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THE INFLUENCE OF CERTAIN CLIMATIC FACTORS ON THE DEVELOPMENT OF ENDOTHIA PARASITICA (MURR.) AND.

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The chestnut blight is at present common from the northern limit of the chestnut, that is, southern New Hampshire and Vermont, to central Virginia. The area which it occupies includes the northern limits of growth of two native species of Endothia, *Endothia gyrosa* (Schw.) Fr. and *Endothia radicalis* (Schw.) De Not. It is also a transition region for several important plant diseases. In the southern portion of this territory bitter rot is one of the commonest and most destructive diseases of apples; in the nothern portion it is a botanical curiosity; and pear-blight, which is so abundant in the more southerly portions of this area, is hardly known from the northern states of New England. Apple scab, on the other hand, is more important in the northern portion than in the southern.

In order to gain more complete knowledge of the behavior of *Endothia parasitica* through this range and if possible to throw some light on the factors which limit the growth of these other fungi, the writer has undertaken a quantitative comparison of the growth and fructification of the fungus with the weather conditions, as far as data are available. While the work is not yet complete, enough data have accumulated to warrant the publication of results. This seems especially desirable in view of the fact that two of the stations, Wilmington, Delaware, and Hartford, Connecticut, must now be abandoned because of the general infection of the chestnut.

PLAN OF EXPERIMENTS

Previous observations on the growth and reproduction of *Endothia parasitica* have been confined chiefly to single localities, with little

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opportunity for comparison. Consequently in this work special care was taken to have inoculations made in the same way and on trees as nearly similar as possible but in different localities. It was desired of course to make observations at stations climatologically as different as possible. The actual location of inoculations was however governed by practical considerations. In order to avoid spreading the chestnut blight beyond its present range it was necessary to confine work to regions where the disease was so well established as to leave no hope of eradication. A quantity of healthy chestnut was obviously necessary. The latter consideration excluded the entire region between Philadelphia and New Haven, Connecticut. With the exception of one locality (Overlook Mountain) the inoculations were all made near regular U. S. Weather Bureau observation stations.[1]

The stations selected were Concord, N. H.; Williamstown and Amherst, Mass.; Hartford, Conn.; Wilmington, Del.; Van Bibber, Woodstock, and Frederick, Md.; Washington, D. C.; and Fairfax and Charlottesville, Va. The distance from Concord to Charlottesville is about 500 miles, or about 5 degrees of latitude. In addition to regular inoculations at these stations inoculations were made at various elevations on Overlook Mountain in the Catskills in order to determine whether difference in altitude would make any perceptible difference in the growth and fructification of *Endothia parasitica*. Overlook Mountain was selected as being the only place known to the writer where chestnut grows through a considerable range of elevation and where the chestnut blight is present. Graylock Mountain near Williamstown, Mass., was first selected but chestnut was not found on this mountain above 1,500 feet.

Work was begun in the spring of 1914 and each station visited once in five or six weeks during the summer of 1914 and twice during the summer of 1915. At each visit ten or more inoculations were made on healthy chestnut trees and the condition of previous inoculations noted. The trees inoculated were uniformly second growth and as far as possible were from 6 to 8 inches in diameter. Wherever these conditions were not met the fact is indicated in the report of observations. The inoculations were made by cutting through the bark with a sharp knife and inserting a quantity of mycelium and spores from a pure culture, usually on corn meal, with a freshly cut twig.

[1] In the selection of these stations, as well as in the interpretation of weather data, the writer had the advice of Mr. L. M. Tarr, local forecaster, U. S. Weather Bureau, New Haven, Conn.

Previous Work on Rate of Growth

Anderson (1, p. 16)[1] conducted experiments on the growth of *Endothia parasitica* on *Castanea dentata* at Charter Oak, Pa., during the summer of 1912, and Rankin (9) during the same summer at Napanoch, N. Y. Both these writers give the average growth for each month during the summer and Anderson gives it for the entire year. The average annual growth[2] at Charter Oak, Pa., for the year ending June 1, 1912, was 15.97 cm. according to Anderson (1, p. 575), while Rankin estimates 12 cm. about the average amount of a season's growth at Napanoch.

Rogers and Gravatt (10) made an intensive study of the spread of the chestnut blight over a small area near Bluemont, Va., and give 6.35 inches (15.87 cm.) as the average annual diameter growth of cankers at this point. They found the average growth on *Castanea pumila* near Leesburg, Va., for the year ending August 15, 1914, to be 6.8 inch (16.08 cm.). There is fairly close agreement among the results from Virginia and Pennsylvania even though they were taken in different years. The growth in New York is, however, considerably less.

Rate of Lateral Growth

Since *Endothia parasitica* kills its host by girdling the parts attacked, vertical growth is of no importance so far as its parasitic qualities are concerned, consequently in this work the rate of lateral growth alone was measured. As careful comparative measurements for various periods of the same year have already been given by Anderson (1) and Rankin (9), special attention was paid to determining the amount of growth for one year at the various points. On this account no cuts were made in the cankers until they were one year old. All measurements made previous to that time were taken from the sunken area in the bark.

Table I gives the annual lateral growth (determined by cutting away the bark) of cankers at the various stations for the years ending in May and in August, 1915, so far as the data are complete. Each figure represents an average of all the normal cankers; that is, cankers which developed only on one side of the cut were not included. These averages are expressed in the nearest centimeter, as that seems to the

[1] Reference is made by number to "Literature cited," p. 31.

[2] All measurements are for lateral growth.

writer to represent about the degree of accuracy with which a number of cankers can be measured. These measurements are not exceptional in any way and in all probability represent about the average growth at those points during the year. In general, the growth for the year ending in May is about the same as that for the year ending in August. This is not true of inoculations made at all seasons however.

Experiments during two seasons (1912–13 and 1913–14) indicate that inoculations of *Endothia parasitica* on Castanea made in the fall do not develop until the following spring. Those made in Maryland during November, 1912, showed no evidence of development until early in the following May. A similar series made early in November, 1913, showed no growth until spring and cankers from inoculations made in April, 1914, developed throughout the summer as rapidly as those made the fall before. These results agree with those of Anderson (1, p. 8) and Rankin (9, p. 244).

Table I

Lateral Growth of Cankers of Endothia parasitica in Various Localities

Locality	Elevation (in Feet)	Year Ending	Cm.	Year Ending	Cm.
		1915		*1915*	
Concord, N. H.	350	May 18	14	Aug. 19	14
Williamstown, Mass.	711 (900)	22	15	16	15
Amherst, Mass. (2 stations).	222	17	16	17	15
Hartford, Conn.	159 (350)	15	16	18	16
Woodstock, N. Y.	1,000	24	15	11	16
Wilmington, Del.	86	14	19	10	20
Van Bibber, Md.	100	14	20	Oct. 7	18
Woodstock, Md.	392	Apr. 27	20	Aug. 9	20
Frederick, Md.	275 (325)	27	23	9	(Sprout girdled. No records.)
Washington, D. C.	112 (300)	22	20	July 28	21
Fairfax, Va.	300	June 6	23	4	21
Charlottesville, Va.	854	Apr. 20	25	(Forest fire; no later records.)	

As is shown by the table, there is a more or less regular increase in the annual growth from Concord, N. H., to Charlottesville, Va. So great is this difference that it must obviously be due to the difference in climate and not to a variation in the trees. The record is unfortunately not complete at Frederick, Md., or Charlottesville, Va. At Frederick the trees inoculated in August proved too small and were girdled before the year was complete. At Charlottesville a forest fire destroyed the inoculated trees some time during the last week in April, 1915.

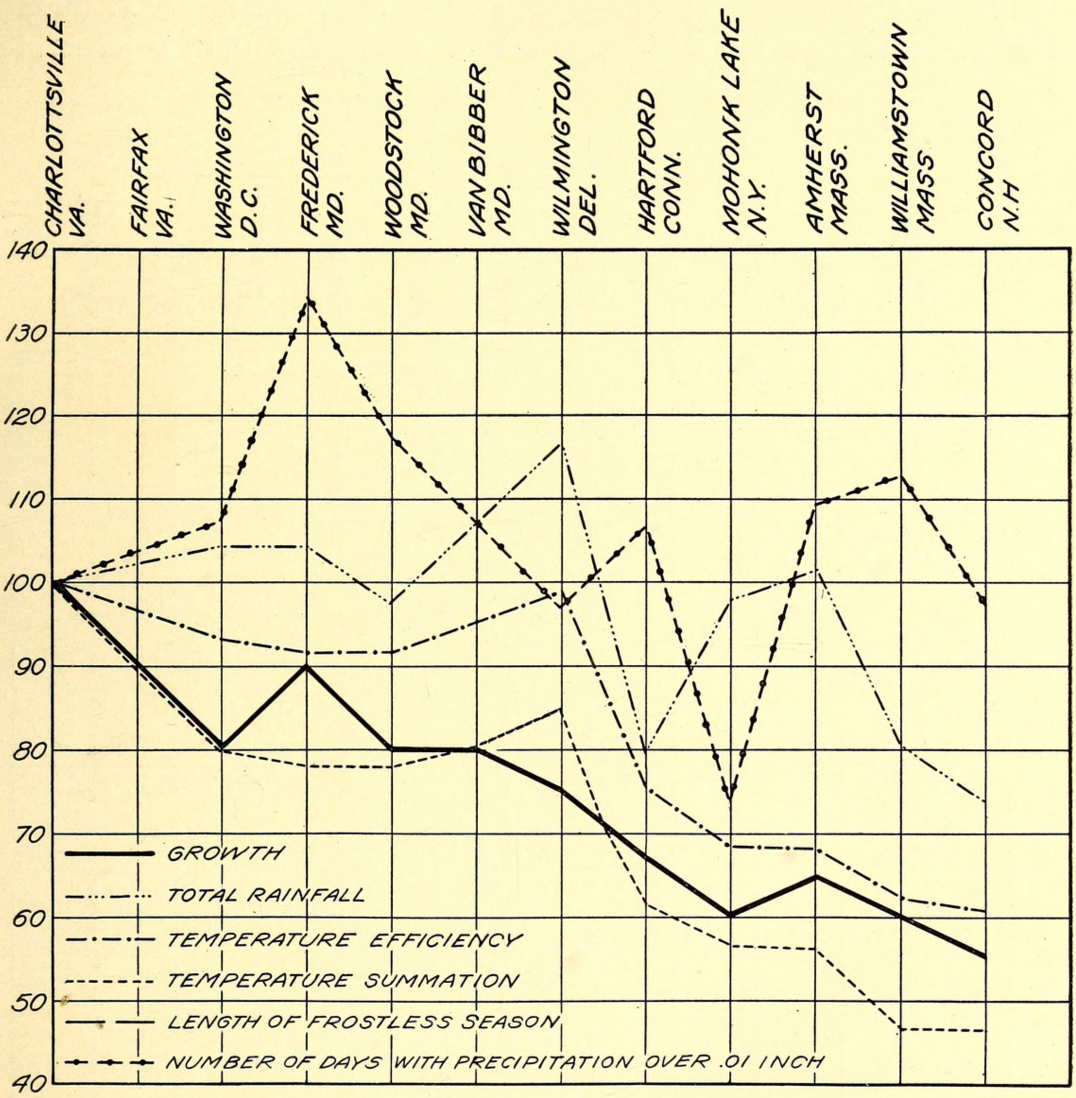

FIG. 1. Graphs showing the growth of *Endothia parasitica* on *Castanea dentata* and climatic data for the year ending April and May, 1915.

The relation of the amount of growth at the various stations is best seen from the curves (Figs. 1 and 2), where the amount of growth is expressed in percentage of that of Charlottesville. The amount at Charlottesville has been used as standard for comparison of all data in making curves, since this is the most southerly point and is near the center of the chestnut belt. This will also make comparisons easy in case points further south are studied as the chestnut blight advances.

For comparison with data just given the amount of annual growth for the years ending in May and August at various elevations on Overlook Mountain (Ulster Co., New York) is given (Table II). While the writer has no accurate data as to the temperature at these various elevations it is interesting and significant that in general

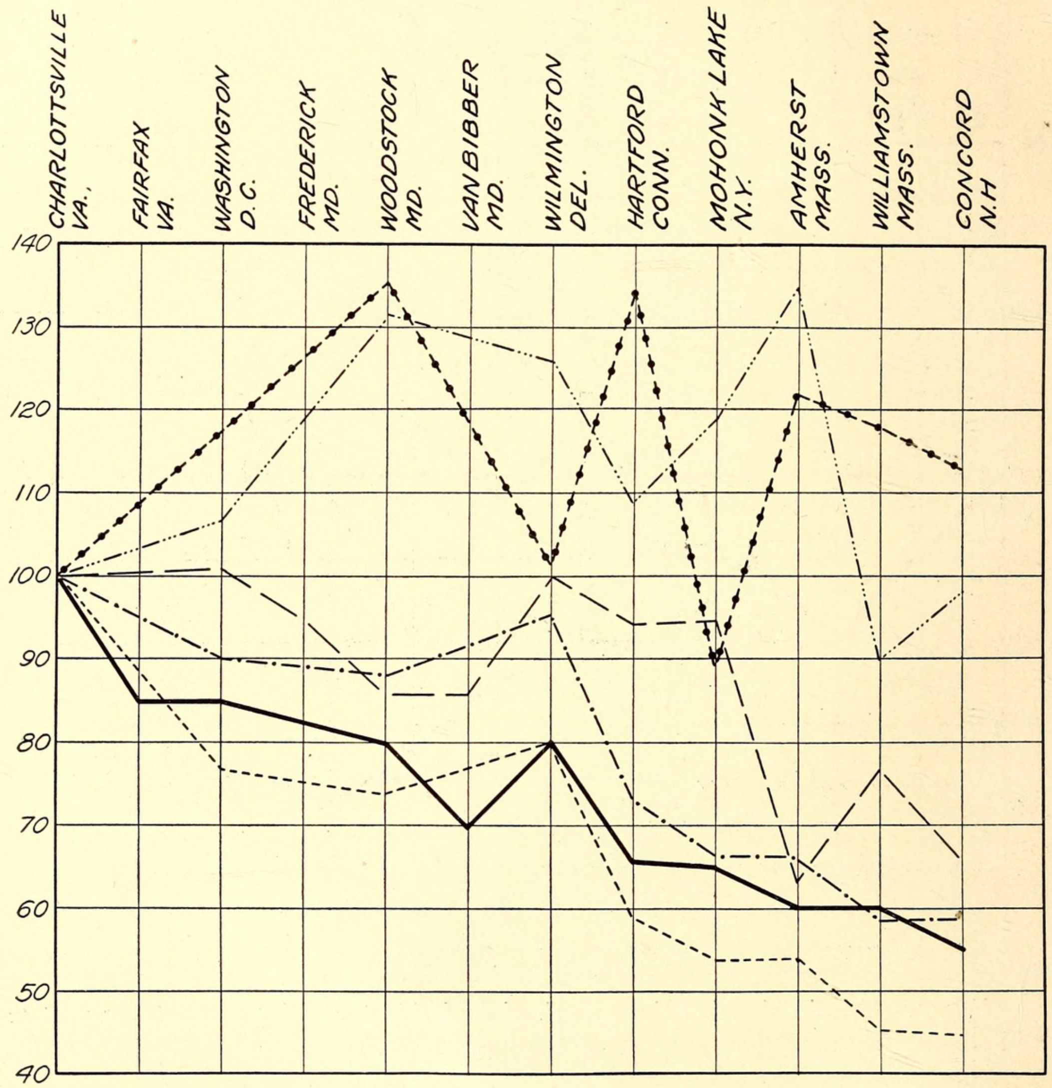

FIG. 2. Graphs showing the growth of *Endothia parasitica* on *Castanea dentata* and climatic data for the year ending August, 1915.

the amount of growth decreases with increased altitude. The only exceptions to this rule are in the case of Station O 4 which, being on the south side of the main ridge of Overlook, showed more growth than Stations O 2 and O 3 on the north side of the ridge. Station O 6 is also an exception to the general rule since though at an elevation of only 1,500 feet it showed but 10 cm. growth for a year. The writer is quite unable to explain this condition beyond the possibility that this reduced growth may be due to the fact that the trees inoculated were in a rather deep and shady ravine.

Table II

Lateral Growth of Cankers of Endothia parasitica at the Various Stations on Overlook Mountain, Woodstock, N. Y.

Station	Elevation (in Feet)	Year Ending	Cm.	Year Ending	Cm.
		1915		*1915*	
O 7	600	May 25	15	Aug. 11	15
S 3	1,000	26	15	11	16
S 1	1,500	24	14	11	15
C	1,500	23	14	11	
O 6	1,500	25	10	Aug. 12	10
O 1	1,900	27	14	12	13
O 2 (north side of ridge)	2,500	26	11	13	11
O 4 (south side of ridge)	2,800	26	13	13	11
O 3 (north side of range)	2,900	26	11	13	10

Climatological Data

In comparing the growth of this fungus with climatic conditions the highest degree of accuracy could be obtained only by carrying on a complete series of meteorological observations in each locality. This procedure, which would have required an observer stationed at each point, was impracticable. Consequently, it was decided to depend entirely on the data regularly furnished by the U. S. Weather Bureau. This, of course, necessitates neglecting certain factors known to be important to plant life. The writer is of the opinion, however, that if progress is soon to be made toward understanding the climatology of plant disease a serious attempt must be made to utilize the meteorological data already available.

While the climatic data available from the Weather Bureau records are not all that might be desired, all the stations except Van Bibber, Md., and Fairfax, Va., furnish daily maximum and minimum temperatures and amount of precipitation, as well as the number of clear, partly cloudy, and cloudy days, and the prevailing direction of the wind for each month. The date of last killing frost in spring and first

TABLE III

Total Precipitation.

	Concord, N. H.	Williams-town, Mass.	Amherst, Mass.	Hartford, Conn.	Mohonk Lake, N. Y.	Wilmington, Del.	Woodstock, Md.	Frederick, Md.	Washing-ton, D. C.	Charlottes-ville, Va.
1914										
April	3.87	5.65	6.59	3.84	4.80	4.04	5.05	4.57	3.20	3.43
May	1.54	1.94	3.56	2.71	4.10	0.89	1.54	2.53	1.72	1.48
June	2.39	2.21	2.32	1.70	2.40	2.95	2.77	3.87	6.20	2.38
July	3.49	4.33	3.53	4.30	3.75	7.17	1.28	2.96	2.32	2.67
August	5.91	5.10	5.11	1.96	2.54	3.13	6.80	5.96	6.00	2.35
September	0.21	0.53	0.52	0.20	0.32	0.86	1.02	1.41	0.66	1.17
October	1.12	1.72	2.09	3.05	3.55	2.19	1.50	1.70	1.65	5.16
November	2.27	2.14	2.62	2.38	3.54	1.75	1.96	1.81	2.06	2.96
December	2.07	1.94	2.89	3.85	3.93	5.90	4.35	4.28	4.49	5.37
1915										
January	3.47	3.45	6.52	5.70	6.56	5.83	7.75	7.35	6.34	5.90
February	2.89	4.14	7.02	4.30	4.46	6.21	4.84	5.06	3.60	4.91
March	Trace	0.41	0.12	0.29	0.28	1.17	1.38	1.07	1.07	0.95
April	2.62	2.12	3.99	1.58	2.01	3.15	1.52	0.70	0.90*	0.49
May	0.99	1.46	1.20	2.53*	2.54*	4.88*	3.86*	4.21*	2.18	2.44
June	1.39	1.73	3.00	1.51	2.65	6.04	6.20	7.14	6.58	5.32
July	10.29	9.37	9.13	6.97	8.24	2.39	3.29	3.59	3.21*	3.71
August	6.26*	4.47*	8.28*	6.83	7.94	6.32	8.77	9.49	7.00	7.83
September	....	....	....	....	....	....	....	....	1.39*	
Total for year ending	May 18 27.04	May 22 29.64	May 17 37.36	May 15 29.30	May 24 35.73	May 14 42.41	Apr. 27 35.96	Apr. 27 38.34	Apr. 22 38.16	Apr. 22 36.78
Total for year ending	Aug. 19 35.68	Aug. 16 33.97	Aug. 17 49.83	Aug. 18 40.22	Aug. 11 43.66	Aug. 10 46.39	Aug. 9 48.76	....	July 28 39.59	....

* An asterisk indicates the month in which ascospores were first observed at the various stations.

TABLE IV

Number of Days with Precipitation 0.01 Inch or More

	Concord, N. H.	Williams-town, Mass.	Amherst, Mass.	Hartford, Conn.	Mohonk Lake, N. Y.	Wilmington, Del.	Woodstock, Md.	Frederick, Md.	Washing-ton, D. C.	Charlottes-ville, Va.
1914										
April	14	14	16	17	8	11	12	11	9	8
May	6	9	11	7	3	5	6	8	7	5
June	8	10	8	12	7	10	14	12	11	11
July	11	13	14	14	10	16	7	12	12	8
August	12	11	10	11	6	9	12	13	10	11
September	4	3	6	4	2	2	5	9	4	5
October	6	5	5	5	2	4	9	7	7	9
November	8	11	7	7	7	2	3	4	4	4
December	10	8	8	9	7	11	17	15	12	16
1915										
January	10	11	12	13	7	13	12	11	14	9
February	8	9	12	11	5	8	8	10	8	7
March	0	6	3	3	2	2	5	7	5	4
April	8	9	7	7	6	9	10	18	7	4
May	9	8	11	11	9	14	16	13	11	10
June	10	11	8	13	7	11	13	12	14	10
July	16	14	20	16	18	7	13	15	13	12
August	15	15	14	13	10	11	15	18	18	15
Total for year ending	May 18 91	May 22 104	May 17 102	May 15 101	May 24 69	May 14 92	Apr. 27 109	Apr. 27 124	Apr. 22 101	Apr. 22 93
Total for year ending	Aug. 19 106	Aug. 16 110	Aug. 17 114	Aug. 18 127	Aug. 11 82	Aug. 10 94	Aug. 9 126	....	July 28 109	....

killing frost in autumn is also available for most of the stations and the regular Weather Bureau observation stations give the percentage of possible sunshine each day as well as atmospheric pressure and direction and velocity of wind.

Among the climatic elements recorded, any direct relation between atmospheric pressure and growth is very difficult to trace. Wind velocity and light while undoubtedly important for a green plant probably have little relation to the growth of *Endothia parasitica*, especially since the advancing edge of the mycelium is under the unbroken bark of the host tree. A careful study of the Weather Bureau data shows no correlation between amount of growth and either the prevailing direction of the wind or the number of clear days during the period investigated. The writer's laboratory experiments also have failed to demonstrate any relation between the amount of light and the growth and fructification of the fungus even when growing on the surface of culture media.

Precipitation

As regards precipitation, there are plainly two elements to be considered: the amount of rainfall and its distribution. Table III gives the monthly precipitation for each station during the course of the investigations, Table IV the number of days with more than .01 inch precipitation for each year during the same period. Careful examination of rainfall data fails to show any relation between either amount or frequency of rain and the amount of growth of the fungus. Amherst, Mass., had practically the same rainfall as Charlottesville, Va. Yet the growth at the latter point averaged nearly four inches greater. Williamstown, Mass., on the other hand, had a much smaller rainfall than Amherst but showed about the same amount of growth. Amherst, Mass., and Hartford, Conn., had much greater rainfall for the year ending in August than for that ending in May, yet the amount of growth was practically the same.

While the different localities show considerable variation both in the amount of rainfall and in the number of days with rain this seems to have no relation to the amount of growth. This is probably best shown by the curves (figs. 1 and 2) of rainfall and number of days with precipitation. The various points of these curves are expressed in percentage of the rainfall and number of days with rain at Charlottesville, Va. The irregularity of the rainfall curves as compared with the curve of growth makes it seem almost impossible that either total amount of rainfall or number of days with rain has any direct effect on the growth of the fungus. This is theoretically very probable since the growing edge of the fungus is in or near the cambium of the host under the bark and its moisture supply must come from the host itself.

It is conceivable that a fungus might be susceptible to changes in the water content of those portions of its host in which it grows, so slight as not to produce a perceptible effect on the host. There is, however, no evidence that such is the case in *Endothia parasitica*. On the other hand Rankin (9, p. 245) who investigated the relation of the growth of *Endothia parasitica* to the water content of the bark of *Castanea dentata* during the summer of 1912 at Napanoch, N. Y., failed to demonstrate that the "variation in the physiology of the tree which results from drought conditions alters to any great degree either the susceptibility of the chestnut tree or the rate of progress of the mycelium in the bark."

With his conclusion the writer's observations entirely agree. In the course of three years' inoculation experiments and field observation the writer has been unable to obtain any evidence that the rate of growth of this fungus is affected by external dryness which does not produce a perceptible withering effect on the host.

Length of Frostless Season

The only remaining factor seems to be that of temperature. Zon (13) has emphasized the necessity of considering the length of the growing period in plant climatology and the advisability of tabulating climatic data separately for the period of growth and the period of rest. While his contention is undoubtedly correct for green plants it is apparently not true in the case of *Endothia parasitica* which has, strictly speaking, no resting season. Field observations and laboratory experiments both show that *Endothia parasitica* will grow whenever the temperature rises above its minimum for growth, which, as Shear and Stevens (11, p. 7) have determined, is about 8° or 9° C. This is apparently true regardless of the previous temperature and whether the host is dormant or not.

Anderson and Rankin (3, p. 574) conducted experiments separately at Charter Oak, Pa., and Napanoch, N. Y., and agree that the chief growth of *Endothia parasitica* occurs between March and October but that the fungus continues to grow during mild periods of winter. During January, 1913, an average lateral growth of 0.51 cm. was recorded for cankers at Charter Oak, Pa., while no growth whatever was recorded in November, December, or February. In this connection Anderson and Rankin call attention to the fact that during January there were ten different days in which a temperature above 9° C. was recorded. As Rankin (9, p. 244) states, "cessation of growth of the mycelium in the bark during fall and winter as well as negative results of inoculations at this time of the year is explained purely on the basis that the temperature is too low for the vegetative activity of the fungus."

Experiments made by the writer with plate cultures of *Endothia parasitica* in the laboratory agree with these field observations. When such cultures were kept at temperatures below their minimum for growth, that is, 7° C., 3° C., and 1° C., for twenty-four hours and then removed to room temperature for twenty-four hours, they grew practically as much while in the warm room as did cultures which had never been in the ice box. So quickly does the fungus recover from the effect of the low temperatures that plate cultures which were kept in the refrigerator for twenty-two hours and at room temperature for only two hours each day showed a measurable growth at the end of a week. Spring weather, with warm days and cool nights or even a warm period in midwinter would then permit growth. In fact plate cultures kept out doors at Washington, D. C., during January, 1915, made a total growth of 1.5 cm. for the month. Anderson and Rankin further state (3, p. 575) that "the mycelium does not seem to be injured in the least by freezing, but remains alive in all parts of the canker during the winter. These investigators report that cultures kept frozen for a month at a time renewed growth naturally on being brought back into the laboratory."

This being the case one would expect to find little connection between the length of frostless season and the amount of growth in the various localities. Table V gives the length of frost-free period in days during the time of the experiment at the various stations. There is of course in general a decrease in the length of frost-free period from Charlottesville northward. This is, however, not regular, since the length of frost-free period is greater at Hartford, Conn., than at Van Bibber or Woodstock, Md., while the growth is of course greater at the latter points. Williamstown, Mass., had a considerably shorter frost-free period than Hartford, Conn., and on the other hand a much longer frost-free period than Amherst, Mass., while the amount of growth at these points is practically the same. The curves, figure 2, in which the length of frost-free period at the various points is indicated in percentage of the period at Charlottesville, show that while there is in general a falling off in the length of frost-free period from Charlottesville to Concord, the agreement between this curve and the curve of growth is not such as to indicate any direct causal relation.

TABLE V

Frost Data for Various Localities

Locality	First Killing Frost in Autumn, 1914	Last Killing Frost in Spring, 1915	Length of Frost-free Period in Days
Concord, N. H.	September 29	May 15	137
Amherst, Mass.	28	20	131
Williamstown, Mass.	29	April 22	160
Hartford, Conn.	October 27	13	197
Mohonk Lake, N. Y.	14	14	183
Wilmington, Del.	28	4	207
Van Bibber, Md.	September 29	15	167
Woodstock, Md.	29	15	167
Frederick, Md.	October 28	15	196
Washington, D. C.	28	3	208
Charlottesville, Va.	28	5	206

TEMPERATURE

In measuring the effectiveness of temperature in plant climatological studies annual or monthly means are obviously of very little significance. As has been frequently pointed out, localities with similar mean annual temperatures may have actually very different climatic conditions. Among the methods of measuring temperature more satisfactorily probably the most used is that of direct summation of daily mean temperatures. Merriam (6) was the first to apply this method in preparing a chart of the climatic zones of the United States. Briefly, the method is as follows: A certain minimum temperature is assumed as a starting point and the amount added to the summation each day is the number of degrees above the assumed minimum which represents the mean temperature for that day. The minimum is sometimes the freezing point but often a somewhat higher temperature.

Recently the Livingstons (5, p. 353) have called attention to the act that although these temperature summations have in many nstances furnished data consistent among themselves and constituting an apparently reliable criterion for the measurement of the intensity and duration aspects of the temperature factor it is improbable that any fundamental or general principle regarding the influence of temperature in a plant is derived from the relations thus brought out. They suggest as more satisfactory for measuring temperature effectiveness a method of calculating temperature efficiencies based on the well-known chemical principle of van't Hoff and Arrhenius, that within limits the velocity of most chemical reactions doubles or somewhat more than doubles for each rise in temperature of 10° C. On this basis the Livingstons (5, p. 366) have prepared a table of approximate efficiency indices for temperatures in whole degrees from 40° F. to 99° F., assuming the efficiency to be unity at 40° and to double with each rise in temperature of 18°, and have prepared maps of the United States comparing temperature summations with the temperature efficiencies calculated according to their tables. The results of the two methods show a rather close general agreement but there are numerous discrepancies in detail.

For purposes of comparison both methods have been used in the present work. In all calculations the mean for each day was determined by the formula: Mean = $\frac{1}{2}$(maximum + minimum). The calculations have been made in the Fahrenheit scale, not because this scale is as convenient as the Centigrade but because all Weather Bureau data are so published.

Direct Temperature Summations

The direct temperature summations have been calculated for all the stations where complete data are available.[4] Forty-five degrees F. has been regarded as the zero point, since it is undoubtedly slightly below the temperature at which *Endothia parasitica* is able to grow (11). The amount added each day is then one half the sum of the maximum plus the minimum temperature as given in the monthly reports of climatological data issued by the Weather Bureau. The sum of these amounts for the 365 days for which the growth of the canker was measured is the temperature summation for the year. Table VI gives these summations for the various localities and the percentage of each when the summation at Charlottesville for the year ending April 23, 1915, is considered 100 percent.

With the single exception of Wilmington there is a fairly regular

[4] The writer is indebted to Mr. Anthony Merryman for much assistance in calculating weather data.

decrease in the temperature summations from Charlottesville northward. A comparison of the curves of growth and temperature summation (figs. 1 and 2) shows that there are some irregularities and that the temperature summation falls somewhat more rapidly northward than does the amount of growth.

TABLE VI

Temperature Summations

Locality	Year Ending	Summation	Percent	Year Ending	Summation	Percent
Charlottesville, Va....	Apr. 20	6,412	100.00			
Washington, D. C....	22	5,153	80.0	July 28	4,941	77.1
Frederick, Md........	27	5,005	78.1			
Woodstock, Md......	27	5,024	78.3	Aug. 9	4,742	73.8
Wilmington, Del......	May 14	5,443	84.9	10	5,169	80.0
Mohonk Lake, N. Y..	24	3,623	56.5	11	3,465	54.0
Hartford, Conn......	15	3,943	61.0	18	3,779	59.0
Amherst, Mass.......	17	3,584	55.9	17	3,479	54.3
Williamstown, Mass..	22	3,017	47.0	16	2,970	46.3
Concord, N. H.......	18	3,045	47.5	19	2,924	45.6

TEMPERATURE EFFICIENCIES

In calculating temperature efficiencies the Livingstons' method was adopted with no change except in the zero point. That is, it was assumed that the efficiency doubled with each rise in temperature of 18° F., since this assumption seems to agree most nearly with the work of the numerous investigators who have sought to determine the application of the van't Hoff-Arrhenius principle to physiology.[5]

There is, of course, no direct evidence that growth in the case of this particular fungus is accelerated by rise in temperature at the rate assumed. The calculations were made rather to determine how closely the general law would apply to this organism under field conditions.

Efficiency was assumed to be unity at 45° F. The writer is however inclined to believe now that 47° might be even more accurate. This makes the formula for calculating efficiency

$$e = 2^{\frac{t-45}{18}},$$

when e = the efficiency and t the daily mean temperature. A table was prepared on this basis and used in calculating the temperature

[5] For a brief résumé of the literature on this point see 5, p. 356–359.

efficiency for each day. The table is obviously the same as that given by the Livingstons (5, p. 366) except that it assumes 45° instead of 40° to equal unity. Whenever the mean daily temperature was below 45° the efficiency was considered zero. The efficiency index of each locality for a year is the sum of the daily indices.

Table VII gives the temperature efficiencies for the various localities studied and the percentage of each based on the temperature efficiency of Charlottesville as 100 percent. This table should be compared first of course with the table of temperature summations. As the figures of the efficiency index at Charlottesville approximately equal the first two figures of the temperature summation at that point a rough direct comparison is possible. In general, it is evident that the temperature efficiency indices fall off less rapidly in amount from Charlottesville northward than do the temperature summations. This is shown more strikingly by the percentages and as is indicated by the figures the curve of temperature efficiency follows the curve of growth more closely for the northern localities than does the curve of temperature summations. The former falls slightly less rapidly than does the growth curve; the latter somewhat more rapidly. The only serious exception is Wilmington which has higher temperature summation and efficiency indices than the other Maryland stations or even Washington, D. C., without a corresponding increase in amount of growth. This discrepancy the writer is wholly unable to explain.

TABLE VII

Temperature Efficiencies

Locality	Year Ending	Efficiencies	Percent	Year Ending	Efficiencies	Percent
Charlottesville, Va....	Apr. 20	635	100.0	....	....	....
Fairfax, Va..........	....	....	....	....	....	....
Washington, D. C....	Apr. 22	594	94	July 28	574	90
Frederick, Md.......	27	586	93	....	....	....
Woodstock, Md......	27	586	92	Aug. 9	562	89
Van Bibber, Md......	....	....	....	....	....	....
Wilmington, Del......	May 13	632	99	Aug. 10	605	95
Hartford, Conn.......	15	481	76	18	463	73
Mohonk Lake, N. Y..	24	435	68	11	421	66
Amherst, Mass.......	17	431	68	17	421	66
Williamstown, Mass..	22	396	62	16	381	60
Concord, N. H.......	18	384	60	19	371	58

When the extent of the territory covered and the necessarily approximate nature of the data and their calculation are considered the degree of correlation between the curves of growth and of temperature is remarkably close. In general the correlation is slightly less perfect when the effect of temperature is expressed by efficiency indices than by direct summation. In either case, there can be little doubt that under climatic conditions in which the optimum temperature of the fungus is rarely greatly exceeded (11, p. 9) the amount of growth made by *Endothia parasitica* depends directly on the amount and duration of heat available. If this conclusion is correct the chestnut blight may be expected to spread somewhat faster in the future than it has in the past unless other factors intervene to check its growth. For instance, the temperature summation for Corinth, Miss. (year ending June 1, 1915), where there is still some chestnut and where *Endothia fluens mississippiensis* was first collected, is 6,561 or 102.0 percent of the summation at Charlottesville. The efficiency at that point is 764 or 120.3 percent of that at Charlottesville. The chestnut blight should then be able to make at Corinth a growth somewhat greater than that at Charlottesville and considerably greater than that at any of the northern points.

At first glance the statement that the amount of lateral growth of *Endothia parasitica* is dependent directly on temperature may seem so simple an explanation as to be artificial. A consideration of the conditions under which the advancing edge of the mycelium lives in the host shows, however, that the biological conditions are unusually constant and that the fungus is very little influenced by many factors of great importance to green plants.

The environmental factors most used in such a classification of plants as that given by Köppen (4), for instance, are many of them negligible. The chemical nature of the medium in which the fungus grows parasitically must be fairly constant since it is always the same portion of the same host species. Certainly the difference between individual trees of this species is so slight that as yet no tree resistant to this fungus has been found.

Light, so important in the growth of green plants, is negligible here. The writer has thus far been unable to demonstrate that light had any effect on the growth or reproduction of this fungus under laboratory conditions and in all probability no light whatever reaches the advancing edge of the mycelium under the bark.

The fungus has, moreover, no resting season. It is almost independent of external moisture supply since it lives in the portion of the host where moisture is most abundant, and where evaporation is very slight, if indeed it occurs at all.

If the biological relations of the fungus are correctly understood it is, while growing as a parasite in or near the cambium of its host, uninfluenced by any environmental condition except that of temperature, at least in the territory it now occupies in this country. And the influence of temperature itself is restricted to an increase or decrease of the amount of growth rather than any permanent cessation of growth such as is brought about by heavy frost in the case of green plants.

Ascospore Production

In studying the relation of climatic conditions to reproduction in *Endothia parasitica* attention was concentrated on the production of ascospores. The time necessary for the development of pycnidia is so short that to determine the factors involved would necessitate an intensive study of a few adjacent localities, with much more frequent visits than were possible in covering so large an area as was involved in the present study.

Previous observations on the production of ascospores have been isolated rather than comparative. Murrill (8, p. 187), in his original description of the fungus, stated: "The winter spores [ascospores] mature in late autumn . . . and germinate the following spring."

Anderson and Babcock (2, p. 36) made several hundred inoculations on various dates from May 29 to July 12, 1912, and recorded the date of appearance of pycnospore horns and perithecia. They conclude that (p. 37): "In general it may be said that under natural conditions in the summer time the spore horns will be developed in from three to six weeks, and that the winter or ascospore stage will develop in ten weeks or more. The fact that the perithecial stage on all these plots appeared in September and October should not be interpreted as indicating that the approach of winter had any influence in bringing about this stage."

Rankin (9, p. 249) made inoculations at Napanoch, Ulster Co., N. Y., each month during the summer of 1912 commencing with May and observed that stromata were not produced on any of the cankers until about the second week of September (p. 254), and that they appeared as quickly on cankers produced by inoculations of July 4 as on those made May 1. Cankers produced from inoculations made at different times from May 1 to August 1 showed uniformly mature perithecia and ascospores by the middle of November. He refers to the perithecial stromata developing "abundantly in the autumn around the old pycnidia."

Rogers and Gravatt (10, p. 45) report that in their inoculations at Leesburg, Va., made on July 21 and August 16, 1912, pycnidia with spore horns were developed by October 6. Although the cankers were examined in March and again in August, 1914, no perithecia were found.

That unfavorable conditions may delay for a long time and perhaps entirely prevent the production of ascospores was first brought to the writer's attention by inoculations of *Endothia parasitica* on chestnut sprouts near Washington, D. C. These inoculations were made in July, 1913, and produced abundant pycnidia within two weeks. Sections of the stromata made in September, 1913, showed numerous fundaments of perithecia. The inoculations were conveniently located and as they were from the first material sent from China by Meyer were frequently examined. The cankers continued to grow normally and in most cases girdled the sprouts and formed numerous stromata with abundant pycnospores and fundaments of perithecia. Up to December, 1914, however, when the sprouts were destroyed by fire, no ascospores had developed.

Field Observations

When this work was begun it was expected that ascospores would be produced in the fall as had been the case in the work of Anderson and Babcock and of Rankin and other investigators. Actually, however, at none of the stations was a single canker in the entire series of inoculations found which had produced ascospores or even mature appearing perithecia during the season for 1914. In 1915, however, quite different climatic conditions existed. Perithecia and mature ascospores were found in abundance not only on cankers arising from inoculations made in 1914 but from those made in May, 1915. The problem then became not so much a comparison of the fructification at different localities as a comparison of the fructification during different seasons at the same locality.

Table VIII gives the results of observations at the various localities on the development of perithecia and mature ascospores. It is evident that no perithecia were produced during the season of 1914 at any of the localities. Observations made December, 1914, at stations as

Table VIII

Observations on the Development of Perithecia and Mature Ascospores at Various Localities

Locality	Inoculations Made	No Perithecia Up to and Including	Perithecia with Mature Ascospores First Observed	Additional Notes
Charlottesville, Va.	Apr. 20, May 21, July 3, Aug. 11, and Oct. 2, 1914.	Dec. 24, 1914.	....	Destroyed by fire last week in Apr., 1915.
Fairfax, Va.	Apr. 21, June 6, July 4, Aug. 1, and Oct. 24, 1914.	Dec. 23, 1914.	June 6, 1915. On cankers from all inoculations except those of Oct. 24, 1915 and Aug. 6, 1915, from inoculations of Oct. 24, 1915.	One of the trees inoculated Apr. 21, 1914, died during that summer and no ascospores were produced on this tree.
Vienna, Va.	Apr. 2, May 14, June 6 and July 18, 1915.	Aug. 1, 1915.	Sept. 21, 1915. Abundant from all inoculations.	Perithecia more abundant on inoculations of June 6 and July 18 than previous ones.
Washington, D. C.	Apr. 22, May 28, June 25, July 28, and Oct. 21, 1914.	Dec. 25, 1914.	A few mature perithecia, Apr. 22, 1915, from inoculations except those of Oct. 21, 1914. Abundant July 28, 1915, on all.	....
Frederick, Md.	Apr. 27, May 30, Aug. 9, and Oct. 19, 1914.	Dec. 20, 1914.	May 14, 1915. A few from inoculations of Apr. 27 and May 30, 1914.	In 1914 there was less development of pycnospore horns from May 30 to Aug. 9 than in the month preceding May 30.
Woodstock, Md.	......do......	Dec. 27, 1914.	Aug. 9, 1915. Numerous on all inoculations.	
Van Bibber, Md.........	Apr. 28, May 14, June 1, July 6, Aug. 10, Oct. 7, 1914; May 14, 1915.	Dec. 28, 1914.	May 14, 1915, from all inoculations except those of Oct. 7, 1914. Oct. 7, 1915, from all inoculations, including those of May 14, 1915.	....
Wilmington, Del.	Apr. 29, May 14, June 1, July 6, and Aug. 10, 1914.	Dec. 28, 1914.	May 14, 1915. Numerous from inoculation of April 29. Few from inoculations of May, June, and July. Aug. 10, 1915. Numerous on all mentioned above.	No perithecia were developed from the inoculations made Aug. 10, 1914, but the number from the earlier inoculations were greatly increased.

TABLE VIII—(*Continued*)

Locality	Inoculations Made	No Perithecia Up to and Including	Perithecia with Mature Ascospores First Observed	Additional Notes
Hartford, Conn.	May 15, June 8, July 15, Aug. 18, and Sept. 24.	Sept. 23, 1914.	May 15, 1915. A few mature perithecia. Aug. 18, 1915. Abundant from all inoculations.	....
Amherst, Mass.	May 17, June 8, July 15, Aug. 17, Sept. 24, 1914; May 17, 1915.	May 17, 1915.	Aug. 17, 1915. From all inoculations, including those of May 17, 1915.	....
Williamstown, Mass.	May 22, June 9, July 14, Aug. 16 and Sept. 25, 1914, and May 22, 1915.	May 22, 1915. Occasional immature perithecia were found on this date.	Aug. 16, 1915. Numerous from all inoculations except those of May 22, 1915.	The trees inoculated May 22, 1915, had unusually thick bark.
Concord, N. H.	May 18, June 11, July 17, Aug. 20, and Sept. 22, 1914, and May 18, 1915.	May 18, 1915.	Aug. 19, 1915. Present in cankers from inoculations on all dates, including those of May 18, 1915.	....

Locality		Inoculations Made	No Perithecia Up to and Including	Perithecia with Mature Ascospores First Observed	Additional Notes
Stations on Overlook Mountain.	Elevation in Feet				
O 7	600	On or about May 25, June 12, July 10, Aug. 12, and Oct. 1, 1914.	Oct., 1915.	May 15, 1915. Abundant.	....
S 3	1,000	Do.	Oct. 1, 1915.	May 24, 1915. Abundant near the center of one canker. Aug. 14, 1915. Abundant in all cankers.	....
S 1	1,500	On or about May 25, June 12, July 10, Aug. 12, and Oct. 1, 1914. and May 25, 1915.	May 24, 1915.	Aug. 11, 1915. Abundant on all, including inoculations of May 24, 1915.	Old cankers which had perithecia were producing pycnospore tendrils in large quantities often in the same stromata.

TABLE VIII (*Continued*)

Locality		Inoculations Made	No Perithecia Up to and Including	Perithecia with Mature Ascospores First Observed	Additional Notes
Stations on Overlook Mountain	Elevation in Feet				
C	1,500	On or about May 25, June 12, July 10, Aug. 12, and Oct. 1, 1914.	May 23, 1915.	Aug. 11, 1915. Present in cankers from all inoculations.	Perithecia less numerous than at the lower stations.
O 6	1,500	Do.	Oct. 1, 1915.	May 26, 1915. Present in cankers from inoculations of May and June 1915. Aug. 11, 1915, abundant in all.	....
O 1	1,900	Do.	May 26, 1915.	Aug. 13, 1914. Abundant.	....
O 2	2,500	Do.	Aug. 12, 1915.	....	....
O 4	2,800	On or about May 25, June 12, July 10, Aug. 12, and Oct. 1, 1914. and May 25, 1915.	May 26. Nearly mature.	Aug. 13. Mature perithecia from one inoculation of May 14.	....
O 3	2,900	On or about May 25, June 12, July 10, Aug. 12, and Oct. 1, 1914.	Aug. 13, 1915.	....	....

far north as Wilmington failed to show any perithecia. Perithecia did, however, develop during the late winter and spring as far north as Hartford, Conn., and up to an altitude of 1,500 feet on Overlook Mountain. Perithecia developed also at both northern and southern stations during the summer of 1915 although they were somewhat less abundant at Wilmington than at other stations and were found at only one of the three highest stations on Overlook Mountain and here only rarely.

TEMPERATURE

On comparing these data (see Table VIII) with the Weather Bureau records it is evident that perithecia may be produced under quite different temperature conditions. In our investigations they were produced between December 25 and April 22 at Washington,

D. C., at Woodstock, Md., Van Bibber, Md., and Wilmington, Del., and they were developed during the period between December 26 and February 15 at Washington Junction, Md. They were also produced in small number at an elevation of 1,000 feet on Overlook Mountain between October 1 and May 2. On the other hand, perithecia have been produced in mid-summer at all stations from Concord, N. H., to Vienna, Va. Perithecia were not produced during the winter or spring north of Hartford, Conn., and low temperature may in this case have been a limiting factor. Certainly perithecia are developed through a considerable range of temperature.

TABLE IX

Monthly Temperature Efficiency Indices for Various Localities

	Charlottesville, Va.	Washington, D. C.	Frederick, Md.	Woodstock, Md.	Wilmington, Del.	Hartford, Conn.	Mohonk Lake, N. Y.	Amherst, Mass.	Williamstown, Mass.	Concord, N. H.
1914										
May	85	76	75	73	..	..	..	..	..	28
June	89	94	96	93	95	71	66	66	63	60
July	107	106	103	101	106	82	75	79	75	75
August	117	98	102	103	109	87	79	82	74	73
September	76	72	67	68	79	65	65	58	51	57
October	57	56	52	57	61	49	46	43	38	37
November	28	25	22	22	27	15	10	9	7	6
December	4	6	5	7	5	3	4	1	4	0
1915										
January	3	5	3	5	4	3	0	0	1	0
February	10	9	4	6	10	3	0	0	1	0
March	6	1	3	2	5	2	0	0	0	0
April	61	56	55	52	52	36	39	36	33	29
May	..	63	..	61	62	47	44	45	42	39
June	..	84	..	77	80	68	63	65	64	58
July	..	105	..	98	110	86	77	82	76	77
August	..	98	..	95	100	80	71	76	67	71

It has been rather generally believed that low temperature was a determining factor in the production of ascospores by pyrenomycetes and ascospores have often been loosely referred to as "winter spores," a term used indeed in connection with *Endothia parasitica* (8, p. 187). That low temperatures are not necessary for the production of ascospores by *Endothia parasitica* is shown by the fact that they developed before September 21, 1915, from inoculations made July 18, 1915, at Vienna, Va., during which time no temperature below 54° was recorded, and the mean temperature was well over 70°. That high temperatures on the other hand are not necessary is shown by the fact that ascospores developed at many stations between December, 1914, and May, 1915, and at Washington Junction, Md., between December 26, 1914, and February 15, 1915. Certainly (see Tables IX and X) the difference between the summer temperatures of 1914 and of 1915 is so slight that the failure of perithecia to develop in the first summer and their abundance in the second summer cannot be due to the difference in temperature.

TABLE X

Monthly Temperature Summations for Various Localities

	Char-lottes-ville, Va.	Wash-ington, D. C.	Fred-erick, Md	Wood-stock, Md.	Wil-ming-ton, Del.	Hart-foid, Conn.	Mohonk Lake, N. Y.	Am-herst, N. Y.	Wil-liams-town, Mass.	Con-cord, N. H,
1914										
May	765	717	663	639	716	540	489	439	408	345
June	921	870	870	858	880	618	599	590	557	539
July	1,000	960	952	934	970	757	702	737	707	684
August	1,048	892	931	952	998	825	745	770	676	676
September	672	643	584	591	712	541	549	488	404	441
October	480	481	432	443	507	341	347	313	74	232
November	188	138	100	125	143	67	26	29	18	23
December	25	36	31	36	29	8	14	3	11	0
1915										
January	8	18	6	12	17	10	0	0	2	0
February	40	33	12	19	35	1	0	0	2	0
March	18	4	2	5	11	3	0	0	0	0
April	501	449	432	430	426	228	281	228	238	163
May	604	549	512	523	539	338	281	290	232	198
June	760	774	754	718	736	640	561	590	591	514
July	993	973	963	869	1,014	807	716	779	727	720
August	899	905	881	885	923	743	641	703	622	644

MOISTURE

There seems, however, to be a fairly constant relation between the appearance of perithecia and the amount of precipitation, or more properly the amount of moisture in the air. For convenience in reference a * has been placed in Table III to indicate the month in which ascospores were first observed at the various stations. At many localities perithecia were first noted in the spring, a season which of course is characterized by high humidity. In each case in which ascospores were produced during the summer the preceding months were characterized by abundant rainfall. July, 1915, at Concord, Williamstown, and Amherst, showed over 9 inches of rain and the perithecial production was correspondingly abundant.

Observations in Ulster County, New York

Perhaps the most complete records regarding the appearance of perithecia and ascospores are the inoculations at Ulster Co., New York. As stated above, Rankin (9) found at Napanoch, N. Y., that ascospores were produced by the middle of November from inoculations made at different times from May 1 to August 1.

Table XI

Monthly Climatological Data for Three Seasons at Mohonk Lake, N. Y.

	Temperature			Precipitation	
	Mean	Summation	Efficiency	In Inches	Days with Over .01 Inch
1912.					
May	58.6	440	54	3.99	11
June	65.6	626	70	1.30	4
July	70.6	802	86	3.42	11
August	64.8	624	67	3.88	12
September	60.8	475	56	3.28	14
October	53.9	...	...	4.50	8
1914.					
May	61.2	489	...	4.10	3
June	64.8	599	66	2.40	7
July	67.0	702	75	3.75	10
August	68.8	745	79	2.54	6
September	63.2	549	65	0.32	2
October	55.7	347	46	3.55	2
1915.					
May	53.6	281	44	2.54	9
June	63.5	561	63	2.65	7
July	68.2	716	77	8.24	18
August	65.4	641	71	7.94	10

The writer made a somewhat similar series of inoculations during the summer of 1914 at Woodstock. Inoculations were made each month in ten different localities on Overlook Mountain. None of these produced perithecia during the season of 1914, but most of them as well as inoculations made in May, 1915, produced perithecia abundantly by the middle of August, 1915. As Rankin made over 1,500 inoculations and the writer made more than twice that number the results were probably not due to chance but to a difference in the weather conditions.

The nearest weather station to these two localities is at Mohonk Lake, in Ulster County, elevation 1,245 feet. Mohonk Lake is between Napanoch and Woodstock, about equidistant from them and has about the same elevation. Observations made at this point while not absolutely identical with conditions at either of the stations would undoubtedly approximate the conditions at both. This was certainly true in the seasons under consideration for the Monthly Weather Reports of that section indicate that the weather conditions recorded at Mohonk Lake prevailed generally over the Eastern Plateau region.

Table XI gives the monthly precipitation, monthly mean temperature, temperature efficiency, and temperature summation, for the growing seasons of 1912, 1914, and 1915, at Mohonk Lake, N. Y. Comparison of the data for the three seasons shows only slight differences in temperature. June and July were warmest in 1912, August and September warmest in 1914. These differences are, however, slight, and can hardly have been significant in preventing ascospore production in 1914, since ascospores have been produced elsewhere at higher as well as lower temperatures.

There is on the other hand a considerable difference in the precipitation of the three years. 1915, when ascospores were produced abundantly before August 15, had much heavier rainfall in July than either of the other years. In 1912 ascospores were produced in November; in 1914, on the other hand, no ascospores were produced. It is then probably significant that August, September, and October, 1912, had a total precipitation of 3.88, 3.28, and 4.50 inches respectively, as against 2.54, 0.32, and 3.55 inches for the corresponding months in 1914, a difference of over 4 inches for the three months in favor of 1912. This difference is best seen from the graphs, figure 3. Distribution of rainfall is probably more important to the fungus than its total amount since most of the moisture for the growth of the fruiting bodies of the fungus must come from the outside.[6] The three months under consideration had 34 days with more than 0.01 inch of rainfall in 1912 and only 10 in 1914.

Even this difference, however, does not give an adequate idea of the difference in the two years, or of the extent and severity of the drought of September, 1914. In August, 1912, the 3.88 inches of rain came mostly after the middle of the month, the 14 rainy days in September were well distributed and October had a rainfall nearly an

[6] The number of days with rain is of great importance to all vegetation in such a region as that on Overlook Mountain where the run-off is very great and comparatively little moisture is left in the soil. The writer has discussed the run-off of this region in another connection (12, p. 265).

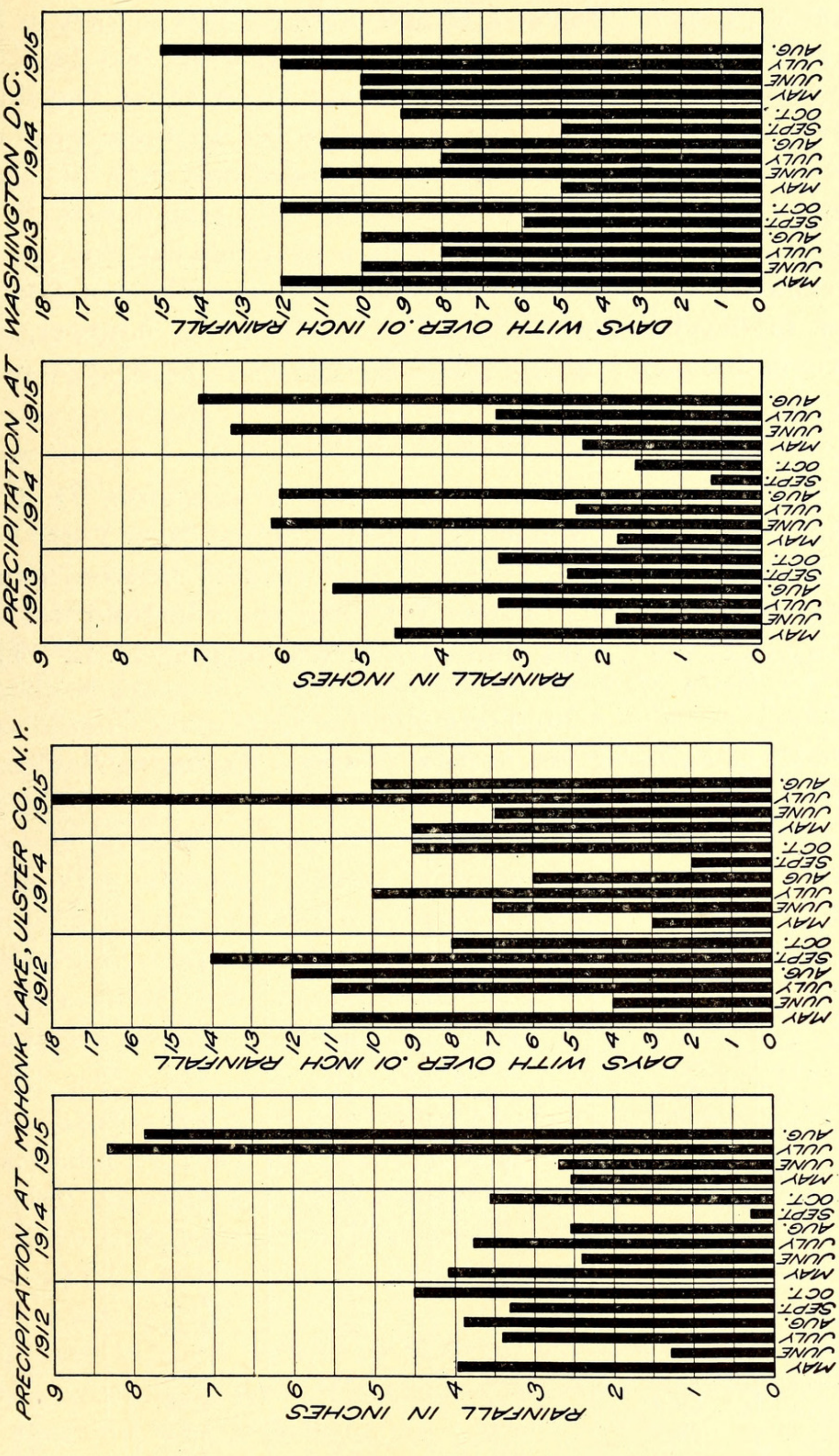

Fig. 3. Graphs showing monthly rainfall and number of days with rain for the growing seasons during three years in Ulster County, New York, and Washington, D. C.

inch above normal. Quite different conditions prevailed in 1914. There was no rain in August after the 21st, only 0.32 inch in September, and no rain in October until the 16th, when two days' rain gave the 3.55 inches of rain recorded. It will be seen then that during almost two months from August 21 to October 16 there were only two days with appreciable rain and these totaled only 0.32 inch, while from August 21 to November 1 there were only four days with any rain. It is of course by no means certain that this extreme drought was the cause of the total failure of the numerous cankers of *Endothia parasitica* to develop perithecia. The condition is, however, very suggestive, and it seems highly probable that a causal relation exists.

Observations near Washington, D. C.

The number of inoculations made near Washington, D. C., is much smaller than of those made in Ulster County, New York. The data available, however, indicate a similar relation between climate and ascospore production. Table XII gives the climatological data for the seasons of 1913, 1914, and 1915 at Washington, D. C. There

Table XII

Monthly Climatological Data for Three Seasons at Washington, D. C.

	Temperature			Precipitation	
	Mean	Summation	Efficiency	In Inches	Days with Over .01 Inch
1913					
May	64.4	602	67	4.55	12
June	73.0	815	91	1.81	10
July	78.0	1011	112	3.24	11
August	74.0	909	97	5.43	10
September	67.0	676	75	2.41	6
October	59.0	417	53	3.37	12
November	48.0	130	25	2.20	8
1914					
May	67.0	717	76	1.72	5
June	73.8	870	94	6.20	11
July	75.9	960	106	2.32	8
August	76.4	892	98	6.00	11
September	66.0	643	72	0.66	5
October	60.0	481	56	1.56	9
November	45.4	139	25	4.49	4
1915					
May	62.5	549	63	2.18	10
June	70.6	774	84	6.58	10
July	76.1	973	105	3.21	12
August	74.0	905	98	7.00	15

is little difference in the temperature of the three summers, although 1913 was somewhat warmer than the others. Both 1913 and 1914, the years in which no perithecia were produced, had a decided drought in the fall months. 1915, on the other hand, when perithecia appeared abundantly by September, had 7 inches of rainfall in August. In this locality, as in Ulster County, New York, perithecia appeared following a period of abundant rainfall and failed to appear in dry weather. It is somewhat surprising that perithecia failed to appear in August, 1914, since the months in Washington had a larger rainfall than the fall months of 1912 in Ulster County. On the other hand, the temperature was much higher in Washington during August, 1914, and the humidity, therefore, presumably lower. This would indicate that it is humidity rather than rainfall as such that determines the production of perithecia. These data are in accord with the assertion originally made by Metcalf (7) that in dry weather spore production was reduced and that dry seasons checked the progress of the chestnut blight.

On comparing the climatological conditions at the two stations for the three years during which observations were made, it is evident that those years in which most ascospores were produced were the years of most abundant rainfall and largest number of days with rain regardless of temperature. If these conclusions are correct, temperature has very little relation to the production of ascospores by *Endothia parasitica*, whereas amount of moisture in the air has a determining relation. This is probable on theoretical grounds since perithecia develop on the dead tissues of the canker separated by a considerable distance from any living tissues of the host, so that moisture which reaches the developing perithecia must necessarily come from the air.

Summary

A quantitative comparison of the available climatic data with the growth and fructification of *Endothia parasitica* at various points from southern New Hampshire to central Virginia has been made.

The area covered includes the northern limits of growth of other species of Endothia and is a transition region for several important plant diseases.

Eleven stations, extending through five degrees of latitude, were chosen, as well as a series of stations at different elevations on Overlook Mountain in the Catskills.

The stations were visited regularly during the summer of 1914.

At each visit ten or more inoculations were made on healthy chestnut trees and notes taken as to the growth of the previous inoculations.

The average annual lateral growth was found to be least at the most northern locality, Concord, N. H., and to increase gradually southward. The growth at Charlottesville, Va., was nearly twice as great as that at Concord, N. H.

A similar relation was found among inoculations made on Overlook Mountain, the amount of growth at elevations of 600 to 1,000 feet being from 20 to 25 percent greater than that at elevations of 2,500 to 2,900 feet.

The stations were all located near regular U. S. Weather Bureau observation stations and no meteorological observations were taken. This necessitated neglecting evaporation entirely, though evaporation is probably less important in the case of a parasitic fungus growing under the bark of a tree than in the case of most green plants.

The difference in the amount of growth of *Endothia parasitica* at the various stations seems to bear no relation to the amount or frequency of rainfall. Amherst, Mass., and Charlottesville, Va. had practically the same rainfall, yet the growth at the latter point averaged nearly eleven cm. greater. On the other hand, stations differing widely in rainfall showed practically the same amount of growth.

The length of frostless season is apparently unimportant, as the fungus has no dormant season. Low temperature retards or even prevents its growth, but growth is resumed as soon as favorable temperature returns. Cultures kept at temperatures as low as 1° C. for twenty-four hours resumed growth almost immediately when removed to room temperature and grew as rapidly as cultures which had never been chilled.

The amount of growth at the various stations is very closely related to the duration and intensity of favorable temperatures.

In tracing the relation between temperature and growth, temperatures were calculated by direct summation as well as by the method of temperature "efficiencies" suggested by Livingston and the results of the two methods compared. The methods give nearly parallel results, though temperature summations agree slightly more closely with amount of growth than do temperature efficiencies.

The time necessary for the development of pycnospores is so short that the climatic factors involved could not be traced.

The fungus in some cases continued to grow parasitically for over eighteen months without producing ascospores.

No mature perithecia were developed at any of the stations during 1914.

Perithecia and ascospores were produced in abundance at many stations during the late winter as well as the spring and summer of 1915.

Air temperature had very little relation to the development of ascospores. They were matured both in midwinter and in midsummer near Washington, D. C., in 1915.

There is a fairly constant relation between the development of ascospores and the amount of atmospheric moisture.

Perithecia were frequently first observed in the spring, a season characterized by high humidity.

The abundant rainfall during the summer of 1915 was accompanied by abundant ascospore production.

The results obtained by Rankin in Ulster County, New York, during the summer of 1912 agree with those obtained by the writer in 1915.

A comparison of the climatological conditions of Ulster County, New York, and Washington, D. C., for three seasons shows that years in which ascospores were produced were the years of most abundant rainfall and largest number of days with rain regardless of temperature.

During the period under investigation dry weather has certainly tended to reduce the spread of the chestnut blight by reducing spore production.

From the data presented in this paper the chestnut blight may be expected to spread somewhat more rapidly in the Southern States than it has in Pennsylvania and the states farther north.

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