INFLUENCE OF TEMPERATURE AND EVAPORATION UPON THE DEVELOPMENT OF APHIS POMI DEGEER[1]

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INTRODUCTION

Entomologists attacking economic problems are ever impressed with the need of a more thorough knowledge of the influence of the environmental factors which control the activities of the insects under investigation. The interrelations between insects and their environment are highly complex, and attempts at their determination are fraught with many difficulties. That any effort in this direction is well worthy of the expense in time and energy there can be little doubt, for, while this is as yet a comparatively unexplored field, there are many instances of the application of a knowledge of environmental factors to the applied control of economic pests. Headlee[3] pointed out the possibilities of the reduction of certain stored grain pests by modifying the relative humidity of the air within the container. Lovett and Fulton,[4] in discussing the control of the codling moth in the Willamette Valley, state:

> Where the evening temperature during May at 8:00 p. m. is 60° or above, the first generation codling moths may be expected to deposit eggs. Consequently when this temperature of 60° at 8:00 p. m. is registered, it is the proper time to apply the "thirty-day" codling moth spray.

A realization of the economic bearing of such information prompted the writer to make observations of certain climatic factors in connection with a study of the activities of several species of apple aphids, a group of insects which seem especially susceptible to climatic influence. A considerable amount of data on evaporation, temperature, and precipitation has been collected which, aside from the bearing upon the present study, should be of considerable general interest to both plant and animal ecologists.

In order to concentrate the study and to avoid scattering the data over too broad a field, observations in this connection were practically limited to a single species *Aphis pomi* DeGeer.

An understanding of the fundamentals of the life history of the species is desirable in considering the data here presented. For this reason the seasonal cycle is briefly reviewed.

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[1] Accepted for publication Jan. 16, 1922.

[2] The writer is indebted to Prof. A. L. Lovett for encouragement in the prosecution of this study, and to Mr. Richard Jones whose painstaking work as Technician in the Department of Entomology relieved the writer of much of the routine work of this study.

[3] Headlee, Thomas J. SOME FACTS RELATIVE TO THE INFLUENCE OF ATMOSPHERIC HUMIDITY ON INSECT METABOLISM. *In* Jour. Econ. Ent., v. 10, no. 1, p. 31–38. 1917.

[4] Lovett, A. L., and Fulton, B. B. FRUIT GROWER'S HANDBOOK OF APPLE AND PEAR INSECTS. Oreg. Agr. Exp. Sta. Circ. 22, p. 8. 1920.

LIFE HISTORY OF APHIS POMI

The green apple aphis passes the winter in the egg stage. The eggs are placed on the bark of the water sprouts and other terminal growths of apple and frequently occur grouped in immense numbers. With the unfolding of the buds in the spring, these eggs hatch, and the tiny nymphs migrate to the newly developed foliage.

These "stem mothers" and the succeeding generations feed upon the succulent foliage of apple throughout the summer. There is no migration to alternate food plants as there is with many species of aphids, and the winged forms which are produced serve merely to disseminate the species.

Reproduction throughout spring and summer is entirely viviparous and parthenogenetic. With the approach of fall, males and oviparous females are produced, and the over-wintering eggs are deposited.

There are a variable number of generations during the season, depending upon environmental conditions.

METHODS EMPLOYED

This work has been entirely in the nature of a field study, and no attempt was made to modify or control the conditions of temperature or moisture.

The experimental plot was located on the college farm at Corvallis, Oreg., about one mile from the Agricultural Building and had an elevation of approximately 225 feet above sea level. This plot consisted of 1- and 2-year-old Greening apple trees planted in two rows about 4 feet apart with the trees about 3 feet apart in the rows. To the westward about 60 to 75 feet distant there was a dense growth of alders along the banks of Oak Creek. These trees, being some 35 feet in height, served to break the force of the strong, westerly "sea breezes" prevalent during the summer months.

As the aphid eggs hatched, numbers of the nymphs were transferred to suitable buds on the experimental trees and here allowed to mature. In obtaining nymphs of the later generations, a number of adults would be placed on a suitable aphis-free leaf cluster. The following day these adults were removed, and the nymphs born during the 24-hour period were allowed to remain. These nymphs were permitted to mature in order to obtain the length of the developmental period. The developmental period was reckoned from the day after birth till the day of the appearance of the first young, inclusive.

The trees upon which the experiments were being conducted were protected by a special type of cage (fig. 1). This consisted of a cylinder of galvanized wire cloth, open at one end. To the open end of this cage was attached a cheesecloth skirt. The cage was inverted over the tree, and held in position at the proper height by means of a stake set near by. The cheesecloth skirt was gathered about the trunk of the tree and tied with a cord. A band of cotton batting placed at the proper height on the tree rendered a perfect fit between the cloth skirt and the tree, and prevented binding of the trunk from the tie-cord. This type of cage is easily removed for examination of the aphids, is as readily replaced, and has proved quite satisfactory for this work.

The evaporation records were obtained by means of a "nonabsorbing" evaporimeter or atmometer (fig. 2) similar to instruments used in many evaporation studies by various workers during recent years. Standardized, spherical, porous, porcelain cups were obtained from the "Plant

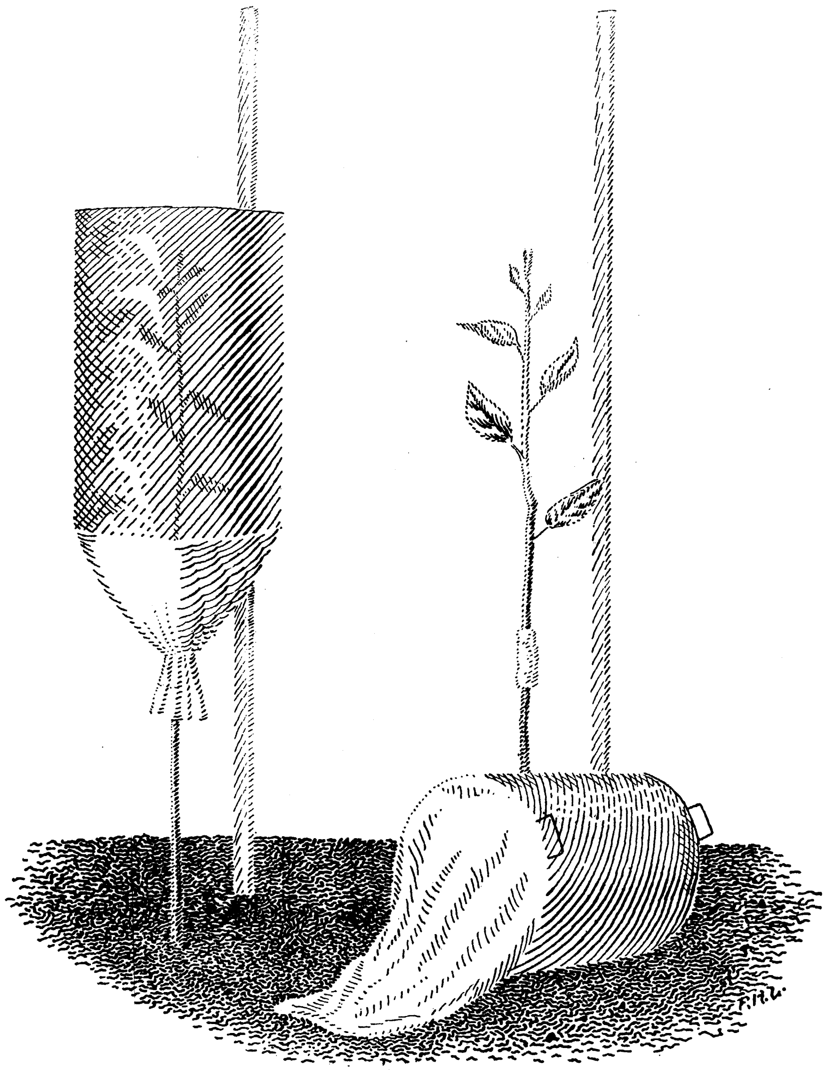

Fig. 1.—Cage used in rearing aphids.

World," and results as here given should be comparable with results obtained elsewhere [5] by means of similar instruments.

Observations were made daily at 9.30 a. m. The amount of evaporation was determined by filling the evaporimeter at this time.

[5] Livingston, Burton Edward. ATMOSPHERIC INFLUENCE ON EVAPORATION AND ITS DIRECT MEASUREMENT. *In* Mo. Weather Rev., v. 43, no. 3, p. 126-131, 2 fig. 1915. References and notes, p. 131.

A graduated pipette was used and readings were made to tenths of cubic centimeters.

Temperature records were obtained by means of a Tycos Dial Type Mercury Recording Thermometer, manufactured by Taylor Instrument

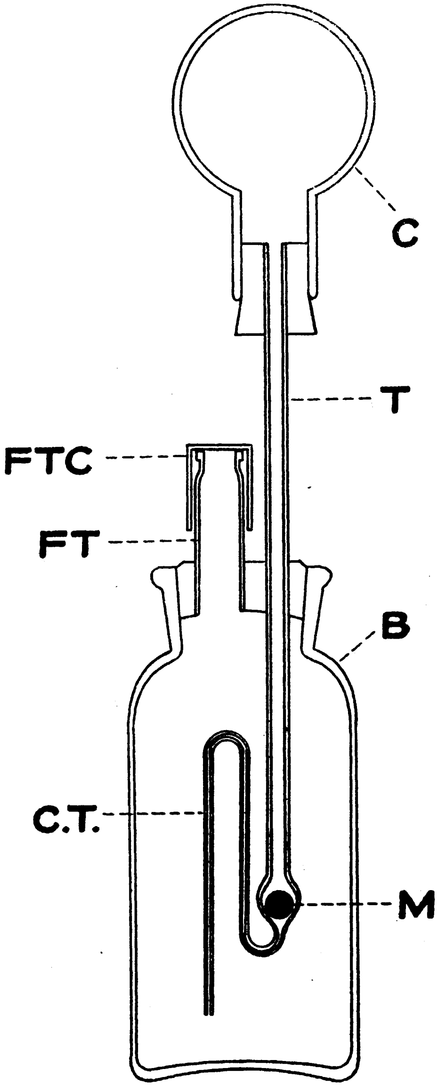

FIG. 2.—Sectional view of atmometer: C, standard, spherical, porous, porcelain cup; T, water supply tube; B, water bottle; FT, filling tube; FTC, filling tube cover; M, mercury drop to prevent return of water from cup; CT, capillary tube.

Companies, Rochester, N. Y. The daily mean temperature was calculated by reading the temperatures on the charts for each half hour and averaging these 48 readings. The mean temperature for any given period of days was obtained by averaging the daily mean temperatures.

For the records of precipitation, the writer is indebted to the Department of Soils of the Oregon Agricultural Experiment Station. Observations on precipitation were made daily at 5.00 p. m. and hence are not exactly comparable with the temperature and evaporation records as given in this paper.

TABLE I.—*Daily evaporation and precipitation, 1919, at Corvallis, Oreg.*

Date.	Evaporation.	Precipitation.	Character of weather.	Date.	Evaporation.	Precipitation.	Character of weather.
	Cc.	*Inches.*			*Cc.*	*Inches.*	
Mar. 31	22.5	0		May 21	......	0	
Apr. 1	11.2	0	Cloudy.	22	49.1	0	
2	......	0	do.	23	22.8	0	
3	13.0	0.15	do.	24	......	0	Partly cloudy.
4	5.7	.65	do.	25	16.4	.55	Cloudy.
5	7.0	.57	do.	26	13.3	0	Do.
6	8.0	.04	do.	27	14.7	0	Do.
7	10.3	0	Partly cloudy.	28	18.0	0	Do.
8	12.7	0	do.	29	9.3	.15	Partly cloudy.
9	......	0	do.	30	16.1	.06	Do.
10	24.0	.20	do.	31	......	0	
11	......	.08		June 1	61.4	0	
12	24.0	0		2	27.7	0	
13	13.8	.12	do.	3	34.0	0	
14	18.8	0		4	45.6	0	
15	14.9	0		5	31.3	0	
16	1.7	.12	Cloudy.	6	30.3	0	
17	4.1	.71	do.	7	......	0	
18	6.5	.47	do.	8	58.7	0	
19	......	.15	do.	9	14.0	.02	
20	18.7	.10	Partly cloudy.	10	10.9	0	Do.
21	......	0		11	13.7	0	Do.
22	34.2	0		12	12.9	0	Do.
23	14.9	0		13	9.5	.08	
24	12.2	T.	do.	14	16.3	0	Do.
25	8.4	.07	do.	15	12.3	.02	
26	......	0		16	18.5	0	Do.
27	31.8	0		17	28.6	0	
28	18.4	0		18	27.9	0	
29	26.4	0		19	23.2	0	Do.
30	34.6	0		20	15.4	0	Do.
May 1	19.7	0		21	21.3	0	Do.
2	17.9	0	do.	22	17.2	0	Do.
3	......	0		23	27.2	0	
4	91.7	0		24	29.4	0	
5	35.6	0		25	30.9	0	
6	39.1	0		26	8.8	.10	
7	26.1	0		27	21.9	0	Do.
8	17.7	0	do.	28	17.0	0	Cloudy.
9	20.2	0	do.	29	29.5	0	
10	......	0	do.	30	24.7	0	
11	24.7	.11	do.	July 1	25.6	0	
12	9.1	.10	do.	2	33.5	0	
13	24.6			3	39.1	0	
14	8.8	.05	do.	4	28.4	0	
15	7.9	.05	Cloudy.	5	20.2	0	Partly cloudy.
16	5.3	.22	do.	6	16.9	0	Do.
17	......	0	do.	7	38.7	0	
18	21.4	0.03	do.	8	47.3	0	
19	21.4	0		9	41.6	0	Do.
20	31.0	0		10	22.0	0.2	

TABLE I.—*Daily evaporation and precipitation, 1919, at Corvallis, Oreg.*—Continued

Date.		Evaporation.	Precipitation.	Character of weather.	Date.		Evaporation.	Precipitation.	Character of weather.
		Cc.	*Inches.*				*Cc.*	*Inches.*	
May	11	18.4	0	do.	Aug.	21	32.3	0	
	12	36.5	0			22	35.8	0	
	13	52.4	0			23	39.2	0	
	14	44.2	0			24	32.5	0	
	15	32.5	0			25	28.7	0	
	16	34.8	0			26	18.3	0	Partly cloudy.
	17	35.5	0			27	31.3	0	
	18	40.2	0			28	39.1	0	
	19	51.3	0			29	28.7	0	
	20	47.5	0			30	15.6	0	Do.
	21	54.0	0			31	11.7	.09	Do.
	22	58.5	0		Sept.	1	29.8	0	
	23	17.5	.08			2	22.0	0	
	24	23.9	0	do.		3	3.9	T.	Do.
	25	16.3	0			4	3.1	.40	Cloudy.
	26	......	0			5	0.7	.70	Do.
	27	54.0	0			6	......	.25	Do.
	28	22.4	0			7	7.8	.01	Partly cloudy.
	29	9.0	0	Cloudy.		8	0.6	.25	Cloudy.
	30	20.5	0	Partly cloudy.		9	8.7	0	Partly cloudy.
	31	15.9	0	do.		10	13.9	0	
Aug.	1	14.9	0	do.		11	2.7	.40	Cloudy.
	2	11.3	0	do.		12	22.0	0	
	3	9.0	0	do.		13	46.0	0	
	4	14.6	0	do.		14	27.8	0	
	5	31.5	0	do.		15	16.1	0	Do.
	6	27.3	0	do.		16	6.5	0	Do.
	7	17.9	0	do.		17	10.9	0	Do.
	8	25.0	0			18	19.4	0	
	9	33.5	0			19	17.6	0	
	10	34.1	0			20	28.2	0	
	11	18.0	.05	Partly cloudy.		21	78.6	0	
	12	16.1	0	do.		22	43.8	0	
	13	36.5	0			23	28.8	0	
	14	59.0	0			24	22.3	0	
	15	47.3	0			25	19.8	0	
	16	21.7	0			26	17.0	0	
	17	13.9	0	do.		27	......	.12	Do.
	18	25.5	0			28	19.7	.4	
	19	34.6	0			29	......	0	
	20	34.2	0			30	6.3	.55	Do.

TABLE II.—*Daily temperature, evaporation, and precipitation at Corvallis, Oreg., 1920*

Date.		Temperature.			Evaporation.	Precipitation.	Character of weather.
		Minimum.	Mean.	Maximum.			
		°*F.*	°*F.*	°*F.*	*Cc.*	*Inches.*	
Mar.	29	35	45.6	58	12.6	0	
	30	24	34.0	48	7.1	0.50	Cloudy.
	31	33	38.6	47	5.9	.32	Do.
Apr.	1	39	41.8	46	10.2	.20	Do.
	2	34	41.1	51	20.4	0	Partly cloudy.
	3	45	48.2	62	....	.04	Cloudy.
	4	44	49.4	62	23.0	.03	Partly cloudy.

TABLE II.—*Daily temperature, evaporation, and precipitation at Corvallis, Oreg., 1920*—Continued

Date.	Temperature.			Evaporation.	Precipitation.	Character of weather.
	Minimum.	Mean.	Maximum.			
	° F.	° F.	° F.	Cc.	Inches.	
Apr. 5	36	44.2	56	....	0.08	
6	44	47.3	55	32.2	.03	Cloudy.
7	33	41.5	54	9.2	.08	Do.
8	32	40.2	50	3.6	.58	Cloudy.
9	40	44.3	55	....	.10	Do.
10	29	45.6	60	....	.10	
11	42	50.6	65	33.6	0	
12	37	45.2	54	3.3	.12	
13	37	43.7	56	7.9	.11	Partly cloudy.
14	41	45.5	56	6.7	.35	Cloudy.
15	29	41.9	56	12.4	.10	
16	30	42.4	52	12.3	.05	Partly cloudy.
17	27	42.7	56	....	.01	
18	42	51.1	64	27.9	0	
19	30	39.7	56	7.9	.24	Cloudy.
20	28	39.0	48	6.0	.11	Partly cloudy.
21	30	39.0	52	5.2	.06	Do.
22	26	39.9	57	....	.09	Do.
23	28	43.9	59	19.5	0	
24	31	49.2	63	....	0	
25	32	54.8	70	42.2	0	
26	36	57.5	78	26.3	0	
27	39	51.7	68	....	0	
28	40	48.5	65	38.3	0	
29	38	46.3	55	13.7	0	
30	37	46.5	59	15.2	.01	
May 1	36	46.1	60	....	0	
2	30	47.5	62	34.0	0	
3	30	48.4	64	17.3	0	
4	31	49.3	64	19.1	0	
5	33	52.6	69	19.0	0	
6	37	58.5	79	24.4	0	
7	46	56.7	78	22.4	0	
8	40	53.0	69	....	.03	
9	27	46.9	66	45.0	0	
10	28	46.6	64	20.8	0	
11	30	48.0	64	21.8	0	
12	30	50.3	68	25.9	0	
13	28	49.0	69	24.3	0	
14	38	55.9	72	33.9	0	
15	35	55.1	73	....	0	
16	50	61.6	80	56.4	0	
17	37	53.5	70	15.9	.23	
18	31	51.5	74	24.2	0	
19	35	52.2	70	25.1	0	
20	34	48.9	66	11.9	0	
21	27	47.5	64	20.4	0	
22	42	52.1	65	....	0	
23	34	48.1	65	33.6	0	Do.
24	25	42.8	59	13.2	0	Do.
25	32	50.9	66	21.5	0	
26	37	52.1	68	15.5	0	Do.
27	34	50.1	69	20.0	.17	
28	34	49.6	68	17.8	.01	
29	26	44.3	61	....	.05	Do.
30	28	47.0	64	31.3	.02	
31	30	52.7	70	31.7	0	
June 1	35	58.4	78	40.2	0	
2	44	64.1	85	39.1	0	

TABLE II.—*Daily temperature, evaporation, and precipitation at Corvallis, Oreg., 1920*—Continued

Date.	Temperature. Minimum.	Temperature. Mean.	Temperature. Maximum.	Evaporation.	Precipitation.	Character of weather.
	° F.	° F.	° F.	Cc.	Inches.	
June 3	47	63.3	88	44.6	0	
4	42	58.6	79	24.7	0	
5	45	58.4	75	....	0	
6	51	53.5	63	23.4	.10	Cloudy.
7	45	52.0	58	5.1	.41	
8	37	52.4	69	12.7	.39	Partly cloudy.
9	38	53.5	72	21.9	0	
10	50	55.5	66	10.5	0	Cloudy.
11	45	54.6	66	16.9	.03	Partly cloudy.
12	49	57.4	74	....	0	
13	54	57.5	62	20.1	.20	Cloudy.
14	44	55.8	67	22.3	.53	Partly cloudy.
15	36	52.0	68	15.2	0	Do.
16	52	58.2	72	14.1	0	Do.
17	38	54.5	71	20.0	.19	Do.
18	39	56.8	71	27.6	0	
19	44	63.2	80	....	0	
20	46	64.5	84	70.1	0	
21	46	59.9	82	28.8	0	
22	33	52.9	62	17.2	0	
23	35	52.2	68	26.6	0	Do.
24	42	53.0	70	16.6	0	
25	39	52.7	67	18.2	0	
26	45	62.4	78	....	0	
27	47	64.7	82	69.6	0	
28	44	64.7	84	26.9	0	
29	49	67.7	89	34.2	0	Do.
30	43	65.3	88	28.8	0	
July 1	45	67.1	88	38.6	0	
2	46	67.3	90	43.3	0	
3	38	58.1	80	....	0	
4	36	59.8	82	....	0	
5	39	62.4	84	93.5	0	
6	48	68.5	89	36.5	0	
7	50	68.1	93	38.7	0	
8	43	60.0	78	23.4	0	
9	39	63.1	85	28.7	0	
10	49	60.6	80	....	0	
11	50	57.2	68	39.9	0	Cloudy.
12	51	56.0	66	7.7	0	Do.
13	52	57.0	62	5.2	.41	
14	48	60.8	76	9.2	Trace	
15	49	64.8	86	22.8	0	Do.
16	56	64.7	88	23.7	0	Do.
17	45	63.5	81	....	0	Do.
18	53	64.4	81	58.2	0	Partly cloudy.
19	50	61.2	74	17.9	0	Do.
20	50	64.1	82	25.0	0	
21	41	59.2	78	21.2	0	
22	41	62.9	82	30.2	0	
23	42	60.9	80	28.6	0	
24	40	59.4	77	....	0	
25	40	63.4	84	65.8	0	
26	49	67.9	88	36.4	0	
27	54	66.0	84	35.7	0	
28	56	60.6	70	12.8	0	Cloudy.
29	40	57.6	70	13.8	0	Do.

TABLE II.—*Daily temperature, evaporation, and precipitation at Corvallis, Oreg., 1920*—Continued.

Date.	Temperature.			Evaporation.	Precipitation.	Character of weather.
	Minimum.	Mean.	Maximum.			
	°F.	°F	°F	Cc.	Inches.	
July 30	44	63.8	83	26.3	0	
31	40	61.9	80	....	0	
Aug. 1	46	64.9	87	63.0	0	
2	45	63.8	84	28.5	0	
3	46	66.6	82	36.3	0	
4	54	69.4	89	36.6	0	
5	53	66.4	84	21.6	0	Cloudy.
6	47	65.8	88	27.7	.05	
7	59	71.6	88	....	0	
8	56	65.6	82	53.3	0	
9	45	63.7	82	27.6	0	
10	48	67.2	88	30.9	0	
11	50	74.5	92	50.9	0	
12	53	76.9	100	49.5	0	
13	47	74.5	100	40.9	0	
14	43	68.4	97	....	0	
15	45	67.2	93	72.9	0	
16	40	61.6	86	32.1	0	
17	32	54.0	75	23.7	0	
18	42	58.4	76	29.6	0	
19	41	67.6	88	47.4	0	
20	42	67.6	96	36.4	0	
21	46	67.0	94	....	0	
22	42	60.7	85	52.4	0	
23	56	67.9	87	33.3	0	
24	48	61.3	77	22.6	0	Do.
25	36	51.9	70	....	.01	Do.
26	43	58.0	76	32.5	0	
27	40	50.7	64	3.8	.22	Do.
28	51	57.8	74	....	.02	Do.
29	30	48.2	67	27.9	.49	Do.
30	37	54.9	74	23.0	0	
31	40	65.3	85	46.4	0	
Sept. 1	41	64.6	90	32.4	0	
2	40	62.1	87	24.3	0	
3	40	58.9	82	20.1	0	
4	50	60.6	78	....	0	
5	33	53.3	71	33.9	0	
6	32	51.4	70	19.7	0	
7	41	55.4	74	16.3	0	
8	47	53.3	62	9.7	0	Do.
9	48	51.5	58	5.0	.08	Do.
10	52	56.4	60	3.3	.23	Do.
11	49	56.9	69	....	.01	Do.
12	48	54.2	68	14.2	1.18	Partly cloudy.
13	44	50.5	58	1.7	.95	Cloudy.
14	37	50.9	69	9.6	.26	Partly cloudy.
15	41	55.7	75	15.2	0	

EVAPORATION STUDIES

During the summer of 1919 a series of experiments was conducted in the hope that the measurement of atmospheric evaporation—combining, as it does, effects of both temperature and humidity—might, under normal outdoor conditions, give a fairly accurate index to the rate of metabolism of *Aphis pomi.* The study was continued during the summer of 1920.

The daily evaporation rates during the periods covered by these investigations are given in Tables I and II and are shown graphically in figures 3, 4, 5, and 6.

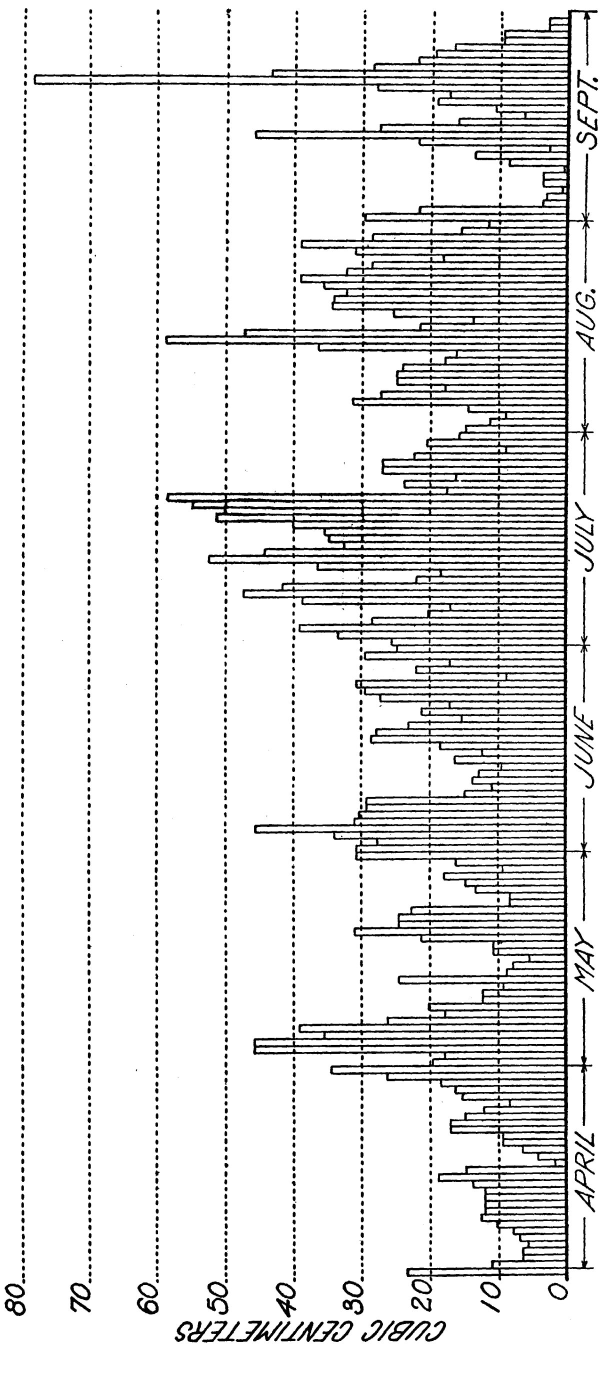

FIG. 3.—Daily records of evaporation, Corvallis, Oreg., summer of 1919.

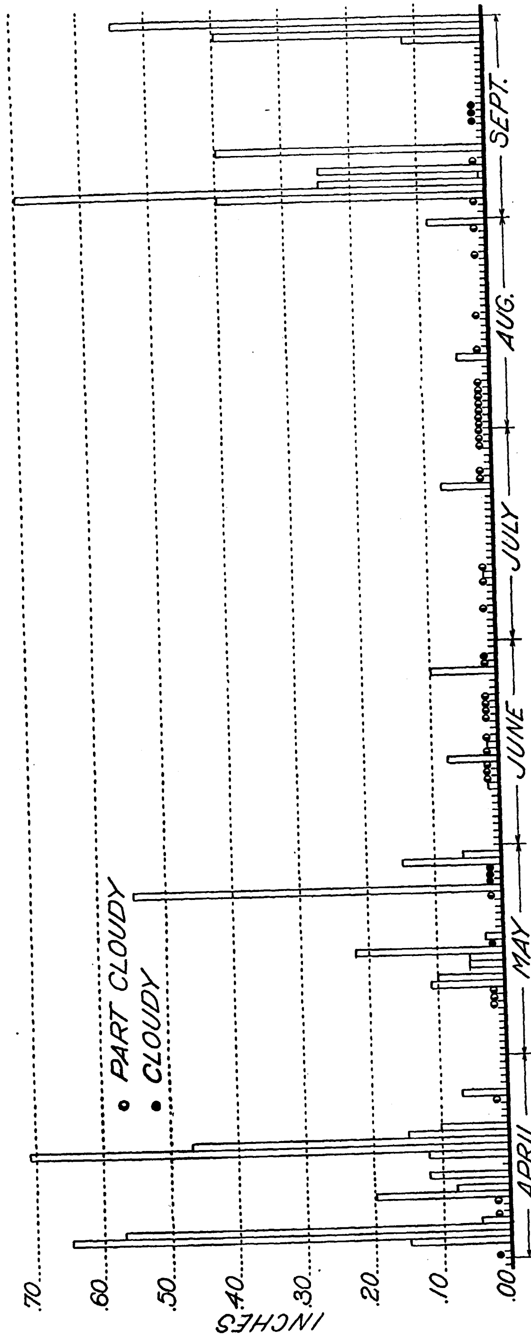

FIG. 4.—Daily records of precipitation, Corvallis, Oreg., summer of 1919.

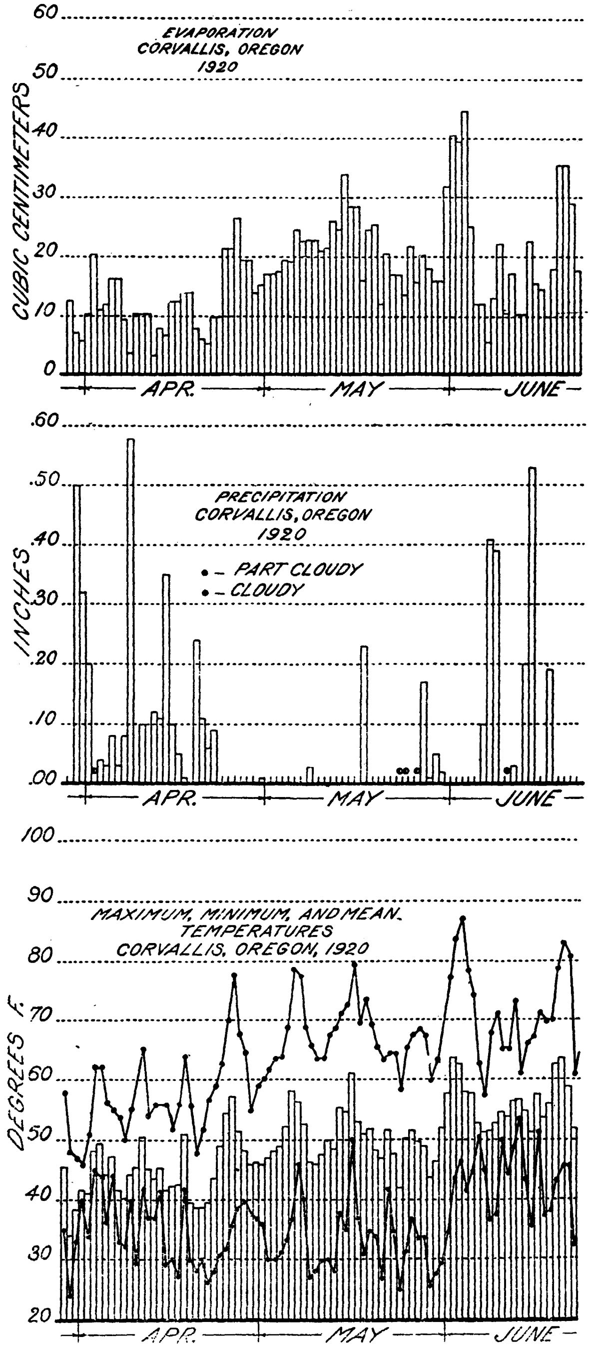

FIG. 5.—Daily records of evaporation, precipitation, and temperature, Corvallis, Oreg., summer of 1920.

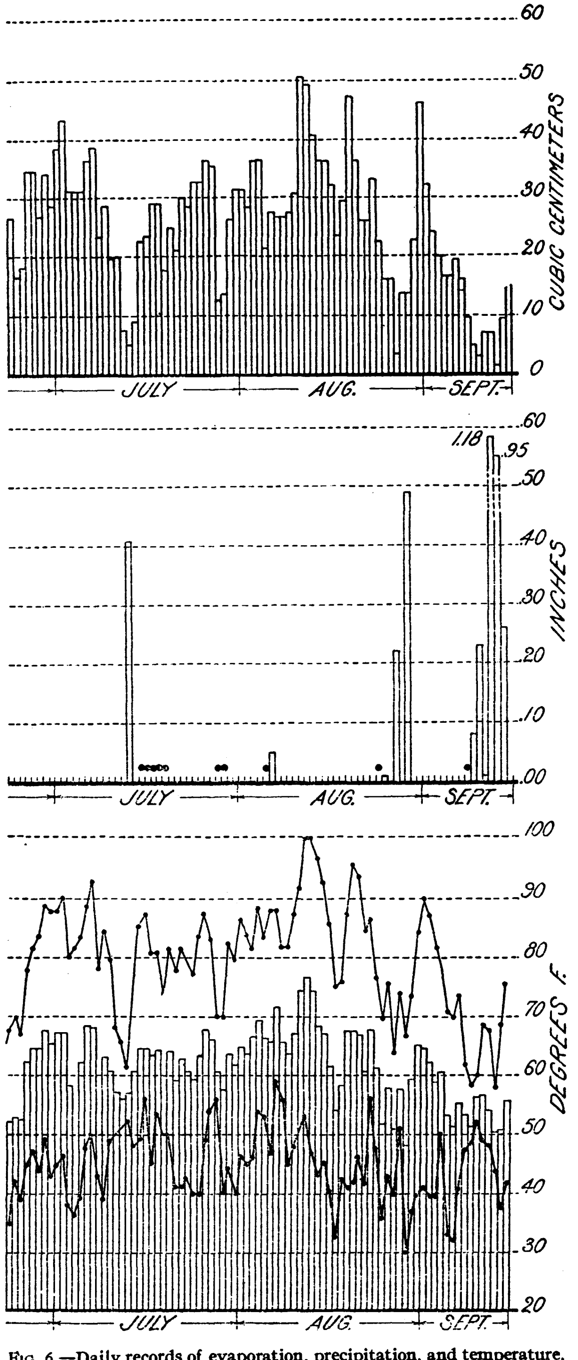

FIG. 6.—Daily records of evaporation, precipitation, and temperature, Corvallis, Oreg., summer of 1920.

During the summer of 1919 the highest daily evaporation of 78.6 cc. occurred on September 21. This was probably due to continuous wind movement rather than to unusually high temperature or low humidity. The highest evaporation recorded during 1920 occurred on August 11, being 50.9 cc. As would be expected, there is a marked correlation between the amount of evaporation and precipitation and temperature, the highest evaporation occurring during periods of high temperature and little precipitation. Wind is also an important factor, and the character and duration as well as the actual amount of precipitation has a great influence upon evaporation. A long period of light rainfall retards evaporation more than a short period of heavy rainfall, although the actual amount of precipitation may be greater in the latter case.

A study of the data here presented shows that there is a general correlation between the rate of evaporation and the rate of development of *Aphis pomi*. On the whole, a high rate of evaporation was accompanied by a rapid development of the aphids, and a low rate of evaporation by a comparatively slow development of the insects. While this correlation seems to be true in a general way, there is considerable variation from the rule. The variation which may occur in the average daily rate of evaporation during any given length of developmental period is illustrated graphically in figure 7.

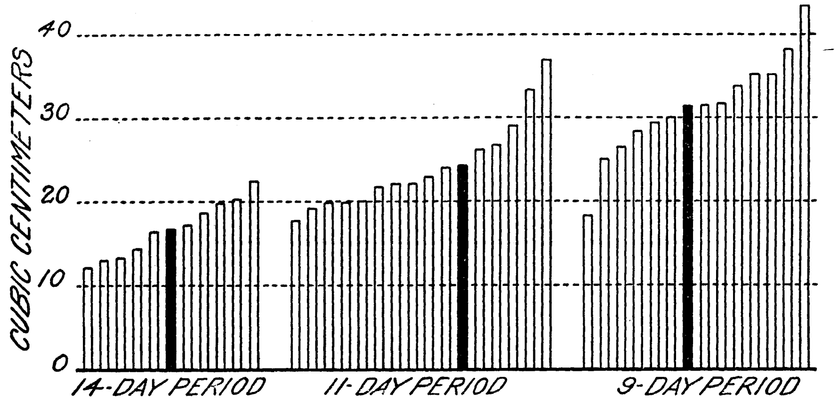

FIG. 7.—Variation in average daily rates of evaporation occurring during 14, 11, and 9 day developmental periods. White bars represent average daily evaporation, individual records. Black bars represent the means of all records of their respective periods.

These results show that under the conditions of this investigation, evaporation, as registered by the standard evaporimeter used, is not a satisfactory measure of aphis metabolism. This condition apparently results from the fact that the combination of factors, humidity, temperature, wind, etc., which influence evaporation, affect evaporation from the standard porous cup in a manner which is not closely comparable to their effect upon the metabolism of *Aphis pomi*.

As pointed out by Livingston,[6] the rates of evaporation from different types of evaporimeters under any given complex of atmospheric conditions are not comparable. It is, therefore, not surprising that evaporation from an instrument as used in these experiments would not give an accurate index of the effects of the atmospheric conditions upon aphis metabolism. It is possible that an evaporimeter more closely simulating the conditions of the aphid body might give a closer correlation between atmospheric evaporation and insect metabolism.

[6] LIVINGSTON, Burton Edward. OP. CIT.

TABLE III.—*Relation of evaporation to rate of development of Aphis pomi, 1919*

Aphid series No.	Date of birth.	Date first young produced.	Developmental period.	Total evaporation.	Average daily evaporation.
			Days.	*Cc.*	*Cc.*
1	Mar. 31	Apr. 29	29	342.5	11.8
2	Apr. 29	May 17	18	410.0	22.8
3	May 17	June 2	16	294.0	18.4
4	June 2	17	15	336.2	22.4
5	3	18	15	335.5	22.4
6	4	18	14	203.6	14.5
7	5	19	14	285.9	20.4
8	6	20	14	277.8	19.8
9	9	23	14	242.7	17.2
10	10	24	14	265.9	18.9
11	12	25	13	260.7	20.0
12	13	24	11	217.4	19.8
13	17	29	12	268.8	22.4
14	18	29	11	240.2	21.9
15	20	July 1	11	243.3	22.1
16	21	2	11	253.5	23.0
17	22	3	11	265.7	24.1
18	23	3	10	248.5	24.8
19	24	5	11	288.8	26.2
20	25	7	12	296.5	24.7
21	26	8	12	304.3	25.4
22	27	8	11	295.5	26.9
23	28	9	11	320.9	29.2
24	29	8	9	256.6	28.5
25	30	10	10	316.0	31.6
26	July 1	11	10	313.0	31.3
27	2	12	10	306.1	30.6
28	3	12	9	272.6	30.3
29	4	14	10	322.4	32.2
30	6	15	9	318.0	35.3
31	7	17	10	368.4	36.8
32	8	19	11	405.5	36.9
33	9	18	9	317.9	35.3
34	11	20	9	345.9	38.4
35	12	22	10	429.0	42.9
36	13	22	9	392.5	43.6
37	14	21	7	286.1	40.9
38	16	24	8	339.4	42.4
39	29	Aug. 9	11	196.9	17.9
40	30	10	11	222.1	20.2
41	31	11	11	245.0	22.3
42	Aug. 3	11	8	192.9	24.1
43	4	17	13	382.5	29.4
44	7	17	10	309.1	30.9
45	8	18	10	305.1	30.5
46	11	19	8	238.0	29.8
47	12	20	8	254.6	31.8
48	13	20	7	238.5	34.1
49	14	23	9	304.3	33.8
50	16	24	8	237.2	29.7
51	19	28	9	286.9	31.8
52	20	30	10	320.1	32.0
53	21	30	9	285.9	31.7
54	23	Sept. 2	10	274.0	27.4
55	24	5	12	263.7	21.9
56	25	7	13	235.8	18.1
57	26	7	12	207.9	17.3
58	27	9	13	193.2	14.8
59	28	12	15	187.2	12.5
60	29	13	15	170.1	11.3

TABLE III.—*Relation of evaporation to rate of development of Aphis pomi, 1919*—Con.

Aphid series No.	Date of birth.	Date first young produced.	Developmental period.	Total evaporation.	Average daily evaporation.
			Days.	*Cc.*	*Cc.*
61	Aug. 30	Sept. 22	24	392.5	16.4
62	31	14	14	170.8	12.2
63	Sept. 1	15	14	187.9	13.4
64	2	15	13	159.0	12.2
65	3	18	15	170.5	11.4
66	5	19	14	183.0	13.1
67	6	19	13	182.3	14.0
68	8	21	13	220.8	17.0
69	10	21	11	211.6	19.2
70	11	23	12	319.6	26.5
71	13	28	15	392.6	26.2
72	16	30	14	315.7	22.5

TABLE IV.—*Relation of evaporation to rate of development of Aphis pomi; summary of data for 1919 and 1920*

Length of developmental period.	Average total evaporation for period.	Average daily evaporation.	Number of records.
Days.	*Cc.*	*Cc.*	
36	453.9	12.6	1
29	342.5	11.8	1
24	392.5	16.4	1
22	406.6	18.5	1
19	412.6	21.7	1
18	408.0	22.7	2
16	294.0	18.4	1
15	265.3	17.7	6
14	236.5	16.9	10
13	256.9	19.7	10
12	265.8	22.1	8
11	266.2	24.2	15
10	305.2	30.5	14
9	284.2	31.6	14
8	252.4	31.5	5
7	262.3	37.5	2

TEMPERATURE STUDIES

The data obtained during 1919 showed that, while there is a general correlation between evaporation and the rate of metabolism of *Aphis pomi*, a measure of evaporation alone is not a satisfactory index to aphid development. During the summer of 1920 the investigation was continued and accurate records of temperature as well as evaporation were maintained.

The daily maximum, mean, and minimum temperatures for the summer of 1920 are given in Table II and are shown graphically in figures 5 and 6. It will be noted that there was considerable daily variation in temperature ranging from a minimum variation of 7° F. on April 1 to the maximum variation of 54° on August 14. In general, the greatest daily variation occurred during periods of high mean temperatures and was correlated with a high rate of evaporation. Periods of little daily variation in temperature were usually accompanied by low mean temperatures, by little evaporation, and frequently by precipitation.

Table V shows the relation of temperature to the rate of development of *Aphis pomi*. The actual mean temperatures of the developmental periods of the several series were first plotted as shown by the circles on the graph, figure 8. It was found that these points lie approximately along

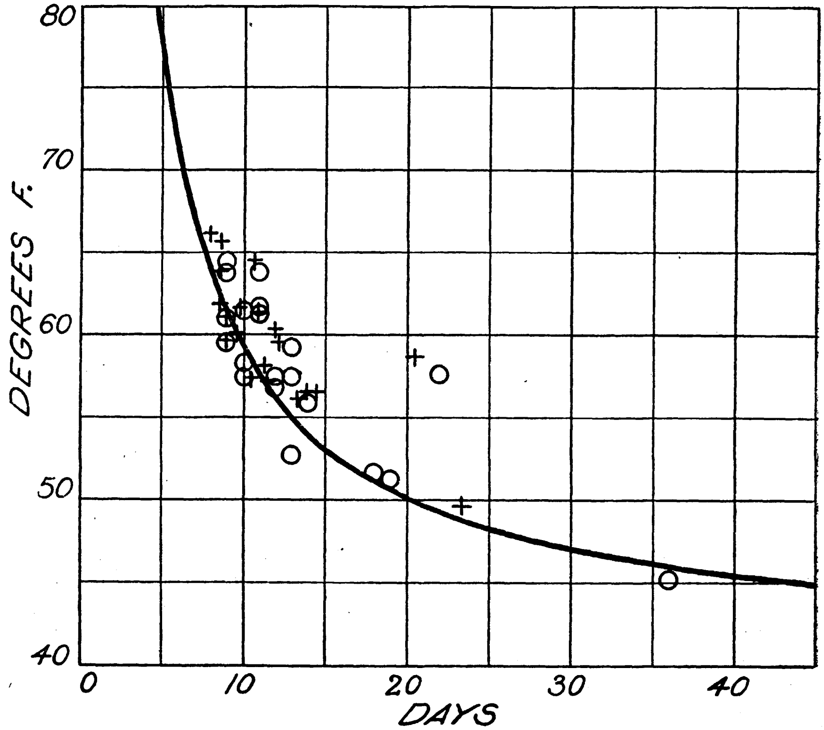

FIG. 8.—Curve showing theoretical relation of temperature to rate of development of *Aphis pomi*.

a hyperbolic curve having the formula $x=\frac{a}{y-b}$.[7] This formula may be expressed by the formula: Length of developmental period in days

$$=\frac{180}{\text{Temperature in degrees Fahrenheit}-41}.$$

If the curve thus plotted be extended it will be found that as the temperature is lowered the development of the aphids becomes less rapid, until at a temperature of 41° F. or less development ceases entirely. In other words, only temperatures above 41° are "effective"[8] in the development of *Aphis pomi*. By subtracting all temperatures of 41° or less and by computing the mean of the remaining temperature readings the mean effective temperatures (Table V) were obtained. By subtracting from the developmental period the time during which the temperature was 41° or less the duration of effective temperature was determined. These data were then plotted on the graph (fig. 8) as indicated by the crosses.

[7] The writer is indebted to Prof. E. B. Beaty, of the Department of Mathematics, Oregon Agricultural College, for the computation of the formula for this curve.

[8] SANDERSON, E. DWIGHT. THE RELATION OF TEMPERATURE TO THE GROWTH OF INSECTS. *In* Jour. Econ. Ent., v. 3, no. 2, p. 113–139, fig. 6–26. 1910. Authors cited, p. 138–139.

TABLE V.—*Relation of temperature and evaporation to rate of development of Aphis pomi, 1920*

Aphid series No.	Date of birth.	Date first young produced.	Developmental period.	Total evaporation.	Average daily evaporation.	Mean temperature.	Duration of effective temperature.	Mean effective temperature.
			Days.	*Cc.*	*Cc.*	°*F.*	*Days.*	° *F.*
1	Mar. 28	May 3	36	453.9	12.6	45.1	23.3	49.7
2	May 3	16	13	312.4	24.0	52.6	10.4	57.4
3	13	June 1	19	412.6	21.7	51.3	14.5	56.5
4	16	3	18	406.0	22.6	51.6	13.9	56.5
5	31	12	12	249.1	20.8	56.8	11.6	57.3
6	June 2	16	14	231.5	16.5	55.9	13.3	56.2
7	9	21	12	216.8	18.1	57.5	11.4	58.1
8	14	27	13	324.0	24.9	57.5	12.2	59.6
9	17	27	10	274.7	27.5	58.2	9.5	60.0
10	21	30	9	238.1	26.5	59.5	8.6	61.8
11	27	July 6	9	265.3	29.5	64.5	8.7	65.7
12	30	9	9	302.7	33.6	63.8	8.7	63.9
13	July 7	18	11	218.8	19.9	61.1	10.9	61.3
14	9	18	9	166.7	18.5	61.0	9.0	61.1
15	18	28	10	273.6	27.4	62.5	9.8	62.7
16	28	Aug. 6	9	226.1	25.1	64.5	8.0	66.1
17	Aug. 12	23	11	368.7	33.5	63.8	10.7	64.5
18	20	Sept. 2	13	298.6	22.9	59.3	12.0	60.2
19	20	11	22	406.6	18.5	57.6	20.5	58.6
20	23	2	10	212.9	21.3	57.5	9.0	59.8

In general, the records as shown on figure 8 do not coincide exactly with the theoretical curve of development. This is no doubt due largely to the fact that observations of the aphids were made only once daily, which would tend to cause a lagging in the recorded rate of development of the insects. Toward the end of the growing season the development of the aphids in some of the series was probably retarded to some extent by the lack of succulence of the plant tissues, in spite of the fact that the most succulent growing tips were selected for rearing the aphids. The extent to which development may be retarded by such a limiting factor is shown by series 19, which was reared upon mature foliage. For its development this series required a period of effective temperature of 20.5 days, although accompanied by a mean effective temperature (58.6°) high enough to permit development in half the time consumed. This effect of the growth of the plant upon the development of *Aphis pomi* was also noted by Baker and Turner,[9] who regard it as a food relationship. It is evident that the condition of the foliage of the food plant frequently constitutes a limiting factor of considerable importance to the activities of *Aphis pomi*.

CONCLUSIONS

Under normal outdoor conditions there is a general correlation between atmospheric evaporation and the rate of development of *Aphis pomi*.

Atmospheric evaporation, as measured by the standard evaporimeter used, does not serve as a satisfactory index to the rate of development of *Aphis pomi*.

[9] BAKER, A. C., and TURNER, W. F. MORPHOLOGY AND BIOLOGY OF THE GREEN APPLE APHIS. *In* Jour. Agr. Research, v. 5, no. 21, p. 983, pl. 75. 1916.

Temperature, during periods when no other factor limits the rate of development of the species, constitutes a more satisfactory index than does the rate of atmospheric evaporation.

The relation of temperature to the rate of development of *Aphis pomi* may be represented by a hyperbolic curve having the formula: length of developmental period in days $= \frac{180}{\text{Temperatures in degrees Fahrenheit} - 41}$.

Plant growth frequently constitutes a factor limiting the rate of development of *Aphis pomi* feeding on slowly growing foliage.

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