A PHYSIOLOGICAL STUDY OF THE CLIMATIC CONDITIONS OF MARYLAND AS MEASURED BY PLANT GROWTH.

(A second contribution from data obtained under the auspices of the Maryland State Weather Service, in 1914.)

DISSERTATION

Submitted to the Board of University Studies of the Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy.

By

F. Merrill Hildebrandt

Baltimore, June, 1917.

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ACKNOWLEDGMENTS.

The study dealt with in this paper was suggested by Dr. B. E. Livingston and carried out under his direction. The writer wishes to express his indebtedness to Dr. Livingston for great assistance rendered in carrying out the study and for helpful criticism of the manuscript. The writer also wishes to thank Dr. H. E. Pulling for valuable suggestions made during the course of the study.

[illegible]

[illegible] the s[illegible] [illegible] was [u]ndertaken by the Maryland [illegible] [illegible] station with the Laboratory of Plant Physiology of the Johns Hopkins University, with the [obj]ect of [illegible] the relations between climatic conditions [illegible] plant [illegible] at different [illegible] in Maryland. Detailed information as to the growth of the plants [illegible] is of course [illegible], [illegible] also [illegible] of these envi-ronmental conditions [illegible]. The plant [illegible] secured in this [illegible] by growing cultures of certain plants in the environmental conditions [illegible] studied and noting the growth [illegible] during definite periods of time. The [illegible] measurements of [illegible] environmental conditions [illegible] for comparison with the [illegible] [illegible] in the region [illegible] observation stations [illegible]. [illegible] general plan of the stu[dy] and a detailed [illegible] the methods used has already been printed by Mclean, [illegible]

Mclean, F. T., A preliminary study [illegible] Maryland, as related to plant growth. [illegible] 1917.

[illegible] studied by this [illegible]

[illegible] true description of the [illegible] [illegible] [illegible] [illegible] [illegible] were obtained [illegible] [illegible] needed to make [illegible] intelligible. This description is mainly taken from McAdie's paper, which dealt with the growth of early-bean [illegible], but for [illegible] [illegible] [illegible] stations, Easton and Oakland. The present paper gives the main results for soy-bean plants, for all of the stations, together with some attempt at interpretation. This study has been carried out partly through financial aid furnished by the Maryland State Weather Service.

The stations employed were Oakland, Chewsville, Monrovia, College Park, Baltimore, Darlington, Collington, Easton, and Princess Anne. One station, Oakland, is in the Allegheny plateau. Four stations are in the piedmont plateau, one (Chewsville) in the Hagerstown valley, two (Darlington and Monrovia) in the hilly country north and west of Baltimore, and one (Baltimore) at the lower edge of the plateau near Chesapeake Bay. Four stations, College Park, Collington, Easton, and Princess Anne, are in the coastal plain. Collington, Easton and Princess Anne are east of Chesapeake Bay, while College Park is west of it [illegible] much further inland, [illegible] [illegible] [illegible] [illegible] demarcation between the coastal plain and the [illegible] plateau. All of the stations except Oakland are [illegible] [illegible] [illegible] elevations,—less than 300 meters (1000 feet) [illegible] sea-level. Oakland has an elevation of [illegible] meters ([illegible] feet). The geographical distribution [illegible] [illegible] Fig. 1 [illegible] [illegible] [illegible] [illegible] and that considerable differences [illegible] [illegible] [illegible] exists between them.

At each of the nine places employed in this investigation, a series of cultures was grown in the open with no covering other than a screen of large-meshed wire netting to prevent injury to the plants. These have been termed the exposed stations. In addition, at Oakland, Baltimore, and Easton, a series of cultures was grown under glazed cold frame sash supported horizontally 1 meter (3.3 feet) above the surface of the soil. These have been termed the covered stations. They were placed within several meters (6.5 feet) of the enclosures containing the plants of the exposed stations and were subjected to the same climatic conditions as the exposed plants except in so far as these conditions were modified by the glazed cold frame sash. At Baltimore a series of cultures was grown in the woods near the Laboratory of Plant Physiology of the Johns Hopkins University. This has been termed the Baltimore Forest Station. These plants like those of the exposed stations had no covering other than a protective wire screen. Owing to their location, they were, of course, subjected to a set of climatic conditions quite different from those acting on the exposed and covered plants at Baltimore. The Forest Station at Baltimore was distant about 150 meters (490 feet) from the exposed and covered stations. There are thus plant data available from 13 series of cultures in all, each series having been exposed to a different set of environmental conditions throughout the season.

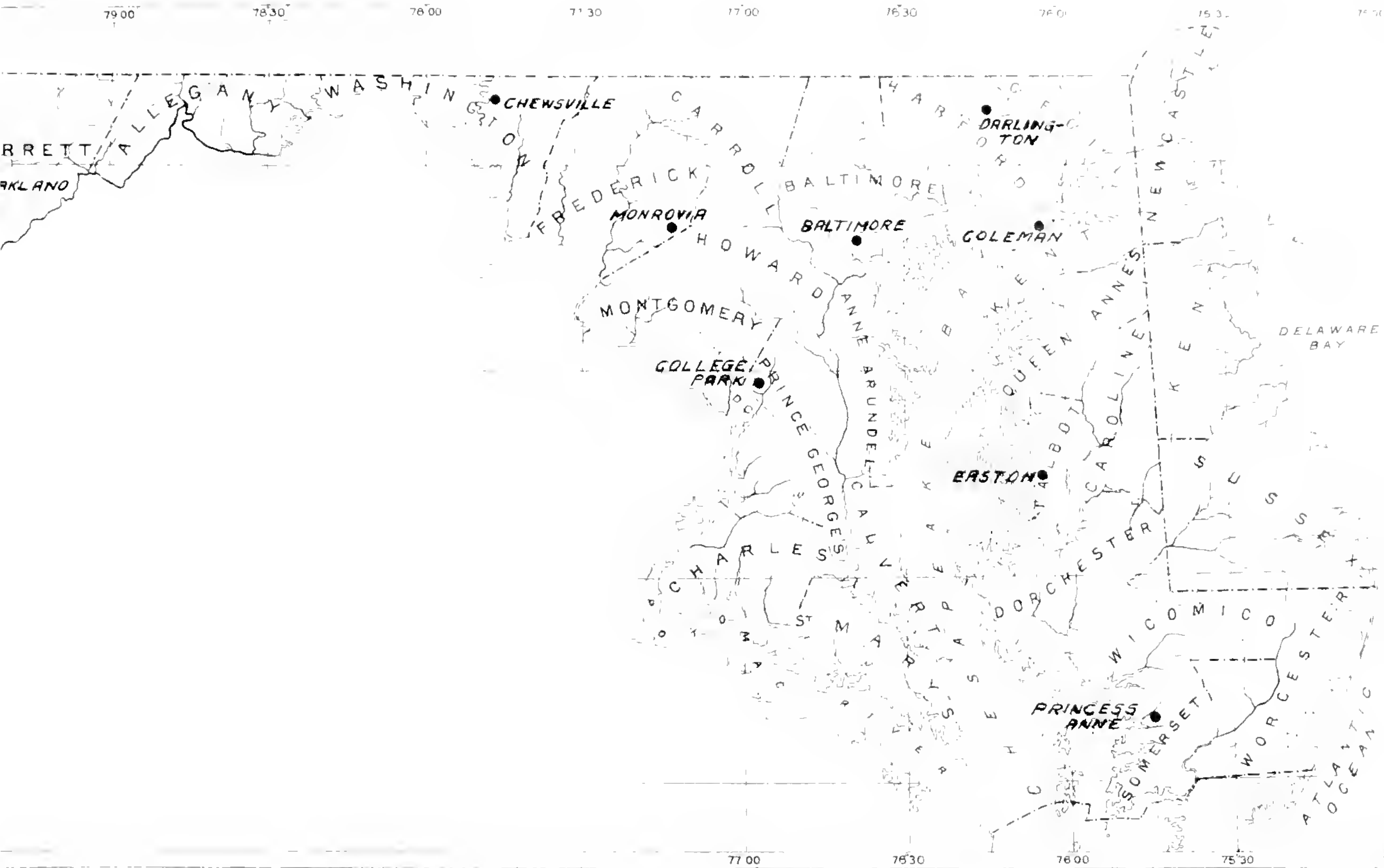

Fig. 1. Map of Maryland, showing locations of stations employed for soy-bean cultures and climatic observations. (After McLean)

The environmental conditions to which the cultures of this experiment were exposed were so controlled that the plants might be regarded as standard plants for the measurement of climatic conditions in accordance with a suggestion made by Livingston and McLean[7]. Since the problem of expressing

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7/ Livingston, B. E., and McLean, F. T. A living climatological instrument. Science, n. s. 43: 362-363. 1916.

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plant growth in terms of climatic conditions that control it

is rendered exceedingly complex by the number of these conditions and their continual variation, as well as by the changing internal conditions of the plant itself, a detailed analysis of the control of plant growth in terms of effective climatic conditions is very difficult, but, as Livingston and McLean suggest, the rate of growth of any plant is itself an expression of the sum total all the effects of the external conditions acting during the growth period, so that a standard plant might be employed as an automatically weighting, integrating, and recording instrument for the comparative measurement of growth conditions as these act on plants. Thus several environments may be measured and compared in terms of their several capacities for producing growth in the standard plant. This method of measuring environment in terms of plant growth can be applied only when it may be assumed that all the standard plants are alike at the beginnings of the several periods of exposure. In the present study the requirement just stated was fulfilled by employing the seed as the starting point for the plants of the various cultures. It was apparent that if the cultures were always started from the seed the plants might be considered as more nearly alike at the beginning of the several culture periods than would have been the case if an attempt had been made to obtain like plants in any other phase of their development. The internal conditions of the plants change continually, however, during growth, and no two of the cultures were the same at the end of the culture periods. This phase of the problem will receive attention later.

As in other problems in which a number of conditions enter into the control of a process, the relations between

conditions and process rate are more easily interpreted the smaller is the number of conditions involved, and conditions may be left out of consideration if they are the same in several experiments. Just as the internal conditions of the standard plant are left out of the arguemt by the single device of having them all alike at the beginning of the exposure period (the instrument being set at zero of its scale, in the words of Livingston and McLean), so selected ones of the surroundings may be left out of consideration by having them alike throughout all of the periods. According to this principle all of the environmental conditions that acted on the plants below the soil surface were kept practically constant at all times and at all stations. Assuming that the artificial control of the subterranean environmental conditions was thus practically constant, the differences observed in the growth of the standard plants were taken to be related almost entirely to the aerial conditions of the surroundings. These are the ones referred to by McLean as climatic, and this term will be used with the same meaning in the present paper. To accomplish this control of the subterranean conditions, the soil was always the same at the beginning of all cultures and its moisture content was generally kept approximately the same throughout all culture periods, by means of the Livingston auto-irrigator. The arrangement and its operation have been described by McLean and will receive some attention below.

The growth rates of the plants [illegible] were compared in terms of their size and weight. Each culture consisted of six plants grown for a period of four weeks from the seed. Cultures were started approximately every [illegible]

During the growing season, [illegible] [illegible], and growth measurements were made after about two [illegible] again after about a month. The plants were harvested at the end of the longer period.

While several different plant species were employed throughout the experimental work, the present paper deals only with the data obtained from soy-bean. A variety of this plant called "Peking", was used. The seeds [illegible] were obtained from the 1917 crop of the Maryland Agricultural Experiment Station. All the seeds were first treated with carbon bisulphide vapor for one week, to destroy insects, after which they were placed in paraffined paper cylinders with tight-fitting covers and stored until ready for use.

The same kind of soil was used in all of the plant cultures, at all stations. It was a rather light soil obtained from an untilled field near College Park, Maryland, and was of the type classified as Norfolk sand by Bonsteel.[3] The top-

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[3] Bonsteel, J. A., The soils of Prince George's County. [illegible]. Maryland Geological Survey. Bulletin [illegible], 1911.

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soil was removed from a small area of the field to a depth of 15 cm., and thoroughly mixed and sifted. It was then placed in cloth sacks and shipped to the various stations, where it was stored in air-dry condition in covered, water-tight, galvanized iron cylinders, until needed for use in the cultures. The soil containers for the cultures were ordinary "[illegible]", porous clay flower-pots, in form like the frustrum of a cone, being smaller at the bottom, and of a cubic capacity of approximately 1560 cc.

In order to secure uniform soil conditions in the various cultures, it was necessary not only that the soil should be of the same character in all of them but also that it should be brought into the same physical condition for the beginning of all cultures. Furthermore, it was desirable that this physical condition be such that it would be retained during the growth periods of the plants. To put the soil into a state of aggregation to be least altered by varying weather conditions (especially heavy rains which pack the soil more or less) it was saturated with water immediately after being put into the pots. This was accomplished by plunging the filled pots into a bucket of water and allowing them to remain submerged until air bubbles ceased to rise. The pots were then allowed to drain.

The soil moisture in the cultures was maintained always above a certain minimum by means of auto-irrigators.[4] This

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[4] Livingston, B. E., A method for controlling plant moisture. Plant World.11:39-40.1908.

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device, as here used, consisted of two cylindrical porous clay cups (of the regular form supplied by the Plant World) connected with each other and with a water reservoir by glass tubes in the form of an inverted J. The cups were placed vertically in the pot, their rubber-stoppered ends level with the soil surface, and were so arranged as to supply water to the soil against a pressure of 30 cm., or somewhat more, of a water column. The moisture content of the soil was thus maintained so that it was never less than about 1[illegible] to 17

per cent, on the basis of dry weight. The [illegible] soil with this water content was rather too wet than too dry for the best growth of the plants here studied.

After preparing the pots and arranging the watering devices the pots were then allowed to remain fallow for about two weeks before planting. Thus the soil was fully drained after the preliminary saturation and had settled into a condition somewhat approaching that of structure equilibrium before the seeds were planted. The seeds were planted [illegible] cm. deep, six seeds in each pot. Care was taken to space them uniformly and to place them about equally distant from the auto-irrigator cups and from the sides of the pots so that all should have, as nearly as possible under the conditions of the experiment, the same soil moisture conditions. When the plants were removed from a pot (about six weeks after that pot had been filled) the soil was discarded and fresh soil from the stored supply was used in refilling for the next following culture.

The weather observations taken by the cooperative observers at each of the stations here employed consisted of daily readings of maximum and minimum thermometers, daily ocular observations of cloudiness, daily measurements of rainfall and general notes as to storms, winds, etc. In addition to these records of the weather observers [illegible] by means of Livingston standardized cylindrical [illegible] with non-rain absorbing mountings.[1] Of [illegible] climatic

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[1] Livingston, B. E., [illegible] porous cup atmometers. [illegible]

Atmometry and the [illegible]. I[illegible]. 1: [illegible], 1-7[illegible], [illegible]-111, 1[illegible]-1[illegible].1[illegible]

[illegible] mentioned above, only [illegible] considered here, namely, those of temperature, light, and evaporation. As was pointed out by McLean, rainfall showed little or no relation to the growth of these plants, since the soil moisture of the cultures was always kept sufficiently high (by the auto-irrigators) for the needs of the plants. The main influence usually thought of as exerted by rain upon plants is of course an indirect one; the rain does not affect the plants but it alters the soil moisture condition and this alteration thus brought about influences the supply of water available to the plant roots. Rainfall data will therefore not be dealt with in this paper. Also, the miscellaneous climatological characteristics reported by the weather observers will not be considered since none of them have been found to bear any relation to the growth of these plants.

The mass of climatic data, instrumental in the case of evaporation and temperature, and observational in the case of light, can obviously not be compared with plant growth until it is simplified in some way. The process of simplification here adopted involves two main steps. The first of these consists in bringing together the daily observations into [illegible]-week and four-week groups [illegible] growing periods. (One way in which [illegible], [illegible], [illegible] to average the daily [illegible] over the [illegible] week period, thus obtaining [illegible]

[illegible] in weighting average values [illegible] second series of values that express [illegible] as they affect the plants. It is clear, [illegible], [illegible] readings of [illegible] after [illegible] expresses [illegible] effectiveness of temperature to accelerate or retard plant growth. It there-fore becomes desirable to replace the actual [illegible] readings by a series of weighted values, more or less directly pro-portional to the temperature effect upon the growth of the plants. Owing to lack of information of a quantitative nature as to the relation between plant growth and environmental tem-perature, this can be accomplished only in a tentative and approximate way at the present time. No attempts have yet been made to derive such weighted values to represent the effectiveness, for plant growth, of any other climatic condi-tion.

The consideration of temperature, light, and evapora-tion now to be given will show how the original climatological data have been grouped for comparison with the plant growth measurements and how the average values have been handled in the present study.

Temperature.

The temperature data used in this study were all obtained from maximum and minimum thermometers read daily at sunset. The daily mean temperature was determined by averaging each days maximum and minimum readings. The maximum and minimum temperatures from which the daily means were determined were secured from the published monthly reports of the U. S. Weather Bureau.[6]

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[6] Fassig, O. L., Climatological Data, Maryland and Delaware Section, numbers from May to November inc. 1914. U. S. Weather Bureau.

McLean has discussed some of the possible ways in which daily maximum and minimum temperature data may be treated in order to obtain weighted values that may represent temperature effect upon plant growth rates. He points out that temperature values as shown by a thermometer do not show a linear proportionality to plant growth. If thermometer readings expressed, even in an approximate way, the effect of temperature on growth, such a relation could only be true up to the optimum temperature, since beyond this point increased temperature results in decreased growth. It would, therefore, be desirable to replace each thermometer reading by an index representing the effect of that particular temperature on plant growth. Three ways of doing this, all of which have been considered by McLean may receive brief mention here.

One way of expressing temperature, which has been used in ecological studies, may be called the remainder summation

method. This is based on the supposition that the growth activities of many or most plants stop when the temperature falls to about 40° Fahrenheit. Above this temperature, growth increases with increased temperature, to an optimum. For convenience, the growth rate for 40° F. may be considered as unity; then it should be 2 for 41°, 5 for 44°, 20 for 59°, etc. If we subtract 39 degrees from any given temperature, then, the remainder will represent, according to this method, the efficiency of the temperature in question for producing growth. A total efficiency value for any period of time, such as the four-week growth periods of the cultures of the investigation here considered, might be obtained by subtracting 39 from each daily mean temperature and summing the remainders for the period. This method has frequently been used in ecological studies where it was desired to obtain approximate expressions of temperature values in terms of their efficiency to produce plant growth.

Another method of weighting temperature values for the purpose before us, and one that has an apparently more rational basis, was suggested by Livingston and Livingston.[1] They

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[1] Livingston, B. E. and Livingston, G. J., Temperatur coefficients in plant geography and climatology. Bot. Gaz. 56:349-375.1913.

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proposed a series of temperature efficiency indices based on the Van't Hoff-Arrhenius law, which states that the velocity of many chemical reactions approximately doubles with a rise

in the temperature of ten degrees Centigrade (18° F.). These authors assume the growth rate to be unity for a temperature of 40° F. and derive a series of values representing temperature efficiencies for higher temperature. In using these exponential indices the assumption is made, as the authors have pointed out, that the plant processes whose relation to temperature is under investigation follow the chemical principle upon which the indices are based. When this scheme is used, the efficiency value for any temperature is represented by the value of the exponential index that corresponds to the temperature value itself. Assuming the growth rate to be unity for a temperature fo 40° F., it should be 1.21 for a temperature of 45°, 2.0 for 58°, etc.

Since most of the temperatures with which we have to deal are below the optimum for plant growth, since temperature and the growth rate appear to be related in an approximately linear manner between 40° and the optimum, (about 75° C.) and since both the exponental and remainder series of index value increase in a practically linear way throughout this range, both of the methods just considered give temperature efficiency numbers that appear to be approximately proportional to plant growth as it is influenced by temperature. It is of course obvious that neither of these methods can properly express efficiencies for temperatures above the optimum since they give numbers which continue to increase with increasing temperature while growth increases with increasing temperature up to the optimum and then decreases with higher temperature. Also, both these methods appear generally to give

approximately proportional results for ordinary growing temperature. This fact has been noted by Livingston and Livingston and again by [illegible]

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[8] Stevens, Neil E., Influence of temperature on the growth of Endothia Parasitica. Am. Jour. Bot. 4: [illegible], 11[illegible]-11[illegible]. 1917. Idem, Influence of certain climatic factors on the development of Endothia parasitica. Ibid. 4:1, 1-33. 1917.

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the climatic data given by McLean.

A third method of expressing temperature as it affects plant growth has been more recently suggested by Livingston[9]. From the results of Lehenbauer's experiments on maize seedlings,[10]

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[9] Livingston, B. E., Physiological temperature indices for the study of plant growth in relation to climatic conditions. Physiol. Res. 1: [illegible], 399-420. 1916.

[10] Lehenbauer, P. A., Growth of maize seedlings in relation to temperature. Physiol. Res. 1; 247-2[illegible]. 1914.

Livingston derived a series of coefficients giving the efficiencies of various temperatures in terms of the growth of this plant. He has called these "physiological temperature indices". The growth rates upon which the index values are based are those shown by the seedlings when exposed for 12 hours to a maintained temperature, the other conditions of the experiment being approximately the same for all experiments. It is suggested that the coefficients thus derived

from the growth of maize under controlled conditions, with different maintained temperatures, may readily express a general relation between plant growth and temperature and may thus be applicable to plants growing under other conditions. The graph of these physiological indices, as related to temperature is of course the graph of maize seedling growth as so related, and it exhibits the same direction of slope between low temperatures and the optimum graphs of temperature efficiencies as derived by the other two methods, but for this portion of the temperature range the slope of the graph of physiological indices is generally steeper than that of the graph of remainder indices, the latter graph having a much steeper slope than that of the exponential indices. This is shown by Livingston and also by Stevens, in the papers cited above. Since they are derived from the actual growth rates of a plant, the physiological temperature indices appear to have a more rational basis than either the remainder or the exponential indices. For this reason, and for others that will appear below, the physiological indices are used in this study for expressing the temperature as it affects the growth of the plants. Two other series of temperature values are presented in the tables of this paper but neither has been found to be as satisfactory for expressing this climatic condition as are the physiolcgical indices. These two other temperature values are (1) the average daily mean temperature for each period, in degrees Fahrenheit and (2) the remainder summation index for each period. In the case of temperature, as in the case of light and evaporation, the value given for each period

represents the average daily value. All of the data here treated, both plant and climatic, have been reduced to daily rates, for reasons which will be given below.

McLean has pointed out three ways in which we may use the daily maximum and minimum temperature record and a temperature coefficient, such as the Livingston physiological index, to get average daily temperature efficiencies for growth periods. (1) We may add the maximum and minimum for each day, divide by two to get the mean temperature for the day, and average the daily means thus obtained to get an average daily mean for the period in question. (This gives the series of numbers shown in the tables of climatic data, line 5.) The physiological index corresponding to the average daily mean for the period may then be taken as the temperature efficiency for the period. (2) We may sum the physiological indices corresponding to each of the daily means, divide this sum by the number of days in the period and thus get an average daily index to represent the temperature efficiency for the period. (3) Lastly, we may average the indices corresponding to the maximum and minimum for each day, thus obtaining an average daily index, add these average daily indices, and divide the sum by the number of days in the period as was done in the preceeding case to get an average daily index. The first method takes account only of the variations between periods. the second involves the differences between periods and the interdiurnal variations, while the third takes account of both differences between periods and the interdiurnal variations and also involves the daily range of temperature. Only

the second of these three methods has been employed in the present paper.

To show the reason for using the physiological temperature summation index in this study, rather than the summation of the remainder or exponetial indices, it will be necessary to anticipate somewhat the discussion that is to follow. The three climatic conditions (temperature, evaporation and light) show a definite seasonal march for each of the stations employed in the investigation. The temperature rises from low values in the spring to a midsummer maximum which is followed by a subsequent fall to low autumnal values. On the other hand, the values representing both light and evaporation decrease, in general, throughout the season. If, now, a generalized curve of plant growth be drawn, plotted against the time of year, and employing average values to represent all the stations together, such a curve follows the seasonal march of the temperature and shows only secondary variations due to the effect of the other climatic conditions. The growth of the plants is thus determined mainly by temperature. Obviously, also, the seasonal march of the temperature values must show the same general form of curve no matter what scheme is used in expressing temperature efficiency. In view of these facts, and in consideration of the general comparative purpose of the present study a method should be used for expressing temperature efficiency, that gives a seasonal march of the efficiency values in accord with the corresponding march of plant growth. Of the three methods mentioned, the physiological efficiency index fulfills this requirement best, and this has accordingly been selected for use throughout the entire

study. An examination of the plant and climatic graphs (to be considered later) will show that the plant values for most of the stations rise above the temperature efficiency values in the middle of the season, and fall below them at its end. This is probably due in part to the effect of high and evaporation as will be brought out below, in the discussion of the plant data, but it may also be related to an inadequacy of the temperature efficiency values to represent the actual effectiveness of temperature in growth control. It appears to be at least suggested that the actual temperature efficiency values for these soy-bean plants increase more rapidly with increase in the temperature itself, for the range here encountered (between 40° and 82°F.), than do the physiological index values derived from Lehenbauer's study of maize seedlings. This whole question deserves much more experimental study. It is a surprising fact that we have available only a single thoroughgoing investigation of the relation of temperature to the growth of higher plants, in spite of the fact that the primary importance of the temperature control of growth is obvious to every observer and has long been qualitatively appreciated. A comparison, for any of the stations employed, of the range of growth values for the plants with the remainder summation values for temperature (which are practically equivalent to the exponential summation values in this study) and with the physiological summation indices will furnish evidence for the verification of these statements. The graphs of the physiological summation indices of temperature efficiency show much steeper slopes than do the corresponding graphs derived from the other two

kinds of temperature indices mentioned above, however, so that the physiological indices are evidently more suitable to represent temperature efficiencies than are either of the other kinds.

Light.

The only records of light conditions that were available for all of the stations of this study were the daily ocular estimates of cloudiness furnished by the cooperative weather observers. To make use of these estimates it was, of course, first necessary to bring these daily percentages of clear sky together for each culture period, so as to derive for each period a single value that might be taken to represent the intensity of the light condition. The method employed to accomplish this is presented in the next following paragraphs.[1]

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[1] The presentation of this method is here practically the same as that previously published. See: Hildebrandt, F.M., A method for approximating sunshine intensity from ocular observations of cloudiness. Johns Hopkins Univ. Circ. March, 1917.

The total heat equivalent of the actual sunshine for any given period at a given station is primarily a function of three terms: (1) the maximum possible number of hours of sunshine (determined by latitude and season); (2) the mean intensity of full sunshine for the period and station, which may be expressed in terms of heat received per unit of a horizontal surface; (3) the condition of the sky, whether overcast, partly overcast or clear. The daily values for the first two of these terms vary in a regular manner throughout the year at any given place, and the ones for the third term are roughly stated in the observer's records, as just mentioned.

The first two terms are combined in the ordinates of the

graph given by Kimball[17] for the maximum possible total radiation received per day at Mount Weather, Virginia. Since this station is at about the same latitude as the stations

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[17] Kimball, Herbert H., The total radiation received on a horizontal surface from the sun and sky at Mount Weather. Monthly Weather Rev. 42:474-487.1914. (See especially fig. 6, p. 484).

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here dealt with, the ordinate from Kimball's graph may be taken as approximate measures of the total maximum possible light intensities for the corresponding dates for all of the Maryland stations. These values represent the total amount of heat received from the sun and sky on clear days at Mount Weather, in gram-calories per square centimeter of a horizontally exposed surface. The method of using this graph and the weather observer's reports, for estimating sunshime intensity for any station and period, will be best shown by an example. Suppose it is desired to estimate the average daily sunshine intensity for some station in the general region of Mount Weather, for the first week of August. The average ordinate value for this week is first obtained from Kimball's graph. For periods as short as a week or two this may be done by averaging the values for the first and last days of the period, since the curve may be taken as a straight line for such short intervals. From the report of the weather observer at the place in question, the number of

clear, partly cloudy, and cloudy days is next determined for the days August 1 to August 7, inclusive, and some arbitrary weighting is given to each kind of day. This was done in the present instance by regarding days reported "clear" as whole days of sunshine, those reported "partly cloudy" as half days of sunshine, and those reported "cloudy" as without any sunshine. The same scheme of weighting must of course be adhered to in all the estimates used for comparative purposes in any discussion. By summing these weighted daily values a number is obtained that represents the equivalent number of clear days for the period considered. Suppose, in the example selected, that this equivalent number of clear days is 3.5 which is 0.5 of the total number of days in the week period. The latter value may be termed "the coefficient of clear weather". By multiplying the average daily intensity value for clear days, as already obtained, by this coefficient of clear weather a value is secured that may be taken as a rough approximation of the average daily sunshine index for the week.

While it is certain that solar radiation affects plants in other ways than through its heating effect, it is no less certain that by far the greater part of the energy of sunshine absorbed by plants is converted into heat (largely as latent heat of vaporization), and it seems probable that the other effects produced upon the plant may be more or less proportional to the total energy equivalent of sunshine. This method of deriving sunshine indices, although it is to be taken as only a rough approximation, has been shown, as a matter of fact, to give quantities rather definitely correlated with the plant growth values in this study. It has been found, for instance, that the amount of dry substance produced

per unit of leaf area in young [illegible] decreases from the beginning to the end of the growing season, in a manner that generally parallels a corresponding fall in the light intensity values as determined in the manner described above.

__Evaporation.__ [illegible] by [illegible] located so as to have the same local exposure as the plant cultures. The atmometer mountings were provided with mercury valves, arranged so as to prevent the entrance of rain. They were read at intervals of about two weeks, the dates of reading being the same as those on which observations were made on the plants. After every reading each atmometer cup was removed and replaced by another that had just been standardized. The used cup was subsequently restandardized so as to detect any change in the coefficient of the cup consequent upon its exposure. When the restandardization showed a change in the coefficient, the mean of the original coefficient and the coefficient found upon restandardization was employed to reduce the reading to the Livingston cylindrical standard. The atmometer readings will therefore be directly comparable to other measurements related to the same standard.

As has been pointed out by Livingston, the porous cup atmometer is somewhat similar to plant foliage in the way in which its evaporating surface is exposed to the surroundings. It may therefore be supposed that the transpiration from the plants for any period should be approximately proportional to the evaporation from the atmometer, except in so far as the transpiration rates may be influenced by conditions within the plant. The work of Briggs and Shantz[13] indicates that evaporation from small open pans and porous cups is influenced by the same external conditions, and [illegible]

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[13] See their paper, cited on p. 45

about the [illegible] compari-son is made for [illegible] of [illegible]. [illegible] two rates do not vary proportionally within the day period, since the internal conditions of the plant exhibit a peculiar daily march,[14] but with such details this study does not need

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[14] [illegible], B. E., [illegible] both moisture and to evaporation. Carnegie Inst. Wash. Pub. 50. 1906.

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to deal. It is [illegible] supposed therefore, that the effective-ness of the external conditions to influence the transpira-tion rates from the plants of this study was approximately measured by the corresponding vapor [illegible] rates from the atmometer. The atmometer readings [illegible] been reduced, in every case, to mean daily rates for the 2-week and 1-week periods taken as indices of the evaporating power of the air as it affected the transpiration rates of the plants.

Plant Measurements.

The first plant measurements were taken after approximately two weeks of growth in the soil. At that time the length of each leaflet from tip to junction with the petiole was determined, as was also the greatest width of each leaflet, measured at right angles to the long axis. The height of each plant was also measured, from the soil surface to the base of the terminal bud. At the end of approximately four weeks of growth the height measurement was repeated, after which the plants were cut off at the soil surface, and the dry weights of tops were subsequently determined. Before drying, photographic prints were prepared of the fresh leaves. By means of these leaf-prints the leaf area (one side) was afterwards determined planimetrically. All linear measurements were made to the nearest millimeter, area measurements to the nearest 0.1 sq. cm., and weight measurements to the nearest 0.01 gram.

[illegible] at [illegible]
averages [illegible].

As has [illegible], each culture originally comprising six plants [illegible] growth from the seed and again after about [illegible] the seed, and the consecutive cultures were started at intervals of about 2 weeks. In many cases, however, the number of plants from which records were actually taken was less than six (it was never less than [illegible] was usually [illegible] in such cases), on account of observable injury due to other conditions than the ones here studied, such as insect attacks, etc. All plant data are, therefore, stated as averages per plant. Also, in many cases, the length of the period varies slightly from 14 days for the two-week periods and from [illegible] days for the four-week periods, and the values have consequently been expressed as daily rates for the respective period. The data [illegible] for the plant measurements for the different periods were strictly comparable. It should be noted, however, that the growing periods were 14 [illegible] long in the majority of cases, and that variations in the length of the culture periods were slight. Considering the [illegible] plant values as [illegible] of the results of plant [illegible] through the periods, the mean [illegible] values [illegible] daily increments or progress [illegible], and they will be termed "daily increments", for their respective periods, in the discussion that follows. Thus, for a plant 10 cm. high at the end of a 17 [illegible] period, [illegible] the mean daily increment of increase in height, etc.,

[illegible] at [illegible]. [illegible] [illegible] ss to which [illegible] in length, [illegible], etc.), these [illegible].

The [illegible]

[illegible] in terms of the [illegible] all [illegible], for all [illegible]. [illegible] all the [illegible]. To [illegible] any kind of value, all of the corresponding values [illegible] [illegible]-week daily [illegible] increments in height, for example, [illegible] expressed [illegible], and the sum was divided by the number of values [illegible]. [illegible] individual value was divided by the unit thus obtained. The data [illegible] expressed [illegible] [illegible] the following [illegible] of the unit thus used [illegible], [illegible] important, it is essential only that all [illegible] be expressed in terms of the same unit. The unit [illegible] employed represents [illegible] the [illegible] quantities which are used in the present study. If [illegible] station had [illegible] employed, [illegible]

[illegible] and [illegible] 1914, to some extent [illegible] stations, to some extent [illegible] in this investigation, [illegible]

[illegible]

[illegible] I. [illegible]

tive values [illegible]

by 100, and are thus given in the tables (Tables I-III).

Table I

[illegible]

for all exposed stations.

[illegible]

Average daily [illegible] temperature [illegible] = [illegible]

Average daily evaporation [illegible] = 11.1 cm.

Average daily sunshine intensity = 44[illegible] [illegible]

PLANT: 1-week [illegible].

Average daily increment in stem height per plant = [illegible]

Average daily increment in leaf area per plant [illegible]

PLANT: [illegible]-week periods.

Average daily increment in stem height per plant = [illegible]

Average daily increment in leaf area per plant = [illegible]

Average daily increment in dry weight per plant = [illegible]

The use of the relative values simplifies the plotting of the graphs upon which the interpretations of such a study as this so largely depend. It also [illegible] possible a direct comparison between the values [illegible] their [illegible]. Furthermore, it is possible to tell from the magnitude of the relative value [illegible] the extent to which the plant [illegible] considered [illegible] that [illegible]

all the [illegible].

To [illegible] the [illegible] [illegible]nal [illegible] value from the relative values given in the tables of this paper, it is [illegible] to [illegible] the [illegible] by [illegible] the relative [illegible]. For example, suppose it is desired to get the actual [illegible] of increase in leaf-area per plant for the [illegible]-week period beginning Aug. 5, and for the station at Coleman. The relative value given in the table is [illegible]. The first operation is to divide by 1[illegible], which gives 1.[illegible] as the true relative value. The average daily increment in leaf area per plant, for the period and station in question, was therefore 1.[illegible] times the value of the standard unit employed for this process of increase in leaf area. Multiplying the unit value ([illegible] sq. [illegible]) as given in table I by 1.[illegible] gives [illegible] sq. cm. as the average daily increment per plant. To obtain the average total leaf area per plant at the end of the period in question, we multiply [illegible] sq. cm. by the number of days in the period ([illegible] in this case) and get [illegible] sq. cm. Since there were 5 plants growing in this culture, the total leaf area of the entire culture at the end of the period is obtained by multiplying [illegible] sq. cm. by [illegible], which gives [illegible] sq. cm. or [illegible] sq. cm., which is the actual areal value determined from the weights of these leaves. All of the original absolute values may be obtained from the relative ones in a similar manner. It is of course evident from the above description of the manner in which the relative values have been derived that they are proportional to the corresponding absolute values. In all subsequent discussion, [illegible]

[illegible] that these [illegible] ones.

Present[illegible] [illegible]

[illegible] history. [illegible] and described. [illegible] part to [illegible] of the growth changes [illegible] plants at the various stations, [illegible] the variations of [illegible] at each station, [illegible] part [illegible] corresponding description [illegible] climatic values, and in part to show attempts to correlate these two sets of data. Owing to the complexity of the problem and to the number and variety of the data to be dealt with, it has been found necessary to depart frequently from a general logical order and to treat matters that are of secondary importance at greater length than would be necessary from a more restricted point of view. Such interpretations as were attempted are of interest partly for their own sake, but mainly because of their bearing upon the general problem of the use of standard plants for the quantitative integration of effective climatic complexes. It must be remembered that the present project the results of which are here dealt with was planned primarily with a view of making a first trial in the use of standard plants in this way, and that such correlations between plant growth and the conditions of the surroundings here considered are [illegible] considered as of secondary importance [illegible]. The discussions will be presented [illegible] interpretations, [illegible], [illegible] is [illegible]

desirable, but the newness of this kind of study and the fact that the fundamental principles and even the terms to be used have not yet been developed make anything approaching a true logical sequence quite impossible.

The various kinds of data to be considered will be brought forward in groups corresponding to their sources. The two-week plant data and the two-week climatic data will first be presented followed by some attempts to correlate the two groups from the view-point of plant physiology. Then the four-week plant and climatic data and their physiological correlation will be presented. These topics will be followed by a special discussion of the data for the covered stations and a similar treatment of the data for the forest station at Baltimore.

[illegible]

constituting the four-week period

[illegible]

The two-week climatic data.

Introductory. The two-week climatic data consists of the relative daily averages of the temperature index, evaporation index, and sunshine intensity for a series of consecutive periods extending over the entire season, each period being about 14 days long. These values thus furnish a continuous record of the season at each station. The four-week periods, however, overlap, each one including the last two weeks of the preceding and the first two weeks of the following period. While the climatic averages based on the four-week data form a smoother curve than do the two-week values, small variations in the conditions are to a great extent obscured by averaging the overlapping periods. The series of two-

week values exhibit [illegible]
each [illegible]
of the corresponding series of four-week values, since the
latter represent overlapping periods, and these will
therefore be made the basis for a somewhat detailed
comparative discussion of the climatic conditions for the
various stations. Temperature will receive attention first
and evaporation and light will afterward be considered in turn. In each case, the general characteristics (common to most or all of the stations) of the seasonal march of the condition considered will be brought out, after which attention will be given to peculiarities of the values for individual stations.

Temperature Conditions

The graphs representing temperature conditions bring out the seasonal march, at each of the various stations, of the average daily relative physiological index. The most obvious general characteristic of this index value is that it is high in summer and low near the beginning and end of the season, for all stations. Graphs of similar form are obtained when daily means and remainder summations are correspondingly plotted but the discrepancy between the midsummer values and those for the beginning and end of the season is much more pronounced in the graph of physiological index values (here employed) than in either of the others. The second general characteristic of all the graphs of the physiological index of temperature is that they possess two maxima, both of which are about the same magnitude. The first occurs in the [illegible]

[illegible] August, [illegible] stated that [illegible] ing Cuiaba, for [illegible] of the [illegible] relatively early in the season, [illegible] of August [illegible] July respectively. [illegible] feature [illegible] (if at all) of these graphs lies in the fact [illegible] the [illegible] upward slope is more gradual (before the occurrence of the highest temperature maxima) than is the downward slope (after the occurrence of the maxima.) [illegible] generalised temperature efficiency graph representing [illegible] of the [illegible] for [illegible] of the stations [illegible] practically [illegible] the [illegible] of the highest [illegible]; [illegible] in the [illegible]. A further [illegible] characteristic of these graphs lies in the fact that the [illegible] values of the [illegible] least [illegible] are not very different for the various stations. The following [illegible] of the graphs [illegible] of the individual stations will serve to bring out the points [illegible] above and will give opportunity to note exceptions to the generalised statements just made.

In regard to the form of the characteristic [illegible] of the temperature efficiency graphs, the [illegible] may be grouped into [illegible] classes: (1) Chemerille and [illegible], (2) [illegible], [illegible] and [illegible]an, (3) Boston [illegible] Princess Anne, (4) College, and (5) Takhoma. The last two stations do not appear to fit [illegible] of the first [illegible] classes [illegible] representing separate classes. These [illegible] discussed [illegible] that the [illegible] of groups 1, 2, [illegible]

[illegible]

[illegible] relatively [illegible] [illegible]

[illegible] able.

[illegible]. [illegible] remaining in the [illegible] beginning August [illegible] [illegible] same than [illegible] [illegible] the [illegible]. [illegible] [illegible] [illegible] [illegible] [illegible] in the [illegible] beginning July [illegible] August [illegible] [illegible] of [illegible] for the last [illegible] [illegible].

[illegible]. [illegible] [illegible] for the [illegible] beginning June 1[illegible], thus giving [illegible] three [illegible] (120, 148, [illegible]) for the period beginning [illegible] 19, [illegible], [illegible] respectively. [illegible] period beginning [illegible].

[illegible]. [illegible] and relatively [illegible], being [illegible] [illegible] average [illegible] [illegible]. [illegible], [illegible] for the last half of Ju[illegible] [illegible] of July. [illegible] [illegible] [illegible] still [illegible]. [illegible] [illegible] [illegible] [illegible] [illegible].

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]			

[illegible]

√ Hildebrandt, [illegible], Leaf-product as an index of growth in soy-bean. Johns Hopkins Univ. Circ. March, 191[illegible].

these periods as would be expected from the behavior of the plants at the other stations.

Before concluding this part of the discussion it is desired to call attention to some peculiarities of the plant graphs which cannot be correlated with the climatic data. The first of these is the occurrence of growth rates for some of the periods very much higher than the climatic data and the assumptions made above would lead us to expect. This condition of affairs is illustrated by the period beginning July 17 for College, the period beginning August 20 for Baltimore, the one beginning July 15 for Darlington, the ones beginning June 24, July 8 and July 22 for Coleman, and the periods beginning July 7 and Aug. 4 for Princess Anne. In all of these cases climatic conditions favorable for growth would seem to obtain. The climatic values for these periods do not, however, appear to be sufficiently different from other periods showing relatively lower plant values to account for the very high plant growth rates. This behavior of the plants may be explained by the fact that two periods showing the same average intensity of climatic conditions may differ greatly in their plant producing power on account of a different distribution of the high and low values of the intensities of the conditions during the period.

In the discussion of the two-week temperature data attention was called to the fact that the graph of temperature values shows two maxima, and that this was connected with a peculiarity in the behavior of the plants. The peculiarity there referred to is that the plants do not, except in the case of the culture at Oakland, respond to the second temperature

~~values in the~~ maximum by a corresponding increase of growth. For Chewsville, as an example, in the period beginning Aug. 11 we have a low value for the leaf-product with a high temperature index and the other conditions at about the seasonal average. For Monrovia in the period beginning Aug. 10 with high temperature value and sunshine at about the seasonal average the plants show, nevertheless, a relatively low value of the leaf-product. This may be contrasted with the period beginning June 15 at this station which, with a leaf-product about the same as that of the first-mentioned period shows less favorable growing conditions, namely, a much lower relative temperature index, a very high evaporation rate and a sunshine value only a little higher than the corresponding value of the period beginning Aug. 10. For College, the periods beginning July 17, July 31 and Aug. 14 with about the same values of temperature and evaporation show magnitudes of 152, 203 and 150, respectively, for the leaf-product. This variation may possibly be related to differences in the value of sunshine intensity for these periods, but the sunshine data are lacking for this station. For Baltimore, the periods beginning July 23, Aug. 6 and Aug. 20 show large variations in the leaf-product with comparatively slight variations in the climatic conditions. Evaporation is slightly less in the period beginning July 23 than in the period beginning Aug. 6 and considerably less in the period beginning Aug. 20, but this seems to be without the expected effect on the plants. For Coleman the plant graph slopes upward to a value of over 200 for the period beginning July 8 while for the period beginning Aug. 5, which has climatic conditions apparently as favorable,

the relative value of the leaf-product is 138. For Easton the leaf-product is lower than would be expected for the period beginning Aug. 17 and for Princess Anne, the plant values for the period beginning Aug. 8 are much lower than for the period beginning July 7 which had approximately the same climatic conditions as the first mentioned period.

A third peculiarity of the graphs that cannot be correlated with the climatic data is that the stem height reaches its highest value for the season before the leaf-product for all station except Darlington and Coleman. For Darlington, the highest value for stem height and leaf-product both come in the period beginning July 10 and for Coleman the maximum value for stem height comes in the period beginning July 22 while the leaf-prodcut reaches its highest value for the season at this station in the preceeding period. At the remaining stations, the highest value of stem height occurs two weeks or a month earlier than the highest value of leaf-product.

The foregoing discussion of the two-week data emphasizes the obvious fact that the problem of correlating the plant and climatic measurements is an exceedingly complicated one. Assuming that the conditions of the experiment give approximately constant root environment, the plant growth rates are a function not only of the climatic factors, three of which are measured for these studies, but of the conditions within the plant as well. We do not at present know how to measure these internal conditions. The growth rate is thus a function of a number of variables some of which are known and some unknown. The object of the preceeding discussion has been sim-

ply to emphasize such relations exi ting within the group of climatic factors, between the two plant measurements, and between these two groups of data as can be seen by inspecting the graphs.

The four-week plant and climatic data.

Exposed Stations.

The general plan of treatment adopted in the case of the two-week data will be follwed in the present discussion of the four-week periods. It will be possible, however, to treat the four-week climatic indices briefly since the graphs of these factors for the longer growing periods cover approximately the same season at each station as the two-week climatic graphs. In accordance, then, with the plan previously laid down for discussing the two-week data, three divisions of the four-week data will be made: (1) A brief consideration of the climatic graphs; (2) A consideration of the relations between the plant graphs. (3) Attempts to correlate the plant and climatic graphs.

The four-week climatic data.

It will be remembered that the cultures were started every two weeks and that each grew for a period of four weeks. The four-week periods thus over-lap, and, as has been mentioned, averages of the climatic factors for these overlapping periods form a smoother graph than averages for the two-week periods. The result of averaging over the longer overlapping periods is to eliminate from the graph all the smaller fluctuations. The four-week graphs therefore show the general seasonal march of the index values for various stations better than do the two-week while the latter show the details of the seasonal

march better than the four-week graphs. This fact will be brought out by a brief reference to them at this point.

The values of the temperature indices for the four-week periods show the seasonal marches of this condition for the various stations, from low values in May to high midsummer values and then to low values again in the last part of the season. The graphs for all of the stations except Oakland show a steeper slope after the midsummer maximum has been passed than for the periods during which the temperature was rising to this maximum. The two maxima which were present in most of the two-week graphs are eliminated in the four-week averages and the graphs of temperature values show instead a period of about six weeks during which this condition remains approximately constant.

The four-week evaporation and light data, show the general characteristics of the seasonal marches of these conditions previously noted as exhibited by the two-week data. It will be seen in the first place, that both graphs exhibit a downward slope from the beginning to the end of the season; and, in the second place, that both graphs show, in addition to their high primary maximum in the early part of the season, one or more secondary maxima later. In some cases the secondary maxima in the evaporation graphs coincide with temperature maxima. Both of these general characteristics shown in the four-week graphs of evaporation and light are shown by the two-week graphs but since small variations are eliminated by averaging the overlapping periods, there are fewer secondary maxima in the four-week graphs. In the case of evaporation, there is usually one secondary maximum occurring in or near

the four-week period including the last two weeks of July and the first two weeks of August. In the case of all stations, this is one of the three four-week periods showing high temperature values. The four-week climatic graphs will not be taken up further here. The method by which the four-week data are derived from the two-week data amounts to the same thing as smoothing the two-week graphs and only the more pronounced characteristics of the graphs remain after averaging. The interest of the four-week climatic data thus lies mainly in its relation to the plant growth rates.

The four-week plant data.

Relations between the plant measurements.

Certain general relations were pointed out, in the case of the two-week data, between the stem height and the leaf-product, and mention was also made of the fact that the leaf-product numbers showed only slight differences in value from the leaf area and dry weight numbers when the actual growth rates are expressed as in the present study, that is, using the average of all of them as a unit to which to refer the individual rates. In the four week data, the rate of stem elongation may be compared with the rate of leaf expansion as determined from actual leaf area, instead of with the leaf-product which is used in the discussion of the two-week data as an index of area. The comparison between leaf area and stem height for the four-week growth periods shows the same general relations as appeared to exist between stem-height and leaf-product for the two-week growth periods. Owing to the fact that the plants

were grown for a longer time, however, there are fewer cases in the four week periods where the rate of stem elongation is greater than the rate of leaf expansion. In most cases the rate of stem elongation is well below the rate of leaf expansion, This relation again illustrates the tendency of the soy-beans to show a low rate of height growth relative to the rate of leaf expansion when both rates are large. A considederation of the plant graphs with the purpose of bringing out the relation between stem elongation rate and the rate of leaf expansion follows below.

For Oakland, the stem height graph is above the leaf area graph for the first three periods of the season and below it for the other five periods. For Chewsville, the three plant graphs follow each other very closely and the differences in their relative positions are probably due, for the most part, to individual variations in the plants of the separate cultures. The Monrovia graphs also correspond closely with the conception of the fact that stem height shows a well-defined tendency to remain below leaf area during the first part of the season. For College, the stem height is well below the leaf area for the entire season except for the two periods beginning June 19 and September 25! The Baltimore graphs show stem height values higher than the corresponding leaf area values in the periods beginning May 14, May 29, June 10, and Aug. 20 due to low light intensities as shown by the graph of sunshine intensity. The Darlington cultures show very high values of the plant growth rates with stem height below leaf area for the entire season. For Coleman, the stem height graph remains below the leaf area graph for all the periods ex-

cept the last where it rises very slightly above the leaf area value. For Easton, the plant growth rates show nearly the same relative values for all the culture periods of the season. For Princess Anne the stem height and leaf area graphs show a departure from the usual behavior during the first three periods of the season. For these periods, leaf area is relatively large and stem height relatively low for some reason not apparent from the climatic graphs.

The most striking relation between the plant measurements for four-week periods exists between the leaf area and the dry weight of the plants. It will be seen that for most of the cultures these two plant growth rates have practically the same relative numerical value for any given period. The Oakland graphs show this in all periods except the period beginning June 5 where dry weight is well above leaf area. For Chewsville, the relation shows very well throughout the season. For Monrovia, the leaf area number shows a rather large deviation from the dry weight number in the periods beginning June 16, June 30 and Aug. 25 but otherwise the two growth rates correspond in relative value during the entire season. The College graphs show close agreement, with dry weight above leaf area during the first part of the season. At Baltimore, the relative leaf area value differs considerably from the relative dry weight value in the periods beginning Aug. 6 and Oct. 1 but the remaining periods show close agreement. The Darlington graphs show close agreement for all periods. For Coleman dry weight and leaf area agree well for all periods, except those beginning Aug. 5 and Aug. 19, and for Easton no large differences occur for any of the cultures. For Princess

Anne, the period beginning Aug. 4 is the only one showing a difference of considerable magnitude between the relative leaf area values and dry weight values.

The property of soy-bean shown by these graphs renders possible the use of the leaf area of the plant as an index of its dry weight. The bearing of this property of soy-bean on its use as a standard plant for climatic investigations has been referred to in a previous paper by the writer.[1]

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[1] Hildebrandt, F. M., Leaf-product as an index of growth in soy-bean. Johns Hopkins Univ. Circ. March, 1917.

The correlation of the plant and climatic values for the four-week periods will be discussed under two heads. The first of these will take up the relation of the four week relative stem height values to sunshine and temperature index values and in the second an attempt will be made to correlate dry weight with the three climatic conditions using the assumptions made in correlating the two week leaf-product values with these conditions. The dry weight is employed in the consideration of the four-week data rather than the leaf area since it is the most frequently used criterion of growth. Also, as has been noted above, the leaf area and the dry weight of the plants in this experiment correspond closely in relative value, and for such rough comparisons as are here made, may be used interchangeably.

Correlation between plant and climatic data.

Relation of stem height to sunshine and temperature. No very definite correlation between the stem height and climatic conditions has been found. After the plants have been grown four weeks, however, the graph representing the rate of growth in height bears a general resemblance to the graph of physiological temperature indices. In the first periods of the growing season, also, the data indicates that the stem height is inversely proportional to the sunshine intensity, this relation being indicated by the fact that the graphs of these two quantities slope in opposite directio s in many cases. The effect of the light is, however, only secondary and does not disturb the relation apparently exinsting between stem height and temperature to any considerable degree. These two relations will be brought out by an examination given below of the graphs for the individual station.

For Oakland, the stem height graph and the graph of temperature values show the same general form, and the stem height and sunshine graphs are opposite in the direction of their slope from the period beginning May 23 to the period beginning July 31. For this station, the other plant graphs parallel the height graph approximately and thus no conclusion could be drawn from the data for Oakland as to whether the difference in slope direction of light and stem height is accidental or due to a real effect of sunshine intensity on the rate of elongation of the plants. A t some of the other stations the height graph shows an opposite direction of slope to the graph

of sunshine intensity, however, when the other plant graphs do not parallel height as they do approximately in the present instance. For Chewsville, the graph of temperature values and the height graph have the same general form if we neglect the period beginning June 16, but here again the plant graphs all show ordinate values so nearly the same that no conclusion can be drawn as to whether the height of the plants is affected by the climate in the manner noted above. The Monrovia graphs, however, support the assumption made as to the way in which light and temperature values are related to stem growth. It will be observed that at this station the general form of the height graph resembles the general form of the graph of temperature indices. From the period beginning May 18 to the period beginning July 27, the graph of stem height slopes in a direction opposite to the graph of light intensity. The height in these cultures is apparently responding to the climatic complex more or less independently of the other plant measurements as will be seen from a comparison of the three plant graphs. The graph of stem height for College has the same general form as the graph of temperature values and is well below it for all the periods except the last. For Baltimore the graph of stem height would indicate again that this plant growth rate is responding somewhat independently of the other two. The graph has the same general form as the graph of temperature indices and shows an opposite slope direction to that of the light graph during the entire season except between the periods beginning June 10 and June 25. and between the periods beginning Sept.19 and Oct. 1. The plant graphs for Darlington all reach abnormally high values. The

resemblanee in general form between the stem height and temperature graphs for Darlington is thus less striking than for the other stations. The effect of light intensity on the stem height for Darlington does not show in the graph. For Coleman, the general resemblance in form between the stem height and temperature graphs is quite close. The light and stem height graphs slope in opposite directions for the interval between the period beginning May 13 and the period beginning June 11 and the interval between the period beginning June 24 and the period beginning July 22. The stem height graph for Easton shows a close resemblance in general form to the graph of physiological indices and is opposite in slope to the sunshine intensity graph from the period beginning May 8 to the period beginning July 20. The stem height graph for Princess Anne shows the typical relation to the temperature index values and is opposite in direction of slope to the sunshine graph from the period beginning May 11 to the period beginning June 23 and from the period beginning July 21 to the period beginning Aug. 18.

There are certain obviuus objections which may be made to the above view of the relation between stem height, temperature, and light. It may be said that the opposite slope of the stem height and sunlight intensity graphs during the first part of the season is purely accidental. The stem height, being apparently determined in the main by temperature values follows the graph of temperature indices, which graph, during the first part of the season has a direction of slope opposite, in general, to the direction of slope of the light graph. Attention has been called, however, to a number

of cases, of which the Monrovia data are a good example, in which the light appears to play a definite, though secondary part. That it is playing such a part is indicated by the fact that the stem height graph, while corresponding to the temperature graph in general form, shows minor variations in slope noted in the course of the discussion which suggest an inverse relation between stem height and sunshine intensity. Another objection to the interpretation lies in the fact that at the end of the season when sunshine intensity is very low the rate of stem elongation falls off very rapidly. This is not what we would expect on the assumption that light and stem elongation are inversely proportional. In answer to this, it may be said that evidence can be secured from the data tending to show that the low light values at the end of the season depress the rate of photosynthesis in the plants. This evidence will be given in a later paper. If the rate of photosynthesis is lowered it is reasonable to suppose that there may be a deficiency in the amount of nutrient available for growing regions, resulting in a diminution of the rate at which the various growth processes take place. We thus secure a possible explanation for the relatively great falling off in height, (and in the other growth rates, as well) occurring at the end of the season. A third objection to the above interpretation is that the inverse relation noted between sunshine and stem growth exists also between stem growth and evaporation. The question as to whether this relation is an accidental one due to the correspondence between the seasonal marches of sunshine and evaporation or whether evaporation and not sunshine is the determining factor here, is rather definitely

answered by the behavior of the soy-beans when grown under glass and in a forest. This behavior indicates that evaporation has only a slight effect on stem elongation as compared to sunshine intensity. The consideration of the covered and forest station which will appear later, will justify this statement.

Relation between dry weight and the three climatic conditions. The last part of the discussion of the four-week data will attempt to show that the dry weight of the plants and the climatic conditions may be correlated using the assumptions made in correlating two-week leaf-product and climate. As was noted in the treatment of the two-week data, these assumptions may be expressed in the following way:

$$\underline{r} = \frac{f(L) \times f(T)}{f(E)}$$

in which the symbols have the same meaning as in the discussion of the two-week data. It was previously brought out that the above equation states the rate of growth to be directly proportional to some function of the light, directly proportional to some function of the temperature, and inversely proportional to some function of the evaporation. f(L), f(T), and f(E) are used in the equation instead of L, T, and E since the environmental conditions do not affect the plant in a simple direct way, but bear a complicated unknown relation to the growth rate. The physiological index, used as a means of expressing temperature in this study is an attempt to evaluate f(T) directly. As has been suggested by Livingston, corresponding indices

might be secured for the direct evaluation of f(L) and f(E). At present, however, such indices are not ~~as yet~~ available, and relative daily rates of evaporation and relative daily sunshine intensity values may be used to represent f(E) and f(L).

In correlating the four-week climatic and plant graphs it has been found, as in the case of the two-week graphs, that the behavior of certain cultures cannot be accounted for by the climatic averages for the period. In some of these cases, the four-week plant values seem to be determined largely by the conditions during the last half of the culture period. This seems especially to be true of those cultures which made a relatively small growth during the first two weeks from the seed, as occurred in the case of most of the cultures for Oakland, Chewsville, and Monrovia. In the following consideration of the plant and climatic values for the four-week growth periods, the four week averages will be used in connection with the climatic values for the two halves of each four-week period. These are given in the two week tables and shown graphically on the two-week graphs. For convenience in reference it may be said here that each culture of the longer growth periods includes the shorter period beginning on the same date and the shorter period next following. That is a four week period beginning July 1 includes the two two-week periods beginning July 1 and July 15 respectively.

During the first three four-week growth periods for Oakland the plant and climatic graphs have the relations that would be expected. From the period beginning May 23 to the period beginning June 19 at this station the value of the temperature index rises gradually, there is a small decrease in

light intensity and a considerable decrease in evaporation rate, with the plant graph rising sharply. The graph of dry weight then descends from the period beginning June 19 to the period beginning July 3 and slightly rises from the period beginning July 3 to the period beginning July 16. Neither of these would be expected from the values of the four-week averages. If , now, the dry weight graph from the period beginning May 23 to the period beginning July 16 be compared with the two-week evaporation graph from the period beginning June 5 to the period beginning July 31 it will be seen that the dry weight exhibits a very consistent inverse relation to the evaporation as shown by the opposite slope of the two graphs from period to period. The dry weight at this station seems thus to be determined during the first five four-week periods largely by the evaporation during the last two weeks of each period. From the period beginning July 16 to the end of the season the graph of dry weight descends following a corresponding downward slope in the graphs of sunshine and temperature indices shown by the four-week averages of these conditions. Evaporation during these periods is low and seems not to affect the plants. The sharp downward slope of the dry weight graph from the period beginning Aug. 14 to the period beginning Aug. 27 is probably accounted for by the fact that the temperature value is very low during the last two weeks of the latter period. For this station sunshine and temperature index values show only relatively small fluctuations throughout the season and the plants exhibit rather clearly the effect of evaporation.

For Chewsville, the values of dry weight for the first

five periods of the growing season are as in the Oakland cultures approximately inversely proportional to the evaporation for the last two weeks of each of the four-week periods. This may be seen by comparing the slope direction of the dry weight graph for the interval from the period beginning May 19 to the period beginning July 14 with the slope direction of the two-week evaporation graph from the period beginning June 2 to the period beginning July 28. The rise in the dry weight graph from the period beginning June 30 to the period beginning July 14 is not as great as would be expected from the low rate of evaporation during the last half of the latter period (see the period beginning July 28 on the two-week graph). It will be noted from the two-week graph, however, that the values of the temperature index and of sunshine intensity are both low for the two-week period beginning July 28 and this probably explains the depresssion of the dry weight value for the four-week period beginning July 14. From the last-named period to the end of the season the values of dry weight are relatively lower than would be expected from the four-week averages. A possible explanation for each of these low values is to be found, however, in the fact that one or more of the three climatic conditions is unfavorable for growth during the last half of the periods. The low value for the four-week period beginning July 6 may be accounted for by low sunshine intensity and high evaporation rate during the last two weeks as shown by the period beginning Aug. 11 on the two-week graph. The last two weeks of the four-week period beginning Aug. 11 show a very low sunlight intensity value (period beginning Aug. 25 on the two-week graph). Dry weight for the period

beginning Sept. 8 is higher than would be expected from the low temperature value due possibly to a relatively high sunshine intensity during the last two-weeks of growth. For the four-week periods beginning Sept. 22 and Oct. 7 both sunlight and temperature index values are low for both of the two-week periods constituting eadh four-week period.

For Monrovia, the dry weight graph rises to a high value for the second period of the growing season in spite of high evaporation rates throughout the period. From the second period to the third period the graph of dry weight descends, probably following a corresponding decrease in sunshine intensity shown by the four-week graph. The still lower value of dry weight for the period beginning June 29 may be explained by the high evaporation rate for the two-week period beginning July 13. The minimum in the dry weight graph at the period beginning July 13 would be expected from the low temperature index value and high evaporation rate for the last two weeks of this period (period beginning July 27 on the two-week graph). The rise in the dry weight from the peridd beginning July 13 to the period beginning July 27 is probably related to the relatively high temperature index value during the last two weeks of the period beginning July 27 although evaporation is also high and light a little below the seasonal average (see the period beginning Aug. 10 on the two-week graph). For the four-week period beginning Aug. 10 dry weight shows a relatively low value as would be expected from the very low light value of the two-week period beginning Aug. 24 which is the last two weeks of four-week period in question. For the four-week period beginning Aug. 24 dry weight rises in spite

of a large decrease in the temperature index value but the high value of sunshine intensity during the last two weeks of the period may account for this behavior of the plant. The last two four-week periods of the season are characterized by low light and temperature index values throughout, which may account for the low plant values shown by these periods.

For College, the four-week climatic values do not seem to account for the low growth rate for the period beginning June 19 nor for the extremely high growth rates for the periods beginning July 17 and July 31 respectively. The first-mentioned period would seem to have good growing conditions (high temperatue index value and low evaporation rate while the last two have about the same temperature as the first with high evaporation rates). Here the climatic conditions during the second two weeks of growth do not seem to give any suggestion as to why the culture started June 19 should show such a low rate of growth in comparison with the cultures started July 17 and July 31. Several points worth calling attention to come out of a comparison of the two and four-week graphs for the cultures started July 3, July 17 and July 31. It will be noted that the two-week culture started July 3 is relatively high in leaf-product (which is proportional to dry weight) but that after four weeks of growth these same plants show a relatively low dry weight. An explanation for this is suggested by the sharp rise in evaporation rate from the first to the second two weeks of this culture period, (periods beginning July 3 and July 17 on the two-week graph). Also, for the series of two-week cultures, the one started July 17 shows the highest leaf product for the season at this station, but

it will be observed that after four weeks of growth these plants show a lower dry weight value than the four-week plants of the culture started July 31 in spite of the fact that the two-week plants of the latter culture have much lower growth values than the two week plants of the former culture, (see the two-week graphs for the two cultures in question). It is therefore evident that some influence operated during the second two weeks of growth of each of these cultures which tended to depress the rate of growth of the plants started on July 17 and accelerate the rate of growth of those started July 31. The two-week climatic graphs show that the rate of evaporation was <u>higher</u> during the second two weeks of the four-week growth period beginning July 17 than during the first two weeks, and that the evaporation during the second two weeks of the four-week period beginning July 31 was <u>lower</u> than during the first two weeks. The shifting of the growth maximum in the two sets of cultures from the culture started July 17 for the two-week plants to the culture started July 31 for the four week plants thus receives a possible explanation in variations in the evaporation rate during the second half of the longer culture periods. While it is true that the changes in evaporation rate upon which the above conclusion is based are slight, it is probable that with high rates such as are found in these three periods, evaporation may be at a critical point for the plants and slight variations in this condition may very well produce relatively large plant effects. The decreasing values of dry weight at this station for the last four periods of the season seems to be most reasonably interpreted as related to the corresponding decrease in temperature index values.

For Baltimore the two-week cultures all show relatively high values for the first eight periods of the growing season. The seedlings of these periods were thus well along in their growth at the end of two weeks, and the climatic conditions during the first half of the culture periods seem to have had a relatively greater influence on the plants here than at stations where the plants were small at the end of the two-week periods. The four-week plants at this station, and the four-week climatic averages thus correlate satisfactorily, as will be evident from the following examination of the graphs. The graph of dry weight slopes upward with the temperature index graph from the period beginning May 14 to the period beginning June 25 and at the same time the graph of evaporation is descending. For the period beginning June 25 good growing conditions (high temperature index and low evaporation rate would seem to account for the relatively high plant value. While the sunlight conditions become less favorable from the period beginning May 14 to the period beginning June 25 the influence of the other two climatic conditions would seem to outweigh this. From the period beginning June 25 to the period beginning July 23 temperature values and sunlight remain nearly constant while the evaporation rate rises. The dry weight graph falls as would be expected. For the period beginning Aug. 6 the temperature index and sunlight are at about the same values as for the preceeding period, but evaporation is lower and the plant graph ascends to a high value. From the period beginning Aug.6 to the end of the season, the low temperature and light values probably account for the rapid decrease in dry weight production shown in the graph representing the value of this

quantity.

The Darlington and Coleman four-week climatic averages and the plant graphs correlate well, probably for the reason given in the case of Baltimore. For Darlington, temperature index value remains practically constant for the first three periods. The graph of dry weight descends from the period beginning May 15 to the period beginning May 30 following a corresponding decrease in sunshine intensity but the slope of the plant graph is not steep probably since evaporation rate is decreased at the same time. From the period beginning May 30 to the period beginning June 13 dry weight production rises a little although sunshine intensity falls again. We may suppose this to be related to the fact that the rate of evaporation also decreases thus counteracting the effect of the decreased light intensity. The period beginning June 26 shows very good conditions and the plant graph rises again. The period beginning July 10 also shows very good conditions, high temperature index, high light intensity and low evaporation rate and the plant graph rises to an extremely high value. It seems impossible to relate the four-week climatic averages for the periods beginning July 10 and July 24, or the conditions during the second two weeks of these periods to the decrease in the plant growth rate from the first period to the second. For the last three periods of the season dry weight decreases with the decreasing temperature index value and sunshine intensity as would be expected. The graphs for Coleman are quite consistent with the assumptions made in regard to the effect of the three climatic factors. The rate of dry weight production rises as the temperature index values increase from

the period beginning May 13 to the period beginning May 28, evaporation rate and sunshine intensity remaining nearly constant; rises again, but only slightly, from the period beginning May 28 to the period beginning June 11 as would be expected from the fact that sunshine decreases considerably, the rate of evaporation decreases and the temperature index rises during this interval. From the period beginning June 11to the period beginning June 24 the dry weight graph descends although the temperature index value and light value both rise. This is probably due to the high evaporation value. The evaporation graph rises in this interval only slightly, however. The temperature index value remains nearly constant from the period beginning June 24to the period beginning Aug. 5 while the plant values behave as follows: from the period beginning June 24 to the period beginning July 8 the plant graph descends, while the evaporation graph rises: the rise in the plant graph from the period beginning July 8 to the period beginning July 22 may be related to the decrease in evapo - ration rate; and from the period beginning July 22 to the period beginning Aug. 5 the considerable decrease in the value of dry weight does not seem to be accounted for by the climatic averages. There is, it is true, a fall in light intensity, during this interval but it is hardly great enough to explain th behavior of the plant graph. That this culture may have been abnormal is indicated by the fact that the dry weight graph rises from the period beginning Aug. 5 to the period beginning Aug. 19 although t e tempera+ure index value for the latter period is very much lower than the temperautre index value fot the former. The period beginning Sept. 2 shows a high relative evaporation rate and a low temperature index value.

Low temperatures and light intensities probably account for the low values of dry weight for the last two periods of the season. The temperature record for this station stops at the period beginning Sept. 2 and the light record at the period beginning Aug. 5, however. For Coleman, as for College, a comparison between the plants for the four-week and the two-week periods brings out several interesting relations between evaporation during the last two weeks of growth and the behavior of the plants. An inspection of the two week graph for Coleman will show that the values of leaf-product for the periods beginning June 24, July 8 and July 22 are very high, while after four weeks of growth the graph of dry weight instead of showing high points for these periods as would be expected from the two-week values, shows relatively low points. Also, the culture started June 11 which shows a relatively low value for the two-week growth period has the highest dry weight of the season for this station after four weeks of growth. This behavior of the plants may be explained by the evaporation values during the last two weeks of the four-week growth periods mentioned. It will be noted that for the four-week culture beginning June 11 the evaporation during the last two weeks is relatively low while for the cultures beginning June 24 and July 8 the opposite condition obtains. The plants of the first-named culture were thus exposed to a lower average evaporation rate during the last two weeks of their growth than those of the two last-named cultures which probably accounts for the high dry weight of the first as compared to the last two. The culture started on July 22 shows a dry weight above those beginning June 24 and July 8 and it will be noted from

the two week graphs that the plants of the earlier culture were exposed to a lower rate of evaporation during the last two weeks of their growth than those of the two cultures started later in the season. It would seem that here, as in the case of the cultures at College, we are dealing with effects of evaporation which are relatively great since this condition is at a critical value for the plants.

For Easton, the dry weight remains constant from the period beginning May 8 to the period beginning May 25 although there is a considerable rise in temperature. This may be related to the rise in the rate of evaporation during this interval. A decrease in evaporation rate would seem to account for the rise in dry weight from the period beginning May 25 to the period beginning June 8. No correlation can be found between the low value shown by the plant graph for the period beginning June 22 and the climatic conditions either as shown by the four-week averages or for the last two weeks of this culture period since these were such as would be expected to produce good growth. The culture beginning July 6 is low, relatively, but this may be due to high evaporation during the last two weeks of the culture period (see the period beginning July 20 on the two-week graph). The dry weights of the cultures beginning July 20 and Aug. 3 are also relatively low, for th same reason perhaps that has been given as accounting for the low weight of the culture beginning July 6. From the period beginning Aug. 17 to the end of the season, the low values of dry weight shown by the plant graph may be considered as due to low values of temperature and sunlight.

The four-week evaporation graph for Princess Anne is incomplete, the data for the periods beginning May 26, June 8 and June 23 not being available, and this renders it difficult to explain the behavior of the plants during the first part of the growing season. The relative temperature index values for this station are high and the evaporation values available for the station all low except the one for the first period of the season. This combination of low evaporation rate and high temperature value would be expected to produce higher rates of growth than were actually shown. The unusually low values of sunshine may be related to the fact that the plants failed to show higher dry weights at Princess Anne. It will be seen from the four-week graph that sunshine intensity is well below the seasonal average from the period beginning June 8 to the end of the season. The behavior of the dry weight for the first four cultures cannot be satisfactorily explained in the absence of the evaporation data for three of the culture periods but from the periods beginning July 7 to the period beginning Sept. 29 inclusive the dry weight and the temperature index values seem to correlate as would be expected since evaporation is too low to affect the plants and sunshine remains at a nearly constant value during this time.

All of the plants discussed up to this point were grown in the exposed stations, that is, in the open with no covering other than a screen of wire netting of large mesh to protect the plants from injury. At three of the stations, Oakland Baltimore, and Easton, as was noted in the introduction to this paper, a series of cultures was also grown under glazed cold-frame sash supported three feet above the ground, these

cultures being designated as the Oakland, Baltimore, and Easton <u>covered</u> stations. The behavior of the plants grown under glass is very different from the behavior of those grown in the open and a description of growth as it took place in these covered stations will now be given.

The cultures grown under glass were placed near the exposed cultures at each of the three places mentioned, so that the climatic conditions for the two would be practically the same except for the effects produced by the glass. That these effects were considerable is shown by the very marked differences between the plants under the glass and exposed plants growing only a few feet distant. The addition of the covering had in fact as great an effect as would have been produced if the plants had been grown in another part of the state.

Only one of the three climatic conditions dealt with, evaporation, was measured for these covered cultures, and we thus have no exact notion as to what sort of climate existed under the glass. The most that can be done is to compare the plants of these cultures with the exposed plants and call attention to such peculiarities of the covered stations as seem to be general for all of them. We may be sure, however, that the climatic conditions under the glass differed from the climatic conditions for the exposed plants in certain definite ways. Measurements show that the rate of evaporation for the covered stations was considerably greater than for the exposed as will be seen by comparing the values given in the tables. We may be certain, also, that some of the incident light was absorbed by the glass and that the light intensity under the glass was thus less than the intensity of the light falling on the

exposed plants. Also, we may be reasonably sure that the temperature under the glass w s somewhat higher than the temperature outside, especially on quiet days when circulation of air would be slight with a consequent slight tendency toward equalization of temperatures under the glass and temperature outside. In considering the behavior of the covered cultures, it will be borne in mind, then, that the evaporation is known to be higher and the light intensity lower for these than for the exposed stations while the temperature is probably higher for the covered than for the exposed.

The effect of the glass was shown by the plants in two ways: (1) growth was always greater for the covered stations than for the exposed, and (2) the plants of the covered stations showed a marked difference in manner of growth from the plants of the exposed stations. The greater growth of the covered plants was shown in some cases by one, in some cases by two or by all three of the growth measurements taken. Not only do the plants show greater growth, but the maxima in the graphs of the various growth measurements for the covered plants do not usually come at the same times as the maxima in the corresponding graphs for the plants grown in the open. The principal effect of the covering on the way in which the plants grow is shown by a disturbance of the relation between dry weight and leaf area. In previous discussion of this relation for the exposed plants it was noted that the relative dry weight and leaf area numbers are approximately the same for the four-week plants. In the case of the covered stations, on the other hand, every culture shows relative leaf area higher, usually very much higher, than relative dry weight. The stem height in the

covered cultures usually shows high values as compared to the corresponding exposed cultures. The tendency noted in previous discussion for this growth rate to fall off relatively, as the plants become larger seems to be to a great extent not active here. The consideration of the covered cultures in detail will bring out the features mentioned above. It should be noted that the culture periods for the covered and exposed plants correspond to within a day or two. That is, the exposed cultures and covered cultures were started at approximately the same time and thus extend over practically the same growth periods. In some cases exigencies of the experiment made it necessary to take measurements on the plants of the covered cultures on the day preceding or the day following the one on which the exposed cultures were measured. This, however, would not introduce enough of a difference in the measurements to interfere with the general comparisons here made. In the comparison between the growth for the exposed and covered cultures, no attempt will be made to account in detail for the differences between the two sets of plants in terms of climatic conditions, since the climatic influences acting on the covered plants are not accutately known. After the peculiarities of the covered plants have been pointed out, however, an explanation of their general behavior will be given which seems most probable in view of all the facts of the investigation.

The covered and exposed cultures for Oakland differ less than the two corresponding sets at the other stations (Baltimore and Easton), but show, nevertheless, the general features outlined above. The plants of the two-week covered cultures for Oakland exhibit a much higher value of the leaf-product than

the corresponding exposed cultures for the perods beginning June 18, July 2, and July 15 and the stem height is greater for the covered station than for the exposed station for the periods beginning June 4, July 2 and July 15. The highest value of leaf-product occurs in the period beginning July 15 for the covered and in the period beginning July 16 for the exposed two-week plants. Both sets of cultures show two maxima, in the plant graphs but these are much higher in the case of the covered plants than in the case of the exposed. In the four-week graphs of the covered plants, leaf area is higher than dry weight for the whole season, while in the exposed plants, the graph of leaf area is well below the graph of dry weight from the period beginning May 23 to the period beginning July 16 inclusive. The maximum for all the growth measurements of the four-week exposed plants occurs in the period beginning June 19 while in the covered set of cultures the maximum occurs in the period beginning July 2. Also, the graphs of the four-week plants all exhibit higher values than the graphs of the two-week plants for most of the culture periods of the season. This is especially true of the leaf-area. The effect of covering the plants with glass would seem to be to produce a relatively high rate of leaf expansion, and this in spite of the fact that evaporation is somewhat higher for the covered than for the exposed plants.

The two-week plant data for the covered station at Baltimore are plotted to a scale one-half as great as the scale used in plotting the exposed plant values on account of the high values of height and leaf-product shown by the covered culture beginning July 9. The values of both leaf-product and

stem height for the plants of the Baltimore covered station are above the corresponding values for the exposed station. Also, the tendency of the plants under the glass to elongate relatively more than the exposed plants is shown by the stem height values for the Baltimore covered station for both two and four weeks of growth. It is interesting to note that the covered plants do not show high values of the plant growth rates for the period beginning Aug. 6 as do the exposed plants. The four-week graphs for the covered plants show very well the tendency of leaf area to reach values relatively higher than dry weight, the leaf area graph being well above the dry weight graph for the entire season.

For Easton the covered plants, as compared with the exposed, show the general tendencies noted above. The two-week growth rates of the covered plants are higher than those of the exposed plants especially stem height. It will be observed that the maximum growth for the season in both the covered and exposed two-week cultures occurs in the period beginning Aug. 3. The four-week plants of the covered cultures show leaf area relatively higher than dry weight. The values for the culture period beginning June 22 are low for the covered cultures as well as in the exposed set. It was noted in the discussion of the latter that the climatic averages and these low values did not correlate. Since the covered plants show low values as well as the exposed, it is likely that we are dealing here with some climatic effect, however, and not with an abnormality of the cultures.

The difference between the behavior of the plants under glass and those in the open should be attributed, it would

seem to difference in light conditions for the two sets of cultures. The weight of the four-week plants under glass is, in most cases, greater than the weight of the plants grown in the open in spite of the higher evaporation rate experienced by the covered plants. If it is assumed that there is a higher temperature under the glass, the increase in dry weight produced receives a possible explanation. Also, an increase in growth in length of the plants when placed under glass is exactly what would be expected if temperature is high and light intensity low as compared with the values of these factors in the open. The relation between stem height, temperature, and light has been sufficiently discussed under the exposed stations, and will not be repeated here, but it will be seen that the behavior of the covered plants supports the assumption made as to the relation of this particular growth rate to the environmental conditions here measured. The fact that the leaf area of the covered plants is high in comparison with their dry weight may be considered as due to a lowering in amount of dry matter produced by photosynthesis per unit of leaf area. Such a lowering might be expected if the light available for photosynthesis is cut down by interposing between the plant and the light source a screen that absorbs a part of the rays. This explanation of the behaviour of the plants is, however, only an assumption and cannot be proved from the data at hand.

Whatever may be the explanation of the behavior of these plants, the facts as they stand show very clearly that the growth of plants under glass is quite different from growth in the open, and the indication here is that the glass acts on the growth rates directly by screening out part of the light,

and indirectly as well, by affecting the other climatic conditions. The habit of growth of the plants is thus altered and probably the amount of photosynthesis per unit leaf area. Such effects, if they are general for plants grown under glass, would obviously be of importance in their bearing on plant physiological experiments conducted in greenhouses. It would seem that growth behind even a single thickness of ordinary glass is quite different from growth in the open, and that in applying conclusions drawn from greenhouse experiments to plants grown under outdoor conditions this fact would have to be taken into account.

The Forest Station.

The nine series of four-week cultures grown in the open and the three series grown under glass include all the soybeans of the experiment except one series which was grown in the woods near the Laboratory of Plant Physiology at Baltimore. This series, the Baltimore Forest Station, was located, as has been noted, about 150 yards from the exposed and covered cultures at Baltimore. The behavior of the plants grown in the woods seems to support very clearly the assumption upon which the behavior of the exposed and covered cultures is explained. Only the evaporation was measured for this station but the sunshine intensity was, of course, very low due to the shading and screening effect of the leaves of the trees above the experimental plants. The temperature would also probably be considerably lower than the temperature experienced by the exposed and covered plants. The modification of growth habit in the case of the forest plants is very striking as can be seen by an inspection of the plant graph for the Baltimore

Forest Station. The soy-beans, short erect growers in the open, and erect under the glass, but with relatively long stems, become runners in the forest. This effect on stem growth, which obviously cannot be explained by the temperature in the case of these cultures, is relatively very great, the highest value for the two-week stem elongation being over 4-1/2 times the seasonal average, and the highest value for the four-week stem elongation being a little less than 4-1/2 times the seasonal average. The four-week plants also show the same change in the relative position of the leaf area and dry weight graphs that was shown by the covered plants. The leaf area graph is above the dry weight graph for the entire season. The forest cultures thus show a similarity to the covered cultures rather than to the exposed. This may be most reasonably accounted for by assuming the similarity in the behavior of the plants to be due to a similarity in the light conditions for these two sets of cultures.

In the introduction to the discussion of the plant data, it was stated that the main purpose of this experiment was to test the use of plants as instruments for measuring climate. The feasibility of this method of measuring climatic conditions has been urged by Livingston and McLean and by McLean,[1]

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[1] McLean, F. T., A preliminary study of climatic conditions in Maryland, as related to plant growth. Physiol. Res. 2: 129-208, 1917.

These authors state that the plant growth rates are a result of the total of all the environmental conditions acting on the

plants and that growth rates are therefore, from this point of view, themselves a measure of the ability of the environment to produce growth. It is assumed that such a method of measuring the environment is susceptible of "standarlization". That is, certain plants may be selected for use as integrating instruments, their growth peculiarites studied, and conditions defined under which their growth rates would measure this or that environmental condition or complex of conditions. It is suggested that the measurement of environment in terms of the growth of standard plants, assuming that it is possible to standardize them, would in all probability give results applicable directly to many purely scientific and practical problems. In the present experiment an attempt is made to grow soy beans under experimental conditions so controlled that the growth of the plants constitutes a measure of a certain part of the environmental complex ordinarily termed climatic, the environmental factors here measured being temperature, sunshine and evaporation.

From this point of view, every growth rate for each of the cultures, both two- and four-week is a measure of the climatic complex made up of the temperature, sunshine and evaporation conditions acting on the plants during the period for which the cultures under consideration was growing. It is, of course, realized that in the present experiment the control of the environmental factors other than the ones to be measured in terms of the growth of the plants was far from complete, and that the above statement is thus only approximately true. Assuming, however, that the control of conditions other than the one to be measured was such that the growth

of the plants was mainly determined by temperature, light, and evaporation, it may be said that the peculiarities of the plant graphs for each of the various stations are measurements of the seasonal climatic complex for that station as this is registered by the growth of two-and four-wek old soybean seedlings. The growth graphs represent graphically the "readings" of the standard plant when grown in the way described and exposed to this seasonal march of conditions. The reading for each period may be regarded as the "plant producing power" of the climatic complex of the growing period. It has been previously brought out that the readings on the standard plants seems to bear some relation to the values of the three climatic conditions dealt with, especially in the case of the four-week plants.

If we average the readings for the season at each of the stations, we get a number which represents the average seasonal value of the plant producing power of the climatic complex as it is registered by each of the growth processes considered. This has been done for the exposed stations for the two-week and for the four-week periods with the results shown in Plate XIII. The ordinates of the graphs of averages represent the average daily relative growth rates for the season for the two sets of plants and the average daily relative intensities of the climatic conditions . The name of the station at which each average growth value was registered is given immediately below the ordinate on which the value is plotted. The total plant producing power of any station for either the two-week or four-week growth periods would be secured by multiplying the average value of this growth rate during the season by

the length of time (expressed as the number of two-week periods) during which it was acting. The length of time during which the average growth rate is active would be the length of the growing season, which, for soy-bean and most agricultural plants, would be the length of the frostless season.

The plant producing power of any station may thus be regarded as equal to the product of two factors, an intensity factor and a duration factor, the first derived from the readings of the standard plant and the second the length of the frostless season. A large value for either of both of these factors at a given station would result in a high plant producing power and a low value for either or both of them would result in a low plant producing power.

The two-week seasonal averages for the nine exposed stations of the two growth measurements taken represented graphically in Plate XIII show that the plant producing power of the climatic complex is about the same whether it is measured by stem height of leaf-product. The range of variation for the former measurement is from 76 for Monrovia to 125 for Baltimore. In terms of stem height thus the average intensity of the Monrovia climatic complex is 61 per cent of that of the Baltimore complex. Similarly, leaf-product varies from a minimum of 77 at Oakland to a maximum of 119 for Baltimore. As measured by leaf-product therefore, the Oakland climate is 65 per cent as efficient as the Baltimore climate. If we introduce the duration factor, however, the plant producing power of Oakland will be still further reduced since the growing season at this station is short, including only 9 two-week periods as compared to the lengths of the growing season at

the other stations which include 11 or 12 two-week periods.

When the two-week averages are compared with the four-week averages, it is seen that the graph of leaf area and dry weight for four-weeks do not parallel the graph of leaf-product for two weeks. That is, the climate, registered in one way by two-week leaf-product (which is approximately proportional to leaf area and dry weight) is registered by the four-week leaf area and dry weight in quite another way. It should be remembered that the two-week and the four-week cultures were carried on over practically the same interval of time at each station so that the plants of both series are registering the same total climatic effect. It will be noted that the two week stem height averages parallel the four-week stem height averages rather closely, however. This behavior of the various growth measurements as it bears on the use of plants for measuring environmental conditions will be discussed below.

As has been noted above, if plants are to be used for the measurement of environmental conditions, it would seem necessary to standardize the plants. It is known that a plant is always changing in its power to respond to external conditions. Also, there is a change in the internal condition of the plant resulting in a decrease in the rate of growth as the plant becomes older. Both of these points have been emphasized in previous discussion. The relatively great effect of evaporation in the second two weeks of growth on the dry weight produced is an illustration of the first type of variation while the gradual falling off of the rate of growth of stems as the plants become older is an illustration of the second type. By starting all the plants from the seed, as was done in the

present experiment, we may be reasonably sure that the zero point of all the integrating instruments is the same. At the end of the growing period however, the "setting" of the instrument is not known, since we do not know what cycle of changes the internal conditions of the plant have gone through. In order to apply the data secured from standard plants to plant growth in general, it would seem necessary to correct the readings of the standard plant in the same way that the readings of any physical instrument are corrected for instrumental variations. At present no way is known by which a number can be given to the reacting ability of a plant or to the stages of the cycle through which the plant passes as it matures. Variations in the internal conditions of the plant such as these here noted must be responsible for the fact that the seasonal averages of the two-week leaf-product value, a plant measurement proportional to the leaf area and dry weight of the two-week plants, registers a given set of climatic conditions different from the way in which this set is registered by actual leaf area and dry weight of the same plants grown for four-weeks.

Several methods suggest themselves by means of which the difficulty noted above may be surmounted. One possibility is to evaluate the internal conditions of the plant and correct the readings for changes in those conditions. This method would involve a detailed study of the standard plant and at best would seem to promise a solution of the problem involving complicated mathematical reductions of the plant readings. There is every reason to believe that a correction formula for plants considered as integrating instruments would, if obtainable, be exceedingly complex. Another, and apparently more hopeful

method would be to find some plant measurement or to evaluate some plant process dependent on external conditions and at the same time not subject to extreme variations due to internal changes in the plants. Or, a measurement or process might be found whose variation due to internal changes would follow some simple, easily determined relation. The fact was noted above that the graphs representing the average seasonal stem height values for two and four weeks of growth were parallel in general. This measurement may, therefore, have the qualifications noted above. That an approximately constant relation exists between the two and four-week stem height may be shown by dividing the two-week seasonal averages for each station by the four-week seasonal average. We find that this gives values of the ratio as shown below:

Oakland-------------	1.21
Chewsville----------	1.16
Monrovia------------	1.18
College-------------	1.19
Baltimore-----------	1.20
Darlington----------	1.07
Coleman-------------	1.20
Easton--------------	1.27
Princess Anne-------	1.15

The average of these ratios is 1.18. If, therefore, the stem height of the soy-bean, grown as a standard plant, be used as a measure of the climatic complex and the measurement be expressed as relative average daily increments as in this study, the two-week readings may be corrected to the four-week readings (considering these as the standard) by dividing each two-week reading by the constant 1.18. Evidence which cannot be given here shows that the rate of photosynthesis also, is dependent

on the three climatic factors here dealt with in a definite way and apparently not subject to large variation due to internal conditions of the plants. Another possible method by means of which to eliminate the internal peculiarities of the standard plant would be to grow the standard plant and plants whose reaction to external conditions was to be expressed in terms of the standard under the same set of environmental conditions and to compare the growth rates. In this way ratios between the standard plant and the plant whose reaction to the given set of environmental conditions is unknown would be secured. We might then grow the standard plants in various environments and predict what growth would be made in those environments by plants whose relations to the standard plant were known.

Conclusions.

The main results of this study may be summarized under the following heads: (1), the interrelations of the climatic measurements, (2) the interrelations of the plant measurements, (3) the relations between the plant and climatic values, and (4) the measurement of the climatic complexes by soy-bean, considered as a standard plant.

The principal features of interest in the climatic data are the correspondence of the sunshine and evaporation graphs and the slight variability of the physiological temperature index as compared to the indices of sunshine and evaporation. From the first of these it may be concluded that the energy absorbed from the sun's rays by the porous cups plays a large part in the determination of the evaporation rate. From the second, it would seem that during any given time interval the air temperature at the various stations here dealt with was less subject to local variation than either the sunshine intensity or the evaporation rate.

The relations between the plant measurements fall into two divisions. (1) The relation between the elongating tendency of the plants and their tendency to expand their leaves, and (2) the relation between the leaf area and the dry weight. The data here given indicate that the rate of elongation is greater than the rate of leaf expansion when both are small, and less than the leaf expansion rate when both are large. Dry weight and leaf area are so related in soy-bean that the <u>relative</u> values of these measurements are approximately numerically equal. Both of the above conclusions apply to the plants of the exposed stations. For the covered stations, the value of stem height is relatively large

and the relative value of dry weight is always less than the relative value of leaf area. The two latter statements also apply to the plants of the Baltimore forest station.

From the data presented in the preceding pages, the following conclusions may be drawn as to the relations between the climatic conditions and the various growth processes. (1) The height of the plants, in so far as it is determined by the conditions here dealt with, seems to be influenced mainly by sunshine and temperature. In the case of the exposed plants the temperature seems to have a preponderating effect with sunshine acting secondarily. The effect of temperature is direct, high temperatures accelerating growth in height and low temperatures retarding it, while sunshine has an inverse effect, high values retarding and low values accelerating the stem elongation rate. In the case of the plants under glass stem elongation rate is relatively high and in the case of the plants of the forest station it is relatively very high. The facts indicate that low sunshine intensity produces some etiolation in all the plants and considerable etiolation in those grown under conditions such that a part of the incident light is absorbed before it reaches the plants as is the case for the glass-covered plants and those grown in the forest. (2) The relation apparently existing between the dry weight of the plants (or the leaf-product which is an index of dry weight in these plants) and the climatic conditions here dealt with may be stated in the form

$$r = \frac{f(I) \times f(L)}{f(E)}$$

in which the symbols have the meaning previously given.

(c) The four-week plants seem, in many cases, to be especially susceptible to high evaporation rates during the last two weeks of their growth.

Considering the soy-bean as a standard plant for the measurement of the efficiency of the climate in various parts of the state of Maryland to produce plant growth, it would appear that during the season of 1914 the three stations in the western part of the state (Oakland, Chewsville, and Monrovia) showed a lower plant producing power than the remaining six stations, the term plant producing power meaning here the effectiveness of the climatic complex to produce growth in young soy-bean plants. It would also appear that the climatic complexes of certain culture periods weremore efficient for growing soy-bean than the averages of the environmental conditions would lead us to expect, while for certain other periods the climatic complexes were less efficient to produce growth than would be expected from the averages for the periods. Taking all the facts of the investigation into account, this would seem to be due to the way in which high and low intensities of the conditions were distributed throughout these periods.

OAKLAND 2 week periods EXPOSED STATION	MAY [illegible] JUNE 5	JUNE [illegible] JUNE 19	JUNE 19 JULY 3	JULY 3 JULY 16	JULY 16 JULY 31	JULY 31 AUG 14	AUG [illegible] AUG 27	AUG 27 SEPT 12	SEPT 12 SEPT [illegible]	AV.
Culture number	1	2	3	4	5	6	7	8	9	
Length of growing period, days	13	14	14	13	15	14	15	16	15	
Number of plants	7	5	5	6	5	6	6	6	4	
Remainder summation index	301	341	401	364	451	369	343	370	282	361
Average daily relative physiological temperature index	60	66	85	78	87	67	69	66	45	69
Average daily mean temperature, deg F	65	61	68	67	68	65	66	62	61	65
Average daily relative evaporation index	153	137	98	79	104	90	71	57	69	96
Average daily relative sunshine intensity	122	122	109	103	116	102	110	83	81	105
Average daily relative increment in stem height	76	96	124	84	96	98	101	53	42	86
Average daily relative increment in leaf product	—	81	87	74	89	78	82	46	—	77

CHEWSVILLE 2 week periods EXPOSED STATION	MAY 19 JUNE 2	JUNE 2 JUNE 16	JUNE 16 JUNE 30	JUNE 30 JULY 14	JULY 14 JULY 28	JULY 28 AUG 11	AUG 11 AUG 25	AUG 25 SEPT 8	SEPT 8 SEPT 22	SEPT 22 OCT 7	OCT 7 OCT 20	AV.
Culture number	1	2	3	4	5	6	7	8	9	10	11	
Length of growing period, days	14	14	14	14	14	14	14	14	14	15	13	
Number of plants	6	6	4	6	5	4	3	5	6	6	6	
Remainder summation index	416	443	412	433	523	450	517	436	302	328	301	422
Average daily relative physiological temperature index	[illegible]	106	119	112	147	112	145	103	48	51	53	98
Average daily mean temperature, deg F	64	71	73	71	76	71	76	70	61	61	62	69
Average daily relative evaporation index	110	115	107	75	108	87	105	90	79	73	64	91
Average daily relative sunshine intensity	121	123	116	106	121	94	98	67	104	73	44	98
Average daily relative increment in stem height	93	12	143	112	126	119	18	76	48	37	37	87
Average daily relative increment in leaf-product	104	110	137	98	139	127	100	52	32	20	4	84

MONROVIA 2 week periods EXPOSED STATION	MAY 18 JUNE 1	JUNE 1 JUNE 15	JUNE 15 JUNE 29	JUNE 29 JULY 13	JULY 13 JULY 27	JULY 27 AUG. 10	AUG 10 AUG 24	AUG 24 SEPT 7	SEPT 7 SEPT 21	SEPT 21 OCT. 8	OCT 8 OCT 19	AV.
Culture number	1	2	3	4	5	6	7	8	9	10	11	
Length of growing period, days	14	14	14	14	14	14	14	14	14	17	11	
Number of plants	3	5	6	4	6	5	6	5	6	6	6	
Remainder summation index	442	454	478	454	536	465	511	435	384	386	262	437
Average daily relative physiological temperature index	105	110	124	112	156	117	144	105	59	53	59	104
Average daily mean temperature, deg F	71	71	73	71	77	72	73	70	62	62	63	70
Average daily relative evaporation index	—	146	152	93	117	120	112	68	96	82	76	106
Average daily relative sunshine intensity	152	122	104	102	110	105	98	82	105	66	52	100
Average daily relative increment in stem height	73	81	121	96	115	90	107	76	20	67	25	79
Average daily relative increment in leaf product	66	90	110	83	138	109	104	112	6	56	9	80

PLATE I.

College 2 week period Exposed station	May 23 – June 6	June 6 – June 19	June 19 – July 3	July 3 – July 17	July 17 – July 31	July 31 – Aug 14	Aug 14 – Aug. 2[illegible]	Aug [illegible] – Sept 10	Sept [illegible] – Sept [illegible]	[illegible] – Oct 10	Oct 10 – Oct 2[illegible]		Av.
Culture number	2	3	4	5	6	7	8	9	10	11	12		
Length of growing period, days.	14	13	14	14	14	14	13	14	15	15	14		
Number of plants	6	5	5	6	4	4	5	6	–	6	6		
Remainder summation index	546	407	526	494	520	444	478	441	378	365	327		450
Average daily relative physiological temperature index	108	103	133	134	148	123	143	115	67	50	53		108
Average daily mean temperature, deg F	71	70	76	74	76	74	72	71	64	[illegible]	62		70
Average daily relative evaporation index	160	154	173	70	142	147	125	107	78	34	62		119
Average daily relative sunshine intensity.	–	–		–	–								
Average daily relative increment in stem height	93	132	115	118	124	118	90	76		48	35		75
Average daily relative increment in leaf-product.	96	123	81	152	203	150	117	62	–	13	10		101

Baltimore. 2 week period. Exposed station	May 14 – May 29	May 29 – June 10	June 10 – June 25	June 25 – July 9	July 9 – July 23	July 23 – Aug 6	Aug 6 – Aug. 20	Aug 20 – Sept 3	Sept 3 – Sept 17	Sept 19 – Oct. 1	Oct 1 – Oct. 14		Av
Culture number.	1	2	3	4	5	6	7	8	9	10	11		
Length of growing period, days	15	12	15	14	14	14	14	14	16	12	13		
Number of plants.	5	–	5	6	6	4	5	5	6	5	5		
Remainder summation index.	451	370	508	487	540	506	51[illegible]	502	515	500	3[illegible]		448
Average daily relative physiological temperature index	77	19	123	125	162	143	160	137	62	67	63		112
Average daily mean temperature, deg F	67	70	73	73	73	75	70	[illegible]	64	64	64		72
Average daily relative evaporation index	127	102	115	80	72	112	110	81	69	48	64		73
Average daily relative sunshine intensity.	137	87	108	60	44	72	77	74	82	87	57		76
Average daily relative increment in stem height	93	–	146	152	183	152	152	141	73	56	46		125
Average daily relative increment in leaf-product	106	–	125	163	194	110	233	130	54	22	44		119

Darlington 2 week periods Exposed station	May 15 – May 30	May 30 – June 13	June 13 – June 26	June 26 – July 10	July 10 – July 24	July 24 – Aug 7	Aug 7 – Aug 21	Aug 21 – Sept 4	Sept 4 – Sept 18	Sept 18 – Oct 2	Oct 2 – Oct 16		Av
Culture number	1	2	3	4	5	6	7	8	[illegible]	10	11		
Length of growing period, days.	15	14	13	14	14	14	14	14	14	14	14		
Number of plants.	6	5	6	4	5	5	–	5	6	5	4		
Remainder summation index	430	432	592	432	512	456	506	472	309	315	438		418
Average daily relative physiological temperature index	87	99	94	98	147	113	146	123	46	57	51		97
Average daily mean temperature, deg. F	68	70	67	70	76	72	76	73	61	62	63		67
Average daily relative evaporation index	130	125	90	62	74	77	74	57	92	97	91		87
Average daily relative sunshine intensity	154	129	42	77	111	111	116	78	92	46	47		100
Average daily relative increment in stem height	110	104	136	131	223	136	–	107	12	19	51		112
Average daily relative increment in leaf-product.	135	129	158	115	195	138		109	29	13	11		118

PLATE II.

COLEMAN 2 week periods EXPOSED STATION	MAY 15 MAY 29	MAY 2[illegible] JUNE 11	JUNE 11 JUNE 24	JUNE 24 JULY [illegible]	JULY [illegible] JULY [illegible]	JULY 22 AUG [illegible]	AUG 5 AUG 19	AUG 19 SEPT 2	SEPT [illegible] SEPT [illegible]	SEPT [illegible] SEPT [illegible]	SEPT [illegible] OCT [illegible]	OCT 13 OCT [illegible]	Av
Culture number	1	2	3	4	5	6	7	8	9	10	11	12	
Length of growing period, days	15	14	13	14	14	14	14	14	14	14	13	15	
Number of plants.	6	6	4	4	6	6	5	6	4	4	4	6	
Remainder summation index	412	466	433	488	560	517	538	520	390	399	—	—	472
Average daily relative physiological temperature index.	81	113	118	130	170	146	158	148	84	85		—	123
Average daily mean temperature, deg. F.	66	72	67	74	79	76	77	76	61	67		-	72
Average daily relative evaporation index.	134	152	137	120	143	155	119	96	132	135	17	43	127
Average daily relative sunshine intensity	142	160	125	61	141	124	118	85	—	—	—	—	120
Average daily relative increment in stem height	79	87	107	135	149	157	121	107	62	53	61	28	96
Average daily relative increment in leaf product.	108	111	97	172	211	194	138	110	33	53	38	4	107

EASTON 2 week periods EXPOSED STATION	MAY 8 MAY 25	MAY 25 JUNE 8	JUNE 8 JUNE 22	JUNE 22 JULY 6	JULY 6 JULY 20	JULY 20 AUG 3	AUG 3 AUG 17	AUG 17 AUG 31	AUG 31 SEPT 14	SEPT 14 SEPT 2[illegible]	SEPT [illegible] OCT 11	OCT 11 OCT 26	AV
Culture number	1	2	3	4	5	6	7	8	9	10	11	12	
Length of growing period, days	17	14	14	14	14	14	14	14	14	14	13	15	
Number of plants	6	4	5	6	4	5	5	5	5	6	6	3	
Remainder summation index	430	453	451	492	532	495	513	519	392	381	326	347	445
Average daily relative physiological temperature index	67	11[illegible]	110	131	154	133	144	146	87	76	64	45	106
Average daily mean temperature, deg. F	5[illegible]	71	71	74	77	74	76	76	67	66	64	62	7[illegible]
Average daily relative evaporation index	95	130	133	91	80	133	128	113	111	104	98	82	108
Average daily relative sunshine intensity	145	172	141	120	124	108	117	77	91	75	64	52	111
Average daily relative increment in stem height	[illegible]	97	112	132	[illegible]	146	132	118	81	45	65	34	95
Average daily relative increment in leaf-product	71	11	112	99	152	130	163	124	64	35	—	-	105

PRINCESS ANNE 2 week periods EXPOSED STATION	MAY 11 MAY 26	MAY 26 JUNE 8	JUNE 8 JUNE 23	JUNE 23 JULY 7	JULY 7 JULY 21	JULY 21 AUG 4	AUG 4 AUG 18	AUG 18 SEPT 1	SEPT 1 SEPT 15	SEPT 15 SEPT 29	SEPT 29 OCT 12	OCT 12 OCT 27	AV.
Culture number	1	2	3	4	5	6	7	8	9	10	11	12	
Length of growing period, days	15	15	15	14	13	14	14	14	14	14	13	15	
Number of plants.	6	5	6	6	6	6	3	6	6	5	5	4	
Remainder Summation index.	358	405	504	493	514	483	513	520	387	365	315	328	432
Average daily relative physiological temperature index.	59	103	101	132	144	123	144	146	34	11	60	43	101
Average daily mean temperature, deg F	65	70	75	74	70	74	76	76	67	65	63	61	70
Average daily relative evaporation index.	117	134	—	—	63	93	101	79	73	79	70	39	84
Average daily relative sunshine intensity.	101	118	103	95	83	76	75	56	79	[illegible]	67	42	86
Average daily relative increment in stem height	67	110	127	124	137	143	155	121	79	55	[illegible]	45	106
Average daily relative increment in leaf-product.	96	116	104	115	163	102	177	138	82	34	18	6	96

PLATE III.

OAKLAND 4-week periods EXPOSED STATION	May 22 – June 17	June 5 – July 3	June 19 – July 16	July 3 – July 31	July 16 – Aug. 14	July 31 – Aug. 27	Aug 14 – Sept 12	Aug 27 – Sept 25	Av
Culture number	1	2	3	4	5	6	7	8	
Length of growing period, days	27	28	27	28	29	27	29	29	
Number of plants	4	5	5	6	5	6	6	6	
Remainder summation index.	688	755	765	795	800	713	714	652	735
Average daily relative physiological temperature index.	66	76	82	83	77	66	65	55	71
Average daily mean temperature, deg F	65	[illegible]	[illegible]	67	67	65	64	62	65
Average daily relative evaporation index	140	109	89	92	77	81	64	63	94
Average daily relative sunshine intensity	122	116	106	110	109	106	97	82	106
Average daily relative increment in stem height	66	78	94	69	72	81	63	47	71
Average daily relative increment in leaf area	41	67	91	75	80	90	72	52	71
Average daily relative increment in dry weight	51	77	108	95	96	85	76	46	79

CHEWSVILLE 4-week periods EXPOSED STATION	May 19 – June 16	June 2 – June 30	June 16 – July 14	June 30 – July 28	July 14 – Aug 11	July 28 – Aug 25	Aug. 11 – Sept 8	Aug. 25 – Sept 22	Sept 8 – Oct 7	Sept 22 – Oct 20	Oct 7 – Nov 3	Av.
Culture number	1	2	3	4	5	6	7	8	9	10	11	
Length of growing period, days.	28	28	28	28	28	28	28	28	29	28	27	
Number of plants.	6	6	4	6	5	4	3	5	6	6	6	
Remainder summation index.	857	915	925	776	973	967	953	736	630	627	470	823
Average daily relative physiological temperature index.	49	113	116	131	131	129	124	76	50	57	37	96
Average daily mean temperature, deg F.	70	72	72	74	74	74	73	66	61	62	58	69
Average daily relative evaporation index	113	111	91	92	18	96	43	20	76	67	71	90
Average daily relative sunshine intensity	125	123	111	114	108	96	83	86	89	53	56	95
Average daily relative increment in stem height	75	103	122	117	91	84	84	50	47	41	31	75
Average daily relative increment in leaf area.	73	91	132	83	89	94	99	57	44	45	12	74
Average daily relative increment in dry weight	78	102	147	87	92	86	80	62	51	38	24	78

MONROVIA 4-week periods EXPOSED STATION	May 18 – June [illegible]	June [illegible] – June [illegible]	June 15 – July [illegible]	June [illegible] – July [illegible]	July [illegible] – Aug [illegible]	July 27 – Aug 24	Aug 10 – Sept 7	Aug 24 – Sept [illegible]	Sept 7 – Oct 8	Sept [illegible] – Oct 17	Oct 6 – Nov.	Av
Culture number	1	2	3	4	5	6	7	8	9	10	11	
Length of growing period, days	28	28	28	28	28	28	28	28	31	28	25	
Number of plants.	3	5	6	4	6	5	6	5	6	6	6	
Remainder summation index.	890	932	932	990	997	974	944	817	770	646	463	851
Average daily relative physiological temperature index.	108	117	118	134	137	131	125	82	56	50	53	102
Average daily mean temperature, deg F	71	72	72	74	75	74	73	66	62	61	58	69
Average daily relative evaporation index.	—	149	123	105	119	116	90	82	89	79	81	103
Average daily relative sunshine intensity	137	113	103	106	108	102	90	74	80	59	58	96
Average daily relative increment in stem height	63	78	84	84	78	91	84	56	44	41	28	66
Average daily relative increment in leaf area	71	108	88	79	71	104	75	70	39	48	12	71
Average daily relative increment in dry weight	70	114	108	99	84	105	81	87	41	48	24	79

PLATE IV.

COLLEGE 4 week periods EXPOSED STATION	[illegible] 1 – JUNE [illegible]	MAY [illegible] – JUNE 13	JUNE 6 – JULY 3	JUNE 13 – JULY 17	JULY 3 – JULY 31	JULY 17 – AUG 14	JULY 31 – AUG 27	AUG 14 – SEPT 10	AUG 27 – SEPT [illegible]	SEPT 10 – OCT 10	SEPT 25 – OCT 24	Av.
Culture number	1	2	3	4	5	6	7	8	9	10	11	
Length of growing period, days	28	27	27	28	28	28	27	27	[illegible]	30	29	
Number of plants.	6	6	5	5	6	4	4	6	6	—	6	
Remainder summation index.	588	450	730	1020	[illegible]	[illegible]	772	727	867	713	662	[illegible]
Average daily relative physiological temperature index.	88	110	121	137	141	141	138	127	91	51	52	110
Average daily mean temperature, deg F	67	71	72	75	[illegible]	75	75	74	67	64	[illegible]	71
Average daily relative evaporation index	169	157	139	110	120	145	141	121	93	81	83	124
Average daily relative sunshine intensity.	—	—	—	—	—	—	—	—	—	—	—	
Average daily relative increment in stem height.	47	75	106	91	91	97	103	72	63		56	80
Average daily relative increment in leaf area	70	92	125	78	98	173	234	126	86		46	110
Average daily relative increment in dry weight	86	110	140	75	114	172	147	122	84	—	51	119

BALTIMORE 4 week periods EXPOSED STATION	MAY 14 – JUNE 10	MAY 29 – JUNE 25	JUNE 10 – JULY 9	JUNE 25 – JULY 25	JULY [illegible] – AUG 6	JULY 22 – AUG 20	[illegible] – SEPT 2	AUG [illegible] – SEPT [illegible]	SEPT [illegible] – OCT 1	SEPT [illegible] – OCT 13	OCT [illegible] – OCT 31	Av.
Culture number	1	2	3	4	5	6	7	8	9	10	11	
Length of growing period, days	27	27	[illegible]	30	32	28	28	32	28		20	
Number of plants.	4	5	5	6	6	4	6	5	6	5	3	
Remainder summation index.	82	878	997	035	052	049	045	897	675	627	619	[illegible]
Average daily relative physiological temperature index.	92	111	124	144	151	150	150	101	62	65	47	10
Average daily mean temperature, deg F	72	72	72	[illegible]	77	77	77	64	64	64	60	71
Average daily relative evaporation index	118	112	49	86	102	111	46	75	67	66	61	90
Average daily relative sunshine intensity	113	97	84	80	86	76	77	78	96	74	50	82
Average daily relative increment in stem height	100	117	138	122	122	131	122	91	67	75	26	104
Average daily relative increment in leaf area.	90	109	115	197	134	141	196	97	72	73	31	115
Average daily relative increment in dry weight	86	113	119	146	134	118	162	42	22	67	40	105

DARLINGTON 4 week periods EXPOSED STATION	MAY 15 – JUNE 13	MAY 30 – JUNE 26	JUNE 13 – JULY 10	JUNE [illegible] – JULY 24	JULY 10 – AUG 7	JULY 24 – AUG 21	AUG 7 – SEPT 4	AUG [illegible] – SEPT 18	SEPT 4 – OCT 2	SEPT 19 – OCT [illegible]	Av.
Culture number	1	2	3	4	5	6	7	8	9	10	
Length of growing period, days	29	27	27	28	28	28	28	25	28	29	
Number of plants.	6	5	6	4	5	5	—	5	6	5	
Remainder summation index.	802	824	821	744	768	762	770	781	621	623	84
Average daily relative physiological temperature index	93	97	46	124	131	130	135	75	53	57	100
Average daily mean temperature, deg F	67	70	70	73	74	74	75	67	62	63	70
Average daily relative evaporation index	128	108	76	69	70	70	72	73	36	39	85
Average daily relative sunshine intensity	142	111	85	11	111	119	97	99	11	70	[illegible]
Average daily relative increment in stem height	102	102	116	147	172	131	—	79	41	62	105
Average daily relative increment in leaf area	166	161	151	196	130	112	—	40	57	54	149
Average daily relative increment in dry weight	124	162	170	178	[illegible]	[illegible]		89	55	[illegible]	144

PLATE V.

COLMAN 4 week periods EXPOSED STATION	May 13 – June 11	May 28 – June 21	June 11 – July 8	June 24 – July 22	July 8 – Aug 5	July 22 – Aug 19	Aug 5 – Sept 2	Aug 19 – Sept 16	Sept 2 – Sept 30	Sept 16 – Oct 13	Sept 30 – Oct 28		Av.
Culture number	1	2	3	4	5	6	7	8	9	10	11		
Length of growing period, days	29	21	27	28	28	28	28	28	28	27	28		
Number of plants	6	6	4	4	6	6	5	6	5	4	5		
Remainder summation index	878	[illegible]	921	1048	1077	1055	1056	910	769	—	—		951
Average daily relative physiological temperature index	97	116	124	150	158	152	153	113	85	—	—		128
Average daily mean temperature, deg. F	69	70	71	77	78	77	77	72	67				73
Average daily relative evaporation index	136	135	124	132	149	137	108	114	134	116	75		123
Average daily relative sunshine intensity	151	143	75	101	133	121	102	—					121
Average daily relative increment in stem height	67	81	94	106	120	109	91	72	53	50	53		80
Average daily relative increment in leaf area	116	150	161	144	135	145	108	89	71		47		117
Average daily relative increment in dry weight	126	153	159	143	134	148	83	113	67	75	43		113

PAXTON 4 week periods EXPOSED STATION	May [illegible] – June 8	May 25 – June 22	June 8 – July [illegible]	June [illegible] – July 20	July [illegible] – Aug 3	July 20 – Aug 17	Aug 3 – Aug 31	Aug 17 – Aug. 14	Aug 31 – Sept 28	Sept 14 – Oct 11	Sept 28 – Oct 26	Oct 11 – Nov 6	Av.
Culture number	1	2	3	4	5	6	7	8	9	10	11	12	
Length of growing period, days	31	28	28	28	28	28	28	28	28	27	28	26	
Number of plants	6	4	5	6	4	5	5	5	5	6	6	3	
Remainder summation index	989	104	943	1024	1027	1008	1032	911	113	707	673	411	866
Average daily relative physiological temperature index	70	111	121	143	141	137	145	117	82	70	56	37	105
Average daily mean temperature, deg F	68	71	73	76	76	75	76	72	67	65	63	58	70
Average daily relative evaporation index	113	112	112	87	110	131	121	112	103	96	85	73	109
Average daily relative sunshine intensity	157	157	131	122	116	113	109	78	76	50	58	60	108
Average daily relative increment in stem height	41	72	41	103	103	113	103	81	56	50	56	30	75
Average daily relative increment in leaf area	74	76	111	70	101	121	121	95	66	61	58	8	82
Average daily relative increment in dry weight	80	81	119	91	113	121	121	81	72	48	52	22	85

PRINCESS ANNE 4 week periods EXPOSED STATION	May 11 – June 8	May 26 – June [illegible]	June 9 – July 7	June [illegible] – July [illegible]	July 7 – Aug 4	July 21 – Aug 18	Aug 4 – Sept 1	Aug 15 – Sept 15	Sept 1 – Sept [illegible]	Sept 15 – Oct 12	Sept 27 – Oct 27		Av
Culture number	1	2	3	4	5	6	7	8	9	10	11		
Length of growing period, days	28	28	27	28	28	28	28	28	28	27	28		
Number of plants	6	5	5	6	6	5	3	6	6	5	6		
Remainder summation index	[illegible]	864	917	1007	937	976	1033	901	750	678	613		880
Average daily relative physiological temperature index	81	102	117	138	130	136	145	110	78	66	52		106
Average daily mean temperature, deg F	67	73	75	75	75	75	76	72	66	64	62		71
Average daily relative evaporation index	126	—	—	—	73	92	90	78	78	74	55		83
Average daily relative sunshine intensity	113	111	94	87	92	80	81	83	81	75	55		87
Average daily relative increment in stem height	62	88	103	100	138	125	178	84	63	[illegible]	44		92
Average daily relative increment in leaf area	123	155	110		127	132	206	102	97	72	36		117
Average daily relative increment in dry weight	[illegible]	140	137	118	137	135	171	77	87	67	78		116

PLATE VI.

OAKLAND 2-week periods COVERED STATION	MAY 2[illegible] – JUNE 4	JUNE 4 – JUNE 18	JUNE 18 – JULY 2	JULY [illegible] – JULY 15	JULY 1[illegible] – JULY 30	JULY 30 – AUG 13	AUG 1[illegible] – AUG 26	AUG [illegible] – SEPT 11	SEPT 11 – SEPT 2[illegible]	AV.
Culture number	1	2	3	4	5	6	7	8	9	
Length of growing period, days.	13	14	14	12	15	14	13	15	13	
Number of plants.	5	6	6	5	6	–	5	5	5	
Average daily relative evaporation index.	172	147	133	109	117	112	112	85	93	120
Average daily relative increment in stem height.	56	112	110	121	126	–	84	70	56	92
Average daily relative increment in leaf product	18	85	121	96	154	–	89	44	9	78

OAKLAND 4-week periods COVERED STATION	MAY 22 – JUNE 18	JUNE 4 – JULY 2	JUNE 18 – JULY 15	JULY 2 – JULY 30	JULY 15 – AUG 13	JULY 30 – AUG 26	AUG 13 – SEPT 11	AUG 26 – SEPT 24	AV.
Culture number	1	2	3	4	5	6	7	8	
Length of growing period, days	27	28	27	28	2[illegible]	27	29	29	
Number of plants.	5	6	6	5	6		5	5	
Average daily relative evaporation index.	160	140	121	113	115	112	99	79	117
Average daily relative increment in stem height.	56	91	88	106	97	–	63	66	81
Average daily relative increment in leaf area.		107	145	155	118	–	-	66	118
Average daily relative increment in dry weight.	51	97	121	123	111	–	86	51	93

BALTIMORE 2 week periods COVERED STATION	JUNE 10 – JUNE 25	JUNE 25 – JULY 9	JULY 9 – JULY 23	JULY 23 – AUG 6	AUG 6 – AUG 20	AUG 20 – SEPT 3	SEPT 3 – SEPT 19	SEPT 17 – OCT 1	OCT 1 – OCT 14	AV.
Culture number	3	4	5	6	7	8	9	10	11	
Length of growing period, days.	15	14	14	14	14	14	16	12	13	
Number of plants.	6	6	4	6	5	5	3	5	4	
Average daily relative evaporation index.	119	95	112	109	117	87	81	77	73	97
Average daily relative increment in stem height	157	160	326	233	197	191	56	70	145	17[illegible]
Average daily relative increment in leaf-product.	111	150	262	187	180	163	51	21	43	125

BALTIMORE 4-week periods. COVERED STATION	MAY 29 – JUNE 25	JUNE 10 – JULY 9	JUNE 25 – JULY 23	JULY 1 – AUG 6	JULY 23 – AUG. 20	AUG 6 – SEPT 3	AUG 20 – SEPT 19	SEPT 3 – OCT 1	SEPT 19 – OCT 19	OCT 1 – OCT 31	AV.
Culture number	2	3	4	5	6	7	8	9	10	11	
Length of growing period, days.	27	29	28	28	28	28	30	28	25	30	
Number of plants.	5	6	6	4	6	5	5	3	5	4	
Average daily relative evaporation index	119	107	107	111	113	102	84	79	75	[illegible]	91
Average daily relative increment in stem height.	156	128	154	231	169	[illegible]	[illegible]	7[illegible]	105	78	156
Average daily relative increment in leaf area.	-		188	[illegible]	131	[illegible]	[illegible]	74	[illegible]		[illegible]
Average daily relative increment in dry weight.	84	54	110	188	103	135	114	64	60	[illegible]	95

PLATE VII.

EASTON 2 week periods. COVERED STATION.	MAY 25 – JUNE 8	JUNE 8 – JUNE 22	JUNE 22 – JULY 6	JULY 6 – JULY 20	JULY 20 – AUG 3	AUG 3 – AUG 17	AUG 17 – AUG 31	AUG 31 – SEPT 14	SEPT 14 – SEPT 28	SEPT 28 – OCT 11	AV.
Culture number	2	3	4	5	6	7	8	9	10	11	
Length of growing period, days.	14	14	14	14	14	14	14	14	14	14	
Number of plants.	4	6	4	3	6	6	5	6	6	6	
Average daily relative evaporation index	166	135	80	112	144	129	131	131	104	108	124
Average daily relative increment in stem height.	129	118	155	177	177	177	185	96	90	—	145
Average daily relative increment in leaf-product.	122	112	87	180	102	210	225	125	55	—	142

EASTON 4 week periods COVERED STATION	MAY 25 – JUNE 22	JUNE 8 – JULY 6	JUNE 22 – JULY 20	JULY 6 – AUG 3	JULY 20 – AUG 17	AUG 3 – AUG 31	AUG 17 – SEPT 14	AUG 31 – SEPT 28	SEPT 14 – OCT 11	SEPT 28 – OCT 26	OCT 11 – NOV 6	AV.
Culture number	2	3	4	5	6	7	8	9	10	11	12	
Length of growing period, days.	28	28	28	28	28	28	28	28	27	28	26	
Number of plants	4	6	6	-	6	6	5	6	6	-	—	
Average daily relative evaporation index.	151	108	96	128*	137	130	131	118	106	104*	116*	120
Average daily relative increment in stem height.	103	128	125	—	134	156	125	75	81	-	—	116
Average daily relative increment in leaf area.	117	191	90	—	138	202	169	104	85		—	137
Average daily relative increment in dry weight.	108	144	86	—	107	140	129	105	56	-	—	109

BALTIMORE 2-week periods FOREST STATION	JUNE 21 – JULY 9	JULY 9 – JULY 23	JULY 23 – AUG 6	AUG 6 – AUG 20	AUG 20 – SEPT 3	SEPT 3 – SEPT 19	SEPT 19 – OCT 1	OCT 1 – OCT 14	AV.
Culture number	4	5	6	7	8	9	10	11	
Length of growing period, days.	18	14	14	14	14	16	12	13	
Number of plants	6	5	—	4	5	4	0	3	
Average daily relative evaporation index.	—	75	82*	67	72	64	57	52	67
Average daily relative increment in stem height.	261	458		396	284	171	121	208	271
Average daily relative increment in leaf-product.	94	104	—	136	59	13	6	21	62

BALTIMORE 4 week periods FOREST STATION	JUNE 21 – JULY 23	JULY 9 – AUG. 6	JULY 23 – AUG. 20	AUG. 6 – SEPT 3	AUG. 20 – SEPT 19	SEPT 3 – OCT 1	SEPT 19 – OCT. 14	OCT 1 – OCT. 31	AV
Culture number	4	5	6	7	8	9	10	11	
Length of growing period, days.	32	28	28	28	30	28	25	30	
Number of plants.	6	5	—	4	5	5	6	3	
Average daily relative evaporation index.		79	75*	70	68	61	55	55	66
Average daily relative increment in stem height.	300	444	-	310	213	200	200	125	256
Average daily relative increment in leaf area.	104	104	—	95	75	40	38	32	69
Average daily relative increment in dry weight.	52	62	-	46	37	30	33	27	41

PLATE VIII.

PLATE IX.

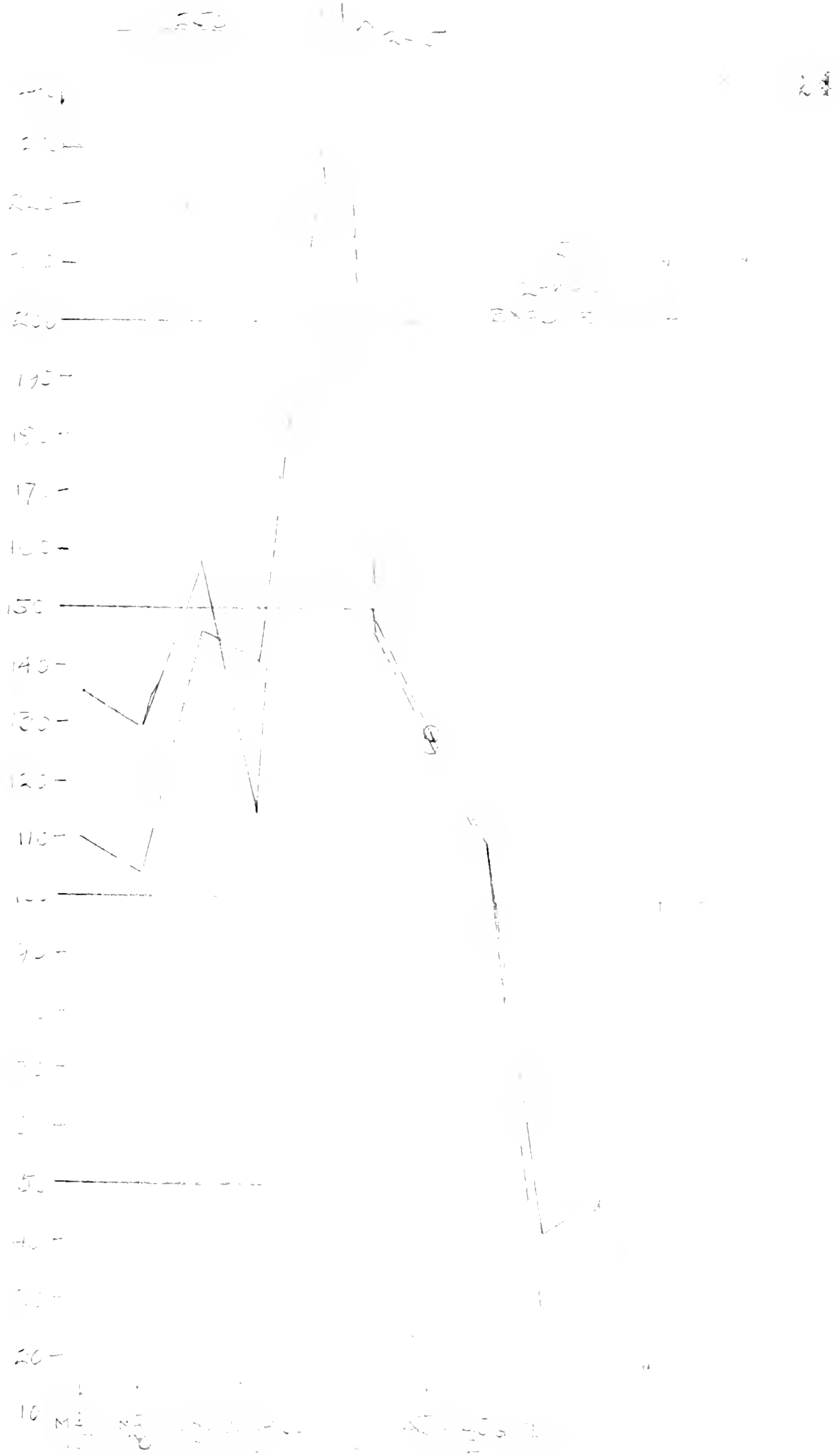
Two-week graphs for Oakland, Chewsville, Monrovia, College Baltimore, and Princess Anne.

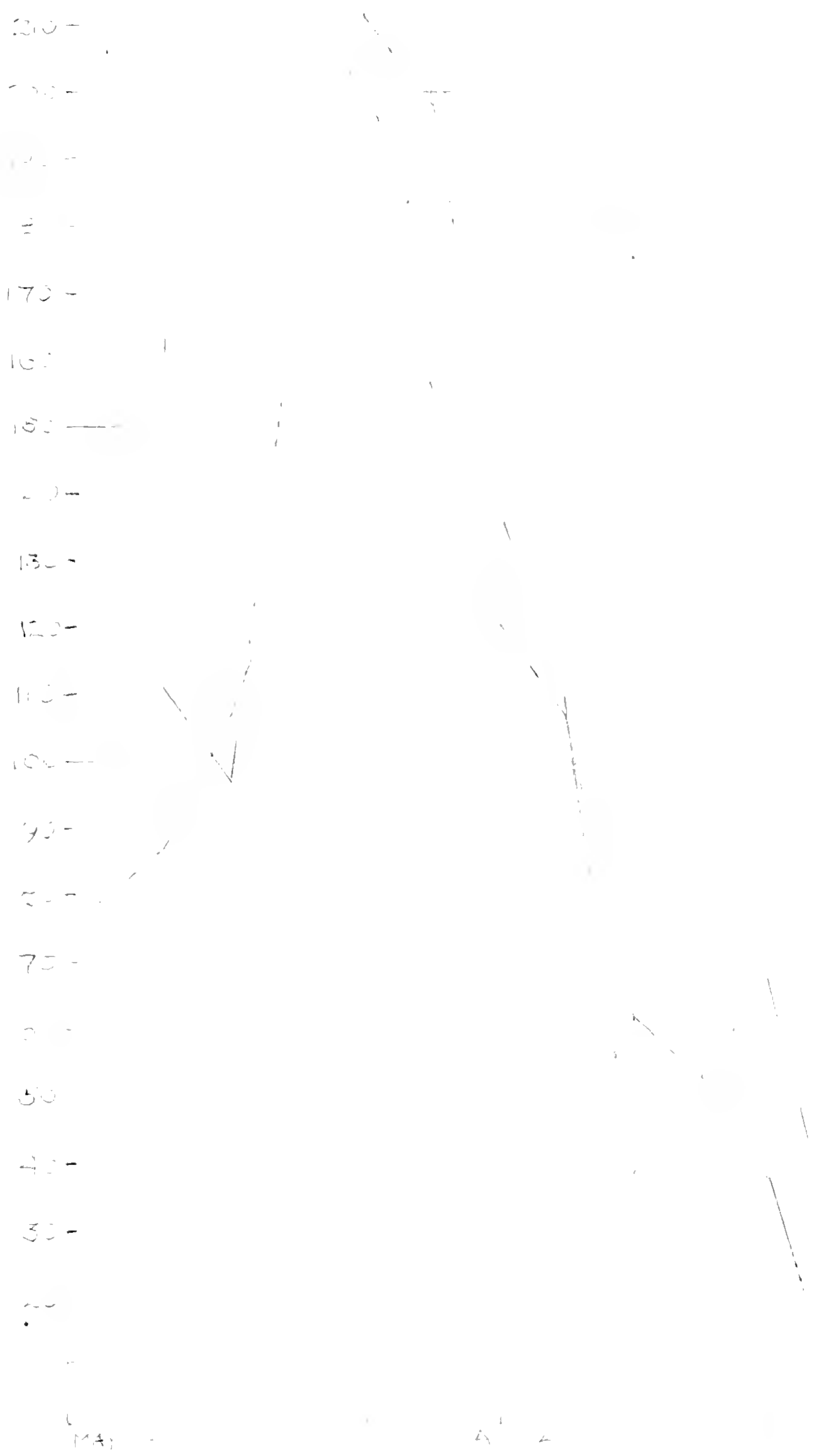
Exposed stations.

PLATE X.

Two-week graphs for Darlington, Coleman, and Easton. Four-week graphs for Oakland, Chewsville, and Monrovia.

Exposed stations.




170
50
30

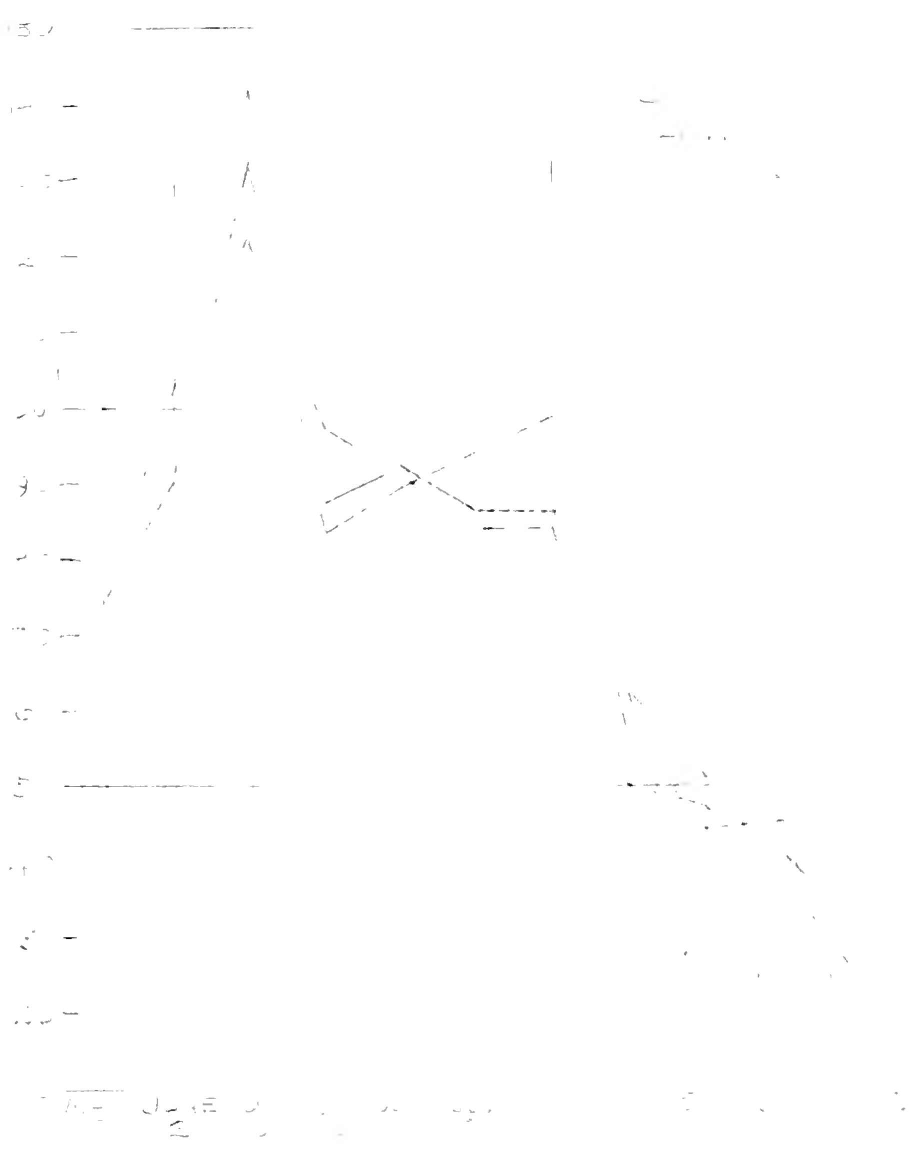


PLATE XI.

Four-week graphs for College, Baltimore, Darlington, Coleman, Easton, and Princess Anne.

Exposed stations.

PLATE XI[illegible].

Two- and four-week graphs for the covered stations at Baltimore and Oakland, and for the Baltimore forest station.

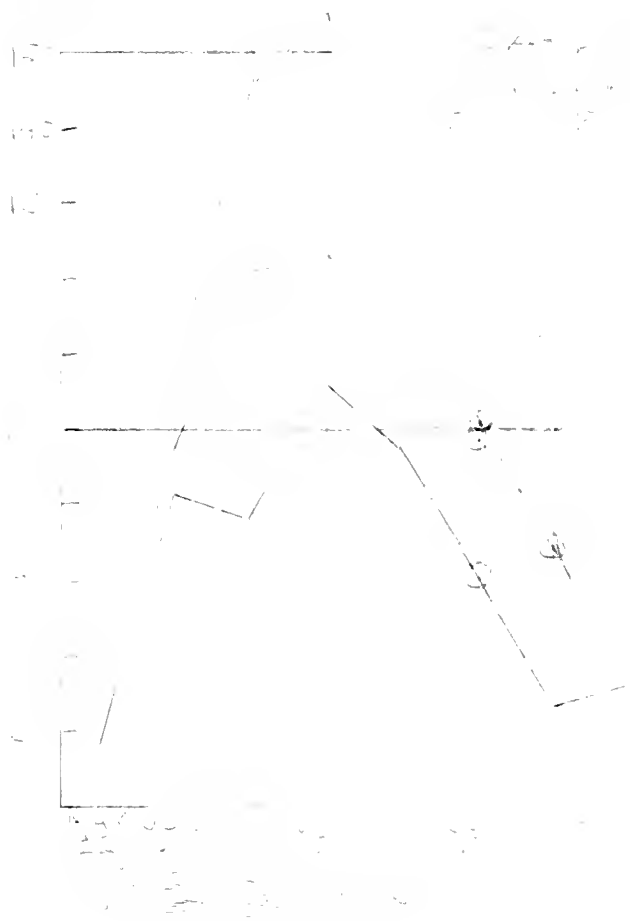


PLATE XIII.

Two- and four-week graphs for the covered station at Easton. Graphs of seasonal averages for all stations. Explanation of conventions used in representing the plant and climatic quantities.

VITA.

The writer was born December 26, 1888 at Baltimore, Maryland. He entered the Baltimore Polytechnic Institute in 1903, graduating in 1907. During the year 1908-1909 he taught in the public schools of Baltimore. In 1909, he entered the Collegiate Department of the Johns Hopkins University, receiving the degree of Bachelor of Arts in June, 1913. During the years 1914-191[illegible], he attended the Johns Hopkins University as a graduate student in Plant Physiology, Physical Chemistry, and Botany. He was engaged in research for the Maryland State Weather Service during the year 1915-1916, and carried on research for the U. S. Forest Service at the Utah Forest Service Experiment Station during the summer of 191[illegible].