations are shown in the following table, each of the averages being based upon from 4 to 7 observations:

TABLE 4

	Effective day-degrees
1st pupa of hibernating generation	109
1st adult of " "	339
1st egg of first " "	406
1st larva of " "	578
1st pupa of " "	1074
1st adult of " "	1308
1st egg of second " "	1414
1st larva of " "	1551
1st pupa of " "	2169
1st adult of " "	2387
1st egg of third " "	2471
1st larva of " "	2632

³For practical purposes it is necessary to use the same threshold of development for the pupa as for the egg and larva. If 50 deg. is used for the pupa instead of 52, the sums of the effective day-degrees will be 265.

Owing to the comparatively small number of observations used in making the above averages the results are not very consistent. They show an average accumulation of 1027 day-degrees for the complete life cycle; that is, from egg to egg, larva to larva, etc. In making the observations no doubt the first individuals were not noted in every case, consequently 1027 day-degrees is probably greater than the actual number that accumulate between the time of appearance of the first individuals of one brood and the first individuals of the next brood.

The minimum accumulation of effective day-degrees during the development period found by adding the minimum for the egg, the larva, and the pupa was 939, the minimum found by treating the entire development period as one period was 950. To get the minimum accumulation for the complete life cycle, we add 50 day-degrees to each of the above to allow for the accumulation during the time which elapses between the date of emergence of the moth and the date of egg deposition. This gives 989 and 1000 respectively as the minimum accumulations for the complete cycle. The average of these three minimums, 989, 1000 and 1027 is 1005. Therefore, after the first individuals of one brood appear we may expect the first individuals of the next brood to appear when 1000 effective day-degrees have accumulated. An equitable distribution of these 1000 effective day-degrees between egg, larva, pupa, and the interval between the emergence of the adult and the deposition of the first eggs would be 158, 532, 260, and 50 respectively. Now if we revise table 4 so as to make it consistent with the above distribution of effective day-degrees, we have the approximate number of effective day-degrees which will have accumulated at the time of the appearance of the first individuals of each of the broods during the season. These are shown in table 5.

TABLE 5.—APPROXIMATE NUMBER OF EFFECTIVE DAY-DEGREES WHICH WILL HAVE ACCUMULATED WHEN THE FIRST INDIVIDUALS OF EACH BROOD APPEAR.

	Effective day-degrees
1st pupae, hibernating generation	82
1st adults, " "	342
1st eggs, first	392
1st larvae " "	550
1st pupae " "	1082
1st adults " "	1342
1st eggs, second	1392
1st larvae, " "	1550
1st pupae, " "	2082
1st adults " "	2342
1st eggs, third	2392
1st larvae, " "	2550

We believe that table 5 shows quite accurately the relation between temperature and the time of appearance of the first eggs, larvae, pupae and adults of the three generations of the codling-moth in central and southern Illinois. These relations will probably hold true in other fruit-growing States, but difference in latitude, altitude, and conditions as to moisture may modify them. Should this be the case, it will be easy to ascertain the relations which apply to localities in which these modifying conditions prevail.

The advantages to be derived from the use of a table showing the relations of effective day-degree accumulations to the seasonal history of the insects are apparent. Temperature records are much more easily kept than records of the progress of the seasonal history of the codling moth based upon field observations and the former are more accurate than the latter. A spray program based upon the above table can be made out and the dates when the sprays should be applied anticipated a week or more in advance. By the use of temperature records the normal daily accumulations and the total accumulations for every day of the season may be ascertained for any locality and from these data the dates when the first individuals of each brood may be expected to appear under normal conditions may be known for that locality.

Spray programs based on fixed dates or on the time of the fall of the petals do not take into account seasonal variations and variations due to local peculiarities, to altitude, to latitude, or to other circumstances which may affect temperature.

The following program is suggested based upon the relation of accumulated effective day-degrees and the time of the appearance of the first larvae of each generation. The program provides for seven sprays, three for the first brood, two for the second, and two for the third. This program is suggested with the hope that it will be thoroughly tested and freely criticised.

TABLE 6.—SPRAY PROGRAM FOR THE CODLING MOTH

			Accumulation of Effective Day-degrees at which spraying should begin to be completed in:										
Spray	Brood of Larvae	Daily Effec- tive Day Degrees	0 da.	1 day	2 da.	3 da.	4 da.	5 da.	6 da.	7 da.	8 da.	9 da.	10 da.
1st													
2d	1st	16	550	534	518	502	486	470	454	438	422	406	390
3d	1st	20	790	770	750	730	710	690	670	650	630	610	590
4th	2d	26	1550	1524	1498	1472	1446	1420	1394	1368	1342	1316	1290
5th	2d	27	2050	2023	1996	1969	1942	1915	1888	1861	1834	1807	1780
6th	3d	27	2550	2523	2496	2469	2442	2415	2388	2361	2334	2307	2280
7th	3d	23	3050	3027	3004	2981	2958	2935	2912	2889	2866	2843	2810

¹The application of the first spray for the codling moth should begin when the petals are about two-thirds off. The time of full bloom is not dependent upon effective day-degrees as defined in the preceding pages and hence the time of the application of the first spray cannot be determined by the accumulation of effective day-degrees.

MR. T. H. PARKS: I would like to know how Mr. Glenn arrived at the conclusion that humidity and evaporation are negligible factors in determining these results? With some other insects, we feel that these factors are even greater than temperature.

MR. P. A. GLENN: The remark did not apply to the Hessian fly or some other insects, but merely to the codling moth.

MR. T. H. PARKS: How do you arrive at that conclusion?

MR. P. A. GLENN: It would take 15 minutes or more to explain that. Humidity does have an effect if you use extreme humidity, but we don't get extreme humidities over a long period of time under field conditions.

MR. W. C. O'KANE: May I ask Mr. Glenn if, in speaking of day degrees, you get at it by the average temperature for the day?

MR. P. A. GLENN: Yes. Above 50 or any degree we want.

MR. W. C. O'KANE: Suppose there were ten hours in a day and in getting at the average you had a comparatively low temperature at the beginning of the day, and then a long period of an optimum, and then drop to a low temperature, as one example; while in another day you had a comparatively high temperature and such a total as would still give you the same average; could you disregard the hourly temperatures during the day?

MR. P. A. GLENN: Yes, My method in making the average was from a continuous record of the temperatures. I added the temperatures for each hour and divided by twenty-four to get the average for the day.

MR. F. C. BISHOPP: I was very much interested in this practical application of these laws of temperature, and I believe it is possible to utilize them to a large extent in our economic procedure; but it seems to me there is necessity for continued work over a good many years in order to eliminate the various factors which creep in to interfere with our theoretical laws or rules.

In that connection I would like to ask Professor Glenn something of the duration of his investigations. How long did they cover?

MR. P. A. GLENN: Three years.

MR. F. C. BISHOPP: As I believe you brought out, in the egg stage for instance, reckoning the day as a unit, there is considerable error when only a portion of a day is utilized in the transformation.

MR. P. A. GLENN: It is only by average of a large number that we arrive at something near the correct results. If we take the day as the unit, the actual length of the period may be nearly a day longer or shorter than the observed time.

PRESIDENT GEORGE A. DEAN: The next paper is by Mr. Peterson.