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An Experimental and Observational Study of the Chinch Bug in Relation to Climate and Weather

BY

V. E. SHELFORD

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AN EXPERIMENTAL AND OBSERVATIONAL STUDY OF THE CHINCH BUG IN RELATION TO CLIMATE AND WEATHER

V. E. Shelford

Introduction

The abundance of the chinch bug (*Blissus leucopterus* Say) has long been associated with variations and peculiar distributions of rainfall and temperature in particular years or series of years. A desire for more detailed evidence from the experimental side led to this investigation. Unfortunately, however, the chinch bug is difficult to study in this way, and at the same time the task could not be made the sole or primary work of even one investigator. Accordingly, general cultures instead of close observation of individuals had to play an important rôle in the work.

The investigation reported in this paper is classifiable under three heads: (1) the study of length of instars and of the life history in relation to different conditions of temperature, humidity, light, etc.; (2) the study of the success of cultures under conditions similar to those under which the instars were studied; and (3) the study of the records of abundance, migration, rise, and decline of the pest in the State of Illinois since 1840.

The work on the chinch bug began with preliminary experiments in 1916 and closed with a few low-temperature experiments in 1926. None of the 1916 data proved to be of such a nature that conclusions could be drawn from them. Chinch bug cultures, however, were carried through the greater part of each summer for ten years. Unfortunately, this was an accessory bit of work, carried on chiefly in connection with codling moth experiments (Shelford, 1927) and made feasible by the fact that the apparatus was running. The same chambers were frequently used for both insects in the earlier years; that is, codling moth pupae were put into the chinch bug cages. The two in no way interfered with each other.

After the codling moth work was completed, chinch bugs were run through the few additional summers to check on the preceding work, but in no case was it possible to improve very greatly the preliminary work. The author gave three-fourths of his time to instruction or other duties; his assistants were devoting most of their time to the engineering curriculum. This is unfortunate because if there is any insect requiring the undivided attention of investigators while the work is in progress, it is the chinch bug. Its persistence and viability varies greatly from year to year. The variation in length of instar periods is much greater than that of most invertebrates. Its habits are such that observation is difficult and special methods are necessary under many conditions. The populations of chinch bugs on the food plants will find their way below the surface of the soil and under the leaf-sheathes, so that nothing but a complete submergence of the plant will insure the observation of all the individuals.

The general results of these experiments, therefore, must be regarded as provisional, and it is hoped that they may afford a basis for intensive study by other workers. At least two observers, with the best possible equipment, should devote all their attention to such a study over a period of two or three years. Finally, of course, the authenticity of results will depend chiefly upon the observation of considerable numbers of life histories carried through under outdoor conditions in addition to cultures, the success of which is determined by the increase, decrease, or dying out of the population. Difficulties of maintaining the cultures are very great. Records of complete life histories of individuals, from egg to adult, are lacking in our work. The quality of the food plants probably differs under different conditions, and identical results cannot be expected from bugs fed on plants actually growing under favorable conditions and those fed on cut plants. A great many observations on the rate of growth and success of any species under variable conditions are essential to bridge the gap between the constant-temperature experiments and fluctuating weather conditions. It was on account of our experience with the codling moth, for which such observations were available, that the very important connection between outdoor progress and the laboratory experiments could be provisionally established for the chinch bug in the form of trial velocity charts.

Equipment and Operation

The laboratory and the general equipment have been described and figured previously (Shelford, 1929, pp. 400-411). The principal chambers used in this work consisted of a two-room unit (*op. cit.*, Figs. 169 and 170) designed to run at two approximately constant temperatures, with humidity control for the separate rooms and with sockets for artificial lights. There were five other chambers (half as large as the improved form shown in Fig. 177) designed to give daily variations in temperature simulating natural days. Some cages were also used in the glass-roofed house. For the study of length of instars it was necessary to isolate individual nymphs and observe their moultings. This was done in glass cages (Fig. 178), each of which was ventilated by a suction pipe (Fig. 179). Ventilation in most of the other experiments was by means of compressed air from the University Power Plant. The air flow, which was adjusted so as to be comparable to that observed in the field, was measured with diaphragm chambers and attached gages (pp. 241-245). Moisture was removed by Crane oil separators (Fig. 100). In the approximately constant temperature chambers the temperature was controlled by means of recirculating ducts (Fig. 93), and the humidity was controlled by means of mixing tanks (perfected design shown in Fig. 176), to which dry air was supplied from the dehumidifier (Fig. 111) and moist air from a humidifier (similar to that shown in Fig. 109). The humidity control for the variable-temperature units consisted of a spray chamber (Fig. 110), which gave a constant humidity at the temperature of the spray water and gave variation in the chambers as the temperature rose and fell. Livingston porous cup atmometers were used in practically all the experiments, though correlations with rate of evaporation did not prove to be important in this or other experimental work. The rate of evaporation represents a summation of different factors which often have opposite effects on the rate of development of insects. Attempts were made to vary the light surrounding the chinch bugs, but the equipment was not well designed for this purpose. The chamber windows consisted of either double or triple window glass, which shut out a large part of the light. Artificial daylight was provided with incandescent lamps and daylight ray filters inside the cages. Arc lamps and 1000-watt daylight bulbs were also used outside the cages.

The experimental procedures, including the methods of recording the observations and calculating the results, as well as the concepts of developmental units and totals, have been explained in connection with the codling moth (Shelford, 1927).

LENGTH OF INSTAR PERIODS AND THE LIFE HISTORY

The life cycle of the chinch bug is comprised of the egg stage, five nymphal stages, or instars, and the adult stage (from the time of moulting until egg-laying is finished). The determination of the length of the life cycle should be made with continuous observations of single individuals, and the difficulties here are rather great. No individual was traced through from the egg to the adult condition in the experiments here reported. The reason for this is evident from an inspection of Figs. 14-25 and from the following résumé of the records.

Methods and Results

In the year 1916, only preliminary experiments were carried on, and we were successful in getting the bugs to breed. In 1917 the bugs bred, but the conditions under which they were kept, coupled with the condition of the bugs themselves, were such that they in no case became at all abundant in the cultures, and most of the cultures died out early in the season. In 1918 the culture work went forward better than the preceding year. Attempts in these years to study the length of instar periods in U-chloride tubes through which a small amount of air was slowly forced, were generally unsuccessful.

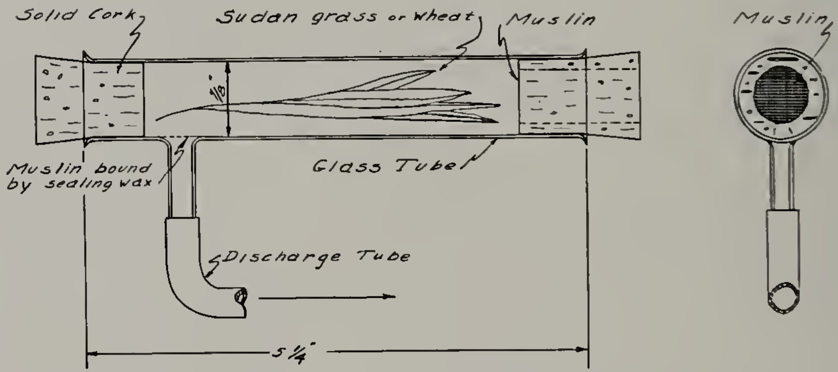

Fig. 1. Plan of tube used inside the culture cages to isolate individuals for the study of length of instars. Circulation was produced by suction.

In 1919 over 500 individuals of different stages were put under observation, but we were unsuccessful with all but 50 of the attempts to carry individuals through a complete single instar. It was thought in 1919 that a piece of cut grass could be placed in a vial and corked with the young bug, but the evaporation from the food materials saturated the air in the small container, so that moisture was precipitated on the sides, and the younger bugs in particular became wet, stuck to the glass, and died. This was the chief cause of our losses, though the tubes with air forced slowly through them and the tubes to which suction was applied (Fig. 1) did not yield a very large number of definite records. A large expenditure of energy gave few or no results, and for some stages no records of length of stage were obtained in that year.

In 1920 the suction system referred to in the description of the apparatus was put into use, the suction tubes being placed in the cultures adjacent to the food plants. The rate at which the air was drawn out of the cage was adjusted so as to be approximately the same as the rate of flow in the normal habitat of the insect. Extremes of humidity, both high and low, were avoided. The results were much better than in previous years. About 80 records were obtained out of 150 to 200 possibilities.

In 1921 the observations were made by Dr. H. Yuasa, a well-known Japanese entomologist then employed by the Natural History Survey and now of the Imperial University, Kyoto, Japan, and at least 75 records were obtained out of about 200 possibilities. The

TABLE I

APPROXIMATELY CONSTANT TEMPERATURE

Showing length of stage for comparable groups of individuals subjected to small variations in temperature and relative humidity. The mean of the highest and lowest numbers of days in each grouping was used as the basis for calculating the percentage of variation. There were two observations per day in some cases, as indicated by half-days in some of the records.

Designation	Year	Temperature (mean degrees C.)	Relative humidity (mean %)	Dates, beginning and ending	Length of stage (days)	Mean of extremes (days)	Variation (+ − %)	Remarks
EGG STAGE								
AL	1921	23.1	86.0	8/9, 8/29	20			
AL	1921	23.1	86.0	8/11, 8/29	18	19	5.2	
BW	1921	30.4	94.2	8/9, 8/18	9			
BW	1921	30.5	94.7	8/11, 8/18	7	8	12.5	
BW	1922	31.4	91.0	7/19, 7/27	8			
BW	1922	31.4	91.0	7/19, 7/27	8	8	0.0	
BW	1925	27.0	40.0	7/28, 8/15	18			
BW	1925	27.0	40.0	7/24, 8/7	14	16	12.5	
AVERAGE							7.5	
FIRST INSTAR								
BW	1922	31.1	92.1	7/27, 8/3	7			
BW	1922	31.0	92.5	7/27, 7/31	4	5.5	27.3	
BW	1925	29.0	85.0	9/21, 9/26	5			
BW	1925	29.0	85.0	8/23, 8/26	3	4.0	25.0	
BW	1925	29.0	85.0	8/15, 8/20	5			
BD	1925	29.0	40.0	8/7, 8/18	11			
BD	1925	29.0	40.0	8/8, 8/14	6	8.5	29.4	
AVERAGE							27.2	

TABLE I—Cont'd

Designation	Year	Temperature (mean degrees C.)	Relative humidity (mean %)	Dates, beginning and ending	Length of stage (days)	Mean of extremes (days)	Variation (+ − %)	Remarks
SECOND INSTAR								
AW	1922	22.1	94.0	7/21, 7/31	10			
AW	1922	22.0	94.1	7/23, 8/2	10	10.0	0.0	
BD	1925	29.0	40.0	8/14, 8/19	5			
BD	1925	29.0	40.0	7/20, 7/26	6	5.5	9.1	
BW	1925	29.0	85.0	8/26, 9/7	12			
BW	1925	29.0	85.0	7/20, 7/28	8	10.0	20.0	
AVERAGE							9.7	
THIRD INSTAR								
BWW	1920	29.1	92.6	8/7, 8/10	3			
BWW	1920	29.5	93.3	8/10, 8/13	3	3.0	0.0	
BWW	1920	28.3	91.3	8/19, 8/22	3			
BWW	1920	28.6	91.2	8/18, 8/21	3.5	3.5	14.3	
BWW	1920	28.4	91.2	8/19, 8/23	4			
BW	1922	32.2	91.3	8/3, 8/7	4			
BW	1922	32.2	91.6	8/3, 8/10	7	5.5	27.3	
AL	1925	26.0	84.9	7/23, 8/5	13			
AL	1925	26.0	85.4	7/27, 8/1	5	9.0	44.4	
BW	1921	29.1	92.9	9/4, 9/9	5			
BW	1921	29.4	93.7	9/5, 9/10	5	5.0	0.0	
AWLL	1921	23.6	90.5	7/30, 8/3	4			
AWLL	1921	23.8	90.4	8/3, 8/8	5			
AWLL	1921	23.6	90.6	7/30, 8/6	7	5.5	27.3	
AWLL	1921	23.8	92.0	8/28, 9/2	5			
B	1925	29.0	85.0	9/7, 9/11	4			
B	1925	29.0	85.0	9/21, 9/25	4			
B	1925	29.0	85.0	9/18, 9/23	5	6.5	38.5	
B	1925	29.0	85.0	8/8, 8/17	9			
B	1925	29.0	40.0	7/22, 8/8	17			
B	1925	29.0	40.0	8/24, 9/1	8	12.5	36.0	
B	1925	29.0	40.0	7/26, 8/5	10			
AW	1926	20.9	92.8	7/27, 8/4	8			
AW	1926	20.9	92.8	7/28, 8/5	8			
AW	1926	20.9	91.8	7/22, 7/30	8.5	9.0	11.1	
AW	1926	20.9	92.6	7/25, 8/4	9			
AVERAGE							22.1	

TABLE I—Cont'd

Designation	Year	Temperature (mean degrees C.)	Relative humidity (mean %)	Dates, beginning and ending	Length of stage (days)	Mean of extremes (days)	Variation (+−%)	Remarks
FOURTH INSTAR								
BWW	1920	28.3	91.3	7/19, 7/22	3			
BWW	1920	28.3	90.5	8/4, 8/7	3	3.0	0.0	
BWW	1920	29.1	92.8	7/6, 7/9	2.5			
BWW	1920	29.1	92.7	7/6, 7/10	4	3.25	23.1	
AWL	1921	23	86.7	8/6, 8/13	7			
AWL	1921	23	86.5	8/17, 8/28	11	9.0	22.2	
BW	1921	30.5	93.8	8/5, 8/8	3			
BW	1921	30.4	93.8	8/4, 8/7	3.5	3.25	7.7	
AW	1922	21.6	93.3	8/2, 8/16	14			
AW	1922	21.8	93.7	7/15, 7/22	7	10.5	33.3	
AW	1922	21.7	93.5	7/12, 7/20	8			
BW	1922	32.6	91.1	8/10, 8/17	7			
BW	1922	32.2	91.5	8/3, 8/10	7			
BW	1922	32.8	90.5	8/12, 8/16	4	6.0	33.3	
BW	1922	32.0	91.5	8/3, 8/11	8			
BW	1922	32.6	91.1	8/10, 8/17	7			
AL	1925	25.6	86.1	7/29, 8/3	5			
AL	1925	25.8	86.4	8/1, 8/5	4	4.5	11.1	
ADK	1925	26.7	89.1	9/12, 9/18	6			
ADK	1925	26.7	89.1	9/28, 10/2	4	5.0	20.0	
ADK	1925	27.3	87.8	9/20, 9/25	5			
ADK	1925	27.3	87.2	9/14, 9/20	6	5.5	9.1	
AD	1926	20.9	33.8	7/24, 8/3	10			
AD	1926	20.8	33.2	7/26, 8/4	8.5	9.25	8.1	
BD	1926	30.2	33	7/23, 7/26	3			
BD	1926	30	33	7/19, 7/23	4			
BD	1926	30.6	33	7/23, 7/25	2.5	3.25	23.1	
BD	1926	29.5	33	7/24, 7/28	3.5			
AVERAGE							17.4	
FIFTH INSTAR								
BWW	1920	29.3	93	7/8, 7/13	5			
BWW	1920	29.1	92.2	7/13, 7/17	4.5			
BWW	1920	29.3	92.9	7/6, 7/12	6	6.0	25.0	
BWW	1920	29.3	92.9	7/7, 7/13	6			
BWW	1920	29.2	92.7	7/10, 7/18	7.5			
ALL	1921	23.3	94.9	9/14, 9/24	10			
ALL	1921	23.4	94.0	9/9, 9/22	13	11.5	13.0	
A	1922	22	93.5	....	12.5	12.5	40.0	Average of 4 readings
A	1922	22.8	92	7/8, 7/18	10			
A	1922	22.8	92.2	7/9, 7/19	10	10.0	0.0	
B	1925	29	40	9/15, 10/28	7.5	8.5	12.5	Average of 10 readings

TABLE I—Cont'd

Designation	Year	Temperature (mean degrees C.)	Relative humidity (mean %)	Dates, beginning and ending	Length of stage (days)	Mean of extremes (days)	Variation (+ — %)	Remarks
FIFTH INSTAR—CONT'D								
B	1925	29	85	7/29, 8/23	7	6.5	39.0	Average of 9 readings
ALL	1925	29.1	80	9/4, 9/20	6			
ALL	1925	29.1	81.5	8/23, 8/30	7			
ALL	1925	29.7	80.6	9/17, 9/23	6	6.5	7.7	
ALL	1925	29.6	81.0	9/27, 10/3	6			
AD	1926	21.1	29.0	7/4, 7/17	12.5			
AD	1926	21.1	29.1	7/3, 7/16	13	12.75	2.0	
AW	1926	21.1	93.1	7/25, 8/8	14			
AW	1926	21.1	93	7/27, 8/9	12.5	13.25	5.7	
BD	1926	30	33	7/21, 7/27	6			
BD	1926	29.8	33	7/23, 7/28	5			
BD	1926	29.5	33	7/28, 8/3	6	6.0	16.6	
BD	1926	29.4	33	7/27, 8/3	7			
BW	1926	29.6	92.6	7/25, 7/30	5			
BW	1926	29.6	93	7/25, 7/29	4.5			
BW	1926	29.8	92.4	7/23, 7/28	5.5	5.0	10.0	
BW	1926	29.6	92.6	7/25, 7/30	5			
AVERAGE							15.6	
AVERAGE FOR ALL STAGES							16.6	

survival of the bugs, however, did not become much higher than this in any of the subsequent work.

In 1925 an additional method was tried which yielded a few results. Test tubes were inverted over growing Sudan grass or wheat, so as to give a saturated atmosphere when desired. The bugs bred and some of the nymphs became adults. About 20 records of length of instar periods were obtained. The writer believes, however, that some modification of this method might be used to yield much better results than any of the other methods. Air could be forced in at the bottom and allowed to pass up around the plant if tubes of a design similar to that shown in Fig. 1 were properly inserted in the ground. In any case, extremely wet conditions have to be avoided, however desirable it is to test them.

In all, 682 life history stages were observed as to time required for each, while temperature and humidity were recorded with moderate accuracy. Of these, 387 were under the less variable temperature conditions, with a daily range of 1-7°C., and 295 were under more variable conditions, with a daily variation of 10-16°C. These observations were distributed as follows: egg, 31; first instar, 55; second, 67; third, 121; fourth, 190; fifth, 215. Tables I-IV show selected data in connection with the length of instar periods, but only those that could be paired for comparison.

The lengths of the several stages at 90% relative humidity and 23°C. mean temperature with 4° or 5° daily variation are estimated to be as follows: egg, 16.5 days; first instar, 6.0 days; second, 5.9 days; third, 5.7 days; fourth, 6.1 days; fifth, 11.2 days; the sum being 51.4 days. The period from egg to adult, on the basis of the combined data shown in Fig. 10 and Table V, is 52.2 days. The average time obtained by taking the sum of the several stages at three combinations of temperature and humidity is shown in Table VI.

TABLE II

VARIABLE TEMPERATURE

Showing length of stage for comparable groups of individuals under more variable temperature than in Table I but with only slight differences in mean relative humidity. The temperature conditions simulated the normal daily fluctuations out of doors (10°C. rise and fall). Percentages were calculated as in Table I. Data for 1919 are omitted because there were no two comparable groups.

Designation	Year	Temperature (mean degrees C.)	Relative humidity (mean %)	Dates, beginning and ending	Length of stage (days)	Mean of extremes (days)	Variation (+-%)
EGG STAGE							
F	1922	26.0	96.8	7/19, 7/27	8		
G	1922	26.9	95.1	7/19, 7/31	12	10.0	20.0
G	1922	28.1	91.5	8/3, 8/7	4		
G	1922	28.1	91.3	8/3, 8/6	3	3.5	14.3
G	1925	30.3	81.4	7/31, 8/7	7		
G	1925	30.9	81.5	8/3, 8/6	3	5.0	40.0
AVERAGE							24.8
FIRST INSTAR							
C	1922	23.8	89.4	8/1, 8/12	11		
E	1922	23.8	86.4	8/16, 8/21	5	8.0	37.5
F	1925	31.5	76.3	8/18, 8/25	7		
F	1925	31.5	76.6	8/20, 8/26	6	6.5	7.7
G	1925	30.1	83.3	9/18, 9/28	10		
G	1925	30.5	83.8	9/16, 9/25	9	9.5	5.3
AVERAGE							16.8

TABLE II—Cont'd

Designation	Year	Temperature (mean degrees C.)	Relative humidity (mean %)	Dates, beginning and ending	Length of stage (days)	Mean of extremes (days)	Variation (+-%)
SECOND INSTAR							
F	1922	26.6	99.5	8/12, 8/16	4		
G	1922	26.8	99.5	8/21, 8/28	7	5.5	27.0
AVERAGE							27.0
THIRD INSTAR							
F	1920	30.3	79.6	7/6, 7/10	3.5		
G	1920	30.9	79.9	7/6, 7/10	4	3.75	6.7
FW	1921	27.0	84.9	9/17, 9/21	4		
GD	1921	27.7	83.1	8/7, 8/10	3	3.5	14.3
F	1922	29.5	93.5	8/31, 9/10	10		
F	1922	29.5	93.5	8/31, 9/10	10	10.0	0.0
F	1925	32.7	86.5	9/12, 9/18	6		
F	1925	32.5	89.1	8/4, 8/10	6	6.0	0.0
E	1925	34.4	74.5	9/11, 9/15	4		
E	1925	34.6	75.3	9/11, 9/14	3	3.5	14.3
AVERAGE							7.1
FOURTH INSTAR							
E	1920	22.1	95.2	7/7, 7/14	7		
E	1920	21.8	95.3	7/18, 7/23	5	6.0	16.6
E	1920	21.9	95.3	7/19, 7/25	6		
F	1920	31.1	76.7	7/10, 7/12	2.5		
G	1920	31.3	76.3	7/5, 7/8	3.5	3.0	16.6
EW	1921	24.0	84.0	8/5, 8/13	8		
EW	1921	23.5	84.6	8/11, 8/19	8	8.0	0.0
G	1925	27.7	83.7	7/27, 8/1	5		
G	1925	28.5	83.9	7/26, 7/31	5	5.0	0.0
G	1925	30.8	76.2	9/27, 9/30	3		
G	1925	30.9	75.0	8/10, 8/17	7	5.0	40.0
E	1925	33.4	74.1	9/15, 9/19	4		
E	1925	33.6	72.5	9/14, 9/18	4	4.0	0.0
AVERAGE							12.2
FIFTH INSTAR							
G	1920	29.0	86.5	7/18, 7/23	5.5		
G	1920	29.0	86.5	7/19, 7/24	5	5.25	4.7
G	1920	27.2	84.3	7/21, 7/27	6		
G	1920	27.2	84.3	7/21, 7/26	5.5	5.75	4.3
D	1922	23.4	93.0	7/14, 7/24	10		
D	1922	23.4	94.0	7/15, 7/26	11	10.5	4.8

TABLE II—Cont'd

Designation	Year	Temperature (mean degrees C.)	Relative humidity (mean %)	Dates, beginning and ending	Length of stage (days)	Mean of extremes (days)	Variation (+-%)
FIFTH INSTAR—CONT'D							
F	1922	25.2	96.0	7/6, 7/12	6		
F	1922	25.0	96.3	7/7, 7/14	7	6.5	7.7
E	1925	34.4	85.3	8/17, 8/20	3		
F	1925	34.0	85.6	9/17, 9/21	4	3.5	14.3
G	1925	29.7	80.2	9/24, 10/2	8		
E	1925	29.2	80.1	8/20, 8/24	4	6.0	33.3
G	1925	29.5	76.6	8/18, 8/23	5		
G	1925	30.2	76.1	8/17, 8/25	8	6.5	23.1
E	1925	30.9	82.1	9/18, 9/23	5		
E	1925	30.9	82.4	9/19, 9/25	6	5.5	9.1
F	1925	32.1	75.1	8/16, 8/21	5		
F	1925	32.6	75.7	8/13, 8/18	5	5.0	0.0
F	1925	32.1	79.4	8/10, 8/16	6		
G	1925	32.9	79.0	10/13, 10/19	6	6.0	0.0
G	1925	33.5	77.0	10/15, 10/22	7		
G	1925	33.6	77.0	10/16, 10/21	5	6.0	16.7
AVERAGE							10.7
AVERAGE FOR ALL STAGES							16.4

Individual Variation

First of all, it is desirable to know the amount of individual variation. The 682 records of stages reveal a surprising amount of variation as to the duration of the same stage under nearly the same conditions. They are, however, so scattered in the years 1919-1922 and 1924-1926 as to permit comparison of only a few. Only paired cases were used to estimate the individual variation.

In Table I the individual variation in the length of all stages at approximately constant temperatures is shown to have averaged ±16.6% of the mean. (The plus or minus percentage was calculated from the mean of the longest and shortest periods under the same conditions; thus a variation of ±20% indicates that when the time is 5 days for the average individual it may be 6 days for the slowest individual, or 4 for the most rapidly developing one.) The average deviation from the mean for the egg is 7.5%, for the first stage 27.2%, second stage 9.7%, third stage 22.1%, fourth stage 17.4% and fifth stage 15.6%. A similar range of variation under more variable temperatures is indicated in Table II, where the average for the egg stage is 24.8%, for the first instar 16.8%, for the second 27%, third 7.1%, fourth 12.2%, and fifth 10.7%, and the average for all stages 16.4%.

These variations are rather large, as compared to the 8% deviation found in the codling moth pupae and percentages of the same order of magnitude in the other stages of the moth (Shelford, 1927). It is evident, therefore, that individual variation may render the results in small series of observations quite irregular, and this consideration further lessens the weight to be given to the smaller number of cases.

Effect of Humidity

The study of instars brought out the great importance of moisture. While high atmospheric humidity is favorable, especially to the early instars, actual liquid water is detrimental or fatal.

Data on all instars from the same stock which were kept under the same temperatures but different humidities are presented in Tables III and IV to show effects of humidity upon length of stage. The average increase in the length of instars per 10% decrease in relative humidity is 25-35%. Generally speaking, the effect of the lowest humidity is greatest in the first and second nymphal stages.

The numerical relation of the length of life history stages of animals to atmospheric moisture (at any fixed temperature) has been but little studied. It is evident, however, that none of the formulae used to express relations to temperature can ordinarily be used and that insects differ greatly as to amount of effect produced by a given difference in atmospheric moisture, expressed as relative humidity in per cent saturation, as saturation deficit, or otherwise. The effect of moisture on the length of chinch bug stages is relatively great. It approaches more nearly a direct proportionality to per cent relative humidity than in many other organisms. Accordingly, to compare the different stages and gain a concept of the magnitude of the effect of humidity on the rate of development of the chinch bug, the data have been reduced to a common basis of 10% difference in relative humidity. This was necessitated by the great differences in humidity for the surviving stage-completing individuals.

The theoretical percentage increase in time with a decrease of 10% relative humidity was calculated as a direct proportion of the difference which occurred in each case. Suppose, for example, two individuals passing through the same stage at the same temperature, one in 10 days at 50% relative humidity, another in 5 days at 90% relative

Table III

HUMIDITY DIFFERENCES

Showing estimated difference in length of stage in groups kept under different conditions of relative humidity and subjected to only small daily fluctuations in temperature, the mean temperature being approximately the same within each group. (Differences of not more than two-tenths of a degree in mean temperature are not regarded as significant.) The differences correlated with relative humidity are estimated on the basis of a 10% change to facilitate comparison. For further explanation see text.

a. Designation	b. Year	c. Dates, beginning and ending	d. Length of stage (days)	e. Temperature (mean degrees C.)	f. Relative humidity (mean %)	g. Difference in mean percentages of relative humidity	h. Estimated number of days at a relative humidity 10% lower than the highest percentage in column f	i. Estimated quotient obtained with decrease of 10% relative humidity	j. Theoretical percentage increase in time with decrease of 10% relative humidity	k. Remarks
EGG STAGE										
B	1922	7/19, 7/27	8	31.4	91					
B	1922	8/25, 8/31	6	31.8	93	2	16.0	2.66	166	Not averaged
B	1925	7/24, 8/7	14	27.7	40					
ALL	1925	8/1, 8/12	11	27.9	84	44	11.68	1.06	6	
B	1925	7/28, 8/15	18	27.6	40					
B	1925	7/30, 8/8	9	27.1	90	50	10.8	1.20	20	
AVERAGE									13	Average of all = 64
FIRST INSTAR										
BM	1919	4/7, 4/25	18	28.2	72					
BW	1919	4/2, 4/7	5	28.3	85	13	15.0	3.00	200	Not averaged
BM	1919	4/7, 4/25	18	28.2	72					
BW	1919	6/12, 6/21	9	28.3	90	18	14.0	1.55	55	
BD	1925	8/7, 8/18	11	29.0	40					
BW	1925	8/15, 8/20	5	29.0	85	45	6.33	1.26	26	
BD	1925	8/8, 8/14	6	29.0	40					
BW	1925	8/23, 8/26	3	29.0	85	45	3.66	1.22	22	
BD	1925	8/8, 8/14	6	29.0	40					
BW	1925	8/15, 8/20	5	29.0	85	45	5.20	1.05	5	
AVERAGE									27	Average of all = 61
SECOND INSTAR										
BM	1919	8/11, 9/1	21	28.0	71					
BWW	1919	8/6, 8/12	6	28.5	97	26	11.77	1.96	96	
BM	1919	4/25, 5/2	7	28.4	74					
BWW	1919	8/6, 8/12	6	28.5	97	23	6.43	1.07	7	
BD	1925	8/14, 8/19	5	29.0	40					
BW	1925	7/20, 7/28	8	29.0	85	45	7.33	.91	−9	Not averaged
AVERAGE									51	Average of all = 31

TABLE III—Cont'd

a. Designation	b. Year	c. Dates, beginning and ending	d. Length of stage (days)	e. Temperature (mean degrees C.)	f. Relative humidity (mean %)	g. Difference in mean percentages of relative humidity	h. Estimated number of days at a relative humidity 10% lower than the highest percentage in column f	i. Estimated quotient obtained with decrease of 10% relative humidity	j. Theoretical percentage increase in time with decrease of 10% relative humidity	k. Remarks
THIRD INSTAR										
BW	1919	4/7, 4/19	12	28.1	86					
BWW	1919	8/24, 9/2	9	28.4	95	9	12.33	1.36	36	
AWL	1921	8/10, 8/17	7	23.2	85					
AWL	1921	8/28, 9/2	5	23.8	92	7	7.85	1.57	57	
AWL	1921	8/10, 8/17	7	23.2	85					
AWL	1921	8/3, 8/8	5	23.8	91	6	8.33	1.66	66	
AWL	1921	7/30, 8/6	7	23.5	91			1.00	0	
B	1925	7/26, 8/5	10	29.0	40					
B	1925	9/18, 9/23	5	29.0	85	45	6.10	1.22	22	
AD	1926	6/21, 6/29	8	20.9	35					
AW	1926	6/22, 6/30	8.5	20.9	92	57	7.95	0.94	−6	Not averaged
AVERAGE									36	Average of all = 29
FOURTH INSTAR										
AWL	1921	8/17, 8/28	11	23.0	86					
AL	1921	9/21, 9/29	8	22.6	96	10	11.00	1.37	37	
B	1925	8/30, 9/5	6	29.0	40					
B	1925	9/7, 9/12	5	29.0	85	45	5.20	1.04	4	
B	1925	8/30, 9/5	6	29.0	40					
A	1925	8/25, 8/30	5	29.1	89	49	5.20	1.04	4	
BD	1926	6/23, 6/26	3	30.3	33					
BW	1926	6/28, 7/1	3	30.6	92	59	3.00	1.00	0	
AVERAGE									11	Average of all = 11
FIFTH INSTAR										
AWLL	1921	8/13, 8/24	11	23.7	85					
ALL	1921	9/14, 9/24	10	23.3	94	9	11.1	1.11	11	
AWLL	1921	8/14, 8/30	16	23.9	87					
ALL	1921	9/9, 9/22	13	23.4	94	7	17.3	1.33	33	
B	1925	8/2, 10/12	7.5	29.0	40					
B	1925	8/13, 10/28	7	29.0	85	45	7.1	1.14	14	
AL	1925	8/19, 8/25	6	28.6	83					
AL	1925	8/31, 9/6	6	28.6	90	7	6.0	1.00	0	
AVERAGE									14	Average of all = 14
AVERAGE FOR ALL STAGES									25	35

TABLE IV

SIMULATION OF DAILY MARCH OF TEMPERATURE AND RELATIVE HUMIDITY

Showing estimated difference in length of stage at the same mean variable temperature simulating the usual day of the season, but under different conditions of relative humidity represented by the mean of percentages ranging lower as the varying temperature went higher, and *vice versa*, in a manner similar to the normal daily march of relative humidity. Otherwise, the treatment of the data is the same as in Table III. Further data as to temperature variation may be secured from Table VII.

a. Designation	*b.* Year	*c.* Dates, beginning and ending	*d.* Length of stage (days)	*e.* Temperature (mean degrees C.)	*f.* Relative humidity (mean %)	*g.* Difference in mean percentages of relative humidity	*h.* Estimated number of days at a relative humidity 10% lower than the highest percentage in column *f*	*i.* Estimated quotient obtained with decrease of 10% relative humidity	*j.* Theoretical percentage increase in time with decrease of 10% relative humidity	*k.* Remarks
FIRST INSTAR										
E E	1925 1925	8/19, 8/27 8/7, 8/10	8 3	31.3 31.3	80.5 94.5	14	6.6	2.20	120	Not averaged
E E	1925 1925	9/26, 10/4 9/8, 9/15	8 7	33.9 33.9	71.0 78.0	7	8.43	1.20	20	
F E	1925 1925	8/18, 8/25 8/22, 8/28	7 6	31.5 31.6	76.3 80.1	4	8.5	1.40	40	
AVERAGE									30	Average of all = 60
SECOND INSTAR										
F F	1919 1919	6/15, 6/20 5/17, 5/21	5 4	33.3 33.5	91.9 96.7	5	6.0	1.50	50	
E D	1922 1922	8/14, 8/21 7/22, 7/27	7 5	23.7 23.7	87.0 97.0	10	7.0	1.40	40	
E E	1925 1925	9/5, 9/11 8/10, 8/13	6 3	31.4 31.4	84.6 90.0	5	9.0	3.00	200	Not averaged
AVERAGE									45	Average of all = 97
THIRD INSTAR										
E F	1921 1921	9/29, 10/4 9/17, 9/21	5 4	28.0 27.0	72.5 84.9	12	4.8	1.20	20	
G F	1925 1925	8/5, 8/12 8/5, 8/9	7 4	31.0 31.3	80.0 90.6	10	7.0	1.75	75	
E E	1925 1925	8/13, 8/19 8/6, 8/12	6 6	33.4 32.3	78.2 92.2	14	0	0	0	
AVERAGE									33	Average of all = 33

TABLE IV—Cont'd

a. Designation	b. Year	c. Dates, beginning and ending	d. Length of stage (days)	e. Temperature (mean degrees C.)	f. Relative humidity (mean %)	g. Difference in mean percentages of relative humidity	h. Estimated number of days at a relative humidity 10% lower than the highest percentage in column f	i. Estimated quotient obtained with decrease of 10% relative humidity	j. Theoretical percentage increase in time with decrease of 10% relative humidity	k. Remarks
FOURTH INSTAR										
E	1922	8/25, 9/1	7	23.6	87.2					
F	1922	8/20, 8/25	5	24.2	91.1	4	10.0	2.00	100	
G	1925	10/13, 10/16	3	32.9	79.8					
G	1925	9/8, 9/12	4	33.0	91.5	12	3.3	0.83	−17	Not averaged
F	1925	8/22, 8/27	5	31.8	77.3					
F	1925	8/6, 8/10	4	32.4	88.8	11	4.9	1.22	22	
F	1925	10/14, 10/21	7	35.6	79.3					
F	1925	9/25, 9/28	3	35.9	86.0	7	8.7	2.90	190	Not averaged
F	1925	9/28, 10/1	3	34.6	82.4					
F	1925	9/25, 9/27	2	34.6	86.6	4	4.5	2.25	125	Not averaged
E	1925	8/26, 9/4	9	32.8	86.1					
E	1925	8/6, 8/11	5	32.9	92.4	6	11.6	2.30	130	Not averaged
AVERAGE									61	Average of all = 92
FIFTH INSTAR										
F	1920	7/25, 8/31	6	29.8	72.7					
G	1920	8/14, 8/19	5	29.8	78.2	5	7.0	1.40	40	
F	1920	7/25, 7/31	6	29.8	72.7					
G	1920	7/18, 7/23	5.5	29.0	86.5	14	5.8	1.06	6	
E	1925	9/27, 10/3	6	34.0	72.6					
E	1925	8/17, 8/20	3	34.4	85.3	13	5.3	1.71	71	
G	1925	8/12, 8/18	6	30.7	73.7					
G	1925	9/12, 9/17	5	30.4	89.5	16	5.6	1.12	12	
F	1925	8/13, 8/18	5	32.6	75.7					
G	1925	8/26, 9/1	6	32.6	82.0	6	5.3	0.88	−12	Not averaged
F	1925	8/16, 8/21	5	32.1	75.1					
F	1925	8/27, 9/1	5	32.3	88.1	13	0.0	0.00	0	
E	1925	9/27, 10/5	8	33.5	73.0					
F	1925	10/1, 10/5	4	33.2	83.8	11	7.6	1.93	90	
E	1925	9/27, 10/3	6	34	72.6					
F	1925	9/17, 9/21	4	34	85.6	13	5.5	1.37	37	
F	1925	10/4, 10/9	5	35.6	81.1					
F	1925	9/3, 9/7	4	35.7	87.8	7	5.4	1.35	35	
AVERAGE									37	Average of all = 35
AVERAGE FOR ALL STAGES									41	63

TABLE V

COMBINED VELOCITY VALUES

Showing developmental units per hour for the life history of the chinch bug, from the laying of the egg to the emergence of the adult (6800 units).

Temperature		Relative humidity percentage															
C.	F.	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
48	118.4	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
47	116.6	0.4	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.3	0.2	0.2	0.1	0.0
46	114.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.5	0.4	0.3
45	113.0	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.2	1.2	1.1	1.0	0.9	0.9	0.8	0.7	0.6
44	111.2	1.5	1.6	1.6	1.6	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.2	1.1	1.0	0.9
43	109.4	1.9	1.9	1.9	2.0	2.0	2.0	1.9	1.9	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2
42	107.6	2.2	2.4	2.4	2.5	2.5	2.5	2.5	2.5	2.4	2.3	2.1	2.0	1.9	1.8	1.7	1.6
41	105.8	2.9	3.0	3.1	3.2	3.3	3.3	3.3	3.3	3.2	3.1	2.9	2.8	2.5	2.4	2.1	1.9
40	104.0	3.5	3.7	3.8	3.9	4.0	4.1	4.2	4.2	4.1	4.0	3.9	3.7	3.5	3.1	2.9	2.6
39	102.2	4.0	4.3	4.4	4.7	4.9	5.0	5.1	5.2	5.3	5.1	5.0	4.9	4.6	4.2	4.0	3.7
38	100.4	4.6	4.9	5.1	5.4	5.6	5.9	6.1	6.2	6.2	6.2	6.1	6.0	5.8	5.5	5.2	4.7
37	98.6	5.0	5.4	5.8	6.1	6.4	6.8	7.0	7.1	7.2	7.2	7.2	7.1	6.8	6.5	6.2	5.8
36	96.8	5.3	5.8	6.3	6.7	7.1	7.5	7.8	8.1	8.2	8.3	8.3	8.1	7.9	7.6	7.3	6.9
35	95.0	5.4	6.0	6.5	7.1	7.6	8.1	8.6	8.9	9.1	9.3	9.3	9.3	9.1	8.9	8.5	8.1
34	93.2	5.3	5.8	6.5	7.1	7.8	8.4	8.9	9.4	9.9	10.1	10.3	10.3	10.1	9.9	9.6	9.2
33	91.4	5.1	5.7	6.3	6.9	7.6	8.3	9.0	9.6	10.2	10.7	11.1	11.1	11.1	10.9	10.6	10.3
32	89.6	4.8	5.3	5.9	6.5	7.2	8.0	8.7	9.4	10.1	10.7	11.3	11.7	11.9	11.7	11.5	11.0
31	87.8	4.4	4.9	5.4	6.1	6.7	7.4	8.2	8.9	9.7	10.4	11.1	11.8	12.3	12.3	12.1	11.9
30	86.0	3.9	4.4	4.9	5.4	6.1	6.7	7.4	8.2	8.9	9.7	10.5	11.2	12.0	12.3	12.2	12.2
29	84.2	3.3	3.7	4.2	4.7	5.4	5.9	6.6	7.3	8.0	8.8	9.4	10.2	11.2	11.7	12.0	12.1
28	82.4	2.7	3.1	3.5	4.0	4.5	5.1	5.7	6.3	7.0	7.7	8.4	9.1	9.7	10.6	11.2	11.5
27	80.6	2.0	2.4	2.8	3.3	3.7	4.1	4.8	5.3	5.9	6.6	7.2	7.9	8.6	9.3	10.0	10.8
26	78.8	1.5	1.8	2.1	2.5	2.9	3.3	3.8	4.3	4.9	5.5	6.1	6.9	7.5	8.1	8.9	9.6
25	77.0	1.1	1.4	1.7	1.9	2.2	2.5	3.0	3.4	4.0	4.5	5.1	5.8	6.4	7.1	7.8	8.4
24	75.2	0.7	0.9	1.1	1.3	1.5	1.8	2.2	2.5	3.0	3.4	4.0	4.6	5.3	6.0	6.6	7.3
23	73.4	0.4	0.6	0.8	0.9	1.1	1.3	1.5	1.8	2.2	2.7	3.1	3.6	4.2	5.0	5.6	6.2
22	71.6	0.2	0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.6	1.9	2.2	2.8	3.2	3.9	4.5	5.1
21	69.8	0.1	0.1	0.2	0.3	0.4	0.5	0.7	0.9	1.1	1.4	1.6	1.9	2.3	2.9	3.3	4.0
20	68.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.7	0.9	1.2	1.4	1.7	2.0	2.4	3.0
19	66.2	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.8	1.1	1.4	1.7	2.0
18	64.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.6	0.8	1.1	1.4
17	62.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.6	0.9
16	60.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5
15	59.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1

TABLE VI

LENGTH OF LIFE CYCLE

Showing average time from egg to adult, determined by adding together the averages for the instar periods under conditions not differing by more than 1.5 C. and 4% relative humidity.

Designation	Mean temperature C.	Mean relative humidity %	Length of life cycle in days
A	22.0	92	59.5
B	28.9	46	45.2
B	30.1	93	31.4

humidity. The difference in relative humidity is 40% and the difference in time is 5 days; therefore, the difference in length of stage corresponding to a 10% difference in humidity would be one-fourth of 5 days, or 1.25 days. Hence, the time at 80% would be 5 plus 1.25, or 6.25 days, and the ratio of the time at the higher humidity to the time at the lower humidity is 6.25:5, or 1.25. This may be compared with the Q_{10} for temperature and may be designated as $Q_{10}\%$.

In the first item in Table III, where the difference in time is 2 days, the value of $Q_{10}\%$, or the estimated effect of a 10% difference in humidity, is calculated as follows:

$$10\% \div 2\% = 5$$
$$2 \text{ days} \times 5 = 10 \text{ days}$$
$$10 \text{ days} + 6 \text{ days} = 16 \text{ days (column } h\text{)}$$
$$16 \text{ days} \div 6 \text{ days} = 2.66 \text{ (column } i\text{)}$$

The values in Table IV are calculated in the same way.

Thus all the values are calculated from the high favorable humidity to the low unfavorable humidity and expressed here as retardation rather than acceleration. It is noteworthy that a decrease in humidity causes a decrease in rate which is expressed in the tables as longer time for development of the stage in question. The facts are expressed in this form because the higher humidities are usually more favorable within the limits shown. Occasionally the relation is reversed, as indicated by the two negative values in column *j* of Table III. These and a class of exceptions to the usual rule, namely, percentages above 100, of which there are two in Table III and five in Table IV, probably result from the individual variation indicated in Tables I and II and discussed in the preceding section. The averages in column *j* have been taken without the negative values and without the items above 100%. The averages with these included are shown opposite in column *k*.

Table III includes items from 1919 to 1925 shown in Table VII to be characterized by an average daily range of less than 8°C. Table IV includes those with a greater daily range (more than 10°C.). The results are, however, generally comparable. It is noteworthy that the difference in humidity has the greatest effect in the first stage and the least effect in the last stage. It is also noteworthy that a decrease of 10% in humidity has a greater effect under the more variable temperatures.

Velocity Curves and Charts

On the basis of these generalizations and some plots of all available data, velocity curves and provisional charts for rate of development have been prepared, as shown in Figs. 2-8, by the method used

TABLE VII

CULTURAL CONDITIONS

Showing averages for each season, 1917-1925, with notes on the success of the cultures. The asterisk indicates groups from which instars were selected for use in Tables III and IV. Data in Tables I and III (for groups with a mean daily range of less than 8°C.) and in Tables II and IV (for groups with a greater daily range) are averages for each stage of the insect and therefore do not agree with the averages shown here for the entire season.

Designation	Mean of maxima (C.)	Mean of minima (C.)	Mean daily range (C.)	Mean of bi-hourly readings (C.)	Mean relative humidity (%)	Evaporation (cc. per day)	Illumination (refer to curves in Figs. 12 and 13)	Per cent of noon sunlight	Number of times started	Remarks on success of culture
1917										
AD	23.4	18.8	4.6	21.1	50	10.65	I	9.5	1	Fair
AM	23.4	18.6	4.8	21.0	80	3.28	I	9.5	1	Fair
BD	28.3	23.2	5.1	25.9	45	11.30	I	9.5	1	Fair
CD	40.8	30.7	10.1	31.7	55	.....	VII	8.0	1	Best
D	41.0	30.7	10.3	32.1	95	1.88	VII	8.0	1	Best
E	40.7	29.8	10.9	31.3	100	1.32	X	0.5	1	Fair
F	41.0	32.0	9.0	33.4	100	.....	VII	8.0	1	Fair
1918										
AW	21.8	21.4	0.4	21.6	77.5	7.77	II	3.5	1	Weak
BD	29.6	25.3	4.3	27.5	65.0	10.45	II	3.5	1	Weak
BWL	28.7	27.2	1.5	28.0	75.0	5.76	II	3.0	1	Fair
BWLL	28.1	26.4	1.7	27.2	75.0	5.85	II	5.0	1	Best
F	40.0	22.8	17.2	33.3	68.0	7.10	VII	8.0	1	Poor
1919										
AWa	24.4	19.0	5.4	21.1	81.7	2.98	IV	0.5	1	Failed
AWb	25.4	18.6	6.8	21.2	80.5	6.42	IV	0.5	1	Failed
AD	25.4	18.6	6.8	21.2	80.5	7.07	IV	0.5	1	Weak
*BW	28.8	27.8	1.0	28.3	84.5	5.48	IV	0.5	1	Good
*BWW	28.0	26.6	1.4	27.3	98.0	1.80	IV	0.5	3	Weak
BD	28.4	27.2	1.2	27.8	62.3	.....	IV	0.5	1	Weak
C	40.5	21.9	18.6	31.2	84.0	14.49	IX	2.0	2	Weak
D	41.7	24.6	17.1	30.3	88.5	10.58	IX	2.0	3	Fair
E	41.7	24.6	17.1	30.3	88.5	10.58	X	0.5	1	Best
*F	41.6	27.0	14.6	34.1	97.0	10.58	XII	9.0	1	Better
G	39.3	24.5	14.8	30.9	76.0	11.66	VII	8.0	2	Fair
P	26.1	15.6	10.5	21.6	79.5	.....	....	9.0	....	....
1920										
AW	18.8	15.5	3.3	16.6	95.6	3.62	IV	0.5	1	Failed
BWWa	33.5	29.2	4.3	31.2	90.4	5.5	IV	0.5	1	Fair
BWWb	30.5	28.6	1.9	29.7	91.4	5.23	IV	0.5	1	Fair
C	33.2	26.1	7.1	28.7	95.1	6.66	IX	2.0	1	Poor
D	29.0	20.3	8.7	23.9	92.0	4.0	VII	8.0	1	Good
E	28.9	19.6	9.3	22.7	94.3	29.6	X	0.5	1	Weak
F	34.4	19.3	15.1	25.0	76.5	11.9	XII	9.0	1	Best
G	36.3	20.2	16.1	27.9	76.9	22.9	VII	8.0	1	Good
1921										
*AWL	24.8	20.5	4.3	22.6	89.2	7.8	IV	0.5	3	Fair
*AWLL	26.7	21.5	5.2	24.1	90.4	7.1	III	1.0	3	Fair
BW	32.0	25.2	6.8	28.4	69.9	10.96	IV	0.5	3	Fair
CWL	33.2	21.4	11.8	27.2	95.2	5.33	VI	4.0	3	Weak
CWLL	33.3	21.3	12.0	27.3	93.6	4.33	VII	8.0	3	Fair
DDLL	33.1	19.5	13.6	26.3	85.8	.....	VII	8.0	3	Fair
*EW	30.2	21.0	9.2	25.5	76.6	.....	X	0.5	3	Fair
*FW	40.0	26.4	13.6	33.2	76.2	.....	XII	9.0	3	Fair
GD	40.8	26.2	14.6	33.5	84.7	.....	VII	8.0	3	Fair

TABLE VII—Cont'd

Designation	Mean of maxima (C.)	Mean of minima (C.)	Mean daily range (C.)	Mean of bi-hourly readings (C.)	Mean relative humidity (%)	Evaporation (cc. per day)	Illumination (refer to curves in Figs. 12 and 13)	Per cent of noon sunlight	Number of times started	Remarks on success of culture
1922										
*ALL	25.2	18.9	6.3	22.0	90.6	4.5	III	1.0	1	Best
AL	23.8	18.6	5.2	21.2	89.8	2.5	III	1.0	1	Fair
*B	32.8	28.6	4.2	34.3	94.4	7.2	IV	0.5	1	Fair
Ce	34.3	20.7	13.6	27.5	91.1	8.7	VI	4.0	3	Fair
CRw	34.0	18.5	15.5	26.2	92.6	9.37	VII	8.0	2	Fair
*D	32.5	18.4	14.1	25.4	84.7	17.82	VII	8.0	3	Weak
*E	30.5	19.0	11.5	24.7	90.7	9.22	X	0.5	1	Fair
F	35.2	20.2	15.0	22.7	96.0	.....	XII	9.0	3	Fair
G	32.3	20.1	12.2	26.1	94.0	4.68	VII	8.0	2	Fair
1923										
ALL	26.7	21.5	5.2	24.1	84.1	7.3	III	1.0	2	Weak
AL	26.5	21.2	5.3	23.9	86.6	8.6	III	1.0	2	Weak
B	34.1	27.8	6.3	31.0	84.2	10.6	III	1.0	4	Weak
Ce	32.7	22.2	10.5	27.5	96.9	8.2	VII	8.0	1	Best
Cw	32.2	22.2	10.0	27.2	97.2	.....	VII	8.0	1	Best
F	32.2	21.3	10.9	26.7	92.2	7.7	VII	8.0	1	Fair
G	32.9	24.6	10.3	28.7	94.5	.....	VII	8.0	3	Failed
1924										
AL	30.2	23.8	6.4	26.4	86.0	.....	I	9.5	1	Good
ALL	31.9	23.9	8.0	27.5	87.1	.....	I	9.5	2	Fair
B	34.5	23.6	10.9	29.1	84.7	.....	I	9.5	2	Weak
Ew	33.6	22.8	10.8	28.1	80.7	.....	X	0.5	1	Good
Fw	34.0	22.7	11.3	28.3	85.2	.....	XII	8.0	1	Good
G	38.2	27.9	10.3	33.4	74.6	.....	XII	9.0	1	Good
1925										
AL	29.8	23.6	6.2	26.7	98.5	7.5	I	9.5	1	Good
*ALL	30.1	24.6	5.5	27.6	83.9	7.3	I	9.5	1	Best
AR	29.8	24.1	5.7	27.7	83.3	13.1	I	0.5	1	Poor
*BW	32.1	25.4	6.7	28.7	89.6	.....	...	9.5	1	Fair
*E	36.6	26.9	9.7	31.7	79.7	15.1	X	0.5	1	Good
*F	39.7	26.1	13.6	33.3	77.6	14.6	VII	8.0	1	Good
*G	37.2	25.5	11.7	31.7	79.3	8.2	VII	8.0	1	Good

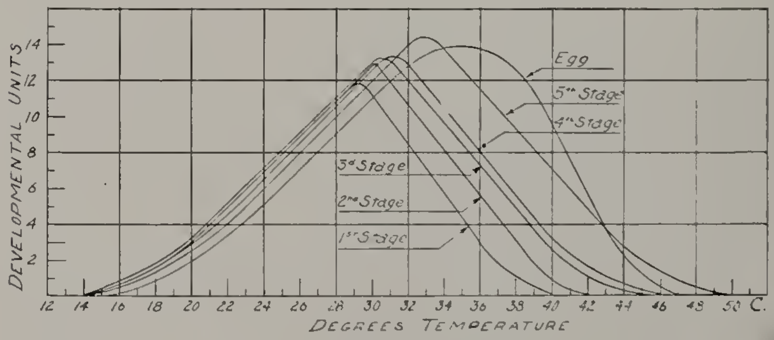

Fig. 2. Curves showing rate of development of the various life history stages at different temperatures along the line of the average daily march indicated by the short oblique lines on Figs. 3-8.

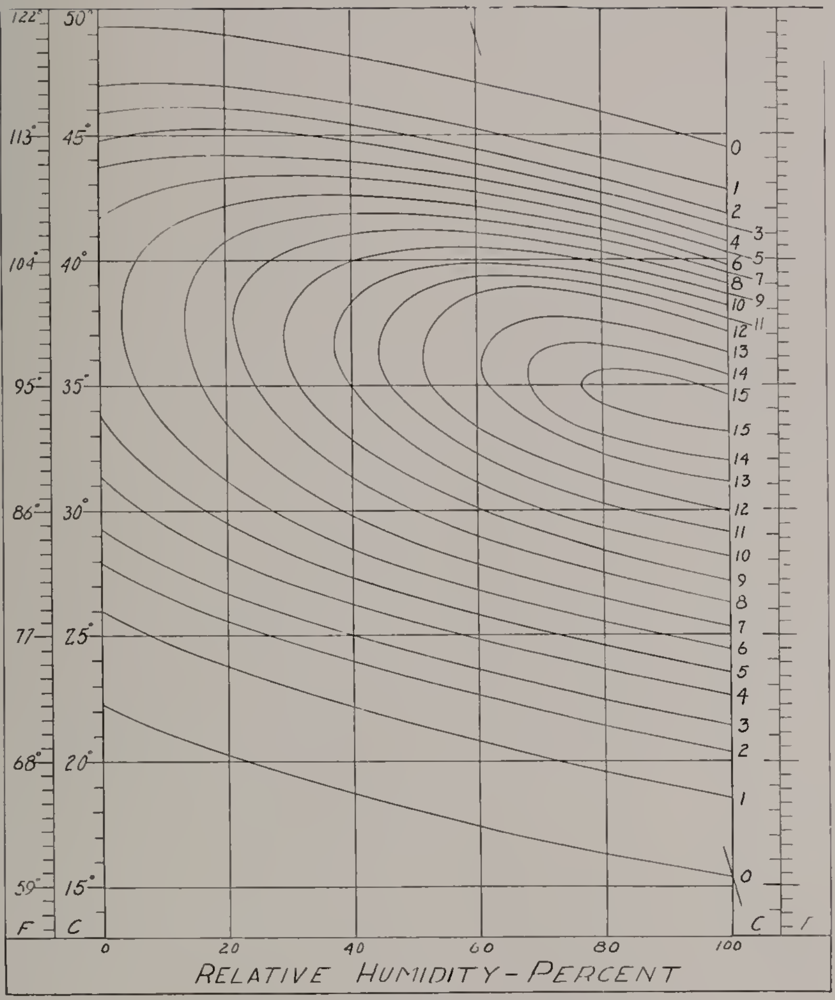

Fig. 3. Provisional chart for the egg stage, based on a developmental total of 1500 Centigrade degree-hour units. Temperature is shown on the vertical scale, humidity on the horizontal. The curved lines represent the *same rate of development* (in developmental units per hour as shown at the right), based on the same length of time to complete the stage, at the various combinations of temperature and humidity through which the lines pass.

with the codling moth (Shelford, 1927). Temperature is represented on the vertical scale in degrees Centigrade and also Fahrenheit, and relative humidity in percentages on the horizontal scale. The equal-velocity lines have been given an upward slant sufficient to show differences in rate of development at the same temperature and lower humidities, roughly comparable to the averages indicated in column *j*

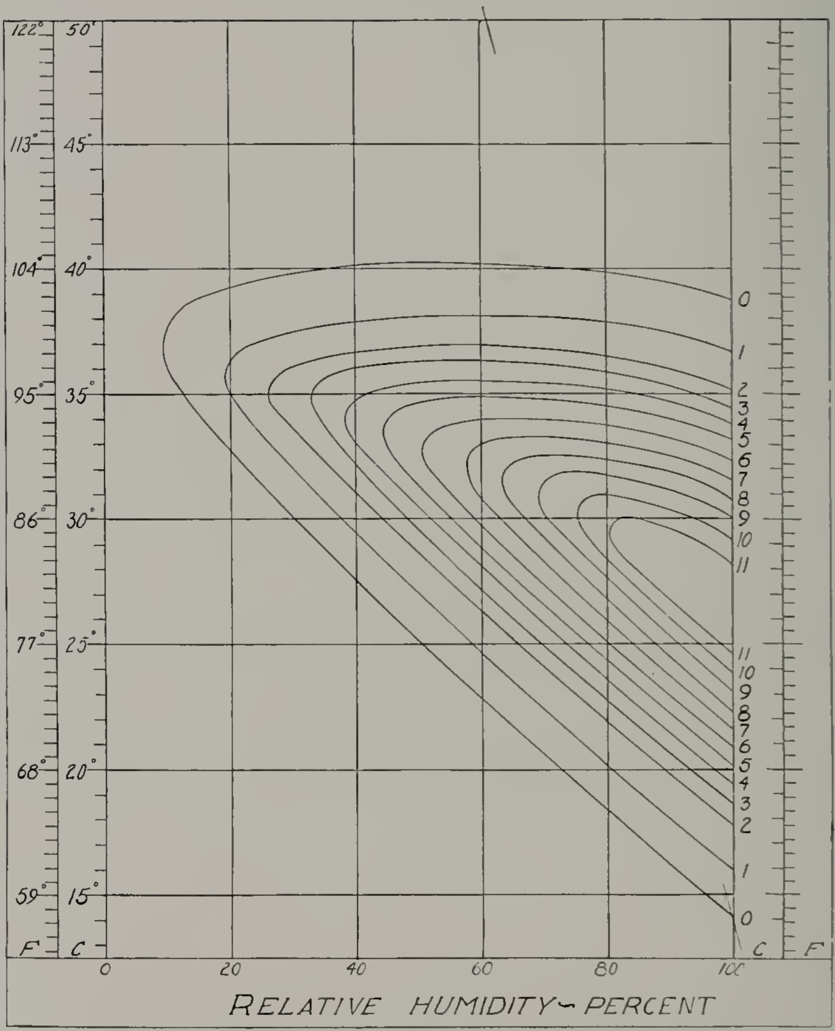

Fig. 4. Provisional chart for the first instar, based on a developmental total of 900 units.

of Tables III and IV. The data are so inadequate, however, that a considerable amount of discretion was necessary on the basis of the experience with the codling moth pupae. Comparison of Figs. 3-8 shows that this difference with humidity apparently becomes less as the insect progresses toward maturity through the various instars. The average percentages were not given full value in the drawing of these charts for two reasons: (1) the insect regulates its surrounding moisture by crawling into cavities and small spaces among the parts of the plant; and (2) a series of experiments referred to above, in which

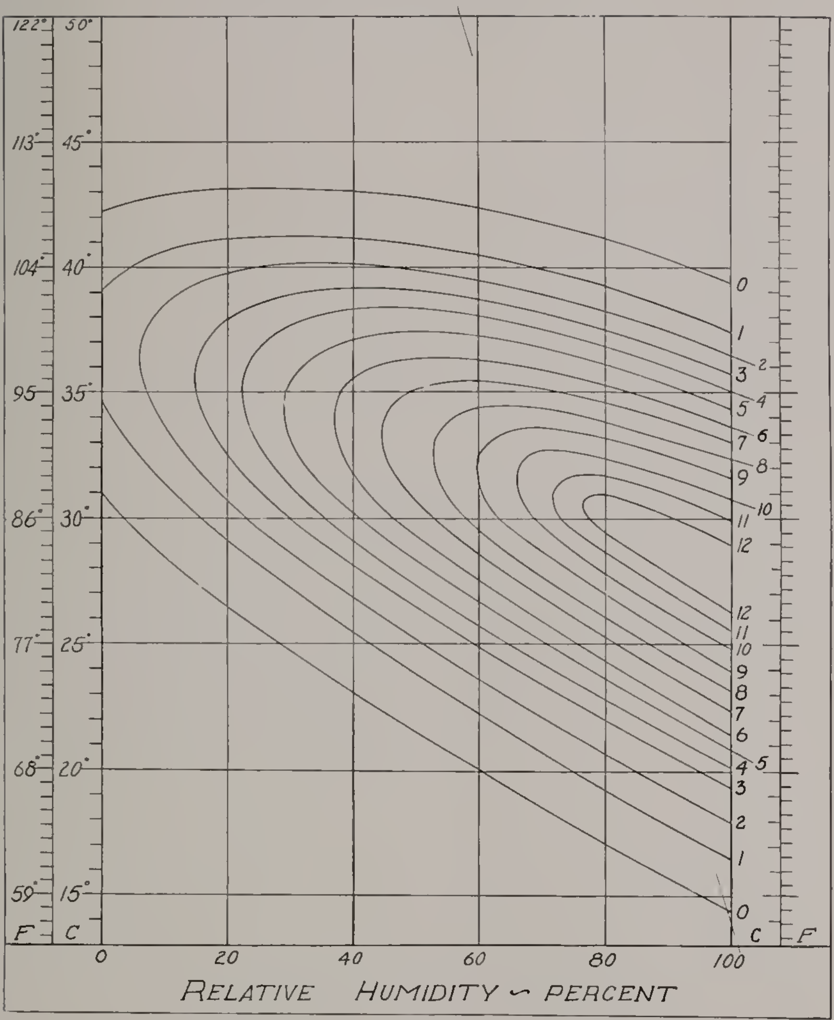

Fig. 5. Provisional chart for the second instar, based on a developmental total of 880 units.

the bugs were fed upon growing plants, indicated less effect of humidity than shown by cut pieces of plant.

The method of reading off the effect of a 10% decrease in humidity from the chart is shown in Fig. 10. X_1 is located on 27° C. and 90% relative humidity and has a velocity value of 10 developmental units per hour. X_2 is located on the same temperature (27° C.) and 80% relative humidity and has a velocity value of 8.5 — a decrease of 15% in rate of development. Again, X_3, on temperature 21° C. and 90% relative humidity, has a velocity of 3.5; and X_4, on the same

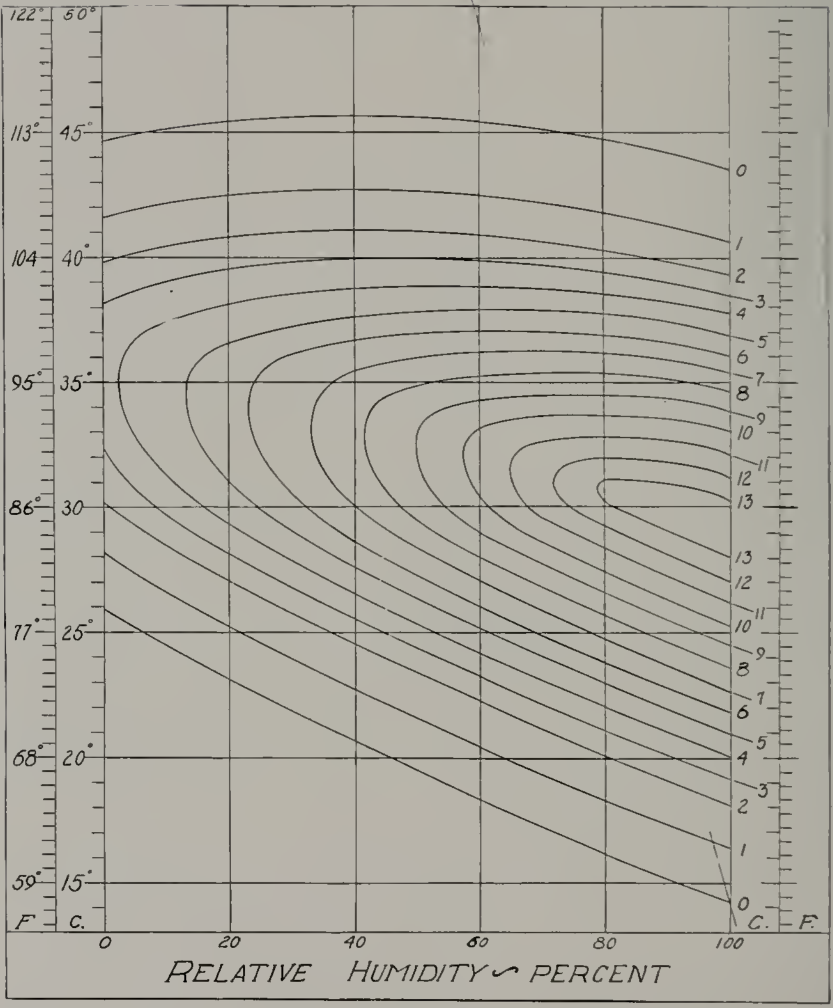

Fig. 6. Provisional chart for the third instar, based on a developmental total of 850 units.

temperature but 10% lower humidity, has a velocity of 2.5. Here the decrease in velocity is 10/35, or 28.5%. It is noteworthy that the percentage difference in velocity increases as the temperature is lowered.

The curves shown in Fig. 2 are in part a straight line (21° to 29°C.) and represent the rates of development under conditions indicated by the oblique line on Figs. 3-8 which runs from 100% relative humidity and approximately 15°C. to approximately 60% relative humidity and 50°C. but varies somewhat as it is the actual average for each stage. This oblique line thus represents the average daily march

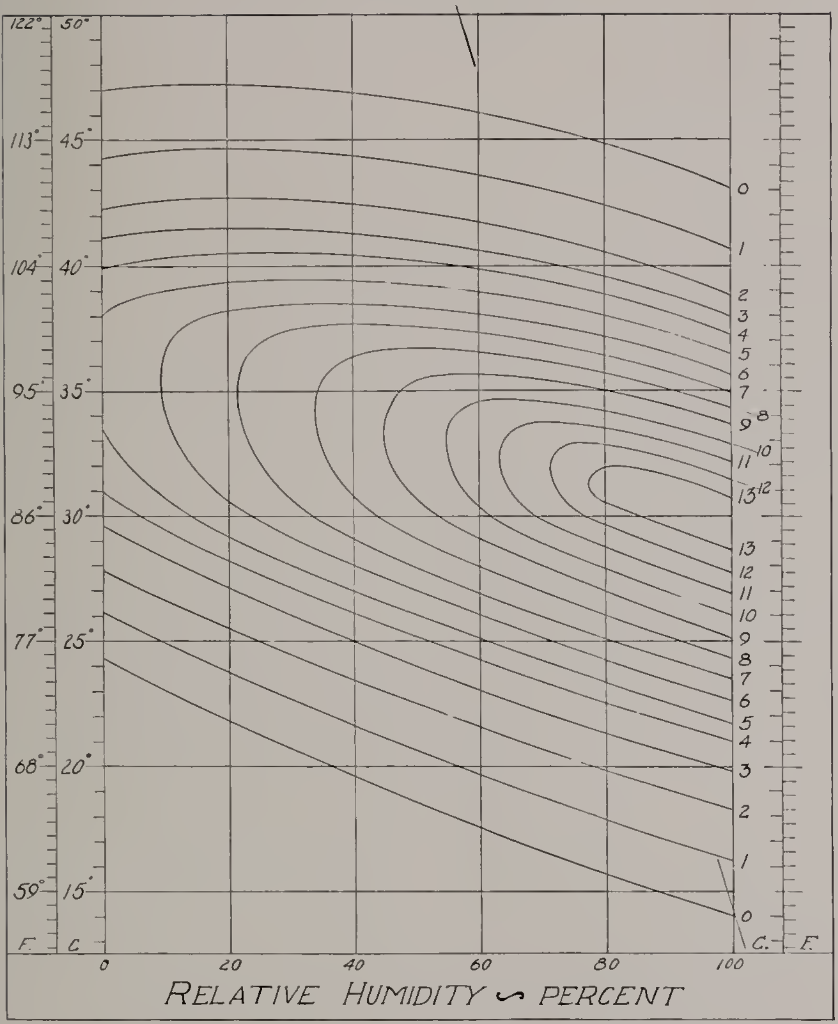

Fig. 7. Provisional chart for the fourth instar, based on a developmental total of 810 units.

of temperature and humidity for the various individuals of the stage in question under the variable-temperature experimental conditions. The development in the egg (Fig. 3) appears to respond less sharply than the various instars (Figs. 4-8).

The velocity values at the various combinations of temperature and humidity were read off these charts (Figs. 3-8) and averaged to give a set of values representing all the life history stages from the laying of the egg to the emergence of the adult, as shown in Table V and Figure 10.

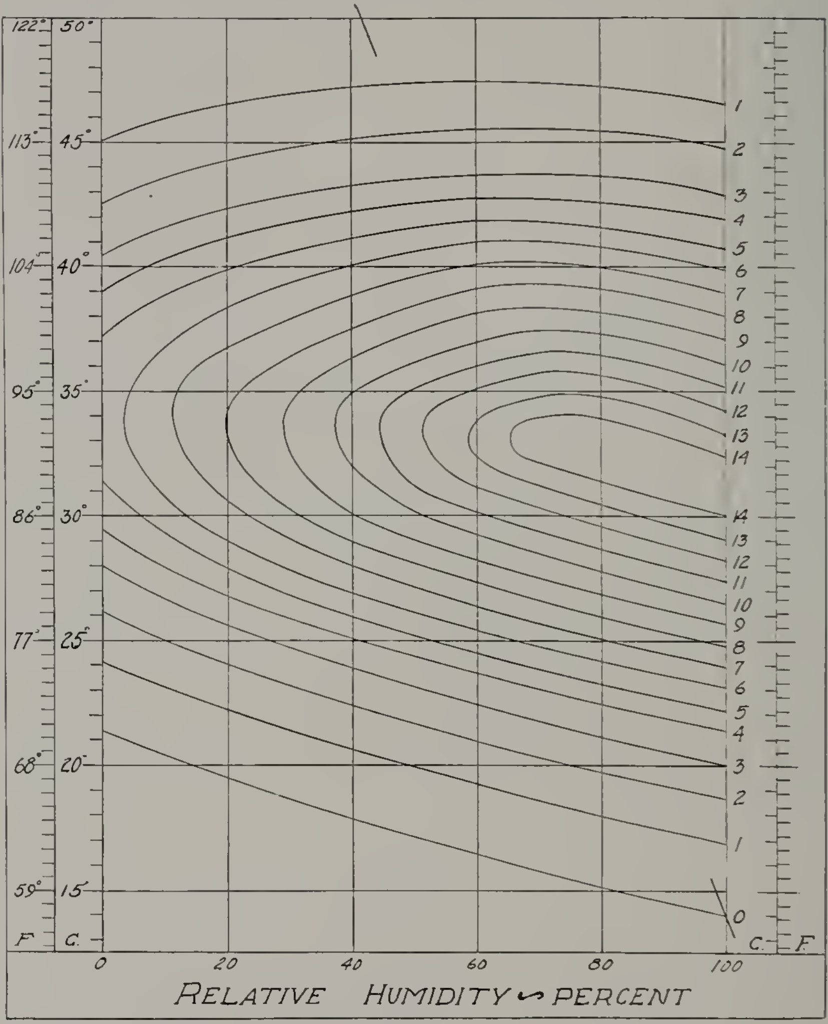

Fig. 8. Provisional chart for the fifth instar, based on a developmental total of 1400 units.

The velocity curve shown in Figure 9 was checked against the values in Table V. This velocity curve is indicated in each of the stages and represents the cross-section of a ridge-like solid on which the equal-velocity lines of Figs. 3-8 would correspond to contours. For a portion of each of these curves the relationship is a straight line (Fig. 2), and within this straight-line portion the product of time and temperature above alpha is a constant (Shelford 1927).

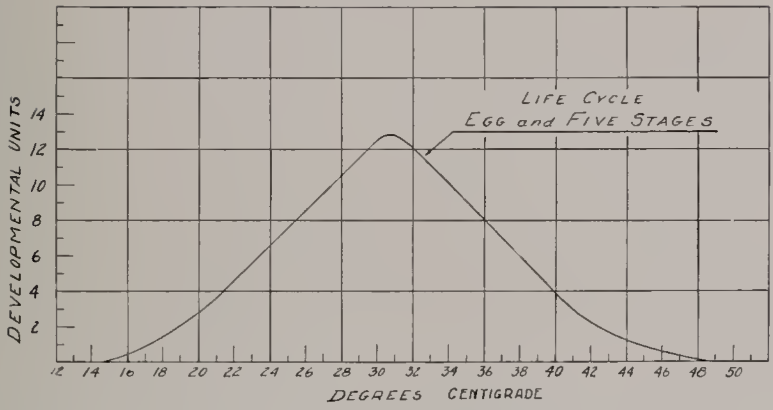

Fig. 9. Curve showing rate of development of the egg and five nymphal stages, based on a developmental total of 6800 units.

Developmental Totals

The developmental total for the life history from egg to adult is 6800 developmental units. Each unit represents the effect of one degree for one hour as indicated by results between 22° and 28°C. These are Centigrade degree-hour units, while Fahrenheit degree-hour units were used in the codling moth work (Shelford, 1927). It has been found in practice that 2-hour intervals are short enough for the purpose; hence 3400 *two-hour* Centigrade degree units are required for this life history. This figure is for temperature fluctuating 1-7°C.

The developmental total for the egg is 1500 degree-hour units, for the first stage 900, for the second stage 880, for the third stage 850, for the fourth stage 810, and for the fifth stage 1400. The sum of these is 6340, but the variation in values shown in the different charts made 6800 necessary for all stages. The sum of the average lengths of a considerable number of instars which were at approximately the same temperature and humidity was taken as a check upon Table VI. The sum of the time-temperature constants, as determined from the items from which Table VI was made, was found to vary only slightly from the average for each instar.

The pre-oviposition period has been little investigated. It is very long in the hibernating individual and relatively short in spring after emergence from hibernation, when it averages 810 of the egg-to-adult units shown in Table V. This makes the total from egg to egg 7610 units. Because of the small number of cases available in this period, it was not possible to determine the effects of variations in temperature and humidity beyond the suggestion that the effects are similar to those

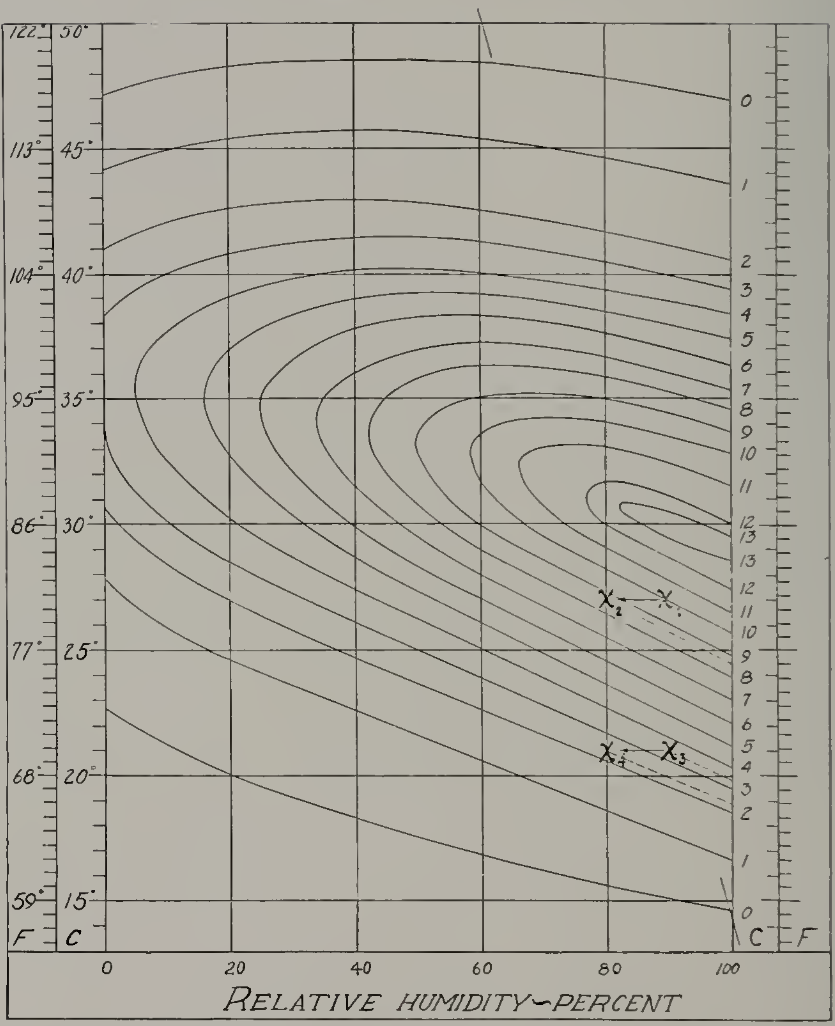

Fig. 10. A composite chart, based on 6800 units as the developmental total for the egg and five nymphal stages. The pre-oviposition period of the adult is not included.

found for the later stages. These separate instar totals for the more variable temperature experiments were checked, however, with tables made from the charts of the various instars. By substitution of the values shown on the charts for the combinations of temperature and humidity (2-hour means), totals averaging close to the figures given were obtained for the more variable temperature. These figures are provisional because there were no outdoor records of instar periods with temperature and humidity data available for checking them.

Overwintering

A considerable number of preliminary experiments with hibernating bugs had indicated that very cold conditions were not necessary; hence, mild moist conditions were mainly tried. In nearly all the years in which cultures were maintained some attempt was made to carry bugs through the winter. In a few cases the bugs were alive in the early spring, but they did not breed.

In 1921-22 an attempt was made to keep the bugs moist and under conditions similar to those out of doors. The temperature was lowered to about freezing in midwinter and then raised to a favorable point in March or April. The bugs were alive in March, but all died under favorable culture conditions.

In the autumn of 1923 the bugs from the several cultures were placed in one culture cage in Chamber A on October 30, and 200 bugs from outdoors were placed in another cage. The temperature was reduced almost to freezing and held there for two months or more and then gradually raised. The humidity was 95%, and grass kept green in the cages. No live bugs were found after March 21.

In the autumn of 1924 the cultures were all placed in the cold chamber, the air was kept very moist (90-95% R. H.) and the temperature lowered to freezing (0°C.) by the first of February. Most of the month of February was at, near, or below freezing, with the humidity high. During March the temperature was gradually raised, so that by April 27 the conditions were good for the growth of bugs. It fell to 18°C. at night and rose to 27°C. during the day. On April 10 the minimum was raised to approximately 20°C. On April 23 mating was noted, but no eggs appeared. Two out of three other cultures showed living bugs but no breeding. Each had contained from 15 to 50 bugs in the autumn.

The Cultures

The second type of investigation of chinch bugs consisted of setting up cultures under known conditions and observing them from day to day to make records of the growth of the nymphal stages and the number of generations.

In the experiments of 1917-1923, wheat was planted in the containers once or twice a week, depending upon conditions, and allowed to sprout, to supply nourishment for the bugs. Some failures were doubtless due to the deterioration of the food supply, for occasionally the wheat died rather suddenly, without sufficient time for a new supply to grow, especially in the drier experiments. Sudan grass was used in 1921 and 1925, with better results.

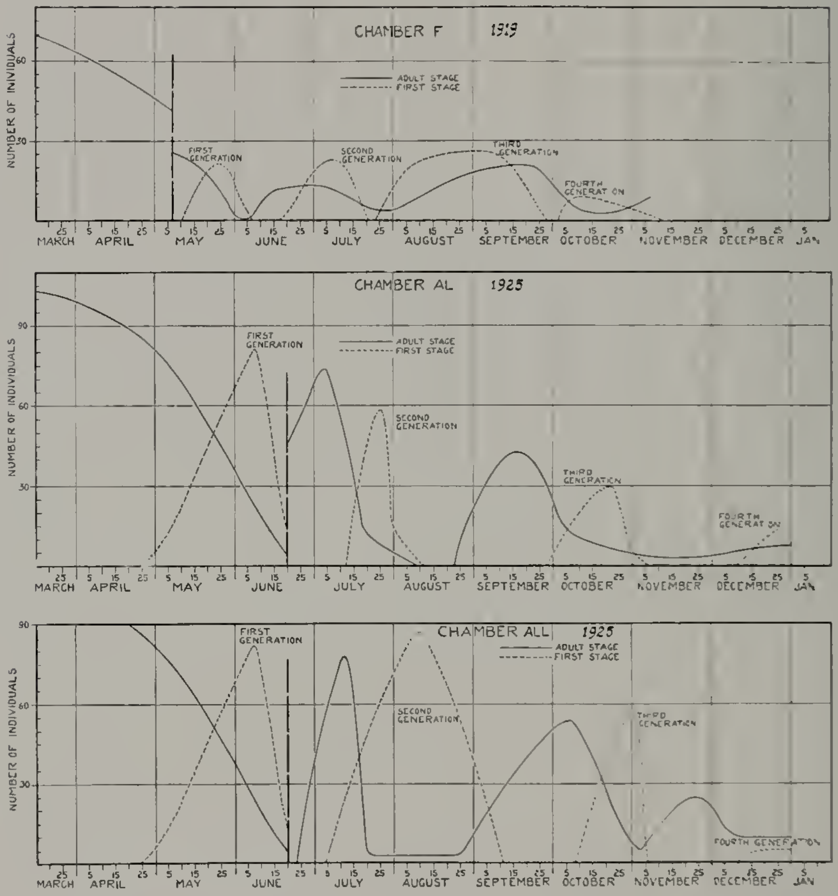

Fig. 11. Curves showing evidence of four generations in cultures in 1919 and 1925.

There are normally two generations of chinch bugs per season, but the number may be increased under favorable conditions. In Fig. 11, which shows the histories of selected cultures grown in 1919 and 1925, with the date of starting and the number of individuals present in each, there appears some evidence of a fourth generation in 1919, although there was no interim when young stages were not present in some numbers in that instance. In 1925 the nymphs that were brought in from the field were put into the experimental cages (chambers AL and ALL) on June 20. Nearly all these nymphs had then progressed to fourth and fifth stages, although a few still remained in the first stage. Thus the majority of them in chamber ALL transformed into

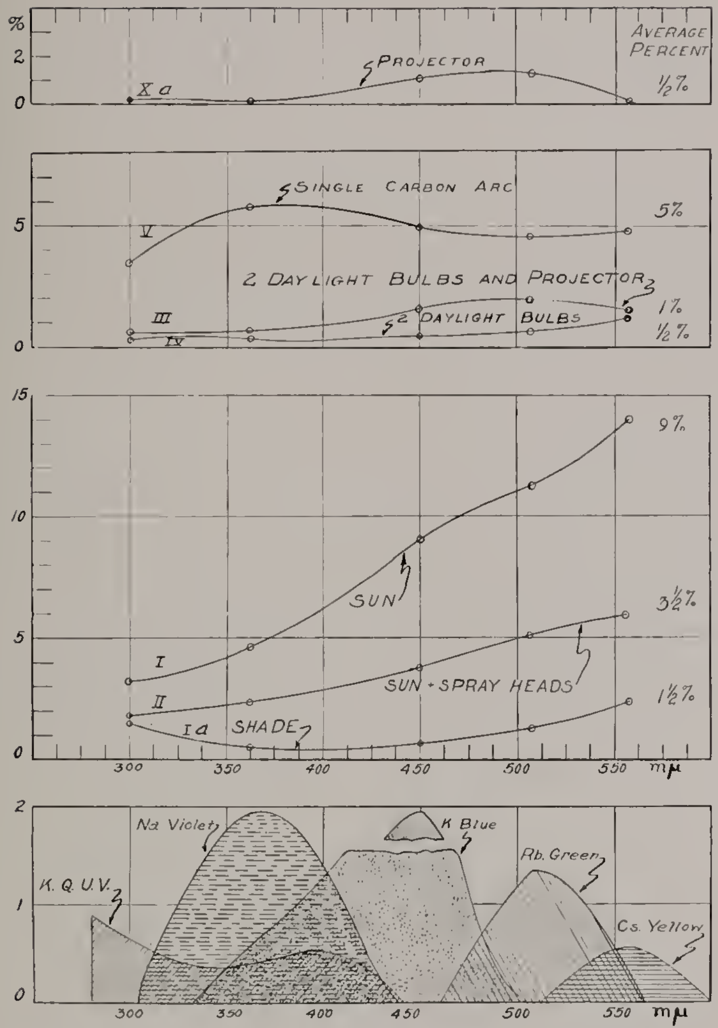

Fig. 12. Curves showing the midday light conditions in the experimental chambers (especially units A and B), indicated in percentage of the midday sunlight of clear days in early July. The measurements were made with screened photo-electric cells with the wave-length sensitivity shown below by the shaded polygons. The Roman numerals on the curves are used in Figs. 14-24 and in Table VII to designate the curves in their relations to particular experiments.

adults by the tenth of July. First-stage nymphs of the second generation then appeared in the culture, and the adults practically disappeared by July 20. Incidentally, the sex of those remaining was not determined, but the presence of males is to be expected and they would not

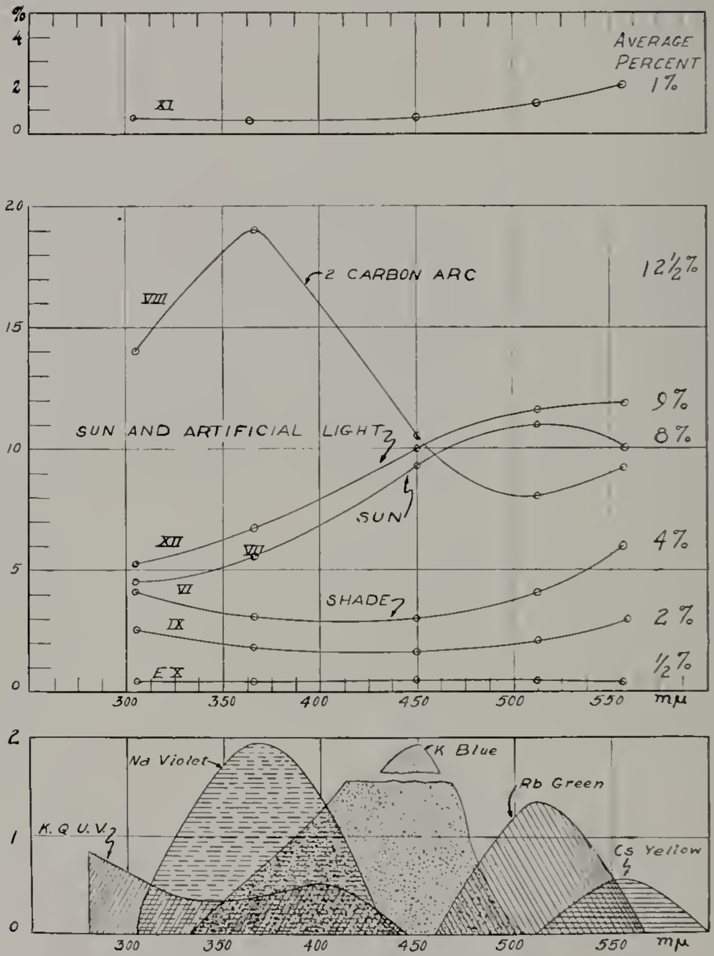

Fig. 13. Similar to Fig. 12 but with particular reference to units C, D, E, F, and G, which were small and had water tanks above and side-walls of double glass.

necessarily participate in subsequent generations as females would. By the end of August the adults began to increase again, through additions from the nymphal stages, and reached a maximum on October 5, almost at the same time that the third lot of first-stage nymphs began to appear. These nymphs reached their maximum number at the end of October and had all disappeared by November 5. The number of adults rose from a minimum at that time to a final maximum about November 25, and their decline in December was followed by the appearance of first-stage nymphs of the fourth generation. The culture in chamber XI,

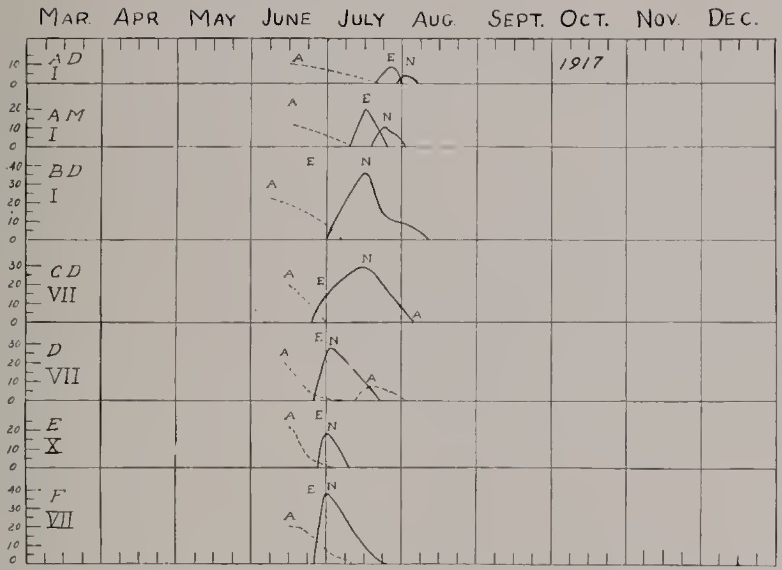

Fig. 14. Curves showing the numbers of chinch bugs placed in the cultures, and their success in breeding, in 1917. A = adults, shown by broken lines. N = nymphs, shown by solid lines. E = eggs. M = mating. Scale at left indicates numbers of individuals. The letters indicate the experimental chambers and the Roman numerals the light intensity, as shown by curves in Figs. 12 and 13. For temperature and humidity see Table VII.

had a similar history but with a somewhat shorter halt between the second and third generations. These data may not be taken as demonstrating beyond any doubt that four generations of bugs occurred. Since the primary purposes of the experiments were to observe the success of general cultures under different conditions and to provide individuals for the determination of the length of instar periods, not all of the adults were removed at the close of each egg-laying period, so that allowance must be made for the bare possibility that some of the individuals recorded as instars were rejuvenated adults. However, it is a noteworthy fact that these evidences of a fourth generation occurred in both cases with the general breeding vigor of the bugs at its highest.

Vigor of Stock

Great differences in the hardiness and fecundity of the stock are indicated by the differences in the success of the cultures shown in Figs. 14-25. In 1919 the bugs were apparently more vigorous than in 1917 and 1918, but their vigor declined in 1920 and reached a minimum in 1921, when all the experiments were started with new stock at least

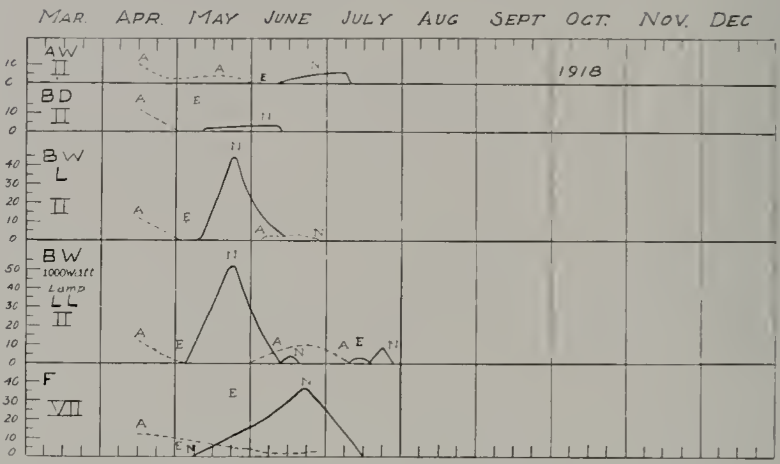

Fig. 15. Curves showing success of all cultures in 1918. For explanation see Fig. 14.

three times without success. The vigor of the bugs then rose from the minimum in 1921 to the maximum in 1925. In each year the experimental stock was obtained from the nearest infested fields, and in no case was the distance from the point of experimentation more than a hundred miles. Stock used in the first year came from Sangamon and Macon counties, where in 1917 and 1918 only slight damage was done. By the end of 1918, however, the bugs increased very greatly over the whole southern and eastern portion of the state, though they failed to do much damage in 1919 on account of unfavorable weather in the spring. The stock used in 1919 came from Christian County. In 1920, 1921, and 1922 the stocks were secured locally (Champaign County), where very slight damage occurred. In 1923 the bugs did considerable damage over a large part of Illinois, and the stocks were taken locally in that year and also in 1924. In 1925 they came from the only area which showed a severe damage to crops, near Stonington, Christian County. It is necessary to assume either that a rhythm of vigor is hereditary in the species or that the weather conditions of autumn and winter and perhaps also of early spring determine the vigor of the stock (through food or otherwise) as a physiological process. It is possible that the breeding vigor increases as the season advances, for it was repeatedly noted that the bugs brought in late in the season bred more successfully than those taken early.

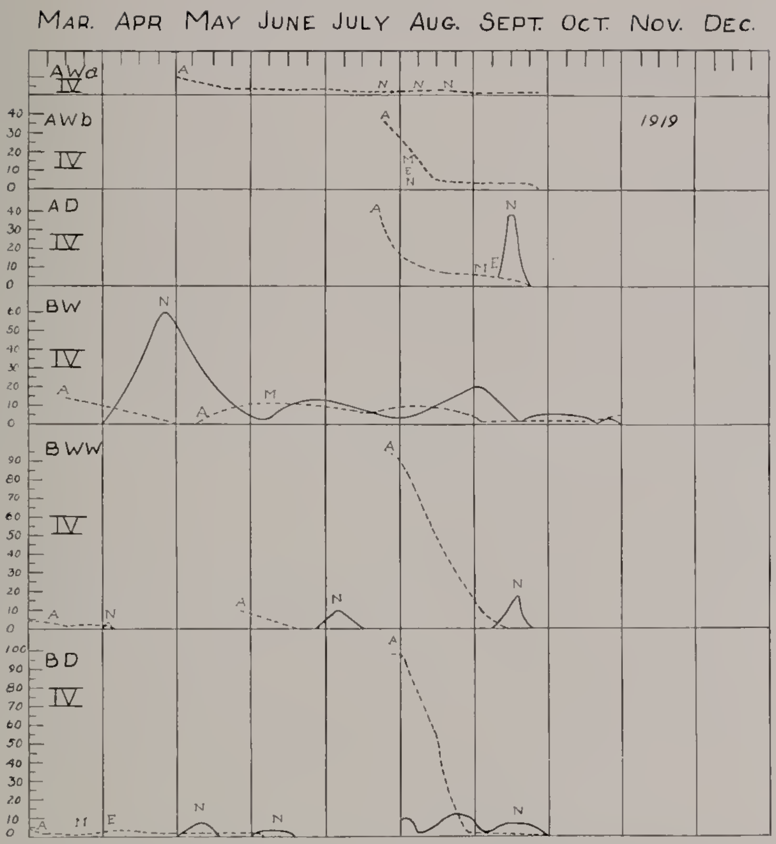

Fig. 16. Curves showing success of six cultures, AWa, AWb, AD, BW, BWW, and BD, in 1919. For explanation see Fig. 14.

Effect of Light

The behavior of organisms may be affected by the quality (wave-length) as well as the intensity of light and by variability of either its intensity or its quality. Various wave-lengths have been found recently to have specific effects upon certain organisms. Some of these specific effects have been found in extra-climatic rays, that is, those wave-lengths outside the limits of the sun's spectrum. The sun's ultra-violet diminishes to zero intensity at approximately 290 millimicrons. It is in the invisible light that most of the effects upon organisms are supposed to be found, largely because of the noteworthy effects upon rickets and the development of vitamins in cow's milk, etc. It is true also that other wave-lengths, particularly some of the invisible heat waves, have specific effects. Furthermore it is well known

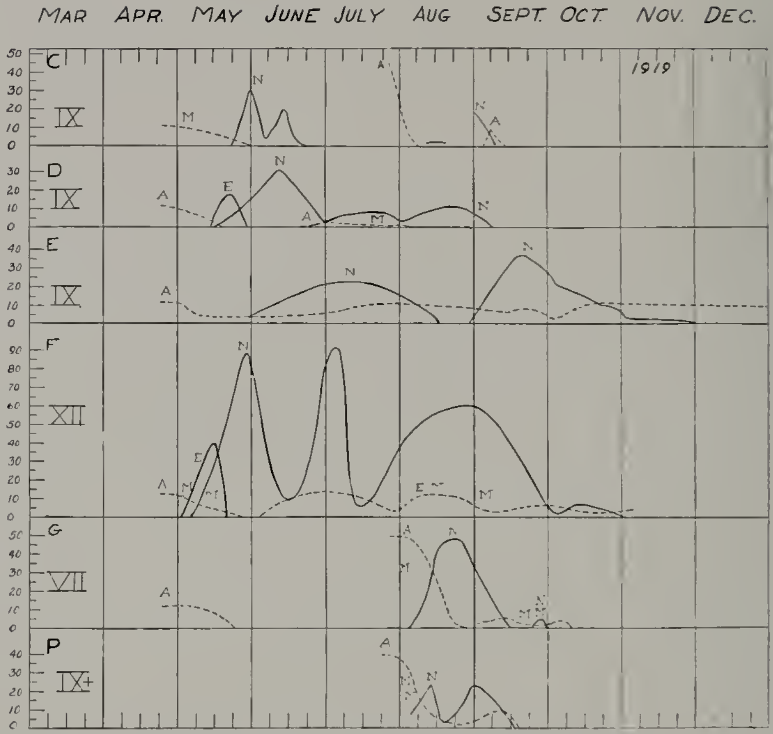

Fig. 17. Curves showing success of six cultures, C, D, E, F, G, and P, in 1919. For explanation see Fig. 14.

that various wave-lengths in the visible spectrum have different effects upon animals and upon certain insects, as shown by their size and success so far as survival and reproduction are concerned.

Unfortunately, window glass does not transmit wave-lengths shorter than 320 millimicrons, and when the sunlight must pass through three thicknesses of glass as in all containers in these experiments, most of the short wave-lengths are eliminated, especially those known to be effective in influencing organisms. The newer kinds of glass transmitting short wave-lengths were not put on the market until near the close of these experiments. Fused quartz, which transmits all wave-lengths practically without selection, was available only in very small pieces and at too great cost. Unfortunately, the conditions under which the experiments were carried on were such as to reduce the intensity of light very greatly. The greenhouse roof was found to transmit only 40 to 60% of the sunlight, and this of course with the short wave-lengths eliminated. The experimental chambers

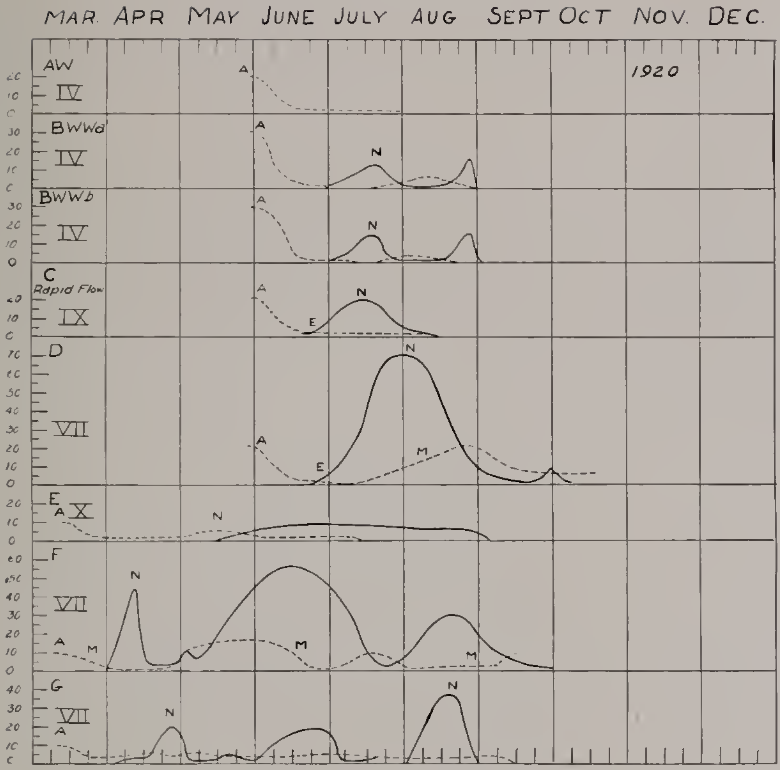

Fig. 18. Curves showing success of all cultures in 1920. For explanation see Fig. 14.

were supplied with double and triple window-glass sides and roofs. The containers themselves had window-glass sides and tops. Thus there were at least three and even four thicknesses of glass between the sun and the chinch bugs. This reduced the light to 10% or less, depending upon the hour of the day and other conditions. In addition, the framework of the greenhouse roof, of the constant-temperature chambers, and of the glass-sided culture cages, all cast shadows from time to time over the food plants and the insects under experimentation.

In this connection mention should be made of the difficulty of maintaining constant or nearly constant temperature in a greenhouse which goes to 43 or 45°C., especially when it is taken into account that a closed chamber exposed to the sun inside such a greenhouse would go to 55°C. or more if uncooled and without air circulating through it. In order to maintain temperatures at points between 20 and 30°C. it is necessary, therefore, not only to circulate the air in the chambers but also to provide some method of cooling. The efficiency of the

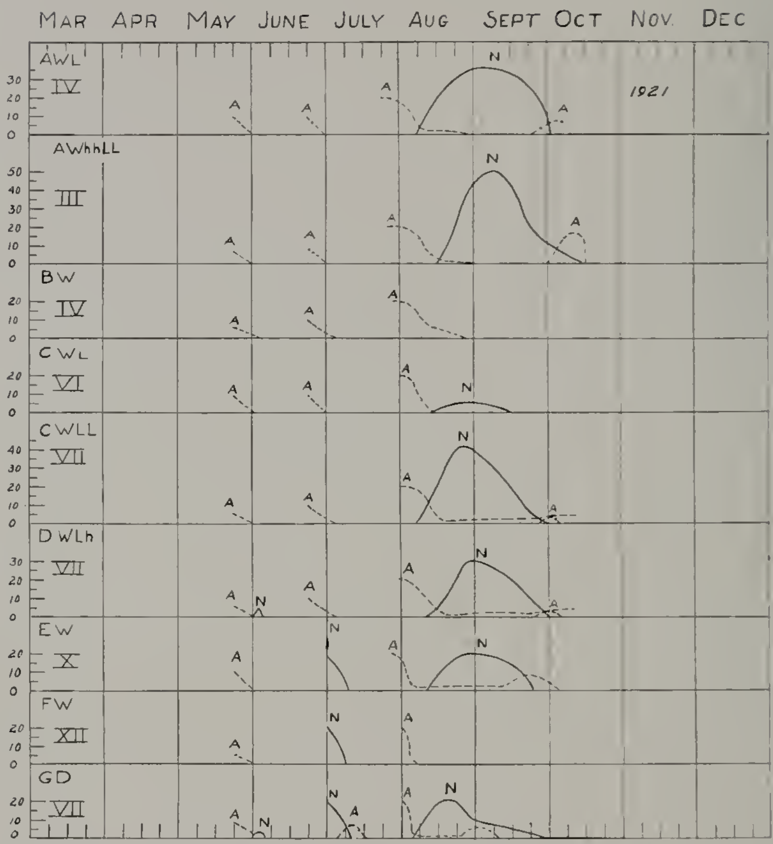

Fig. 19. Curves showing success of all cultures in 1921. For explanation see Fig. 14.

apparatus available, while supposedly adequate, was so low as to necessitate the addition of spray-heads to cool the glass sides and in some cases the tops of the units. This reduced the light intensity very materially, through reflection and partly by the dirtying of the glass with iron from the well water used. The tops of the variable-temperature chambers were provided with water tanks made of glass, with automatic controls so that more water flowed through the tanks when the temperature was high. The light was thus filtered through water two or three inches deep, and the accumulation of iron on the bottoms of these tanks resulted in a still further decrease of the transmitted light, in spite of cleaning two or three times daily. It is apparent, therefore, that the apparatus available, either on the market or installed at the time these experiments were begun, was altogether inadequate for the control of light.

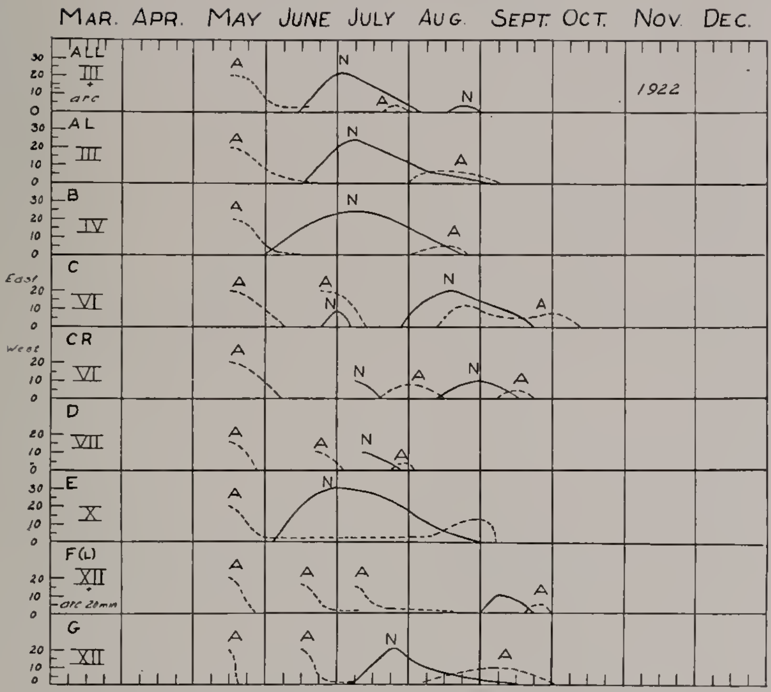

Fig. 20. Curves showing success of all cultures in 1922. For explanation see Fig. 14. In culture ALL, the white flaming arc was applied for a period which was increased from 10 to 30 minutes as the days shortened after June 21. In culture CR the flow of air was rapid and the evaporation high.

Artificial light was supplied from nitrogen-filled, clear-glass and "day-light" lamps and by white flaming arc lamps, such as are used in making motion pictures. On account of the large amount of heat produced by the nitrogen-filled lamps it was impracticable to install any but those with relatively low wattage inside the chambers with controlled temperature. When any of these lights were installed outside the chambers, the light reaching the cultures was greatly reduced by the three or four thicknesses of window-glass which intervened.

Unfortunately, when the experiments were being planned, no method of measuring the quality and quantity of light was at hand. It was not until the close of the experimental work that methods were developed to a point where they could be utilized. Accordingly, the amount of artificial light supplied in the form of Mazda lamps was far smaller than would otherwise have been selected. The instruments used in measuring light were the photo-electric cell and the Macbeth illuminometer, which was used a little beginning in 1922. Previous to that time no measurements were made.

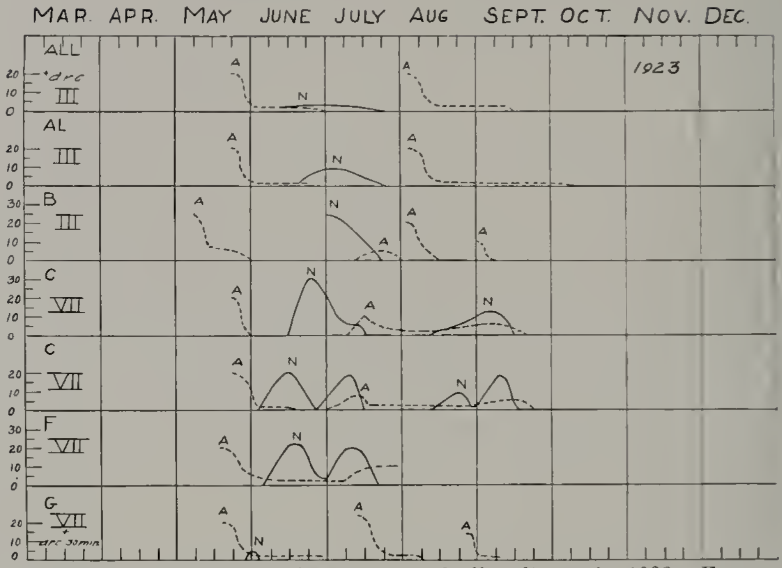

Fig. 21. Curves showing success of all cultures in 1923. For explanation see Fig. 14. The arc was applied to culture ALL 5 minutes per day and to culture G 30 minutes per day.

After the close of the experiments, however, the entire series of illumination types were checked over with a set of photo-electric cells made by Professor Jakob Kunz of the Department of Physics. The development of these cells involved a large amount of investigation, an account of which has been published elsewhere, and in the end the forms of the cells were such that only a type developed after the experiments were finished could have been used to record light continuously within the experiments. This is due to the fact that the ordinary type cell has an area of sensitive surface and an aperture similar to that of the eye, that is, a circular aperture, opening to a hollow sphere sensitive on the inside. The cell which might be used for recording of light intensity in biological work has a fully exposed hemispherical convex surface. Cells of the concave type mentioned above were placed so as to face the sun in connection with an apparatus which turned on artificial lights shining on the experiments whenever the sun was obscured by a cloud. The measurements made with the photoelectric cells were continued with the cells covered with ray-filters of colored glass—red, yellow, green, blue, violet, and ultra-violet—each of which transmits principally the colors named. Finally, in the early part of July, 1925, series of measurements were made on clear days to

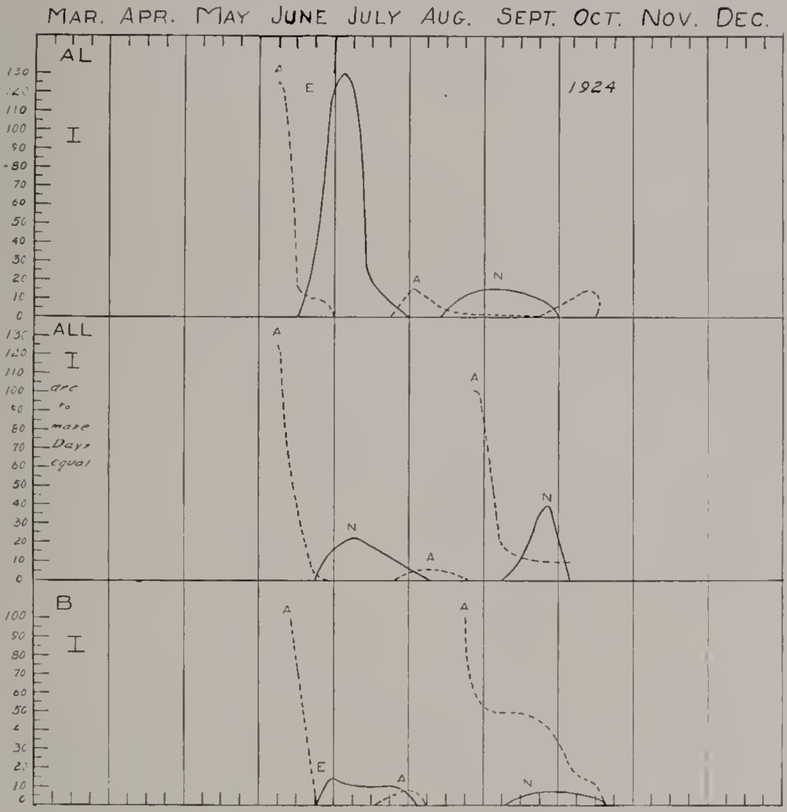

Fig. 22. Curves showing success of three cultures, AL, ALL, and B, in 1924. For explanation see Fig. 14. The arc was applied to culture ALL long enough to make days equal and to culture F 30 minutes per day.

compare the intensity of sunlight with the light passing through the greenhouse roof and the walls of the various chambers and cages in which the chinch bugs had been reared.

The light conditions thus determined for the different experiments are shown in Figs. 12 and 13, and the results obtained with cultures under these conditions are shown in Table VII. The amount of light is expressed in the table as the percentage of noon sunlight in early July. The percentages given are the percentages at noon. It must be understood that the light declines much more rapidly in the afternoon and increases much more slowly in the morning in these enclosures than in the open. In Figs. 12 and 13 a correction has to be made for the graphs indicating fairly high intensity of light at 305 millimicrons because, as shown in the lower graph, while this is the highest point

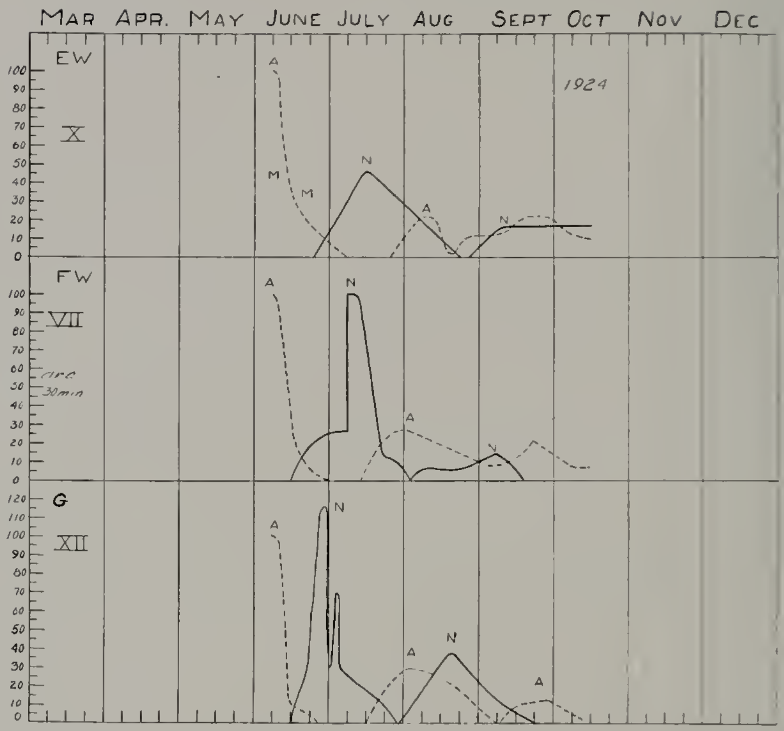

Fig. 23. Curves showing success of three cultures, EW, FW, and G, in 1924. For explanation see Fig. 14. The arc was applied to culture ALL to make days equal.

in the curve the sensitivity of the cell and screen reaches to 425 and the second maximum at 400. The sodium cell of the "ultra-glass" probably measured practically all the light indicated. The white flaming arc, which was used in A wherever noted, is particularly intense in the violet, the proportion being in excess of that of daylight.

The light conditions appear to have had relatively little effect upon the chinch bugs; that is, the difference between the results at 8% and at 9.5%, as indicated by the experiments in 1917 (Fig. 14), is as great as the difference between the results at 12% and at 0.5%. Again, in 1918 in culture BWL (Fig. 15), 3% was less successful than 5%. Further, in 1919 (Figs. 16 and 17), 0.5% in culture BWW was almost as successful as 9% in culture F. The temperatures in the latter were doubtless more favorable. In 1920 (Fig. 18) bugs in F were somewhat more successful in maintaining a population than those in G, and the day was longer in F than in G. In 1921 (Fig. 19) there is only a slight difference between 0.5% and 1% in chamber A. The bugs in

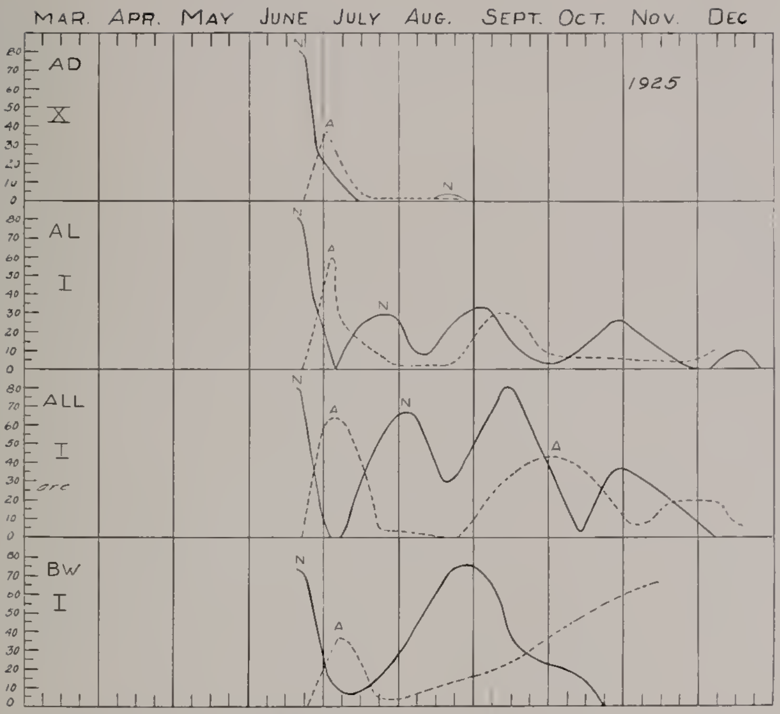

Fig. 24. Curves showing success of four cultures, AD, AL, ALL, and BW, in 1925. For explanation see Fig. 14.

chamber C flourished better under the stronger light. The results in 1922 (Fig. 20) indicate that the bugs in A were favored in one case by an extended day produced by the white flaming arc, but in F and G the results were better with less light. In 1923 (Fig. 21) the two identical cases flourished best without the use of the arc in A, while in F and G the arc appears to have favored the development of the bugs. In 1924 (Fig. 22) the results in A with the use of the arc were not as good as without it. The same is essentially true in F and G. In 1925 all cultures were unusually successful, there being little difference between those in which the arc was used and those in which it was not used, and the light which was turned on automatically when the sun went under clouds appeared to have little effect. All cultures in this year were especially vigorous, as was the case also in 1919. Sudan grass, which was utilized for food in 1924 and 1925, is probably better for such experiments than is wheat, which was used in earlier years; but a comparison of the results in 1919 and 1925 with those of other years indicates that apparently the vigor of the bugs is an outstanding cause of the differences in success.

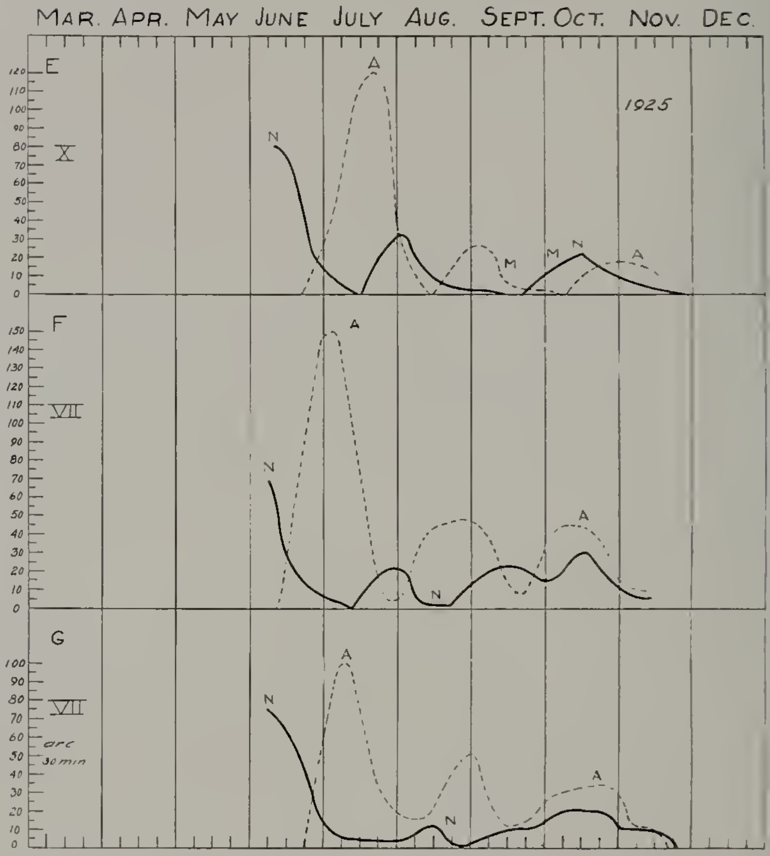

Fig. 25. Curves showing success of three cultures, E, F, and G, in 1925. For explanation see Fig. 14.

In container E, which was run every year with about 0.4% of noon sunlight at noon, the cultures showed a better development, with one or two exceptions, than some of the other cages with much more light. It stands out strikingly in every year. In 1919 (Fig. 16) the E culture was somewhat slower, but nearly as good as the F culture. In 1920 (Fig. 18) the E culture made as much development as some of the lighted cultures. In 1921 it held its own fairly well, and in 1922 (Fig. 20) it was one of the most successful of the cultures. A, B, C, and E were the only cultures which did not have to be started two or more times in 1922 due to failure. Culture E, although provision for which was accidentally omitted from Fig. 21, in 1923 made as good a showing as F of the figure.

All of these facts seem to indicate that intensity of light is not a very important direct or indirect factor within the limits tested in these experiments. It is true that very little of the light of shorter wavelengths could pass through the three or four thicknesses of window-glass covered at all times with dust and dirt which unavoidably accumulated.

An examination of Table VII and the culture graphs in Figs. 14-25 shows no consistency as regards the effect of light and only a little as regards other factors. Usually the addition of more light gave a little better culture. Usually the higher humidity gave best results, but the results on the whole are inconsistent. This is probably due to differences in the food plants, the occasional growth of other insects in the cultures, etc.

ABUNDANCE IN NATURE

The distribution area of chinch bugs includes the eastern half of the United States, and the area in which they do greatest damage to crops is in the central part of the Mississippi Valley. There are records of occurrences of single and scattered bugs in Mexico and Central America and in the western parts of the United States and occasionally in southern Canada.

History in Illinois

The records of chinch bug outbreaks in Illinois date back to 1840, when there was slight damage to crops in the western part of the state. There was some damage near Springfield, in the central part, in 1844, and in the west-central and northeastern parts in the following four years, 1845-1848. The next period for which the records indicate considerable damage covered seven years, 1853-1859. Another outbreak started in 1861 in the northern part of the state and covered several localities in 1862, one of which was in the extreme north and another in the extreme south. Several outbreaks occurred in 1864 and 1865, but the state remained free from complaints of damage during the next five years. In 1871 there was a severe outbreak covering all the north-central portion, and this was followed by damage over practically all the state for three succeeding years, 1873-1875. The chinch bugs then practically disappeared for five years but suddenly came forward in great numbers in 1881 and 1882. After another decline they began again to do heavy damage in the southern half of the state in 1885, and by 1888 the whole state was subject to extreme damage, but the bugs were very scarce in 1889 and 1890. Except for moderate outbreaks in 1891 and 1894, they were on the decline for a decade and remained at very low ebb for another decade. The next important outbreak had its beginning in 1909 and lasted until 1919, persisting

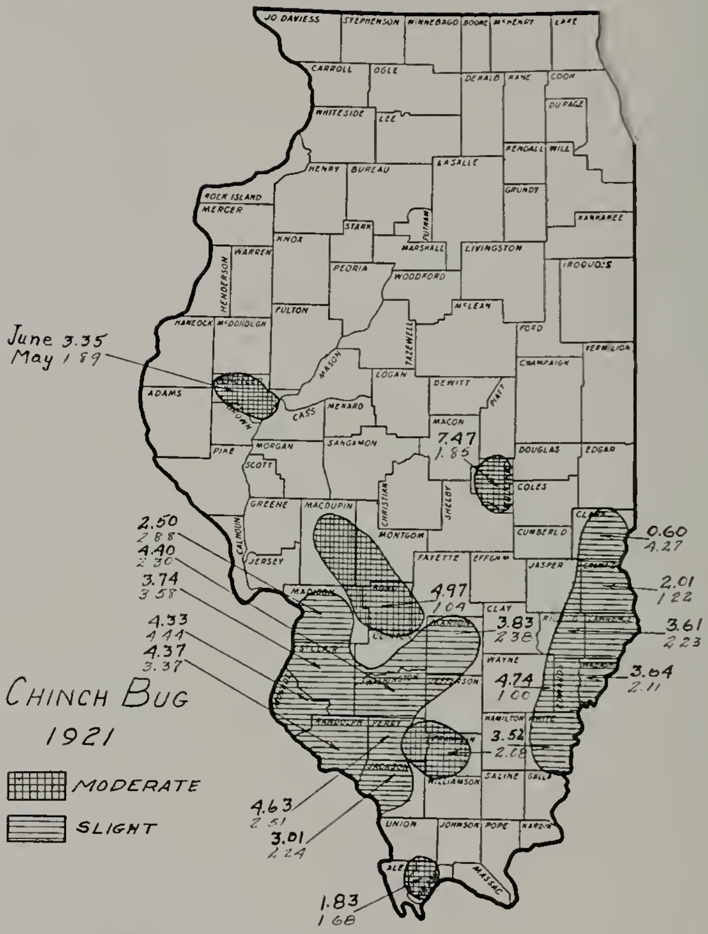

Fig. 26. Map of Illinois showing reported areas of damage to crops by chinch bugs in 1921, together with inches of rainfall in May (lower figures) and in June (upper figures) in each locality.

through this entire period in Washington County and the adjacent areas. The areas of infestation shifted considerably in 1920 and gradually spread for four years in patch-work fashion over the state. During most of this period Christian County was the center of devastating outbreaks. The chinch bugs declined in 1925, and while they did some damage in 1927 they continued to decline to a minimum in 1929. This was followed by a very material increase during the summer of 1930, though it came too late in the season to do any damage to crops.

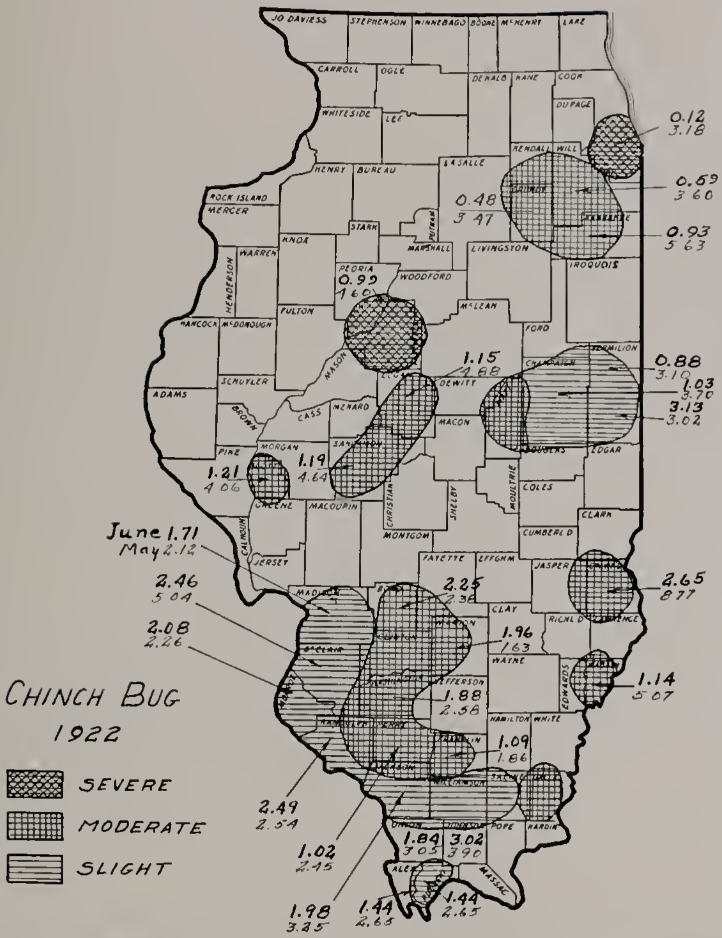

Fig. 27. Map of Illinois showing reported areas of damage to crops by chinch bugs in 1922, together with inches of rainfall in May (lower figures) and in June (upper figures) in each locality.

Figs. 26-30 show the distribution of infested areas from 1921 to 1925. The erratic shifting of the areas of abundance from year to year is characteristic and has to be explained on the basis of favorable weather and either the perennial presence of the bugs or their flight from infested areas. In the southern half of the state the former is the more likely explanation.

Weather Relations

The fluctuations in abundance of chinch bugs have long been associated with weather conditions. The early writers refer to late spring rains as causing the destruction of the bugs. It was pointed out

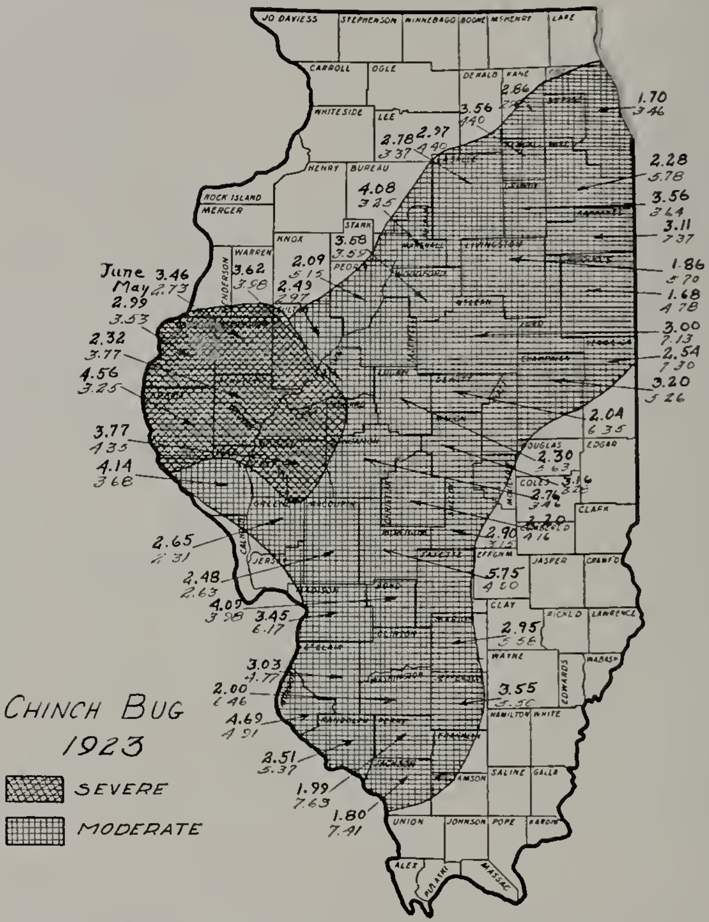

Fig. 28. Map of Illinois showing reported areas of damage to crops by chinch bugs in 1923, together with inches of rainfall in May (lower figures) and in June (upper figures) in each locality.

by Thomas (1879) that a dry May and June and two dry summers are essential to the development of excessive numbers of these pests. Though they are apparently absent from large areas in spring, the small numbers which are present in a given area may develop rapidly if the season is very favorable and may increase to enormous numbers by autumn, and enough of them may survive the winter to build up a population that will do a great deal of damage in the following year even if the weather then is adverse. The variation in vitality and fecundity referred to above is, however, a subject for the most careful investigation from a physiological viewpoint. Their decline is probably

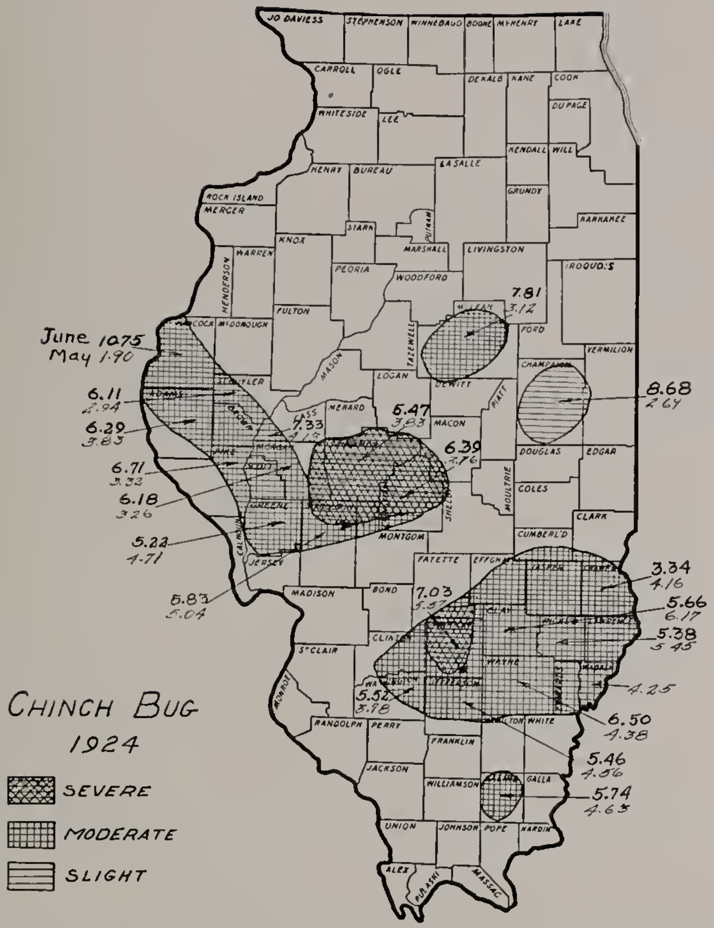

Fig. 29. Map of Illinois showing reported areas of damage to crops by chinch bugs in 1924, together with inches of rainfall in May (lower figures) and in June (upper figures) in each locality.

less closely correlated with external conditions than is their rise to abundance, but both are not so simple as was commonly supposed in the past. In some years the bugs practically disappear from most localities in Illinois, so that specimens can hardly be found. In the last 20 years the only area in which it has been possible to find bugs at all times is an area in the southwestern part of the state, east of St. Louis, reaching into the western half of Marion County and Fayette County, the southern half of Christian County, and the northern half of Washington County.

The importance of late spring rainfall has been confirmed by the writer's examination of weather records for localities in Illinois and

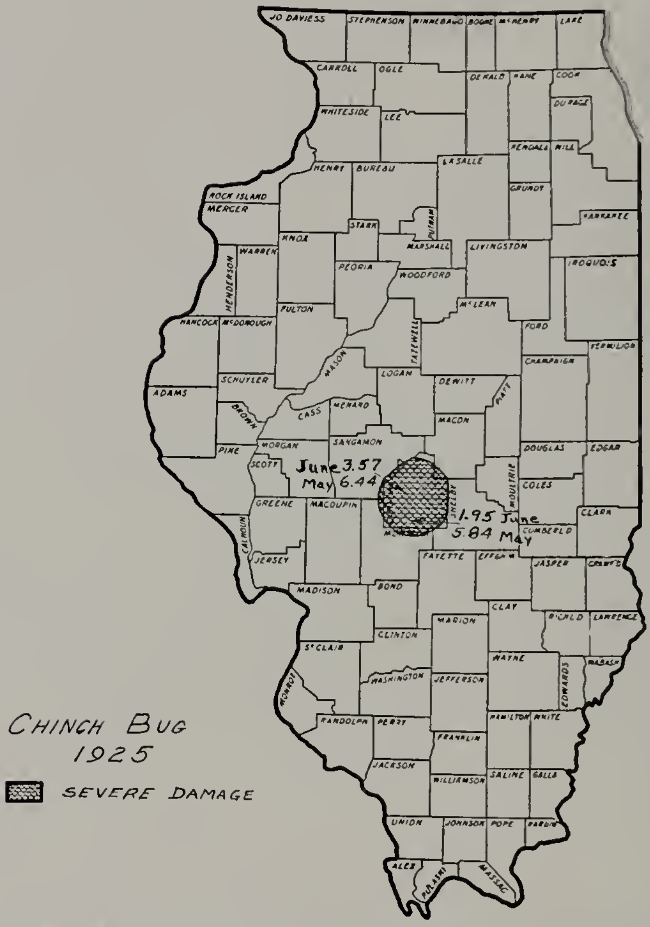

Fig. 30. Map of Illinois showing reported area of damage to crops by chinch bugs in 1925, together with inches of rainfall in May (lower figures) and in June (upper figures).

elsewhere. An exhaustive study was made of the data for periods of abundance and scarcity of bugs as indicated by reports of damage to crops in various parts of the state since 1853. Special analysis was given to a very large number of cases in which a year of severe damage was followed by a year of no damage, and to an almost equally large number of cases in which the reverse was true. In each case a hythergraph was made, according to the plan used in the study of the codling moth (Shelford, 1927), by plotting the mean temperature against the mean rainfall for each month of the year. The results are summarized in Figs. 31-34.

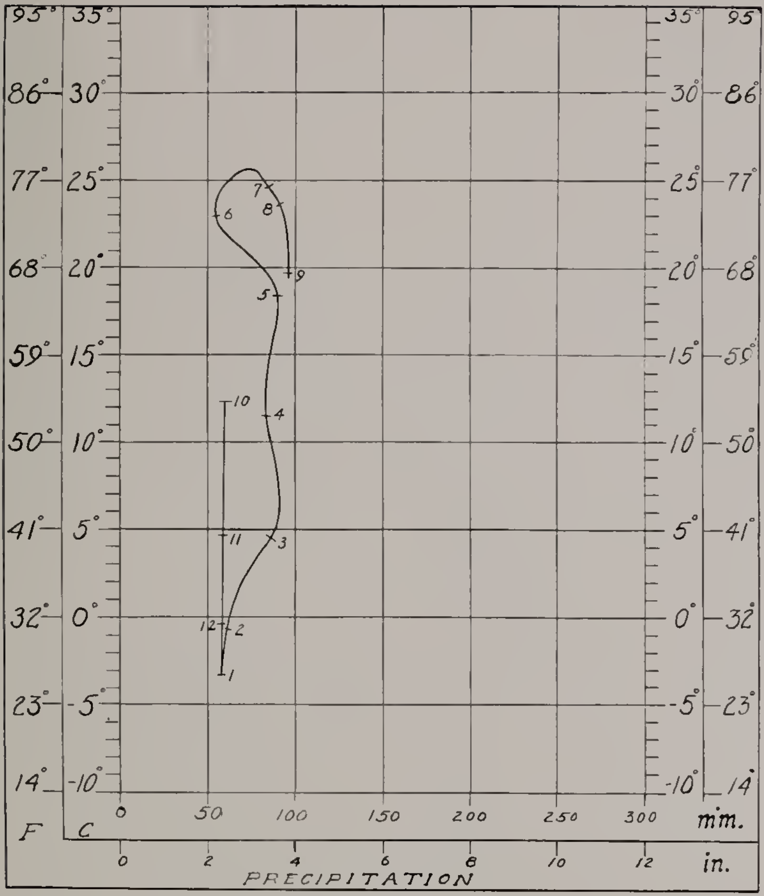

Fig. 31. Hythergraph showing average conditions in years in which damage to crops was severe.

Fig. 31 shows the mean march of local temperature and rainfall from month to month, beginning with October (10) and ending with September (9), in years of severe damage to crops in Illinois. Here it is noteworthy that May (5) is relatively dry and warm, the rainfall averaging approximately 3.5 inches, or 83 mm., and the temperature averaging approximately 18°C. June (6) is still drier, with only a little more than 2 inches rainfall, so that the line swings to the right in July and August.

In Fig. 32, which represents average local conditions in years of no damage by chinch bugs, the rainfall is seen to be heavier in spring than in summer. The mean for May is 4.7 inches, or 117 mm., and for

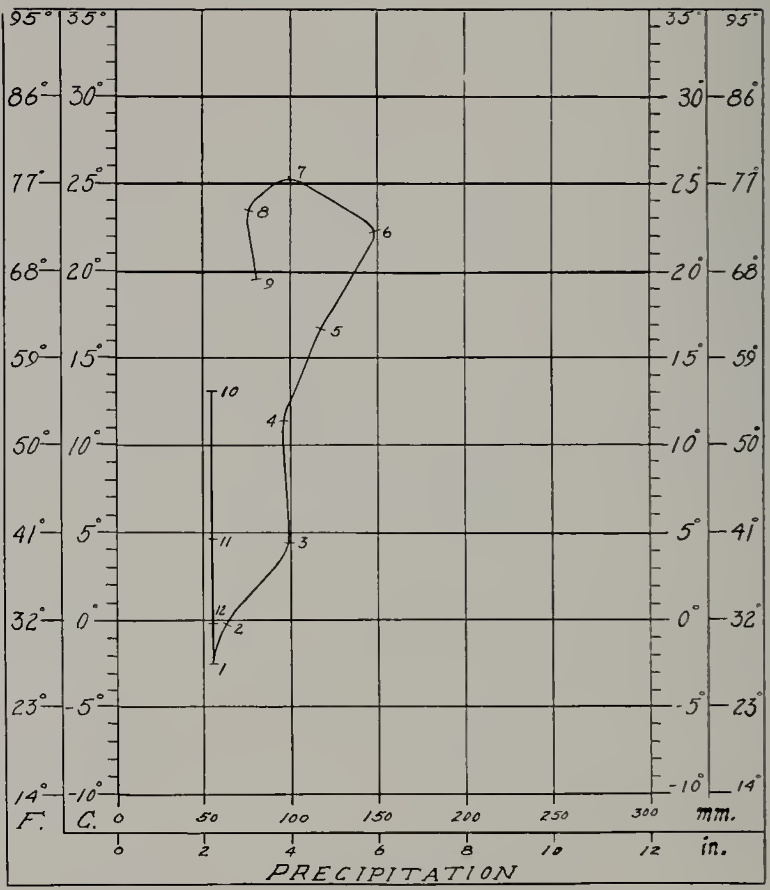

Fig. 32. Hythergraph showing average conditions in years in which no damage was done to crops.

June it is almost 6 inches, or almost 150 mm. The trend in July and August is toward the left, the reverse of the trend in Fig. 31. The temperature in May averages about 17°C.

Numerous exceptions to these general rules for May and June may be noted in Figs. 26-30. Evidently the amount of rainfall in May and June is not the only factor in the abundance of the bugs. Temperature also must be taken into account, and some allowance should be made for the relative vigor of the bugs. For further light on this problem, periods of waxing abundance may be compared with periods of waning abundance, as follows: Fig. 33 is a generalized picture of conditions favorable to development of chinch bugs *in the following year*. This

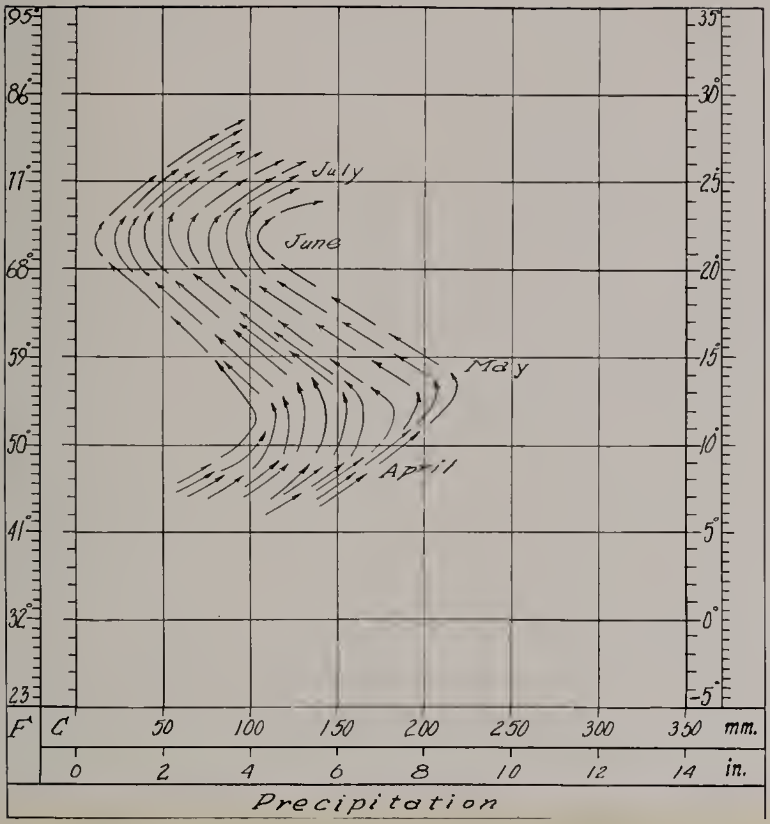

Fig. 33. Hythergraph showing average conditions in years of abundant bugs and severe damage. The diagram is formed from data on such years when preceded by one or more years of no damage.

is based on a detailed analysis of 90 cases in which a scarce year was followed by an abundant year. The mean monthly rainfall in May ranges from 4 to 8 inches, or from 100 to 200 mm., but June is decidedly drier than May, and the trend after June is toward the right-hand side of the figure. It is evident that there is considerable truth in the contention that two dry years are prerequisite to a chinch bug outbreak. Indeed, the June of the year preceding an outbreak is usually drier than the June of the outbreak.

Fig. 34 represents the results of an analysis of 96 cases in which a scarce year was preceded by an abundant year. Here the rainfall is relatively great in May and June, and the general trend is the reverse of that found in Fig. 33. Decline of bugs in years with little rainfall in May and June was no doubt due to other adverse factors.

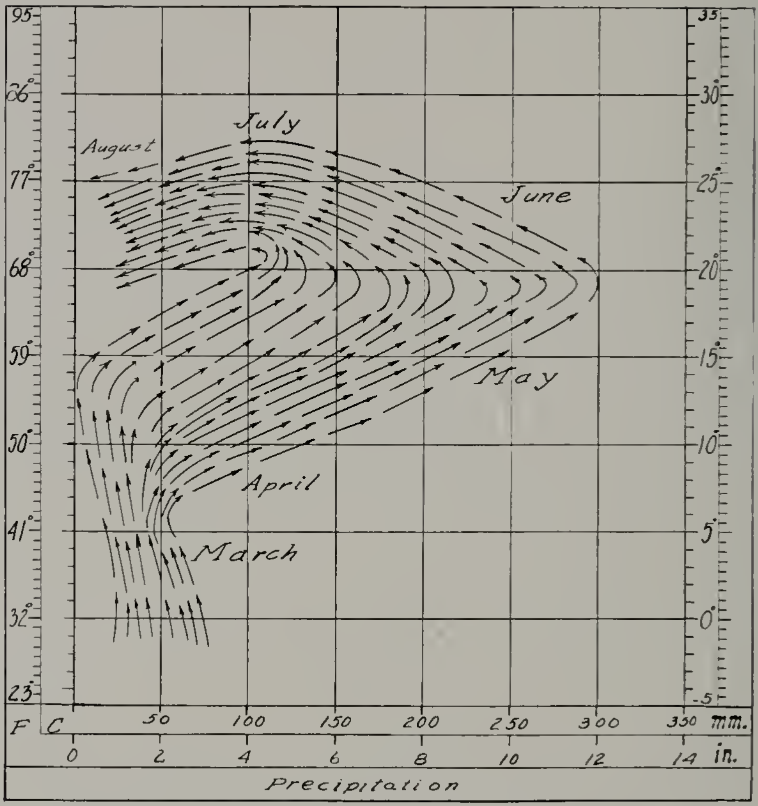

Fig. 34. Hythergraph showing average conditions in years of no damage that were preceded by years of severe damage.

Only a few exceptions to the usual seasonal trend were found. In 1919, after a year of no crop damage, the bugs became very abundant and caused severe damage in spite of the comparatively large amount of rainfall in May. The rainfall was distributed over 16 days of that month, and at many stations in the infested area it ranged from 5 to 9 inches, but it may have missed the critical period of the bugs very generally. Other examples in which heavy spring rains failed to stop the progress of the bugs may be seen in the maps for 1921 and 1924 (Figs. 26 and 29), in which it appears that the rainfall was sometimes greater in the counties where the damage was severe than in the counties where it was moderate or slight.

There is no evidence that low temperatures or other conditions in the winter months have material effects on the abundance of chinch bugs in the following season. At least, winter temperatures as repre-

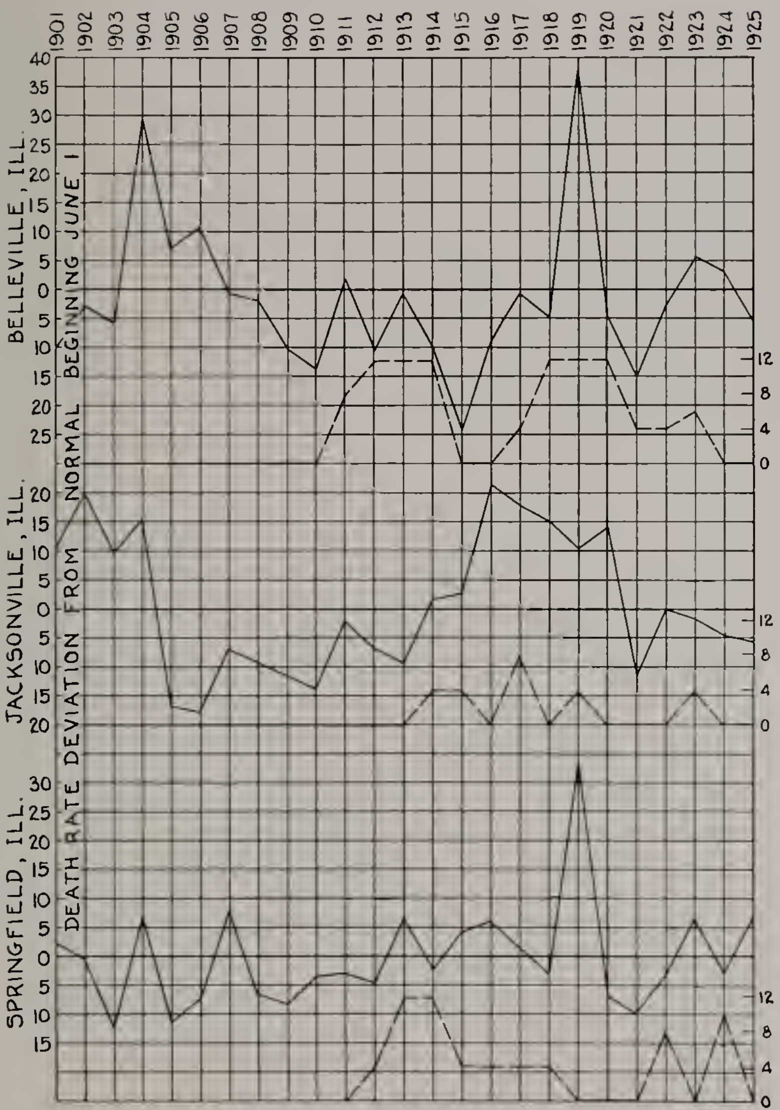

Fig. 35. Graphs suggesting correlation between human death rate in Belleville, Jacksonville, and Springfield, 1901-1925, and chinch bug damage to crops in each locality during a part of this period. The solid lines indicate deviation from the normal death rate for each city and refer to the scale of percentages at the left. The broken lines, indicating degrees of damage to crops in the county in which each city is located, refer to the scale at the right, which consists of relative values assigned to the several degrees of reported damage, as follows: 4 = slight; 8 = moderate; 12 = severe. The bugs were very scarce in the first decade.

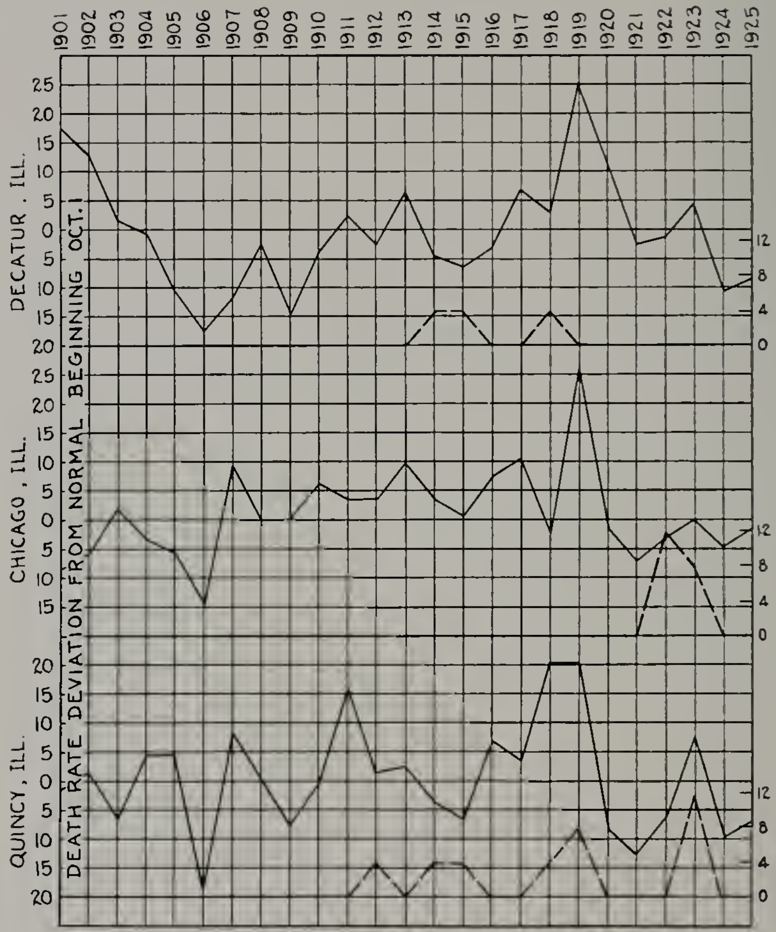

Fig. 36. Graphs suggesting correlation between human death rate in Decatur, Chicago, and Quincy, 1901-1925, and chinch bug damage to crops in each locality during a part of this period. For explanation see Fig. 35. The bugs were very scarce in Macon County and Adams County during the first decade and in Cook County during the first two decades.

sented by monthly means do not appear to affect abundance. This was checked for Virginia, Wisconsin, and Ohio as well as Illinois. Bugs have done severe damage following unusually cold winters in Beloit, Wisconsin, and unusually warm winters in Virginia, and the opposite extreme in both places.

A great deal of attention was given to examining old records with a view to learning more about the way in which weather controls the chinch bugs. This, however, proved not to be very profitable. The

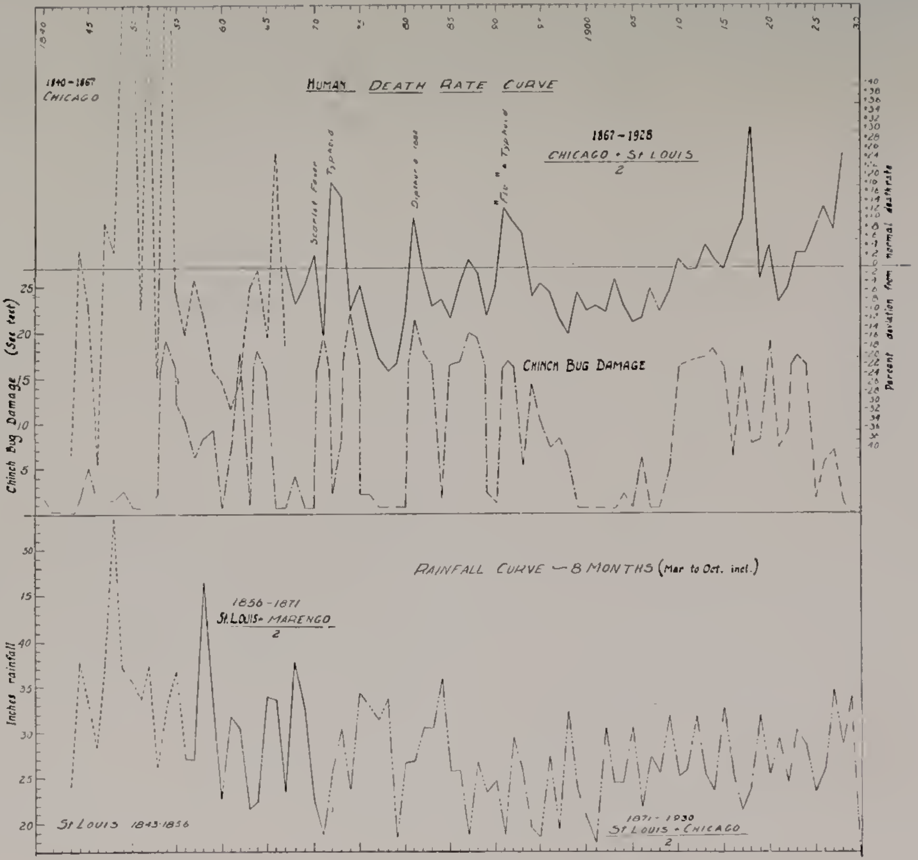

Fig. 37. Graphs showing variations in human death rate and rainfall in Chicago and St. Louis, and in chinch bug damage throughout Illinois, 1840-1930. The death rate in Chicago alone from 1840 to 1867 (dotted part of first curve) and in Chicago and St. Louis (averaged) from 1867 to 1928 (solid line) is indicated with reference to the scale at the right. The chinch bug damage is represented by the dash-dot line with reference to the scale at the left, the construction of which is explained in the text. The lower broken line indicates the rainfall in St. Louis alone from 1843-1856, the average for St. Louis and Marengo from 1856 to 1871, and the average for St. Louis and Chicago from 1871-1930.

chinch bugs are of such a character that they can be killed off in numbers by the rain of a single night, and it is impossible to know the distribution of rain from the older records, as the rain from day to day is not given. After gathering a large amount of information from literature, from colleagues in other states, and from the records of the State Entomologist's Office, it was decided that further pursuit of this line of work was not advisable. Any further light thrown on this aspect of the chinch bug problem probably must come mainly from the detailed and whole-hearted efforts of investigators in a position to devote careful attention to the numbers of the bugs and to their relations to conditions as they occur in the field, and from the correlation of such findings with careful physiological studies. Our difficulty lies in the fact that except for a limited period we have no knowledge of the abundance of bugs in the autumn and again in the spring, or in early spring and again at the close of the crop season. In cases where data of this kind have been obtained the tendency is to confirm the findings of the writer and the older investigators. The exceptions usually indicate that the distribution and character of the rainfall is more important than its total amount in a given period.

The writer accidentally discovered some evidence of apparent correlations between death rate in man and the abundance of chinch bugs. In some localities the chinch bug damage is great in years in which the human death rate is high. Analyses of the available data by simple comparison were carried out for a number of cities and over a number of years, with results as shown in Figs. 35 and 36 for six localities from 1900 to 1925. A more comprehensive comparison is afforded in Fig. 37, which represents the reported chinch bug damage throughout Illinois since 1840 in comparison with rainfall and death rate in two cities, Chicago, and St. Louis. The crop damage in each year was estimated by counties; each county with severe damage was assigned a value of 3, moderate damage 2, and slight damage 1; and then the sum of these assigned values for all the counties in the state was divided by 2 in order to obtain the rating for the year, and in that way the scale at the left of Fig. 37 was constructed. The lack of vital statistics for St. Louis and of weather records for Chicago in the earlier years made it impossible to obtain averages throughout the period covered by the records of the insect. It will be noted, however, that there is fairly close correlation between the periods of high death rate and great chinch bug abundance. The death rate usually rises in dry periods and falls in wet periods, and the chinch bug damage frequently follows these fluctuations rather closely, sometimes coinciding with them and sometimes lagging one year. In this connection it is worth repeating that variation in the vigor and fecundity of the bugs themselves is postulated as a factor not noted hitherto.

Conclusion

The chinch bug is a very sensitive insect. The immeasurable factors, such as quality of food, presence of aphids or other insects, variations in the soil or in the food plants, and changes in the vigor of the bugs, interfered with the success of the cultures and so far overshadowed the experimental differences in temperature, humidity, and light as partly to vitiate the results of experiments designed to determine the effects of these factors. This same sensitivity of the insect also makes it difficult to draw conclusions from the data of field observers. While it is evident that young chinch bugs may be killed by rain, still a large total rainfall in a particular month does not always result in their destruction throughout an area, for the rain may fall too slowly or may be too localized in small showers. Field observations of outbreaks have not been exact, and in the absence of quantitative observations on the abundance of the bugs, refinement of conclusions is not practicable. The results of the present study, however, may be summarized as follows:

1. Individual variation in the lengths of instars and life histories is very great, probably on account of the sensitivity of the bugs.

2. Low humidity affects the first instar strikingly and each succeeding stage to a lesser degree.

3. The relations of the rate of development to temperature and humidity are expressible in developmental units, and for each stage an equal-velocity chart is presented, similar to those used by the author in his study of the codling moth.

4. The success of the bugs in a long series of cultures shows that their vigor varies from year to year. The bugs were very strong in 1919 and 1925, producing three or four generations in each of these years. They were weakest in 1921. This does not, however, correspond with the severest outbreaks of the bugs in the state. It does indicate the possible importance of internal factors not directly correlated with the immediate surrounding conditions but determined earlier. It is necessary to consider *unbalance* in the bugs themselves as well as the *unbalance* in the system of nature of which they are a part.

5. In the early history of the outbreaks in Illinois there was a striking correlation between human death rate and chinch bug damage. With better developed agriculture and improved sanitary conditions this relation has become less striking.

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INDEX

Indexes and tabulations of species, with the exception of plankton specie tables in articles IV and V, are not duplicated in this index to the volume. The reader is referred to page 99 for an index to names of fish species, page 113 for a tabulation of Illinois birds, page 389 for an index of plant lice hosts and page 439 for an index of plant lice species.

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ERRATA

Page 99, column 1, line 1, omit *34*
Page 155, line 8, omit *The wings of the holotype . . . nymphs and one pupa.*
Page 178, couplet 32, for *Hind tarsi*, both lines, read *Hind tibiae*
Page 196, line 9, omit *Sexual forms and mating pairs . . . October 22, 1930.*
Page 228, line 19, for LINNAEUS read (LINNAEUS)
Page 306, line 24, insert and read *under* following *(1911b)*
Page 340, line 23, before *Setaria viridis* insert and read *Sedum artissimum*
Page 405, line second from bottom, prefix author's name, DAVIDSON, J.
Page 420, line 3, Fig. 75, for *Paducia antennatum (Patch)* read *Cinara laricis (Hartig)*
Page 426, Fig. 166, before *apterous* insert and read *cauda*,