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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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During the summer of 1914 an elaborate investigation was undertaken by the Maryland State Weather Service in cooperation with the Laboratory of Plant Physiology of the Johns Hopkins University, with the object of ascertaining some of the relations between climatic conditions and the growth of certain plants at different stations in Maryland. Detailed information as to the growth of the plants used is of course necessary, as is also corresponding knowledge of those environmental conditions that are considered as climatic. The plant records were secured in this case by growing cultures of certain plants in the environmental conditions to be studied and noting the growth made during definite periods of time. In order that a corresponding series of measurements of some of the environmental conditions might be available for comparison with these growth measurements the cultures were located at certain of the regular U. S. Weather Bureau observation stations at various places in the state. The general plan of the study and a detailed consideration of the methods used has already been printed by McLean¹, who

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

did all of the field work personally. The original data dealt with in the present paper are taken from the records obtained by McLean and it will be necessary to give here only

so much description of the ways in which these measurements were obtained as is needed to render them intelligible. This description is mainly taken from McLean's paper, which deals with the growth of soy-bean plants, but for only two of the stations, Easton and Oakland. The present paper gives the main results for soy-bean plants, for all of the stations, together with some attempts 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, Coleman, 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, Coleman, Easton, and Princess Anne, are in the coastal plain. Coleman, Easton and Princess Anne are east of Chesapeake bay, while College Park is west of it and much farther inland, near the line of demarcation between the coastal plain and the piedmont plateau. All of the stations except Oakland are at comparatively low elevations, -less than 310 meters (1000 feet) above sea-level. Oakland has an elevation of 475 meters (2500 feet). The geographical distribution (see fig. 1) of these stations is such that considerable differences in climatic conditions 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 McLean³. Since the problem of expressing

³ Livingston, B. E., and McLean, F. I. A living climatological instrument. Science, n. s. 43: 362-363. 1916.

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 detected 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 argument by the simple 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 were measured and 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 two weeks

during the growing season, at each of the stations employed, and growth measurements were made after about two weeks and 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 seed was of pure strain obtained from the 1913 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-

Bonsteel, J. A., The soils of Prince George's County. Pub. Maryland Geological Survey. Baltimore, 1911.

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 "6 inch", porous clay flower-pots, in form like the frustrum of a cone, being smaller at the bottom, and of a cubic capacity of approximately 1980 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

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

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 tops level with the soil surface, and were so arranged as to supply water to the soil against a pressure of 35 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 10 to 13

per cent, on the basis of dry weight. This particular 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 2.5 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 station 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 evaporation was measured by means of Livingston standardized cylindrical porous cups with non-rain absorbing mountings.⁵ Of the five sets of climatic

⁵ Livingston, B. E., A rotating table for standardizing porous cup atmometers. Plant World 15:157-162. 1912. Idem,

Atmometry and the porous cup atmometer. Ibid. 18:21-30, 51-74, 95-111, 147-149. 1913

observations mentioned above, only those will be 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 the 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 observations 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 two-week and four-week groups corresponding to the two and four-week growing periods. One way in which to do this, for instance, is to average the daily readings over the two-week or the four-week period, thus securing an average daily value for the

climatic measurements in question. The second step consists in weighting average values in such a way as to furnish a second series of values that express the climatic conditions as they affect the plants. It is clear, for example, that the readings of a thermometer do not express the effectiveness of temperature to accelerate or retard plant growth. It therefore becomes desirable to replace the actual thermometer readings by a series of weighted values, more or less directly proportional 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 temperature, 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 condition.

The consideration of temperature, light, and evaporation 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.

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. ✓

✓ 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°, 3 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.⁷ They

⁷ Livingston, B. E. and Livingston, G. J., Temperature coefficients in plant geography and climatology. Bot. Gaz. 55:349-375.1913.

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 of 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 32° C.) and since both the exponential and remainder series of index values 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 temperatures. This fact has been noted by Livingston and Livingston and again by Stevens³ and it is also obvious from

⁸ Stevens, Neil E., Influence of temperature on the growth of *Endothia Parasitica*. *Am. Jour. Bot.* 4: 2, 112-118.1917.
Idem, Influence of certain climatic factors⁸ on the development of *Endothia parasitica*. *Ibid.* 4:1, 1-33.1917.

the climatic data given by McLean.

A third method of expressing temperature as it affects plant growth has been more recently suggested by Livingston⁹. From the results of Lehenbauer's experiments on maize seedlings,¹⁹

⁹ Livingston, B. E., Physiological temperature indices for the study of plant growth in relation to climatic conditions. *Physiol. Res.* 1: 8, 399-420.1916.

¹⁹ Lehenbauer, P. A., Growth of maize seedlings in relation to temperature. *Physiol. Res.* 1:247-288.1914.

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 possibly 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 temperature 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 physiological 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 exponential 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 light 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 85°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 efficiencys 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. ♡

♡ 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 Kimball¹² 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

¹²Kimball, 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. 8, p. 484).

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 sunshine 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 soy-bean plants 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. Evaporation was measured in these studies by means of cylindrical porous cup atmometers located so as to have the same local exposure as the plant cultures. The atmometer mountings were provided with mercury valves so arranged 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 evaporation readings should 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 Chantz indicates that evaporation from small open pans or porous cups is influenced by the same external conditions, and in

about the same way as is plant transpiration, if the comparison is made for periods of a day or more. Of course the 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

¹⁴ Livingston, B. E., The relation of desert plants to soil moisture and to evaporation. Carnegie Inst. Wash. Pub. 50. 1906.

to deal. It has been supposed therefore, that the effectiveness of the external conditions to influence the transpiration rates from the plants of this study was approximately measured by the corresponding evaporation rates from the atmometer. The atmometer readings have been reduced, in every case, to mean daily rates for the 2-week and 4-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 from the seed. At that time the length of each leaflet from tip to junction of blade and 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 weight 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, ^eareal measurements to the nearest 0.1 sq. cm., and weight measurements to the nearest 0.01 gram.

The reduction of plant and climatic measurements to averages for the period and to relative values.

As has been stated previously, each culture originally comprising six plants was observed after about two weeks of growth from the seed and again after about four weeks from 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 3 and was usually 4 or 5 in such cases), on account of observable injury due to other conditions than the ones here studied, such as insect attack, 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 28 days for the four-week periods, and the averages per plant have consequently been expressed as mean daily values for the respective period. This method renders the plant measurements for the different periods more strictly comparable. It should be noted, however, that the growing periods were 14 and 28 days long in the majority of cases, and that variations in the length of the culture periods were slight. Considering the 2-week and 4-week plant values as measures of the results of plant processes acting through the periods, the mean daily values represent mean daily increments or process rates, 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 14 day period, $\frac{1}{14}$ cm. is regarded as the mean daily increment of increase in height, etc.,

for that period. Letting the word growth represent the particular process to which the given kind of measurement refers (as increase in height, increase in leaf area, etc.), these may be spoken of as growth increments.

The mean ^a daily growth increments and the mean climatic values for the respective periods have been expressed in terms of the corresponding average of all the periods considered, for all exposed stations. This procedure renders all the values directly comparable. To obtain this unit for any kind of value, all of the corresponding values (as all 2-week daily mean increments in height, for example, for all exposed stations) were summed, and the sum was divided by the number of values summed. Then each individual value was divided by the unit thus obtained. The data are expressed as these ratio values, which will be termed relative values in the following discussion. The absolute magnitude of the unit thus used for expressing each kind of value is, of course, not important, it is essential only that all comparative values be expressed in terms of the same unit. The unit here employed represents in every case simply the average of all similar quantities that are used in the present study. If another station had been employed, or if the season had been longer or shorter at any station, the values of these comparative units would have been different. The magnitudes of these units thus depend to some extent upon the climatic conditions encountered at the various stations in the summer of 1914, to some extent upon the number and location of the stations, to some extent upon the nature of the soil used in this investigation, and to some extent upon the physiological

nature of the soy-bean plant. The values of these various units are all given in table I. To avoid decimals the relative values secured as noted above, have all been multiplied by 100, and are thus given in the tables (plates I-VIII).

Table I
SEASONAL AVERAGES.
for all exposed stations.

CLIMATIC

Average daily physiological temperature index = 56.39
Average daily evaporation index = 16.2 cc.
Average daily sunshine intensity = 442 calories per sq.cm.

PLANT: 2-week periods.

Average daily increment in stem height per plant = 3.56 mm.
Average daily increment in leaf-product per plant = 112 sq.mm.

PLANT: 4-week periods.

Average daily increment in stem height per plant = 3.20 mm.
Average daily increment in leaf area per plant = 122 sq. mm.
Average daily increment in dry weight per plant = 3.29 mg.

The use of these relative values simplifies the plotting of the graphs upon which the interpretations of such a study as this so largely depend. It also renders possible a direct comparison between the values for any two cultures irrespective of their date or station. Furthermore, it is possible to tell from the magnitude of the relative value for any culture the extent to which the plant or climatic measurement under consideration departs from the mean of that measurement for

all the cultures of the study.

To obtain the original or absolute plant or climatic value from the relative value as given in the tables of this paper, it is necessary only to reverse the arithmetical procedure by which the relative value was derived. For example, suppose it was desired to get the actual mean daily rate of increase in leaf-area per plant for the four-week period beginning Aug. 5, and for the station at Coleman. The relative value given in the table is 108. The first operation is to divide by 100, which gives 1.08 as the true relative value. The average daily increment in leaf area per plant, for the period and station in question, was therefore 1.08 times the value of the common unit employed for this process of increase in leaf area. Multiplying this unit value (122 sq. mm.) as given in table I by 1.08 gives 132.0 sq. mm. as the average daily increment required. To obtain the average total leaf area per plant at the end of the period in question, we multiply 132.0 sq. mm. by the number of days in the period (26 in this case) and get 3696 sq. mm. Since there were 5 plants measured in this culture, the total leaf area for the entire culture at the end of the period is obtained by multiplying 3696 sq. mm. by 5, which gives 18490 sq. mm. or 184.9 sq. cm., which is the actual areal value determined from the prints 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, when plant

and climatic values are referred to, it will be understood that these are the relative values rather than the absolute ones.

Presentation and physiological interpretation of data.

Introductory. The plant and climatic data will now be presented and described. The discussion will be devoted in part to descriptions of the growth changes observed in the plants at the various stations, and for the various periods at each station, in part to corresponding descriptions of the climatic values, and in part to some 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 may appear necessary from a more restricted point of view. Such interpretations as are here attempted are of interest partly for their own sake, but mainly because of the bearing they may have on the general problem of the use of standard plants for the comparative integration of effective climatic complexes. It must be remembered that the general 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 rendered apparent are to be considered as of secondary importance to the main purpose. These discussions will be presented more in the form of a running narrative, with digressions at many points, than is ideally

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.

Presentation of the Data.

Two methods of presenting the data of the experiment have been employed in this paper. The relative numbers, derived as noted above, have been given in tables, together with the dates of the first and last days of each culture period and other information including the length of the period, the number of plants in the culture, etc. Also, a set of graphs is presented showing graphically certain parts of the information given in the tables.

The tables of plant and climatic data for the various stations employed are shown in plates I-VIII and will be described below. There are, in addition, several tables given in the text which will be described elsewhere. Plates I-VIII contain 26 tables in all. Nine of these, shown in plates I-III inclusive, contain the plant and climatic data for the two-week culture periods for the exposed stations; nine, shown in plates IV-VI inclusive, give the data for the four-week culture periods for the exposed stations; four, shown in plate VII, give the data for the two-and four-week culture periods for the covered stations at Oakland and Baltimore; and four, shown in plate VIII give the data for the two-and four-week culture periods for the covered station at Easton and for the Baltimore Forest Station.

In all of the tables, the first line gives the name of the place at which the plants were grown, the length of the culture periods (whether two-or four-week), and the character of the exposure of the plants, that is, whether the station is exposed, covered, or forest. The first line of all the tables

gives also the dates of the beginning and end of each culture period, at the head of the column in which the data of that particular culture period are ~~placed~~ placed. The second line of each table gives the culture numbers. These numbers being given the various cultures for convenience in reference. When several kinds of stations occur at one place, cultures of the same number cover approximately the same time period. For instance, at Baltimore, there is an exposed station, a covered station, and a forest station. The two-week cultures numbered 8, for the exposed, covered, and forest stations, at Baltimore each grew from August 30 to September 3. In some cases, cultures ~~numbered~~ of the same number for the exposed and covered stations show a difference of a day in the lengths of their respective periods owing to the fact that it was impossible to take measurements on both the exposed and covered plants on the same day. The third line of all the tables gives the length of each culture period in days, this number being obtained for any period by subtracting the dates given at the head of the column containing the data for that period. The fourth line in all the tables gives the number of plants used in obtaining the plant measurements. In all the tables, a dash appearing in place of a relative value indicates that the data necessary for calculating this relative value is lacking. An asterisk placed opposite a climatic index shows that the index was not plotted in the graphs (to be described later). This is done in the case of most cultures where no plant data are available for comparison with the climatic values. The last column of each of the tables gives averages, for the station, of the plant and climatic values presented.

The two-week tables for the exposed stations show in line 7 the remainder summation index for the respective culture periods. As has been noted, this is obtained by subtracting 30° from each daily mean and summing the remainders for the period. Line 8 gives the average daily relative physiological index determined in the manner previously described. Line 9 gives the average daily mean temperatures. Line 10 the average daily relative evaporation index and line 11, the average daily relative sunshine intensity. Line 12 shows the values of the average daily relative increment in stem height and line 13 the values of the average daily relative increment in leaf-product. The two-week tables for the covered stations correspond to the two-week tables for the exposed stations except that no temperature or sunshine data is available, and the tables thus contain only the relative evaporation indices and the two plant measurements. This is also true of the Baltimore Forest station. The four-week tables correspond line for line with the two-week ones except that the four-week tables show the average daily relative increment in leaf area instead of the average daily relative increment in leaf-product, and a line is added to the four-week tables giving the average daily relative increment in dry weight. Each four-week value of relative daily physiological temperature index, relative daily evaporation index, and relative daily sunshine intensity was obtained by averaging the relative values of these climatic factors for the two-week periods constituting the four-week period in question. The four-week period value of the remainder summation index for any period was obtained by adding the values of this index for the two two-week periods making up the four-week period under consideration. The average

daily mean temperature for the longer period was obtained by taking the mean of the two average daily means for the two-week period.

The graphs, shown in plates IX to XIII, present graphically certain of the data given in the tables. In all of the graphs, the ordinates represent magnitudes of the plant and climatic relative values and the abscissas represent the time of the year. The ordinate scale is given at the left of each set of graphs for convenience in reference, and the dates of the beginnings of successive culture periods are shown on the base line. For the first two-week period for Oakland, thus, the ordinates show the average daily relative values of the plant and climatic measurements for the two-week period beg. Mar. 27. The 100 line of the ordinate scale is the value, as was previously noted, of the seasonal average for the state of each of the plant and climatic measurements taken. An explanation of the method of representing each of the measurements shown in the graphs is given in the legend of plate XIII.

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 preceeding 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 the march of the climatic conditions at each of the various stations in somewhat greater detail than do the corresponding series of four-week values, since the latter represent overlapping periods, and the former will therefore be made the basis for a somewhat detailed and comparative discussion of the climatic conditions for the various stations. Temperature will receive attention first and evaporation and light will afterwards be considered together. 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 present 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 have about the same magnitude. The first occurs in the last two weeks of

July and the second in the last two weeks of August, this statement being true for all the stations considered excepting Oakland, for which station they both occur relatively early in the season, in the last two weeks in June and July respectively. A third feature which is common to most (though not all) of these graphs lies in the fact that the upward slope is more gradual (before the occurrence of the high midsummer maxima) than is the downward slope (after the occurrence of the maxima.) A generalized temperature efficiency graph representing averages of the corresponding values for all of the stations is not symmetrical about the ordinate for its highest midsummer value; it slopes upward less rapidly than downward. A fourth general characteristic of these graphs lies in the fact that the final low index values of the frostless season are not very different for the various stations. The following consideration of the graphs for some of the individual stations will serve to bring out the points mentioned above and will give opportunity to note exceptions to the generalized statements just made.

In regard to the forms and other characteristics of the temperature efficiency graphs, the nine stations studied may be grouped into five classes: (1) Chewsville and Monrovia, (2) Baltimore, Darlington and Coleman, (3) Easton and Princess Anne, (4) College, and (5) Oakland. The last two stations do not appear to fit into any of the first three classes and they are not alike so they must not be regarded as representing separate classes. These five groups are discussed in order below. It will be noted that the stations of groups 1, 2, and 3 are located near each other, and this

probably accounts for the fact that they show similar graphs of the temperature values.

Chewsville and Monrovia. The graph of physiological temperature indices for Chewsville shows all the characteristics mentioned as general throughout the series of stations. It rises gradually during the first three periods, (period beginning May 19 to period beginning June 16), then drops slightly during the fourth period (beginning June 30) after which it rises for the period beginning July 14 to a maximum of 149. The value for the 5th period (beginning July 28) is relatively low (112), after which the maximum (145) occurs for the period beginning August 11. The index value in question then decreases rapidly during the next two periods attaining a magnitude of 48 for the 8th period (beginning Sept. 8) and remaining low until the end of the frostless season. Monrovia has the same sort of graph as Chewsville, the maxima coming in the periods beginning July 13 and August 10. The minimum relative value of the temperature index is 33 for the period beginning Sept. 21.

Baltimore, Darlington, and Coleman. At Baltimore, the physiological temperature values increase gradually to a maximum of 132 for the period beginning July 9. The second maximum comes in the period beginning August 6 after which there is a relatively rapid decline of the index values to 62 for the period beginning September 3. The Darlington graph has its first maximum in the first two weeks of July and its second in the two week period beginning August 7, and then falls off rapidly to a minimum of 46 for the first period in September.

The graph for Coleman shows a gradual rise, two maxima for the periods beginning July 8 and August 5 and a rapid fall. The temperature record is incomplete at this station and the low values for the end of the season are therefore not available.

Easton and Princess Anne. At Easton there is a gradual rise to a maximum of 154 for the first period in July, the second maximum coming in the period beginning August 17. The curve then falls to a minimum of 46 in the last period of the season. The Princess Anne curve shows the two typical maxima in the periods beginning July 9 and August 18 with a minimum of 43 for the last period of the growing season.

College. The College graph of physiological indices is unusual in showing a marked rise for the period beginning June 19, thus giving the graph three maxima (139, 148, and 143) for the periods beginning June 19, July 17, and August 14 respectively. The graph drops rapidly to a value of 50 for the period beginning September 25.

Oakland. The temperature index values for Oakland are all relatively low, being considerably less than the seasonal average employed as unity. This graph shows two maxima, one for the last half of June and the other for the last half of July. Each of these maxima will be seen to occur about a month earlier than the corresponding ones for the other stations here studied. The Oakland graph is also unlike those for the other stations in that its downward slope is more gradual than in the other cases. Its final relative value is

43 for the 2-week period beginning Sept. 1, which was the last full period for this station, before the occurrence of a killing frost. The most outstanding characteristics of the Oakland season in respect to this temperature efficiency graph, as compared with the seasons at the other stations, are (1) general low values of the physiological temperature index, (2) short duration, owing to the occurrence of late spring and early fall frosts, and (3) the early occurrence of the maximum. The marked differences between the Oakland graph and those for the other station here dealt with are no doubt largely due to the relatively high altitude of this station as compared with the altitudes of the others, as has been mentioned by McLean in his comparative study of the Easton and Oakland seasons based on these same data.

Leaving the one for Oakland out of account, the other eight temperature efficiency graphs may be described as a single generalized graph, in the following general terms. Beginning with a relative index value of about 80 (for the first part of May) the graph rises to a maximum (about 150) for the first part of July, falls slightly and rises again to a second maximum of about the same value as the first, for the first part of August, and finally falls to a minimum value of about 50 for the last period of the frostless season. That the initial values are not lower is no doubt due to the fact that the various series of cultures were not started until somewhat later than the beginning of the ~~corresponding~~ frostless season. (See McLean's paper cited above.)

Evaporating power of the air and sunshine.

The two-week graphs of the values for atmospheric evaporating power and sunshine will be treated together since the seasonal marches of these two climatic conditions exhibit the same general characteristics. Three points may be noted in regard to the seasonal marches of these two climatic indices. (1) Both graphs have, in general, a downward slope from the beginning to the end of the season. (2) In the majority of cases they agree in direction of slope, from period to period, throughout the season. (3) They agree in having a primary maximum, with a very high value, for the early periods of the season and one or more secondary maxima, with lower values, for periods that occur later. The secondary maxima of the graphs for light and evaporation sometimes (but not always) coincide, as to time of occurrence, with a corresponding maximum of the graph for temperature efficiency. The following consideration of the individual station graphs for these two conditions may serve to bring out these points.

For Oakland the primary maximum in the graph of atmospheric evaporating power (155) occurs for the first period (beginning May 25). The value of the evaporation index then decreases steadily to a relative minimum of 59 for the first two weeks in July, after which it increases to a maximum (104) which corresponds in time of occurrence (period beginning July 6) to the second maximum of the graph of temperature efficiency. After passing this maximum the graph descends again, to the low values 57 and 69 for the last two periods (beginning August 27 and Sept. 12). The sunshine intensity

index varies from an initial value of 122 to a final value of 81, with maxima for the periods (beginning July 16 and August 14). Inspection of these two graphs for Oakland shows that the direction of slope is the same from period to period, for the greater part of the season. For Chewsville the two graphs agree in direction of slope throughout the entire season except between the periods beginning August 25 and Sept. 3. Both curve graphs are approximately parallel to the graph of temperature efficiency for this station from the period beginning July 14 to the period beginning August 25 and both have a downward slope, in general, from the beginning to the end of the season, and they agree in direction of slope from the period beginning June 15 to that beginning October 6. The maximum of the evaporation graph for the period beginning July 27 corresponds to a secondary minimum in the graph of temperature efficiency for College. The graph of the evaporating power of the air has a primary maximum for the second period (beginning May 28) and a well-marked secondary maximum for the period beginning July 22. No sunshine data are available for this station. For Baltimore the two graphs in question agree in direction of slope up to the period beginning July 9 after which the evaporation graph ascends to a secondary maximum which corresponds, in a very rough way, to the double maxima of the temperature efficiency graph. For Darlington the general statements made at the beginning of this discussion hold throughout the greater part of the season. The atmometric values for this station are relatively very low; all but two of them are lower than the seasonal average employed as unity in the present study.

For Coleman the sunshine record is incomplete, but the two graphs generally agree in direction of slope so far as comparison is possible, excepting between the periods beginning July 17 and July 31. For Easton and Princess Anne, the curves are typical. Evaporation data are lacking for the periods beginning June 8 and June 17 at the latter station.

The comparatively close agreement, in their main characteristics, between the corresponding graphs for sunshine and evaporation, for all the stations employed in this study, together with the fact that the latter graph exhibits no well-defined relation to the graph of temperature efficiency appears to indicate that the rate at which water evaporated from the white cylindrical cups employed as atmometers in this investigation was determined to a considerable extent by the amount of radiant energy absorbed by the cups and that the air temperature played a secondary part in the determination of this rate. The fact that the physiological temperature coefficient is used for expressing temperature does not operate against this conclusion since, as has been previously stated, other methods of expressing temperature give curves which slope for the most part, in the same direction as the curve of physiological temperature indices. A large effect of sunshine on evaporation, the sunshine being measured by a black bulb sunshine recorder, has been found by Briggs and Shantz⁵. These authors were able to calculate approximately the amount

⁵ Briggs, L. J., and Shantz, H. L., Hourly transpiration rate on clear days as determined by cyclic environmental factors. Jour. Agric. Res. 5:323-350.1916.

of evaporation from a shallow blackened tank using a formula which involved sunshine intensity and the saturation deficit of the air, and in which sunshine has a preponderating influence. They also state that an approximate proportionality exists between the loss from the tank and the loss from Livingston porous cup anemometers. While the cups and the tank respond in different ways to the daily cycle of changes in the evaporating power of the air, a certain average ratio exists between the evaporation from the tank and the evaporation from the cups. It would therefore be expected from their work that evaporation from Livingston porous cups would be largely influenced by sunshine intensity, and that temperature would show a secondary influence on evaporation as measured by these instruments. It must be remembered, also, that the evaporation measurements of this experiment were made in the plant enclosures, while temperature was measured by thermometers located in a shelter about 1 1/2 meters (5 feet) above the ground and often 4 or 5 meters (15 feet) from the plant enclosures. This may account in some measure for the apparent absence of any marked effect of temperature on the evaporating power of the air as measured by porous cup anemometers.

It may be noted here that the temperature efficiency values for the various stations here considered, exclusive of Oakland are much more nearly alike for any given two-week period than are the sunshine and evaporation values. The values of these three climatic indices for the first two weeks of June and for the first two weeks of August, for these

eight stations are given in table 2. Since the dates of observation were not the same for all stations, these values have been approximated from the graphs, but they may be considered as sufficiently accurate to illustrate the manner in which the data at hand support the conclusion just stated.

Table 2.

Values of the three climatic indices for the first two weeks in June and the first two weeks in August with ratios of highest to lowest values for each index.

Station.	Evaporation		Sunshine		Temperature efficiency (physiological index)	
	1st 2 wks. of June	1st 2 wks. of Aug.	1st 2 wks. of June	1st 2 wks. of Aug.	1st 2 wks. of June	1st 2 wks. of Aug.
Cheysville	115	90	120	95	105	120
Monrovia	146	115	122	103	110	125
College	136	147	-	-	103	133
Baltimore	109	110	92	75	102	132
Darlington	115	78	115	112	98	125
Coleman	145	135	145	120	115	132
Easton	132	135	105	115	112	140
Princess Anne	125	95	110	75	102	135
Ratio of highest to lowest value in above series.	1.5	1.9	1.8	1.6	1.2	1.3
Average for the 2 periods.	1.70		1.70		1.25	

If the highest value given for each of the three indices and for each of the two periods be divided by its lowest value to

ratios presented in the rest to the last line of the table are obtained. Each ratio represents the magnitude of the range of variation of the climatic index that it represents for the eight stations in question. The average ratio value for these periods is given in the last line. It thus appears that the geographical range of variation in the temperature efficiency index is markedly less than is the corresponding range of variation in the index of either sunshine or evaporation. This relation holds generally throughout the season. In short, the temperature efficiency values exhibit a smaller degree of geographical or local variation than is exhibited by the index for sunshine and the evaporating power of the air.

THE 2-WEEK PLANT DATA.

Introductory. As has been stated, the plant measurements that were taken about two weeks after the beginning of each culture included stem height and leaf dimension. From these have been derived two 2-week data in each case, which are given in the tables, (1) the relative mean daily rate of increase in stem height per plant and (2) the relative mean daily rate of increase in total leaf-product per plant, both for the two-week period. As McLean has pointed out, the relative daily rate of increase in total leaf-product for a period of about 4 weeks is very nearly proportional to the corresponding rate of increase in actual leaf area, and it seems safe to suppose as McLean did, that the 2-week leaf-product values are to be regarded as indices of increase in the area of the leaves. Therefore one of these 2-week plant values represents the stem-producing power of the plant and the other stands for its leaf-producing power, under the given set of external conditions acting during the 2-week period. Since the plants are taken to be alike at the start, (seeds) these two derived plant values should be the same for all individuals if all were subjected to the same effective environmental conditions throughout the period, and when the various plants are exposed to different environments the values just mentioned become criteria by which the effectiveness of one environment may be compared with that of another of course with reference to the particular set of internal conditions represented by the plants at the beginning of the tests. The two plant values just mentioned may thus be regarded

as relative measures of the effectiveness or efficiency of the environmental complex for the 2-week period considered, as it acted to produce stem elongation and leaf-product increase, upon the soy-bean seeds employed in this investigation. The values of these two plant indices are of course given in the tables in terms of the corresponding average for all cultures considered, employed as unity, just as in the case of the other relative values, and they all represent daily rates for the 2-week period in question. For convenience, the following discussion will refer to the graphs rather than to the tables, but of course tables and graphs both present the same data, in every case. This discussion will be given under the three following headings: Correlations between the two plant graphs; Trends of the plant values and their seasonal averages for the various stations; and Relations between plant and climatic graphs.

Correlations between the two plant graphs. It is readily observed that the two graphs showing relative rates of increase in stem height and in leaf-product have a pronounced tendency to exhibit the same general direction of slope from period to period, throughout the season, for all stations. In many cases the two plant graphs not only slope in the same general direction (upward or downward) but their corresponding angles of slope are nearly the same and their corresponding ordinates are about equal, so that the two graphs nearly coincide for considerable portions of their length. In other words, there appears to have been a pronounced general agreement between the effectiveness of the surroundings to produce stem elongation and its effectiveness to increase the magnitude of the leaf-product, as shown by these cultures. If this agreement were perfect it

would mean, of course, that the environment existed the same influence upon the process of leaf-surface increase (as measured by leaf-product), and either of these two criteria would be a measure of the other. But the coincidence of the two graphs is not by any means perfect and it becomes necessary to study their differences, especially with reference to the corresponding relative values of their ordinates.

Inspection of the graphs shows that, leaving those for Oakland out of account the index of height increase is frequently greater than the other plant index for the early and late portions of the frostless season, and that this relation generally is reversed for the middle portion. In other terms, the graph for stem elongation generally lies below the other graph for the middle of the season and above it for the beginning and end of the season. In still other words, the seasonal maxima of leaf-product values are generally relatively higher than those of stem elongation, while the seasonal minima of the former are lower than those of the latter. It may be stated, as an approximation, that when these two plant values are both above 100 the leaf-product values are the higher of the two, while when both are below 100 the elongation values are the higher. In the case of Oakland, both values are comparatively very low throughout the season and while the index of stem elongation reaches somewhat above 100 for two periods, this index is never surpassed in magnitude by the index of leaf-product increase.

The generalization just indicated, being a relation between the rates of two plant processes, seems to be a physiological one, dependent upon the nature of the soy-bean plant, and

hence determined by the internal conditions of the seed. Within the range of environmental conditions encountered in this study it appears that the taller and more leafy the plant becomes in the first 2 weeks of growth, the lower is the value of the ratio of final height to final foliar expanse. The two growth processes here considered are therefore clearly inter-related so that neither one alone is to be regarded as a criterion of plant growth in general. In the cases here studied it may be of value to consider the average of these two indices as a tentative index of the general growth of the plants during the first two weeks from the seed, and inspection of the 2-week graphs leads to the impression that averaging the two values is the most promising way to obtain from them a single index of plant growth. The two graphs are always so nearly parallel throughout the season at all stations here dealt with (nearly coinciding for many periods, as has been stated) that the charts have not been further complicated by introducing these average graphs, but their form is readily appreciated from the two graphs that are given. Still another possible way to obtain a single index for the growth-behavior of the plant as a whole may be obtained by determining the ratio of the 2-week rate of stem elongation to the corresponding rate of leaf-product increase.

The general relation between the two plant values, upon which the discussion just given is based, does not always hold, however, and the following more detailed discussion of the plant graph forms for individual stations will be of value in showing the main exceptions. As has been mentioned, for Oskana the height value lies above that for leaf-product throughout

the season. The two graphs have the same general direction of slope excepting between the periods beginning July 13 and July 31. For Chewsilla the height graph exhibits the same general direction of slope as does the leaf-product graph from period to period, throughout the season, and the former lies well above the latter for the last 4 periods (beginning Aug. 25, Sept. 8, Sept. 22 and Oct. 7). For the periods beginning June 16 and June 30 the same relation holds, although the index values are large, especially in the case of the first of these two periods. For Monrovia the two plant graphs follow each other very closely throughout the entire season. The graphs for College, for the periods beginning July 13, July 17 and July 31 illustrate the tendency of the height values to decrease relatively to those of leaf-product when both values are large. For the periods beginning Sept. 10, Sept. 25 and Oct. 13 for this station, however, both values are small and still the height lies above the other, and for the period beginning June 19 the relation between the two graphs is reversed, although both values are relatively high. For Baltimore, the periods beginning June 10, July 23 and Aug. 20 exhibit exceptions to the proposition that the height graph should lie below the graph of leaf-product when both plant values are large. The generalization is true, however, for the period beginning Aug. 3, in which case the values are both large and the leaf-product graph lies well above the other. For Darlington the two graphs agree very well in form throughout the season, except for the period beginning July 10 in which case the generalization holds and, with both plant values high, the one for height is considerably lower than the other. For Columbia the

generalization holds fairly well. For most of the generalization holds, with three exceptions: the height index is lower than the other for the period beginning May 8, although both indices have low values, and this relation is reversed for the periods beginning June 22 and July 20, in spite of the fact that both values are large in these cases. For Princess Anne the graphs show the values of the height index as higher than those of the other index for the periods beginning June 23, July 7 and July 21, although both indices are large for all three periods. Otherwise these graphs agree with the generalization.

The fact that the generalization given above holds in the great majority of the cases here studied renders the exceptions of special interest with reference to the causal relations involved. It may be supposed, assuming that the plants were all alike at the beginning of all cultures and that no disturbing influence was introduced by soil conditions, that the periods characterized by exceptions to this generalization should also be characterized by some sort of corresponding peculiarities in the aerial environmental complexes. Now, a study of the charts for the exposed stations brings out the following fact; most of the 2-week periods for which both plant values are large and yet the index of stem elongation is greater than that of leaf-product increase, are characterized by low indices of sunshine intensity. This suggests that the plants of these cultures experienced an acceleration in their rates of stem elongation due to low light intensity, in that that they exhibited some of the effects of terminal etiolation. They seem to show a somewhat increased rate of stem elongation and a somewhat decreased

rate of leaf expansion, as compared with plants receiving more light radiation. This interpretation is not to be regarded as at all well established, but it is at least a suggestion of one way in which the external condition of light intensity and duration may be registered in such plants as were here employed.

Trends of the plant values and their seasonal range for the various stations.

The following consideration of the seasonal courses of the 8-week plant values for the various stations will be limited in extent, since most of the facts and deductions that seem to be of importance in this connection can be better brought out later. Attention will here be called only to two generalizations regarding the plant graphs: (1) The plant graphs begin with values of about 100, rise to high midsummer values and then fall to low values at the end of the season. (2) Differences in the magnitudes of the midsummer maxima constitute the chief discrepancies between the graphs for the various stations.

Oakland shows lower values of the stem height and leaf-product than any other station owing largely to the low values of the temperature that prevailed at this station throughout the season. The data of this study indicate in all cases that the climate of Oakland is far as it affects the plants quite like that of any of the other stations employed. Both plant graphs for this station show the typical low values at the beginning and end of the season, however, with midsummer maxima of 124 for the stem height and 89 for the leaf-product. Champaign shows typical graphs, the highest value reached by the stem height being 147 and by the leaf-product 139. The end of the season at this station is characterized by very low values

of leaf-product. The graphs for Monrovia are also type 1, with low values for the period beginning May 18 and low values at the end of the season after a midsummer maximum of 121 for stem height and 138 for leaf-product. An explanation for the low values shown by the periods beginning Sept. 7 and Oct. 8 may lie in the fact that the minimum temperature dropped in both these periods to a point only several degrees above freezing. For both Chersville and Monrovia the plant values are for the most part less than 100, with relatively low midsummer maxima of 135 and 203 for the stem height and leaf product, respectively. The Baltimore plant graphs begin with high values, and reach maxima of 153 and 233 for stem height and leaf-product respectively. For Darlington the main features of the plant graphs that serve to distinguish this station from others are the very high maxima of 228 for the stem height and 255 for leaf-product, for the period beginning July 19 and the relatively high values shown by the graphs for the beginning of the season. The midsummer maxima for Coleman are 150 and 211 stem height and leaf-product, respectively. The plant graphs for Easton show relatively low values of the midsummer maxima for the plant indices, 146 being the highest value reached for height and 163 for leaf-product. Also, the plant values are low for the beginning of the season for this station. The midsummer maximum for the height value for Princess Anne is 135 and the corresponding maximum for the leaf-product value is 163.

The plant graphs as may be seen from the above statements of their main features, fall into three groups: (1) The California graphs. These show values of the leaf-product index below 100 for 11 periods and similar low values of the stem-

height index for all points except those beginning June 14 and Aug. 13. The indices in these graphs are not relative, high. (2) The graphs for Shenandoah, Maryland, Ridge Road and Eastern Shore, Virginia, Highway of the plant growth rate show that in the U.S. and graphs, the values being about 2 1/2 times the seasonal average here considered as 100. (3) The graphs for College, Baltimore, Washington, and College are provided in that they exhibit high relative values of their maxima. From the present point of view then, the interesting characteristics of the graphs are summarized in the above classification and the statement that ^a they show a seasonal march from low values in the early part of the season to high values with a subsequent falling off to low values in the later parts of the season.

Correlation of plant and climatic data.

In attempting to correlate the plant and climatic data the graph representing the plant and climatic measurements for all the cultures of the investigation were inspected to determine whether a general scheme of correlation could be formulated that would explain in a consistent manner the characteristics of the plant behavior in terms of the corresponding climatic values. It was found possible to formulate such a scheme but since each of the three climatic conditions measured acts on the plant in a number of ways, the most that could be accomplished was a determination of what seemed the predominant influence on the plant of each of the three environmental conditions here considered. The conclusions reached as to the principal effect of these environmental conditions are given

help. Subsequent reference to the data plotted in the graphs will show the extent to which the scheme adopted can be applied. The correlation scheme is not to be considered as final in any sense, but merely as a suggestion upon which a fairly consistent explanation of the data of the present study may be made.

The most reasonable basis for correlating the plant and climatic graphs, as determined from inspection, seems to be one that assumes growth is conditioned mainly by the temperature, sunshine having a direct effect, and both conditions accelerating the growth processes as they increase. Evaporation will be assumed to have an inverse effect on growth, the latter decreasing as the former increases. These assumptions may be stated in the following manner:

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

In which I represents the rate of the plant process under consideration, T , L and E represent temperature, light, and evaporation respectively. Some such simple working hypothesis as the above facilitated the attaching of the consolidated graph-lem presented by a group of plant and climatic data and is here presented. We do not, of course, know what form the functions of T , L , and E will have, but it is probable, at least, that T and L are in the numerator of the fraction which is to be used to represent tentatively the relation between the plants and the climate, and that E is in the denominator.

The plant growth when examined, varied by series, for the various stations with the above assumptions in mind might be

expected to show certain relations to the climatic values. If the seasonal relation holds it would be supposed, that the plants would show a high growth rate whenever the temperature value is high unless at the same time either light is very low (i.e. showing a value of 50 or less) or the evaporation very high (i.e. showing a value of 150 or more). When the temperature index is low, the plant growth would be expected to show low values, the amount by which it is depressed being less in those periods for which the other climatic conditions are favorable than in the periods for which they are unfavorable. "high" and "low" will be used, in general, as above and below the seasonal average for the state, since it is obviously impossible in the qualitative method of treatment used in this study to assign any definite values to the extremes. Also the correlation between the plant and climatic data for the two-year periods will take into account only the leaf-product. This is done for the reason that the leaf-product, is approximately proportional to the leaf area and dry weight for soy-beans.

✓ Hillebrandt, W. W., Leaf-product as an index of growth in soy-bean. Johns Hopkins Univ. Circ. March, 1917.

as has been shown by McLean and by the writer in a previous paper,¹² and the dry weight of plants is the most generally accepted criterion of their growth. The previous discussion of the relation between leaf-product and stem height, has shown that they vary in the same direction and, in many cultures, to the same extent. A correlation of the stem height in

this part of the paper would involve repetition and is unnecessary.

For Orlind the leaf-product graph follows the temperature graph from the period beginning June 5 to the period beginning July 21. At the periods July 21, Aug. 14, and Aug. 27 the temperature remains approximately constant and the rate of leaf expansion follows the light graph. Light parallels temperature, and both parallel leaf-product from the period beginning July 22 to the period beginning July 31. The question as to which of the two factors is the determining one here would seem to be answered by the behavior of the plants for the periods beginning June 5, July 21, Aug. 14, and Aug. 27. In the period beginning June 5 the plant graph parallels with the temperature efficiency value although the sunshine graph rises, and in the periods beginning July 21, Aug. 14, and Aug. 27 where the temperature remains nearly constant, the leaf-product follows sunshine intensity. The very high evaporation rate for the period beginning June 5 does not seem to have had such effect on the plants. For Chewsville, leaf-product follows the temperature index graph during the greater part of the season. The plant graph shows a tendency to rise above the graph of temperature values during the first part of the season and to drop below it at the end, this being due perhaps to high values of sunshine intensity during the early periods and low values during the later ones. For the periods beginning Sept. 22, and Oct. 5 leaf-product follows the graph of light intensity, the temperature value remaining nearly constant. It will be noted that the period beginning Aug. 11 with climatic conditions apparently favorable for growth shows a low leaf-product. None of the

average than values for this station seems to have been high enough to affect the plant. Leaf-product at Maryland follows the graph of temperature index well in general. In the period beginning June 1, June 15, July 15, and July 25 high values of evaporation probably depress the rate of leaf expansion since the temperature lines for these periods are well above the seasonal average for the state. For some reason not apparent from the climatic graphs, the period beginning Aug. 15 shows a relatively low value of leaf-product and the period beginning Sept. 21 a relatively high value. The plant graph for College shows a number of peculiarities which cannot be adequately correlated with the climatic data. Leaf-product has a relatively lower value for the period beginning June 15 and a relatively higher value for the period beginning July 17 than would be expected. The plant graph lies well below the temperature graph from the period beginning Aug. 14 to the end of the season due probably to low values of sunshine intensity. The light data are not available for this station, however. The rise in rate of leaf-production from the period beginning May 25 to the period beginning June 8 may be explained by the slight fall in evaporation rate, although this fall is slight. Baltimore shows relatively high values of leaf-product for the periods beginning June 25 and July 9 as would be expected from the fact that the temperature value is high and the evaporation low for these periods. The reason for the high value of leaf-product for the period beginning Aug. 6 is not clear. Darlington is distinguished from the rest of the stations by a very high leaf-product for the period beginning July 1, the value recorded being 105,

practically three times the average for the state. It will be observed that this period has high values of sunshine and of the psychological temperature index and a low value of evaporation, a combination of conditions which would be expected to be optimal for plant growth. The high value of leaf-product for the period beginning June 13 as compared to those beginning May 25 and May 30 is probably related to the relatively low evaporation rate during the period beginning June 13. The same, similar observations are made for the periods beginning July 10 and Aug. 7 for the latter are lacking and no comparison of the periods is possible. For Colston, the leaf-product follows the graph of temperature values in general from the period beginning May 13 to the period beginning July 22. The relatively low values of the leaf-product for the periods beginning Aug. 5 and Aug. 12 cannot be satisfactorily correlated with the climatic data. For Easton, high values of the temperature indices seem to account for the high values of the leaf-product for the periods beginning July 6, July 20, Aug. 3, and Aug. 17. The graph of leaf-product lies well below the graph of temperature values during the last part of the season. The period beginning Aug. 25 would be expected to show a higher value for the plant growth, as that is actually found but the low value of sunshine for this period may explain the low plant value. For Princess Anne the leaf-product graph follows the temperature graph practically throughout the season. Evaporation and sunshine intensity are both low for this station and the evaporation would therefore not be expected to influence the plants. The low sunshine values for the periods beginning June 23, July 7, July 21, Aug. 4, and Aug. 18 may be related to the fact that leaf-product does not show values as high for

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 10 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-product 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 existing 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-week² data will be followed 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 consideration 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. ✓

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Hildebrandt, W. 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 directions in many cases. The effect of the light is, however, only secondary and does not disturb the relation apparently existing 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. At 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

resemblance 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 obvious 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:

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

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. $\underline{f(L)}$, $\underline{f(T)}$, and $\underline{f(E)}$ are used in the equation instead of $\underline{L}$, $\underline{T}$, and $\underline{E}$ 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 $\underline{f(T)}$ 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 depression 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 each 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 period 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 temperature 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 higher 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 lower 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 11 to 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 24 to 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 evaporation 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 the 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 the temperature index value for the latter period is very much lower than the temperature index value for 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 the 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.

The common Stations

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 covered 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 was 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 accurately 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 periods 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. ^{✓✓}

[✓] 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 "standardization". That is, certain plants may be selected for use as integrating instruments, their growth peculiarities 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-week 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 or 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 two-week way by 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 relative 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 preceeding 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

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

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 were more 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 25	JUNE 5	JUNE 19	JUNE 3	JULY 10	JULY 31	AUG. 19	AUG. 27	SEPT. 12				
	JUNE 5	JUNE 19	JUNE 3	JULY 10	JULY 31	AUG. 14	AUG. 27	SEPT. 12	SEPT. 25				AV.
Culture number	1	2	3	4	5	6	7	8	9				
Length of growing period, days.	13	14	14	13	15	14	13	10	13				
Number of plants.	4	5	5	6	5	6	6	6	4				
Remainder summation index.	331	354	401	364	431	369	343	370	262				361
Average daily relative physiological temperature index.	66	66	65	70	67	67	64	66	45				69
Average daily mean temperature, deg F.	65	64	68	67	68	65	66	62	61				65
Average daily relative evaporation index.	153	139	78	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	70	82	46	-				77

CHEWSVILLE 2 week periods. EXPOSED STATION.	MAY 14	JUNE 1	JUNE 16	JUNE 30	JULY 14	JULY 28	AUG. 11	AUG. 25	SEPT. 8	SEPT. 22	OCT. 7		
	JUNE 2	JUNE 16	JUNE 30	JULY 14	JULY 28	AUG. 11	AUG. 25	SEPT. 8	SEPT. 22	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	13	13		
Number of plants	6	6	4	6	5	4	3	5	6	6	6		
Remainder summation index.	416	443	442	433	523	450	517	436	302	328	301		422
Average daily relative physiological temperature index.	72	100	119	112	147	112	145	103	48	51	53		98
Average daily mean temperature, deg F.	69	71	73	71	76	71	76	70	61	61	62		69
Average daily relative evaporation index.	110	115	107	73	108	87	105	80	79	73	64		91
Average daily relative sunshine intensity.	121	124	116	106	121	114	98	67	104	73	44		98
Average daily relative increment in stem height.	93	93	143	112	126	98	98	76	48	37	37		87
Average daily relative increment in leaf-product.	104	110	137	96	159	127	100	52	32	20	4		84

MONROVIA 2 week periods. EXPOSED STATION.	MAY 18	JUNE 1	JUNE 15	JUNE 29	JULY 13	JULY 27	AUG. 10	AUG. 24	SEPT. 7	SEPT. 21	OCT. 5		
	JUNE 1	JUNE 15	JUNE 29	JULY 13	JULY 27	AUG. 10	AUG. 24	SEPT. 7	SEPT. 21	OCT. 5	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	484	536	463	511	433	384	386	262		431
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	36	4		80

COLLEGE 2-week periods EXPOSED STATION	MAY 23	JUNE 6	JUNE 19	JULY 3	JULY 17	JULY 31	AUG. 14	AUG. 27	SEPT. 10	SEPT. 23	OCT. 7	OCT. 21	Av.
	JUNE 6	JUNE 19	JULY 3	JULY 17	JULY 31	AUG. 14	AUG. 27	SEPT. 10	SEPT. 23	OCT. 7	OCT. 21		
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.	543	109	526	494	520	494	478	477	378	335	327		450
Average daily relative physiological temperature index.	108	103	137	134	148	133	143	115	67	50	53		108
Average daily mean temperature, deg F.	71	70	76	74	76	74	76	71	64	61	62		70
Average daily relative evaporation index.	160	154	123	96	143	147	135	107	78	34	62		119
Average daily relative sunshine intensity.	-	-	-	-	-			-	-	-	-		
Average daily relative increment in stem height	93	152	115	118	124	118	90	76		48	37		95
Average daily relative increment in leaf-product.	96	123	81	152	203	150	117	62	-	13	10		101

BALTIMORE 2-week periods EXPOSED STATION	MAY 14	MAY 29	JUNE 10	JUNE 25	JULY 9	JULY 23	AUG. 6	AUG. 20	SEPT. 3	SEPT. 17	OCT. 1	OCT. 15	Av.
	MAY 29	JUNE 10	JUNE 25	JULY 9	JULY 23	AUG. 6	AUG. 20	SEPT. 3	SEPT. 17	OCT. 1	OCT. 15		
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	10	12	13		
Number of plants.	5	-	5	6	6	4	5	5	6	5	5		
Remainder summation index.	151	370	508	489	546	506	543	502	535	500	513		448
Average daily relative physiological temperature index.	97	119	123	125	162	140	160	157	62	67	93		112
Average daily mean temperature, deg F.	69	70	73	73	75	75	76	75	64	64	64		72
Average daily relative evaporation index.	127	102	115	80	92	112	110	81	69	58	64		93
Average daily relative sunshine intensity.	137	63	108	60	94	72	79	74	62	69	57		96
Average daily relative increment in stem height	93	-	146	152	183	152	152	149	73	56	96		125
Average daily relative increment in leaf-product.	106	-	125	163	194	110	233	130	54	22	47		119

DARLINGTON 2-week periods EXPOSED STATION	MAY 15	MAY 30	JUNE 13	JUNE 26	JULY 10	JULY 24	AUG. 7	AUG. 21	SEPT. 4	SEPT. 18	OCT. 1	OCT. 15	Av.
	MAY 30	JUNE 13	JUNE 26	JULY 10	JULY 24	AUG. 7	AUG. 21	SEPT. 4	SEPT. 18	OCT. 1	OCT. 15		
Culture number	1	2	3	4	5	6	7	8	9	10	11		
Length of growing period, days.	13	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	393	432	512	456	506	472	309	315	358		418
Average daily relative physiological temperature index.	87	99	94	95	149	113	146	123	46	59	54		97
Average daily mean temperature, deg. F.	68	70	69	70	76	72	76	73	61	62	63		67
Average daily relative evaporation index.	130	123	90	62	74	77	79	64	62	67	67		87
Average daily relative sunshine intensity.	154	129	92	77	111	111	116	78	92	96	43		100
Average daily relative increment in stem height	110	104	145	141	229	146	-	107	42	15	59		113
Average daily relative increment in leaf-product.	135	129	155	115	295	148		108	29	15	11		118

COLEMAN 2-week periods EXPOSED STATION	MAY 13	MAY 20	JUNE 11	JUNE 24	JULY 9	JULY 22	AUG 5	AUG 17	SEPT 2	SEPT 16	SEPT 29	OCT 13	AV.
	MAY 28	JUNE 11	JUNE 24	JULY 9	JULY 22	AUG 5	AUG 17	SEPT 2	SEPT 16	SEPT 29	OCT 13	OCT 26	
	1	2	3	4	5	6	7	8	9	10	11	12	
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	393	-	-	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	67	67	-	-	72
Average daily relative evaporation index.	139	152	137	120	143	155	119	96	132	135	17	93	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	67	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	JUNE 8	JUNE 22	JULY 6	JULY 20	AUG 3	AUG 17	SEPT 31	SEPT 14	SEPT 28	OCT 11	AV.
	MAY 23	JUNE 8	JUNE 22	JULY 6	JULY 20	AUG 3	AUG 17	SEPT 31	SEPT 14	SEPT 28	OCT 11	OCT 26	
	1	2	3	4	5	6	7	8	9	10	11	12	
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.	97	112	110	131	154	153	144	146	87	76	64	46	103
Average daily mean temperature, deg. F.	65	71	71	74	77	74	76	76	67	66	64	62	71
Average daily relative evaporation index.	93	130	133	91	86	133	128	113	111	104	98	82	108
Average daily relative sunshine intensity.	148	172	141	120	124	108	117	77	97	73	64	52	111
Average daily relative increment in stem height.	43	87	112	132	140	146	152	118	81	43	65	34	95
Average daily relative increment in leaf product.	71	11	112	99	152	130	103	129	64	35	-	-	105

PRINCESS ANNE 2-week periods EXPOSED STATION	MAY 11	MAY 26	JUNE 8	JUNE 23	JULY 7	JULY 21	AUG 4	AUG 18	SEPT 1	SEPT 15	SEPT 29	OCT 12	AV.
	MAY 26	JUNE 8	JUNE 23	JULY 7	JULY 21	AUG 4	AUG 18	SEPT 1	SEPT 15	SEPT 29	OCT 12	OCT 27	
	1	2	3	4	5	6	7	8	9	10	11	12	
Culture number:	1	2	3	4	5	6	7	8	9	10	11	12	
Length of growing period, days.	15	13	15	14	14	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.	378	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	94	71	60	45	101
Average daily mean temperature, deg. F.	63	70	75	74	76	74	76	76	67	65	63	61	70
Average daily relative evaporation index.	117	134	-	-	63	83	101	73	73	78	70	39	84
Average daily relative sunshine intensity.	101	118	103	85	88	96	75	86	79	82	67	42	86
Average daily relative increment in stem height.	62	110	107	124	197	143	155	127	74	65	53	45	106
Average daily relative increment in leaf product.	96	116	104	113	103	102	177	138	82	34	18	6	96

OAKLAND		MAY	JUNE	JUNE	JUNE	JULY	JULY	JULY	AUG	AUG			AV.
4-week periods.		23	3	19	3	16	31	14	27				
EXPOSED STATION		JUNE	JUNE	JULY	JULY	AUG.	AUG.	SEPT.	SEPT.				
		19	3	16	31	14	27	12	25				
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	66	67	67	67	65	64	62				65
Average daily relative evaporation index.		146	119	89	92	97	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	83	86	83	76	46				79

CHEWSVILLE		MAY	JUNE	JUNE	JUNE	JULY	JULY	AUG.	AUG.	SEPT.	SEPT.	OCT		AV.
4-week periods.		19	2	16	30	14	28	11	25	8	22	7		
EXPOSED STATION		JUNE	JUNE	JULY	JULY	AUG.	AUG.	SEPT.	SEPT.	OCT	OCT	NOV		
		16	30	14	28	11	25	8	22	7	20	3		
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	29	28	27			
Number of plants.		6	6	4	6	5	4	3	5	6	6	6		
Remainder summation index.		857	915	925	976	973	967	953	735	630	629	490		823
Average daily relative physiological temperature index.		99	113	116	131	131	129	124	76	50	52	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	98	96	93	80	76	69	71		90
Average daily relative sunshine intensity.		125	123	111	114	108	96	83	66	89	59	56		95
Average daily relative increment in stem height.		75	103	122	97	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	142	87	92	86	85	62	51	38	24		78

MONROVIA		MAY	JUNE	JUNE	JUNE	JULY	JULY	AUG.	AUG.	SEPT.	SEPT.	OCT		AV.
4-week periods.		18	1	15	29	13	27	10	24	7	21	8		
EXPOSED STATION		JUNE	JUNE	JULY	JULY	AUG.	AUG.	SEPT.	SEPT.	OCT	OCT	NOV		
		15	29	13	27	10	24	7	21	8	13	2		
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	31	28	25			
Number of plants.		3	5	6	4	6	5	6	5	6	6	6		
Remainder summation index.		890	932	932	990	777	774	744	817	770	646	463		851
Average daily relative physiological temperature index.		108	117	118	134	137	131	125	82	66	59	53		102
Average daily mean temperature, deg F.		71	72	72	74	75	74	73	66	62	65	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	94	86	59	58		96
Average daily relative increment in stem height.		63	78	84	84	78	91	84	56	41	41	28		66
Average daily relative increment in leaf area.		71	108	88	99	71	104	75	70	39	48	12		71
Average daily relative increment in dry weight.		70	114	108	99	89	105	81	87	41	48	24		79

COLLEGE 4 week periods EXPOSED STATION	MAY 9 JUNE 6	MAY 23 JUNE 13	JUNE 6 JULY 3	JUNE 19 JULY 17	JULY 3 JULY 31	JULY 11 AUG 14	JULY 31 AUG 21	AUG 14 SEPT 10	AUG 27 SEPT 15	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	27	27	29	30	29		
Number of plants.	6	6	5	5	6	4	4	6	6	—	6	
Remainder summation index.	888	750	730	1020	1014	1004	772	727	827	715	662	902
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	73	75	75	75	75	74	69	63	62	71
Average daily relative evaporation index.	109	157	139	110	120	145	141	121	93	61	83	124
Average daily relative sunshine intensity.	—	—	—	—	—	—	—	—	—	—	—	
Average daily relative increment in stem height.	47	75	100	91	91	97	103	72	63	—	56	80
Average daily relative increment in leaf area.	70	42	125	78	98	173	209	126	86	—	46	110
Average daily relative increment in dry weight.	86	110	140	95	119	172	199	132	84	—	51	119

BALTIMORE 4 week periods EXPOSED STATION	MAY 14 JUNE 10	MAY 29 JUNE 25	JUNE 10 JULY 9	JUNE 25 JULY 23	JULY 11 AUG 6	JULY 23 AUG 20	AUG 6 SEPT 3	AUG 20 SEPT 17	SEPT 3 OCT 1	SEPT 17 OCT 14	OCT 1 OCT 31	AV.
Culture number.	1	2	3	4	5	6	7	8	9	10	11	
Length of growing period, days.	27	27	23	28	28	28	28	30	28	25	30	
Number of plants.	4	5	5	6	6	4	6	5	6	5	3	
Remainder summation index.	821	878	997	1035	1052	1049	1045	897	695	629	619	863
Average daily relative physiological temperature index.	98	111	124	144	151	150	150	101	60	65	47	110
Average daily mean temperature, deg F	70	72	73	76	77	77	77	69	64	64	60	71
Average daily relative evaporation index.	118	112	93	86	102	111	96	75	69	66	61	90
Average daily relative sunshine intensity.	113	99	84	80	86	76	77	78	86	74	50	82
Average daily relative increment in stem height.	100	119	138	122	122	131	122	91	69	75	56	104
Average daily relative increment in leaf area.	90	109	115	147	134	141	196	97	72	73	101	115
Average daily relative increment in dry weight.	86	113	119	146	134	118	162	92	70	67	105	105

DARLINGTON 4 week periods EXPOSED STATION.	MAY 13 JUNE 13	MAY 30 JUNE 26	JUNE 13 JULY 10	JUNE 26 JULY 24	JULY 10 AUG 7	JULY 24 AUG 21	AUG 7 SEPT 4	AUG 21 SEPT 18	SEPT 4 OCT 2	SEPT 18 OCT 16	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	28	28	28	
Number of plants.	6	5	6	4	5	5	—	5	6	5	
Remainder summation index.	802	824	824	744	768	762	778	781	624	653	842
Average daily relative physiological temperature index.	93	97	96	124	131	130	135	95	53	57	100
Average daily mean temperature, deg F	69	70	70	73	74	74	75	67	62	63	70
Average daily relative evaporation index.	128	108	76	68	76	70	72	73	59	59	85
Average daily relative sunshine intensity.	142	111	85	74	111	114	97	89	97	70	101
Average daily relative increment in stem height.	103	100	116	147	172	131	—	78	44	63	106
Average daily relative increment in leaf area.	136	161	151	196	230	192	—	40	57	89	148
Average daily relative increment in dry weight.	154	148	170	178	264	167	—	89	56	72	144

COLEMAN 4-week periods EXPOSED STATION	MAY 13	MAY 20	JUNE 11	JUNE 24	JULY 5	JULY 22	AUG 5	AUG 19	SEPT 2	SEPT 16	SEPT 30	AV.
	JUNE 11	JUNE 24	JULY 5	JULY 22	AUG 5	AUG 19	SEPT 2	SEPT 16	SEPT 30	OCT 13	OCT 28	
Culture number	1	2	3	4	5	6	7	8	9	10	11	
Length of growing period, days	27	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	818	879	921	1048	1017	1055	1058	910	769	—	—	959
Average daily relative physiological temperature index	97	116	124	150	158	152	153	116	85	—	—	128
Average daily mean temperature, deg. F	69	70	71	77	78	77	77	72	67	—	—	73
Average daily relative evaporation index	146	145	129	132	149	137	100	114	131	116	95	128
Average daily relative sunshine intensity	151	143	93	101	133	121	102	—	—	—	—	121
Average daily relative increment in stem height	69	81	94	106	100	109	84	72	53	50	53	80
Average daily relative increment in leaf area	116	150	167	144	135	145	108	89	71	—	41	117
Average daily relative increment in dry weight	126	153	159	143	134	148	83	113	67	75	43	113

EASTON 4-week periods EXPOSED STATION	MAY 8	MAY 25	JUNE 8	JUNE 22	JULY 6	JULY 20	AUG 3	AUG 17	AUG 31	SEPT 14	SEPT 28	OCT 11	AV.
	JUNE 8	JUNE 22	JULY 6	JULY 20	AUG 3	AUG 17	AUG 31	SEPT 14	SEPT 28	OCT 11	OCT 26	NOV 9	
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	889	104	743	1024	1027	1008	1032	911	113	707	673	477	866
Average daily relative physiological temperature index	90	111	121	143	144	139	145	117	82	70	56	37	105
Average daily mean temperature, deg. F	68	71	73	76	76	75	78	72	67	65	63	58	70
Average daily relative evaporation index	115	132	112	89	110	131	121	112	103	96	85	93	109
Average daily relative sunshine intensity	159	137	131	122	116	115	108	78	96	80	58	60	108
Average daily relative increment in stem height	41	72	71	103	103	113	103	81	56	50	36	30	75
Average daily relative increment in leaf area	74	76	111	107	101	121	121	95	66	64	58	8	82
Average daily relative increment in dry weight	80	81	119	91	113	121	121	81	72	48	52	22	83

PRINCESS ANNE 4-week periods EXPOSED STATION	MAY 11	MAY 26	JUNE 9	JUNE 21	JULY 7	JULY 21	AUG 4	AUG 18	SEPT 1	SEPT 15	SEPT 29	AV.
	JUNE 11	JUNE 23	JULY 7	JULY 21	AUG 4	AUG 18	SEPT 1	SEPT 15	SEPT 29	OCT 12	OCT 27	
Culture number	1	2	3	4	5	6	7	8	9	10	11	
Length of growing period, days	28	28	29	28	28	28	28	28	28	27	28	
Number of plants	6	5	5	6	6	6	3	6	6	5	6	
Remainder summation index	103	409	777	1007	1171	976	1033	1017	750	618	643	880
Average daily relative physiological temperature index	81	102	117	138	136	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	86	81	83	81	75	55	87
Average daily relative increment in stem height	63	88	103	106	138	123	138	89	63	56	44	92
Average daily relative increment in leaf area	125	155	116	—	127	132	206	102	97	72	36	117
Average daily relative increment in dry weight	132	150	137	118	137	135	171	71	87	67	58	116

PLATE VI.

OAKLAND 2-week periods, COVERED STATION	MAY 22	JUNE 4	JUNE 18	JULY 6	JULY 15	JULY 30	AUG. 13	AUG. 26	SEPT. 9	SEPT. 24	AV.
	JUNE 1	JUNE 18	JULY 2	JULY 15	JULY 30	AUG. 13	AUG. 26	SEPT. 9	SEPT. 24		
Culture number:	1	2	3	4	5	6	7	8	9		
Length of growing period, days.	13	14	14	13	15	14	13	16	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	127	96	154	—	89	44	91		78

OAKLAND 4-week periods. COVERED STATION	MAY	JUNE	JUNE	JUNE	JULY	JULY	JULY	AUG.	AUG.	AV.
	22	4	18	2	15	30	13	26	7	
	JUNE	JULY	JULY	JULY	AUG.	AUG.	SEPT.	SEPT.		
	18	2	15	30	13	26	11	24		
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.	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.	57	97	121	123	111	-	86	59		93

BALTIMORE 2-week periods. COVERED STATION	JUNE 10 25	JUNE 25 .9	JULY 9 23	JULY 23 6	AUG 6 20	AUG 20 3	SEPT 3 19	SEPT 19 1	OCT 1 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	177	191	56	70	155	172
Average daily relative increment in leaf-product.	111	150	262	147	180	163	51	21	43	125

BALTIMORE 4-week periods. COVERED STATION.	MAY	JUNE	JUNE	JULY	JULY	AUG	AUG	SEPT	SEPT	OCT	Av.
	29	10	25	7	23	6	20	3	19	1	
	JUNE	JULY	AUG	SEPT	OCT	OCT	OCT	OCT	OCT	OCT	
	25	9	23	6	20	3	19	1	19	31	
Culture number	2	3	4	5	6	7	8	9	10	11	
Length of growing period, days.	21	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	77	97
Average daily relative increment in stem height.	156	128	134	231	169	153	151	72	103	78	136
Average daily relative increment in leaf area.	-	-	108	730	131	174	151	74	101		154
Average daily relative increment in dry weight.	84	54	116	188	103	153	114	64	60	57	75

EASTON 2-week periods. COVERED STATION.	MAY 25	JUNE 8	JUNE 22	JULY 6	JULY 20	AUG 3	AUG 17	AUG 31	SEPT 14	SEPT 28	AV.
	JUNE 8	JUNE 22	JULY 6	JULY 20	AUG 3	AUG 17	AUG 31	SEPT 14	SEPT 28	OCT 11	
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	113	89	180	162	210	225	125	55	—	142

EASTON 4-week periods. COVERED STATION	MAY 25	JUNE 8	JUNE 22	JULY 6	JULY 20	AUG 3	AUG 17	AUG 31	SEPT 14	SEPT 28	OCT 11	OCT 26	NOV 9	AV.
	JUNE 22	JULY 6	JULY 20	AUG 3	AUG 17	AUG 31	SEPT 14	SEPT 28	OCT 11	OCT 26	NOV 9	NOV 23	DEC 7	
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 23	AUG 6	AUG 20	SEPT 3	SEPT 19	OCT 1	OCT 14	AV.
	JULY 9	AUG 23	AUG 6	AUG 20	SEPT 3	SEPT 19	OCT 1	OCT 14	NOV 5	
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	6	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 9	JULY 23	AUG 6	AUG 20	SEPT 3	SEPT 19	OCT 1	OCT 14	NOV 5	AV.
	JULY 23	AUG 6	AUG 20	SEPT 3	SEPT 19	OCT 1	OCT 14	NOV 5	DEC 13	DEC 27	
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	10	68	61	55	55	66		
Average daily relative increment in stem height.	300	449	—	310	213	200	200	125	256		
Average daily relative increment in leaf area.	104	104	—	95	73	40	38	32	69		
Average daily relative increment in dry weight.	52	62	—	46	37	30	33	27	41		

PLATE IX.

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

Exposed stations.

CONCENTRATION
ZINC
PERCENTAGE

COLLEGE
EXPOSED AT-TIME

MAY 1 10 15 20 25 30
JUNE 1 5 10 15 20 25 30
JUL 1 5 10 15 20 25 30
AUG 1 5 10 15 20 25 30
SEP 1 5 10 15 20 25 30

PLATE X.

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

Exposed stations.

PLATE XI.

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

Exposed stations.

P. 100-100-100
 100-100-100
 100-100-100

PLATE XII.

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.

Legend.

Explanation of conventions used in the representation of the plant and climatic quantities.

————— Dry weight.

————— Leaf-product.

————— Stem height.

————— Temperature index values.

————— Evaporation index.

————— Sunshine intensity.

The dates shown are those of the first day of each cultural period. The numbers under the dates are culture numbers corresponding to the numbers shown in the second line of the tables. The numbers in the vertical column at the left give ordinate values.

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 1914-1917, 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 1916.