RELATION BETWEEN TEMPERATURE AND CROPS.

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INTRODUCTION.

The determination of definite relationships between weather conditions and the growth of crops is difficult on account of the complex influences involved. These are so intimately related that the isolation of any one factor is practically impossible, and we are still without exact statements of the plant requirements of any single climatological element, with the possible exception of rainfall. Smith (1) and Briggs & Shantz (2) have made some investigations of the rainfall requirements which are interesting and helpful, but further information, even in this connection, is needed.

At present, as Swingle (3) has stated, "The life history requirements and the limits of the power to resist unfavorable environmental conditions are far better known for many microscopic lower plants, such as bacteria, fungi, and algæ * * *, than for the most important crop plants whose culture provides employment for tens of millions of human beings, and whose products constitute the daily food of hundreds of millions."

The particular weather element with which this paper deals is that of temperature. What is needed is a determination of the heat requirements of each crop and a method of evaluating air temperature records in terms of their efficiency to meet these requirements, and some suggestions are made herein along the latter line. When the whole problem is finally worked out it should be possible to state the normal efficiency of each locality, as regards heat, to meet the needs of each crop, possibly in terms of percentage of perfection.

METHODS OF INVESTIGATION.

Prof. Cleveland Abbe (4) in his "First report on the relation between climates and crops," compiled a complete survey of all investigations which had been undertaken along this line up to 1891. For the most part the temperature studies were carried on by means of what has been termed the "summation method." This at first consisted in adding together the daily mean temperatures during the life history of any crop—say from the time of planting to harvesting corn—the idea being that a certain number of degrees of temperature would produce the same stage of development from year to year. It was early discovered, however, that these temperature sums varied greatly from one year to the next.

The first improvement in this method was the introduction of a "plant zero," or the consideration only of those temperature readings above a certain minimum, below which the plant made no progress in growth. The temperature most frequently considered as a plant temperature "zero" was 42°F, and this amount was subtracted from each daily temperature before determining the sums for the season. This method presumed, of course, that the effectiveness of temperature in promoting plant growth was directly proportional to the number of degrees above this minimum, no limit as to maximum being fixed.

Faults of summation method.

In order to demonstrate the futility of this method, which has been so extensively used and is still considered efficient by some, the splendid phenological records of Mr. Thomas Mikesell (5) and his temperature readings at Wauseon, Ohio, have been studied and tables compiled, using maize as a representative cereal crop and the peach as a fruit crop. In the case of maize, temperature summations were made for the period between planting and blossoming for 27 years, also from blossoming to ripening for the same years. Both sets of figures show wide variations from year to year, ranging from 1,232 in 1897 to 1,919 in 1895 for the earlier life phase. Even wider differences obtained in the later phase, the extremes being 897 in 1907 and 1,607 in 1906.

In the case of the peach five different periods were considered, using 27 years' records. The first period was *from January 1 to blossoming each year;* the second, from blossoming to ripening; the third, from January 1 to ripening; the fourth, from the date of blossoming one year to date of blossoming the next; and the last, from the date of ripening one year to the date of blossoming the next. Table 1 shows the extreme values in each period and the range of variation expressed in percentage of the smaller to the greater.

TABLE 1.—*The least and the greatest temperature summations in the life phase of the late Crawford Peach, as observed at Wauseon, Ohio, by T. Mikesell from 1883 to 1912.*

[The fourth line gives the corresponding percentage when maximum instead of mean daily temperatures are used.]

Summation.	Jan. 1 to blossoming.	Blossoming to ripening.	Jan. 1 to ripening.	Blossoming to ripening.	Ripening to blossoming.	Average.
Least	183	2,766	3,030	3,565	486	....
Greatest	362	3,991	4,347	4,947	1,250	....
Percentage	*50*	*70*	*70*	*75*	*38*	*61*
Max (%)	**64**	**71**	**72**	**78**	**61**	**69**

It is evident from these wide variations that the summation method of studying the temperature requirements of crops is not productive of consistent results.

The various summations noted above were made from the mean daily temperatures. Similar summations were also compiled from the maximum temperatures instead of the means, and considerably closer results were obtained. The resulting percentages corresponding are given in the last line of Table 1 in black-face type, and they attain an average of 69 per cent, compared to an average of 61 per cent with mean temperatures. These closer results may be explained by the well-known fact that two days may have the same mean temperature, but *one is cloudy and cool throughout with no plant growth,* while the other has a clear and cooler night with a clear but warmer daytime with considerable growth. The clear daytime would have the higher maximum temperature and the greater weight it would thus secure in the summation process would more correctly represent the value of this day to the plant.

If the summation methods are to be continued, therefore, it is recommended that maximum temperatures rather than the mean daily temperatures be used. But neither gives satisfactory results.

The exponential method.

As a modification of the summation method of studying the efficiency of air temperature in promoting plant growth, Lehenbauer (7), Livingston (8), and others have made use of Van't Hoff's law regarding chemical action as accelerated by increase of heat. They reasoned that as plant growth is largely chemical in nature, it should increase and double with each rise of 18 Fahrenheit degrees in temperature, as it does in purely chemical reactions. The fomula used is: $u=2^{\frac{t-42}{18}}$, where u is the value to be found and t is the temperature on the Fahrenheit scale.

u is therefore the exponential function of the temperature itself, hence a temperature of 60° F. has a value of 2, 78° F. of 4, etc. Lehenbauer found, by actual tests on the growth of maize seedlings, that the growth rate at maintained temperatures followed Van't Hoff's rule, only for medium temperatures. It gives increasingly higher value, for higher temperatures and is therefore more accurate up to a certain limit, which is the temperature for the optimum growth rate, beyond which its values are much too high, because increase in temperature beyond the optimum means decreasing growth rate. This method fails, then, for one reason, as Zon (**9**) has pointed out in the case of the summation process, because it does not take account of this decrease in growth rate beyond the optimum temperature.

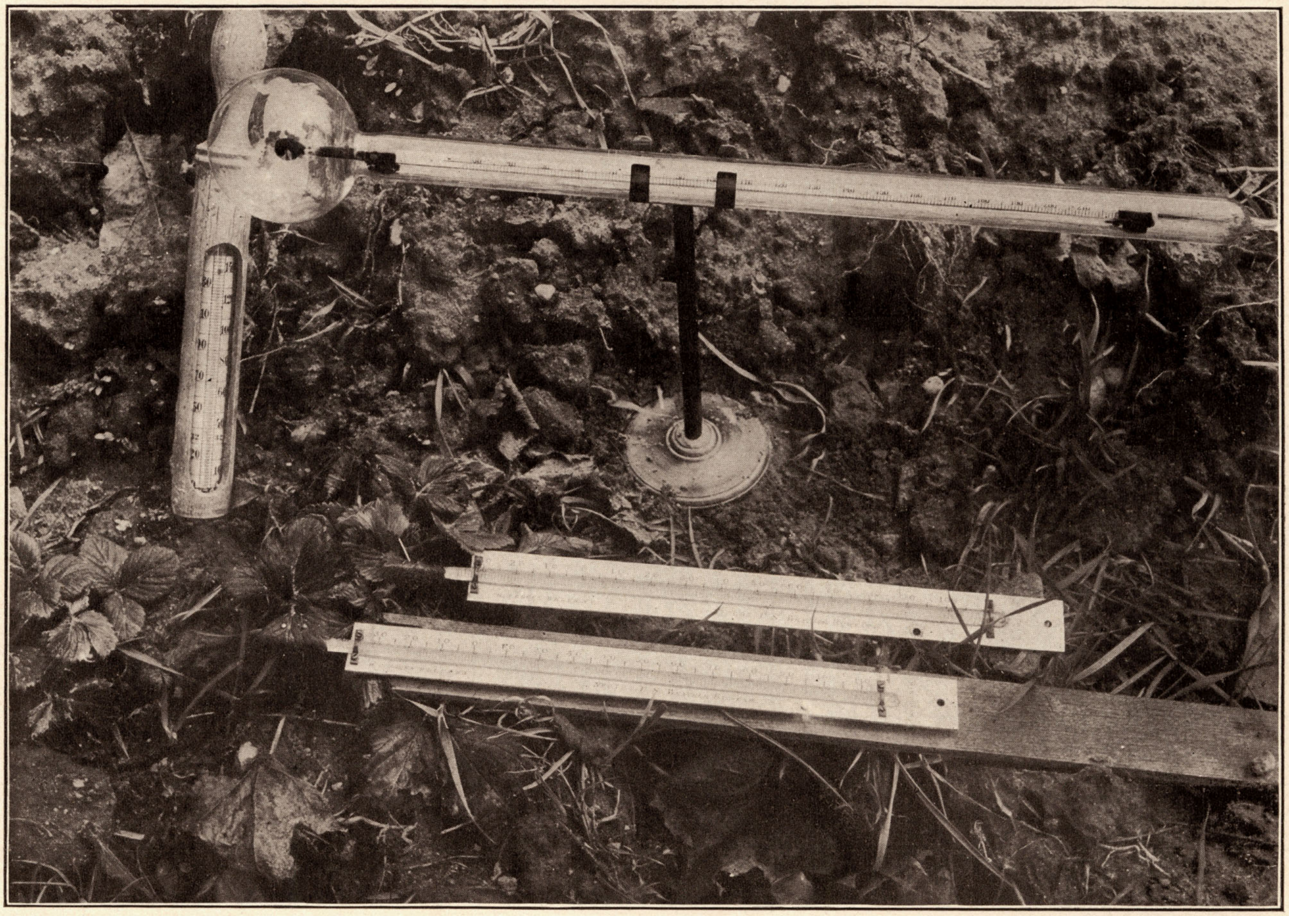

FIG. 1.—View of the exposures of thermometers furnishing the data for this study of plant and soil temperatures at the U. S. Weather Bureau station at East Lansing, Mich.

The physiological index method.

Realizing this fact Livingston (**10**) has worked out a series of indices of temperature efficiency for plant growth, based on Lehenbauer's measurements of growth of maize seedlings as influenced by temperature. He used the curve established by Lehenbauer and simply measured the rate of elongation at each temperature, using the elongation which took place at 40°F. as unity. At 89°, which was the optimum temperature for growth, the index was 122.3, after which it rapidly decreased to unity again at 116° F.

Livingston realized five imperfections in this method, viz: (1) It was established on a single plant species; (2) the seedling stage only was considered; (3) the shoot elongation was the only process of growth considered; (4) the environmental conditions were more limited than they are in nature; (5) measurements were made under maintained temperature conditions while in nature temperature conditions are exceedingly variable. He claims, however, that his method will be found to be an improvement over previous methods.

In order to test his assumption his indices were applied to the daily temperatures, both mean and maximum, during the two growth phases in maize at Wauseon, Ohio, previously mentioned, for the two years in which the extreme values were obtained by the summation process. It was believed that if the method had merit it would bring these extreme results nearer together. Table 2 shows the values obtained.

TABLE 2.—*Results obtained by the physiological index method of determining temperature efficiency, devised by Livingston, as compared with temperature summation results, during the two phases of growth in maize during years of extreme values as regards temperature requirements.*

Phase of growth.	Year.	Summation method (mean above 43°F.).	Livingston method. Mean temperature.	Livingston method. Maximum temperature.
Early growth phase (appearance above ground to blossoming)	1895	1,919	4,234.0	5,962.0
	1897	1,232	2,796.4	4,373.8
Relation of lower to higher in percentage		64	66	74
Later growth phase (blossoming to ripening)	1906	1,607	3,204.7	6,029.5
	1907	897	1,596.2	3,549.7
Relation of lower to higher in percentage		56	50	59

While the Livingston method brought the thermal values slightly closer together in the case of the earlier life phase, there is an even greater difference in the results obtained in the two years during the later growth phase, when mean daily temperatures are used, but a very small improvement when maximum readings are considered. The closer results obtained with the maximum temperature readings, instead of the means, amounted to 8 per cent and 9 per cent in the two phases, respectively, which supports the contention earlier made that maximum temperatures should be used. But even with these the results are not satisfactory with any system so far advanced.

Plant temperature.

The author believes that sufficient attention has not been given to the matter of temperatures of the growing plant in studies of the relationship between temperature and growth. The various parts of the living plant, by reason of their color and texture, have far different powers of absorbing and radiating insolation from those of the air which surrounds them. Many investigators have shown that leaf temperatures are higher when the sun is shining, than the surrounding air. Ehler (12) found that the temperature of pine leaves in bright sunshine, even in winter when insolation values are at their lowest, was 2 to 10 degrees C. ((3.6 to 18 degrees F.) higher than the surrounding air. Askenasy (13), Ursprung (14), Miss Matthaei (15), and Smith (16) have each found leaves of plants warmer than the air, the difference in temperature depending on the clearness of the sky, the season of the year, time of day, wind velocity, humidity, and possibly other factors, the difference amounting to as much as 40 degrees (F.) or more in some extreme cases.

During the past two years some observations have been made of the leaf temperature of the garden strawberry, *Fragaria vesca* growing on the Weather Bureau grounds at East Lansing, Mich. (lat. 42° 44'; long. 84° 26'; alt., 855 feet above sea level). These observations have been made in a rather crude way, by means of cylindrical-bulb minimum thermometers, as shown in the photograph herewith (fig. 1). The growing leaf was simply folded around the bulb and held in close contact with it by means of a pin or small splinter of wood. Care was taken to use a new leaf frequently. It is realized that this method did not give strictly accurate data as to the internal leaf temperature, and yet the results are believed to be but slightly in error compared to the very wide variations in temperature noted between the leaf and surrounding air temperatures. The difference between the readings of two thermometers similarly mounted to determine plant-leaf temperature was slight, never reaching 1 degree (F.), which would indicate that the readings obtained were approximately correct. Readings were made daily of the registered minimum temperature, and also the current temperature at 7 a. m., midday (regularly at 2 p. m. in 1916), and at 7 p. m. Alongside the plant-temperature thermometers a soil thermometer was exposed, with its bulb about 1 inch below the surface, and also a black-bulb in vacuo "solar radiation" thermometer. The two latter

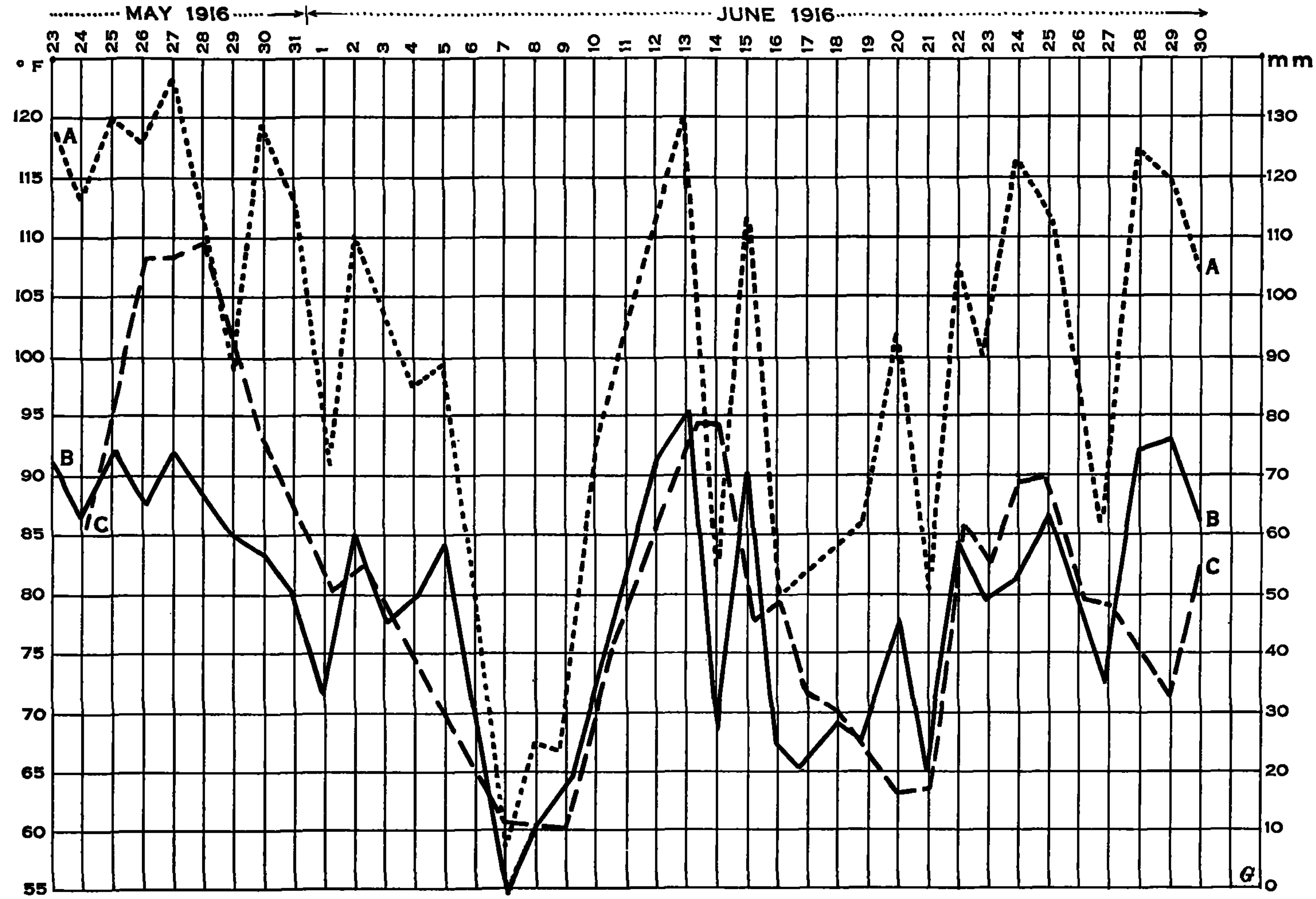

FIG. 2.—Curves of radiation, temperature, and plant growth at Weather Bureau office, East Lansing, Mich.
A=Daily readings of "solar radiation thermometer" (°F).
B=Midday readings of the plant thermometer (°F).
C=Daily elongation, in millimeters, of four plants; measurements made at 2 p. m.

thermometers were read thrice daily during the growing season of 1916 at the same hours as the plant thermometers.

For lack of space but one month's daily records are reproduced as Table 3 of the present paper, but it will serve to illustrate the characteristic variations in readings. The plant thermometer readings were usually lower than the air temperature in the early morning, the minimum usually being about 3 or 4 degrees (F.) lower than the air, the differences being greater, of course, when the weather was clear with but little wind velocity. The plant cooled off more rapidly than the air in the early evening, so that at 7 p. m. it was usually 3 or 4 degrees (F.) lower in temperature than the surrounding air. On very warm days, with clear skies and still air, differences as great as 9 or 10 degrees (F.) were observed. But the most striking difference made by placing a marked leaf against a stake which had been firmly driven into the ground alongside the plant at the beginning, and marking the height of the leaf tip on the stake daily at 2 p. m. The total daily elongation (in mm.) of the four plants was used in plotting the curve. The plants were kept well watered throughout the experiment. In connection with the curves of growth rate and plant temperature in figure 2, there is given curve *A* for the radiation thermometer. Figure 3 has, in connection with the same growth-rate curve, *C*, curves of soil temperature, *S*, and of the maximum and mean air temperatures (*Mx* and *m*). It will be noted that the parallelism between the plant temperature (*B* in fig. 2) and growth-rate curves is closer than that between any other temperature curve and that for growth rate.

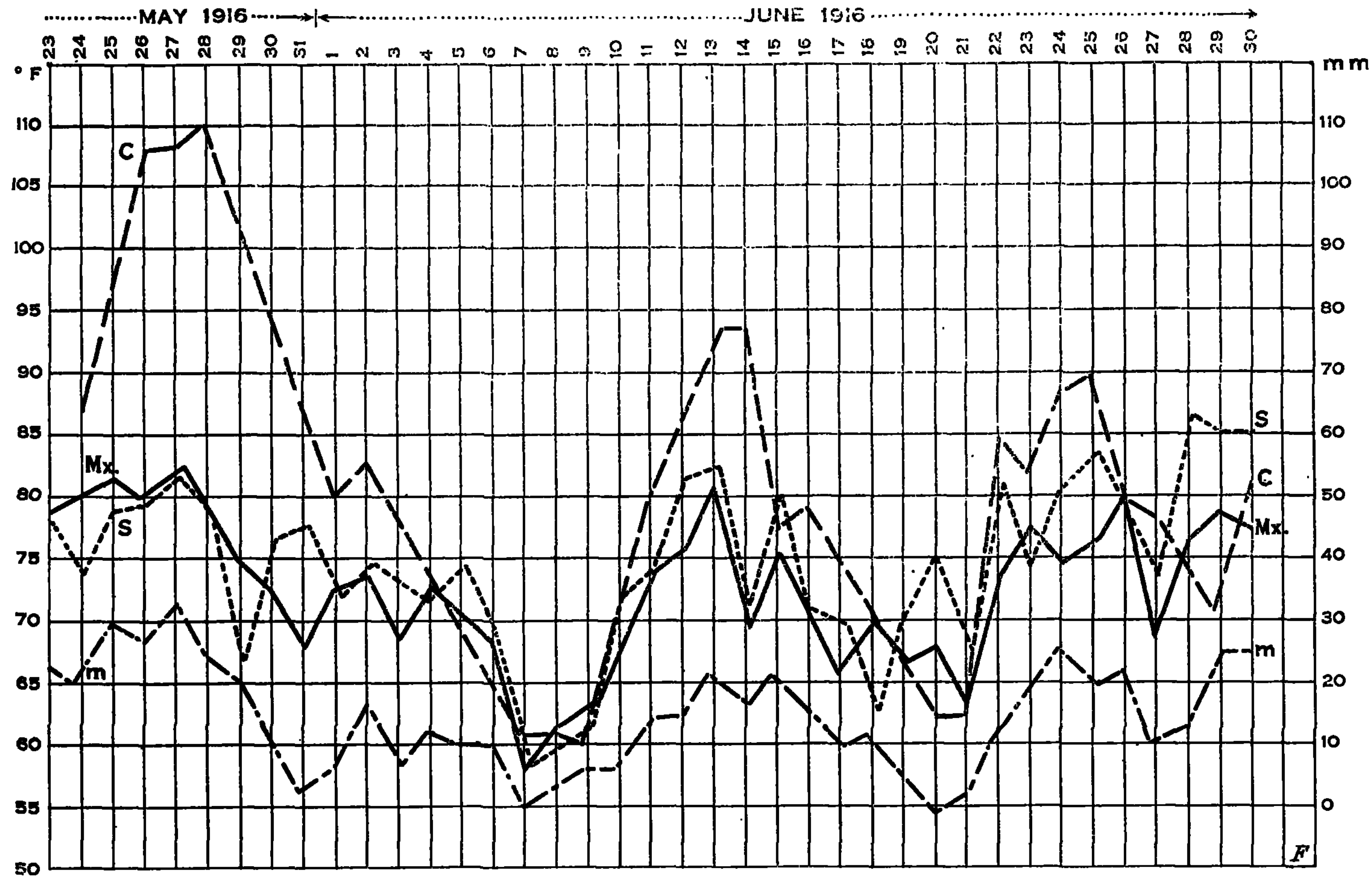

FIG. 3.—Curves of soil and air temperatures, and plant growth at Weather Bureau office, East Lansing, Mich.
C—Total daily elongation of four plants, measured at 2 p. m. (cf. fig. 2).
Mx—Maximum air temperature daily.
m—Mean daily air temperature.
S—Soil temperature, read at 2 p. m. daily.

between leaf and air temperature occurred during the heat of the day, when they frequently amounted to 20 degrees (F.), and on a few occasions reaching 36 degrees (F.). The plant was at the higher temperature at the midday observation on all but 41 out of the 304 days that readings were made. These 41 days were all dark and cloudy, many of them with rain falling at the time of observation.

The fact that there is a close relationship between growth rate and the temperature of the plant itself is clearly shown by curves of growth rate, *C*, and of plant temperature, *B*, reproduced in figure 2. The curve of growth rate (*C* in fig. 2) is based on plant elongation measurements made on four plants—two gladioli and two soy beans—growing near the point where temperature readings were taken. The measurements of growth were

The closer connection between the temperature of the plant itself and the rate of growth and development was demonstrated by another experiment conducted as follows: On April 6, 1916, before there were any visible signs of awakening in plant life out-of-doors, a cherry tree was removed from the college nursery to the botanical greenhouse. Thermograph records of temperature were obtained both out-of-doors and in the greenhouse until the blossoms opened. This event occurred in the greenhouse on April 19, thirteen days after removal from out-of-doors, while cherry trees of the same variety in the open air did not blossom until May 9, or twenty days later. From the temperature traces the total "temperature hours" was computed, indoors for the 13 days and out-of-doors for the 33 days, by giving to each hour a value equal to its temperature minus 42°F. This gave 9,048 for the greenhouse and 4,228 for the open air. Evidently the air temperatures were not reliable sources from which to determine the amount of heat which was required to bring out the blossoms. A third temperature trace was constructed by interpolating from the four-daily plant temperature readings (minimum, 7^a, 2^p, and 7^p) which was only roughly correct, but which gave a total of 7,877 by the same system. If the effect of transpiration is taken into account, one may safely assume that the shaded tree in the greenhouse was about 2.7 degrees (F.) cooler than the thermograph bulb, if we accept Darwin's (17) figures for the reduction due to transpiration. This would bring the thermal value in the greenhouse down to 8,237 as compared with 7,877 out-of-doors, which is remarkably close.

brightly, while the difference between plant and air temperatures is lessened in proportion to the density of cloudiness. The 304 observations of plant temperature at midday have been collected under three headings: (1) those taken in bright sunshine; (2) those with a partially obscured sun; and (3) those when the sky was thickly overcast. Out of a total of 115 observations in clear weather, the average excess of plant temperature over that of the air was 15.2 degrees (F.); 88 partly cloudy days showed an average of 9.7 degrees excess, while on 101 cloudy days the average excess of plant temperature was 0.9 degree. These all refer to midday observations.

With this as a basis the writer has evolved a formula for evaluating air temperature readings as to their efficiency in promoting plant growth. The formula makes use of these temperature excesses in clear, partly cloudy,

TABLE 3.—*Plant, soil, and "solar radiation" temperatures at East Lansing, Mich., compared with instrument shelter readings, during the month of August, 1916.*

[Location: All readings are taken on the south side of the Weather Bureau building on the Michigan Agricultural College campus, within fifteen feet of one another.]

Date.	Minimum.		7 a. m.			2 p. m.				7 p. m.			State of sky.
	Plants.	Shelter.	Soil.	Plants.	Shelter.	Solar radiation thermometer.	Soil.	Plants.	Shelter.	Soil.	Plants.	Shelter.	
1916.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	
Aug. 1	55.9	59.2	70.0	60.0	63.0	118.0	96.0	92.0	81.2	80.0	61.0	69.0	Clear.
2	46.0	49.0	65.8	55.8	60.1	124.0	94.0	100.0	85.0	83.0	67.5	76.0	Clear.
3	58.0	62.5	72.0	67.0	69.5	101.0	87.0	85.5	86.3	78.0	66.0	71.2	Partly cloudy; light sprinkle 1:20 p. to 1:30 p.
4	59.5	64.0	69.5	66.1	71.3	125.0	94.0	104.0	92.5	82.0	74.0	79.5	Partly cloudy.
5	67.9	70.1	74.0	69.0	71.2	128.0	94.0	107.0	89.0	82.0	74.0	80.2	Clear.
6	68.5	72.2	76.0	74.0	78.0	124.0	94.0	100.0	94.3	84.0	77.0	85.8	Clear.
7	70.9	75.1	76.5	75.1	79.1	98.5	92.0	84.0	89.0	82.0	76.0	82.2	Partly cloudy with showers.
8	67.1	70.1	74.0	70.0	71.5	128.0	88.0	97.0	83.0	78.0	66.0	74.0	Partly cloudy.
9	55.1	59.0	68.0	61.8	64.6	118.5	86.0	96.0	82.0	76.0	63.7	70.0	Clear.
10	56.1	59.1	66.0	61.0	65.2	109.8	82.0	86.1	84.0	76.0	74.2	80.3	Clear a. m.; cloudy p. m.
11	66.8	69.1	73.5	70.2	72.8	109.0	83.0	91.0	82.0	76.0	68.5	75.0	Partly cloudy.
12	52.2	55.0	64.5	57.4	62.0	122.0	84.0	92.0	82.0	70.0	63.5	69.2	Partly cloudy.
13	49.0	50.9	61.5	52.0	54.9	118.5	82.0	83.0	71.8	70.0	54.0	61.1	Clear.
14	43.9	44.6	58.0	49.1	53.9	88.5	74.0	73.0	71.0	68.0	57.0	62.0	Mostly cloudy.
15	45.0	48.3	58.5	52.6	56.0	102.0	82.0	83.0	80.0	73.0	65.0	71.0	Mostly cloudy.
16	57.9	62.0	67.5	64.1	65.1	120.0	92.0	98.0	84.5	79.0	69.0	74.3	Clear.
17	56.8	59.8	66.5	62.0	64.0	121.0	91.0	96.0	88.2	78.0	64.0	73.3	Partly cloudy, clouds thin.
18	60.0	64.7	70.0	68.1	72.3	116.0	88.0	100.0	88.0	83.0	72.0	78.0	Partly cloudy to cloudy.
19	67.0	70.1	72.5	72.3	75.0	120.0	93.0	103.0	95.7	84.0	75.0	84.0	Clear.
20	65.2	68.1	72.0	70.0	73.1	136.0	100.0	113.0	98.2	82.5	75.5	83.7	Clear.
21	65.0	68.1	74.0	70.9	74.0	113.5	100.0	108.0	96.2	86.0	75.5	84.0	Clear.
22	68.6	73.8	76.0	72.8	76.5	129.5	96.0	104.0	87.2	80.0	64.0	69.3	Clear.
23	48.9	52.2	64.0	53.0	57.0	124.0	91.0	103.1	78.0	76.0	59.0	68.0	Clear.
24	48.9	54.1	64.0	56.0	61.0	127.8	90.5	97.8	86.0	78.0	65.5	74.0	Clear until 4:30 p. m., then partly cloudy.
25	48.9	52.1	62.0	53.1	57.0	94.0	86.0	85.0	78.7	73.0	69.5	66.2	Clear.
26	51.9	56.0	64.3	58.0	60.2	70.0	70.0	66.0	65.0	68.0	60.0	62.1	Cloudy.
27	43.6	46.7	58.0	48.0	51.7	108.0	72.0	86.0	71.0	68.0	54.0	60.0	Partly cloudy to clear.
28	38.9	41.0	56.0	45.0	48.0	118.0	74.0	103.0	75.0	70.0	55.0	62.5	Partly cloudy to clear.
29	46.0	49.4	50.0	53.1	57.0	110.5	77.0	92.0	79.0	72.0	59.0	65.8	Clear.
30	49.0	54.5	62.0	56.5	60.9	118.0	80.0	102.0	80.1	72.0	58.0	67.0	Clear.
31	50.0	54.1	62.0	58.1	62.0	103.0	78.0	87.8	83.0	74.0	64.5	73.1	Partly cloudy, thin clouds.
Sum	1,728.5	1,834.9	2,077.6	1,902.1	2,007.9	3,564.1	2,690.5	2,918.3	2,586.9	2,381.5	2,046.9	2,251.8	
Mean	55.8	59.2	67.0	61.4	64.8	115.0	86.9	94.1	83.4	76.8	66.0	72.6	

It is a fact that the higher temperature produced by sunshine is only one factor in promoting plant growth, as the actinic action of sunlight plays an important part in the metabolic processes going on within the plant. Whether the increase in temperature can be taken as a measure of the increased effectiveness of sunshine in this second influence is problematical, and needs investigation.

A working formula.

A study of the readings which have been made at East Lansing, shows that sunshine is a controlling factor in determining plant temperature, and furthermore that plant temperature largely determines the rate of plant growth and development. Cloudiness thus enters into the problem in that it lessens sunshine. The plant is much warmer than the air when the sun is shining

and cloudy weather, which in round numbers are 15, 10, and 1 degree, respectively; but the last amount has been disregarded as being too small to materially affect the results obtained through a formula which is considered still rather crude. If we indicate by

X, the number of days having a maximum temperature above 42°F.;

m, the sum of all maximum temperatures above 42° during the period X;

C, the number of clear days during this period;

P, the number of partly cloudy days during this period;

T, the effective temperature-total sought;

and let

$t = m - 42X$,

then we may write our formula

$$T = t + 15C + 10P.$$

Although recognizedly imperfect and held subject to amendment after further investigations, this formula will be found to bring about much closer results than the simple summation method or any other modifications of it so far advanced.

The final formula which is to be brought out with further study, will take into consideration more accurate values for plant temperature, and give proper weight to the effect of wind velocity, humidity, and both the caloric and actinic value of sunshine.

In conclusion it should be stated that these studies are only preliminary to others which the author hopes to make with the aid of more accurate instruments and methods. It is realized that an enormous amount of research must be carried through before the final goal is reached and an exact formula established for expressing the complete relationship between climatic or weather conditions and crop production; and that this is only a minute contribution toward the desired end.

The valuable suggestions and assistance rendered by Drs. E. A. Bessey and R. P. Hibbard, by Profs. A. R. Sawyer, C. W. Chapman, and others of the Michigan Agricultural College, are gratefully acknowledged, as is also the assistance given by Mr. B. B. Whittier, observer, in making many thermometric readings.

SUMMARY.

The relation between weather and crop production is vital and important, but definite statements as to the exact relationships existing are lacking, for the most part, especially in regard to the rôle of temperature. In the latter respect we need a statement of the plant's thermal requirements and a method of evaluating air temperature in terms of its efficiency to meet these requirements.

The method most generally used has been called the summation process, consisting of simply adding together the mean daily air temperatures during the life phase of a crop, in order to find the thermal requirement. This produces widely differing results from year to year. The same process yields somewhat more consistent results if one employs maximum instead of mean temperatures; but the summation process is ineffective.

Van't Hoff's law, when introduced into the study by the exponential method, also fails to produce consistent results, mainly because it does not take into account the optimum temperature for growth.

Livingston's "physiological index" method of evaluating temperatures is based on a reasonable footing in that he used actual growth rates resulting from differing temperatures; but it does not produce much closer results when it is actually applied to the problem.

It is believed that the temperature of the plant itself should be given more consideration, as it is much warmer than the air when bathed in sunshine. Observations carried on at East Lansing during 1915 and 1916 show that this excess in temperature of the plant over the air in clear weather averages about 15 degrees, in partly cloudy weather 10 degrees, and in cloudy weather less than 1 degree (F.). Curves expressing plant growth rates and plant temperatures show parallelisms more decided than other temperatures observed, including maximum and mean air temperatures, soil temperatures, and readings of the "black-bulb in vacuo." A test of the number of heat units required to cause a cherry tree to blossom in the greenhouse and out-of-doors shows remarkably close results when plant temperatures are considered, but a consideration of air temperatures alone gives a wide variation.

A formula is evolved for determining the effectiveness of air temperature in promoting crop development, as follows: $T=t+15C+10P$, t being the sum of maximum temperatures above 42° during a certain period, after that amount has been subtracted from each temperature, C being the number of clear and P the number of partly cloudy days during the period.

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DAMAGE BY HAIL IN KANSAS.

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In Kansas damage by hail is most serious in the fields of growing wheat, and in the wheat-growing belt of the United States it is a widespread practice to insure against such loss by hail. It therefore seemed reasonable, to the writers, to expect to find that in this wheat belt there had been made a close study of the occurrence of hail. So far as they have been able to ascertain, however, no systematic collection of data relative to hailstorms in Kansas—the greatest wheat-growing State of the Union—has ever been attempted beyond the statistics of losses sustained there by the companies issuing hail insurance. This omission seems all the more striking in view of the fact that reliable estimates indicate hail-caused damage amounted to more than $6,000,000 during 1915 alone—an amount of damage many times greater than ever resulted from the tornadoes of any single year and probably greater than the average annual damage from unseasonable frosts. Yet both tornado and frost occurrences have been studied at length.