Butler University Botanical Studies

Volume 5 *Butler University Botanical Studies* Article 8

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(1929-1964)

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The *Butler University Botanical Studies* journal was published by the Botany Department of Butler University, Indianapolis, Indiana, from 1929 to 1964. The scientific journal featured original papers primarily on plant ecology, taxonomy, and microbiology. The papers contain valuable historical studies, especially floristic surveys that document Indiana's vegetation in past decades. Authors were Butler faculty, current and former master's degree students and undergraduates, and other Indiana botanists. The journal was started by Stanley Cain, noted conservation biologist, and edited through most of its years of production by Ray C. Friesner, Butler's first botanist and founder of the department in 1919. The journal was distributed to learned societies and libraries through exchange.

During the years of the journal's publication, the Butler University Botany Department had an active program of research and student training. 201 bachelor's degrees and 75 master's degrees in Botany were conferred during this period. Thirty-five of these graduates went on to earn doctorates at other institutions.

The Botany Department attracted many notable faculty members and students. Distinguished faculty, in addition to Cain and Friesner , included John E. Potzger, a forest ecologist and palynologist, Willard Nelson Clute, co-founder of the American Fern Society, Marion T. Hall, former director of the Morton Arboretum, C. Mervin Palmer, Rex Webster, and John Pelton. Some of the former undergraduate and master's students who made active contributions to the fields of botany and ecology include Dwight. W. Billings, Fay Kenoyer Daily, William A. Daily, Rexford Daudenmire, Francis Hueber, Frank McCormick, Scott McCoy, Robert Petty, Potzger, Helene Starcs, and Theodore Sperry. Cain, Daubenmire, Potzger, and Billings served as Presidents of the Ecological Society of America.

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RELATION OF ANNUAL RING FORMATION TO RAINFALL

As Illustrated in Six Species of Trees in Marshall County, Indiana

By RAY C. AND GLADYS M. FRIESNER

The rate of growth of trees is dependent upon a number of factors, some internal and hereditary and others external and environmental in character. Variations in growth from day to day and year to year within the same individual are related more definitely to environmental than to internal factors. Of the environmental factors, light, temperature and available water are perhaps the most important. The relation of tree growth to any one of these three factors is not simple or direct but rather a relation to the factor-complex. At any time when any two of these factors are adequate while the third is inadequate to support maximum growth, then that third factor becomes the limiting factor toward which there is the most direct relation on the part of the plant. In our area, during the normal growing season, temperature and light are more often adequate with available water becoming the limiting factor. It is thus seen that growth curves of trees will more often show a relation to rainfall curves than to those for any other single factor. Pearson (14) has pointed this out clearly.

The relation of growth curves to rainfall is not a simple one. Such factors as the following enter to make the relation complex: the time of year when the rains come, the proportion which comes during the growing season, how well they are distributed over the growing season, the topography and its relation to run-off, the character of the soil and its ability to store water from times of abundant to times of inadequate rainfall.

Douglas (4) has shown a definite relation between the width of annual rings in western conifers and rainfall. Fuller (6) has shown that there is a positive correlation between growth and rainfall in 46 out of 66 years in the case of a single section of *Quercus borealis maxima* and that in an additional 10 years the growth is influenced by a "carry-over of rainfall excess or deficiency from the preceding year." Robbins (15) found that in oak the mean monthly temperature of May and June shows an inverse relation to annual increase in growth rings and that there is a close relation between amount of annual growth and the rainfall for the months of March through June. He also found that rainfall deficiencies or excesses will vary in their effect upon growth depending upon the time of year when they come. If they come in the spring their effect will be reflected in the growth of the same year but if they come chiefly in late season their effect will be more noticeable the following year. Diller (3) found that growth in *Fagus grandifolia* shows an inverse relation to temperature for the month of June and a direct relation to rainfall for the same months. This fits well with the results obtained during 1940 from dendrometer and dendrograph studies on Fagus (5) in which it is clearly shown that the great majority of growth in this species occurs during the month of June. Previous work done in our laboratory on 11 trees of *Quercus alba,* 17 of *Q. montana,* 16 of *Q. velutina* and 9 of *Q. borealis maxima* (Kleine, Potzger, Friesner, 9) showed that there is a very close correlation between annual growth and rainfall for the months of June, July and August. This work was done on sites with considerable relief and hence subject to execessive run-off. It is thus unlikely that any appreciable reserve of water can be stored in the soil during the dormant season. It is, therefore, all the more apparent that there should be a relation between growth and rainfall during the growing season. Diller (3) found that drought years show their effect the following year while the results of Kleine, Potzger and Friesner (9) indicate that the time when drought-year effects will be apparent depends upon the time of year when the drought occurred and also upon the topography of the site where trees are growing. If the drought is in late spring and early summer its effect will be apparent during the present season. If it comes in autumn or winter it may have an effect the following season if the site is such as to he able to store up reserves of water, but if it is such that run-off is great or for any reason little reserves can be stored, it may show no independent effect at all. This was well shown in the studies of Lodewick (10) on long-leaf pine.

MacDougal and Shreve (13) found that growth data from stump sections of *Pinus radiata* showed correlation with total annual rainfall in 65% of the years. They found that no periods of seasonal rainfall showed any correlation with average growth of trunk even when rainfall for the growth period and one preceding month was considered. In redwood the correlation between total rainfall and growth was 64% and that between rainfall from December to September was 71%. Antevs (1) has shown that whether or not there is a correlation between tree growth and rainfall depends upon whether available water is on the "dry limit," i. e. whether it has become the limiting factor. When available water becomes the limiting factor tree growth shows a correlation in the Great Basin in 75% of the years. Lodewick (10) found 64% corelation between diametral growth in long-leaf pine and rainfall for the period March 1 to October 15 and 73% if the rainfall period is shortened to begin March 16.

Avery, Creighton and Hock (2) found very little positive correlation between annual ring formation in hemlock and rainfall for either August-February or March-July. Only a sligbt inverse correlation was found for mean March-July temperature.

Goldthwait and Lyon (8) concluded that the total rainfall absorbed by the soil during the growing season (May-July) was the most important member of the complex of climatic factors affecting growth in white pine. Residual effects from the snowless period of one year are sometimes reflected in the amount of growth next year. Lyon (12) studying four species of evergreen conifers, one deciduous conifer and one deciduous broadleaf tree found varying degrees of correlation between growth and rainfall and temperature. White pine proved to be more sensitive to water supply than any others studied. It showed a positive correlation between growth and rainfall for various combinations of months and also with temperature of the early spring. Scotch pine showed closest correlation with April-August rainfall, Norway spruce with March-May rainfall while Austrian pine showed closer correlation with rain which fell prior to the growing season. Of the deciduous trees European larch showed the closest correlation with water supplied by abnormally high March temperatures and with air temperatures for May. Red oak showed closest correlation with rain which fell during its growing season. This agrees with our earlier results in an area of high relief (Kleine, Potzger, Friesner, 9). In an earlier study Lyon (11) found that growth in hemlock showed strong correlation with rainfall in years of unusual drought or unusually well watered years but little correlation in years when rainfall was little less or little more than usual. Schumacher and Day (16) concluded that hemlock, some stands of long-leaf pine and some of short-leaf pine showed little significant correlation with average monthly rainfall, while other stands of both species of pine showed significant correlation with the average monthly rainfall of 15-month periods from June of one year to August of the next year. Oak data from North Carolina showed a correlation to both average monthly rainfall and its distribution.

MATERIALS AND METHODS

Sections were cut from stnmps and farther up the trunks of 17 specimens of *Quercus borealis maxima* (Marsh) Ashe, 4 specimens of *Quercus alba* L., 6 specimens of *Fraxinus americana* L., 2 specimens of *Acer saccharum* Marsh., and 1 specimen each of *Liriodendron tulipifera* L. and *Carya cordiformis* (Wang) K. Koch. The sections varied in age but only 40 years of growth, i. e. 1900 to 1939 inclusive were used from each inasmuch as rainfall data were available only for that period. The sections were cut from a forest located on the south side of Road 10, 8 miles west of the junctions of Roads 31 and 10. The location is thus in Marshall county, 8 miles west of Argos, Indiana.

Rainfall data were secured from the U. S. Weather Bureau station located in Plymouth approximately 9 miles northeast of the forest in which the trees under study grew. Rainfall curves were plotted for the calendar year, for the year beginning November 1 and ending October 31, for the periods May-August, June-August and June.

Growth as shown by annual ring width was measured along 8 equidistant radii of each section of each species. Measurements were made under an 8X magnifier and to the nearest quarter of a millimeter (the ruler used was graduated into half-millimeters). Curves were plotted for the sum of the 8 radii for each section individually and for the average of all sections of the same species. Glock (7) states that the best record of the effectiveness of growth factors upon growth is obtained by averaging the measurements from all radii studied. He used 6 as an effective number. In the present paper curves are drawn from the sums (not averages) of 8 radii for each section. Lodewick (10), on the other hand, found no striking difference between results obtained from 4 radii and from only 1 radius.

OBSERVATIONS AND RESULTS

The percentage of correlation between the annual growth curve of each tree specimen and the rainfall curves for 5 different periods of the year is shown in table I. It will be seen that the highest percentage of correlation between growth in *Quercus borealis maxima* (17 specimens) and rainfall occurs most often for the period June-

TABLE I

Percentage of correlation between growth and rainfall

Tree	Annual	Percentage of Correlation Nov.-Oct.	May-Aug.	June-Aug.	June
Quercus borealis maxima					
39- 1	48	50	51	55	39
39- 2	51	50	46	48	47
39- 5	48	44	49	52	55
39- 6	48	53	55	58	55
39- 8	48	43	45	51	51
39- 9	66	70	68	74	55
39-11	58	53	55	54	67
39-13	54	67	61	64	64
39-17	48	56	58	58	64
39-18	79	86	77	67	51
39-19	63	76	67	64	58
39-24	66	76	77	74	55
39-26	45	50	48	58	64
39-28	57	60	58	67	61
39-29	66	73	70	74	67
39-30	45	48	55	52	58
39-31	51	59	58	68	58
Quercus alba					
39- 3	52	58	52	55	48
39-23	60	79	67	77	68
39-25	64	59	65	68	55
39-27	67	76	74	74	61
Fraxinus americana					
39- 4	48	67	61	61	60
39-14	54	67	61	71	48
39-15	42	57	71	71	61
39-16	57	64	67	77	68
39-20	66	55	67	68	51
39-22	78	65	80	61	74
Acer saccharum					
39-10	60	56	58	57	47
39-12	54	57	58	61	63
Carya cardiformis	51	50	40	45	52
Liriodendron tulipifera	67	67	61	74	61

August with the single month of June running a close second. The lowest degree of correlation occurs most often between annual growth and total annual rainfall. These results are in agreement with those obtained earlier in our laboratory for several species of Quercus growing in the more dissected area of south central Indiana (9). In the 4 specimens of *Quercus alba* the highest percentage of correlation between annual growth and rainfall occurs for the period November-October with almost as high for the period June-August. The lowest percentage of correlation comes more often for this species in June. The small number of specimens studied in this case do not warrant definite conclusions. The 6 specimens of *Fraxinus americana* show the highest percentage of correlation more often for June-Augnst with May-August a close second. The lowest percentage of correlation is more often with the annual rainfall. So few specimens of *Acer saccharum, Carya cordiformis,* and *Liriodendron tulipifera* were available that conclusions are not warranted regarding them. The true degree of correlation between the width of annual rings and rainfall is really higher than the percentages shown in table I indicate. This is due to "carry-over" effects which occur under certain conditions discussed below in connection with tables VI-VIII. Two definite periods of "carry-over" effects were found, viz. 1921-23 and 1929-1932.

Table II shows the results when an attempt is made to correlate growth with the years when rainfall for the various periods is conspicuously more than the preceding year. The figures given show the percentages of the years having conspicuous rainfall increases when growth in each individual tree is also greater than the preceding year. It will be seen that the percentages range for the various trees and the various rainfall periods from 25 to 100. In years when rainfall for the calendar year is 10 inches more than for the preceding year 25% to 75% of such years reveal an increase in growth over the preceding year. The average for all 31 specimens is 50%. In years when rainfall for November-October is 10 inches more than for the preceding year, growth is also more in an average for all specimens of 67% of the years. In years when rainfall for May-August is 5 inches more than for the same period of the preceding year, growth is also more in an average for all specimens of 70% of the years. When the rainfall is 5 inches more for the period of June-August the percentage is 59. The highest percentage is shown when

TABLE II

Correlation between growth and rainfall for years when rainfall is conspicuously more than the preceding year. Figures are percentages of the years when growth is also greater than the preceding year.

Tree	Annual 10 ins. more	Nov.-Oct. 10 ins. more	May-Aug. 5 ins. more	June-Aug. 5 ins. more	June 3 ins. more
Quercus borealis maxima					
39- 1	25	75	100	75	40
39- 2	50	50	50	75	40
39- 5	75	50	25	50	80
39- 6	50	75	100	100	40
39- 8	50	25	25	50	60
39- 9	50	100	100	75	100
39-11	25	50	50	25	80
39-13	50	100	100	75	80
39-17	25	50	75	50	80
39-18	50	100	100	75	80
39-19	50	75	75	50	80
39-24	50	75	75	50	80
39-26	50	75	75	50	80
39-28	50	75	75	50	80
39-29	75	75	75	75	80
39-30	50	50	75	50	80
39-31	50	50	75	50	80
Quercus alba					
39- 3	50	75	75	50	80
39-23	50	50	75	50	80
39-25	50	100	100	75	100
39-27	75	75	75	75	80
Fraxinus americana					
39- 4	25	50	50	25	60
39-14	75	75	75	75	60
39-15	50	75	75	50	60
39-16	50	100	100	75	100
39-20	75	75	75	50	80
39-22	25	50	75	25	60
Acer saccharum					
39-10	50	50	50	50	60
39-12	50	50	75	75	20
Carya cordiformis	50	50	75	50	80
Liriadendron tulipifera	75	75	75	75	80
Average % of Years	50	67	70	59	72

June rainfall is 3 inches more than for June of the preceding year, viz. 72%. When these figures are analyzed more closely it will be found that the percentage of correlation between growth and rainfall in years when rainfall is conspicuously more than for the preceding year depends upon whether the increase in rainfall follows a year when rainfall for the period under consideration was deficient or approximately normal. If available water is already near its optimum then an increase is of little consequence; but if available water is near the "dry-limit," then an increase is of great consequence. The data in table II do not separate these two factors. Further light will be thrown on this point by the data in table IV.

Table III presents results when annual growth is correlated with rainfall in years when the latter is conspicuously less than in the preceding year. It will be seen that in years when rainfall for the calendar year is 10 inches less than the preceding year, growth is also less in an average for all specimens of 62% of the years. When rainfall for the period November-October is 10 inches less than the preceding year the average percentage of years with reduced growth is 82. In years when rainfall for May-August is 5 inches less than for the same period of the preceding year, growth is also less in 74% of the years. When rainfall is 5 inches less for June-August than for the same period of the preceding year, growth is also less in 72% of the years. When rainfall for June is 3 inches less than June of the preceding year, growth is also less in 70% of the years.

A more detailed consideration of these percentages reveals that a reduction in rainfall as such is not the critical factor controlling growth. The important factor is whether the reduction in rainfall follows a year when rainfall was above normal or a year when it was about or below normal. If the reduction in rainfall brings the water available for growth to the point where it becomes a limiting factor, then a high degree of correlation between growth and rainfall is found. This point will be further illuminated in table V and also in tables VI-VIII.

It should be expected that growth is likely to be affected by conspicuous reductions in rainfall in more years than by conspicuous increases. A comparison of results in table II and III shows that this appears to be true except for the month of June. When rainfall for the calendar year is 10 inches more than the preceding year, growth is more in 50% of the years; but when rainfall is 10 inches

TABLE III

Correlation between growth and rainfall for years when rainfall is conspicuously less than the preceding year. Figures are percentages of the years when growth is also less than the preceding year.

Trees	Annual 10 ins. less	Nov.-Oct. 10 ins. less	May-Aug. 5 ins. less	June-Aug. 5 ins. less	June 3 ins. less
Quercus borealis maxima					
39- 1	16	0	30	75	25
39- 2	33	50	30	50	75
39- 5	16	0	30	50	50
39- 6	16	0	30	75	25
39- 8	33	0	30	50	50
39- 9	66	100	90	75	75
39-11	84	100	90	75	100
39-13	50	100	90	100	75
39-17	66	100	90	75	75
39-18	66	100	90	100	75
39-19	66	100	90	75	75
39-24	66	100	90	75	75
39-26	66	100	75	75	75
39-28	50	100	75	50	50
39-29	66	100	90	100	75
39-30	50	100	60	50	50
39-31	66	100	90	75	75
Quercus alba					
39- 3	84	100	60	50	75
39-23	84	100	90	75	75
39-25	84	100	90	100	75
39-27	66	100	90	75	75
Fraxinus americana					
39- 4	84	100	75	75	100
39-14	66	100	90	75	75
39-15	50	100	90	100	100
39-16	84	100	90	75	75
39-20	84	100	75	50	75
39-22	84	100	90	75	100
Acer saccharum					
39-10	66	50	75	100	75
39-12	66	50	60	25	25
Carya cordiformis	66	100	75	50	75
Liriodendron tulipifera	84	100	75	75	75
Average % of Years	62	82	74	72	70

less, growth is less in 62% of the years. When rainfall for November-October is 10 inches more, growth is more in 67% of the years; but when rainfall is 10 inches less, growth is less in 82% of the years. When rainfall for May-August is 5 inches more, growth is more in 70% of the years; but when rainfall is 5 inches less, growth is less in 74% of the years. When rainfall for June-August is 5 inches more, growth is more in 59% of the years; but when rainfall is 5 inches less, growth is less in 72% of the years. When rainfall for June is 3 inches more, growth is more in 72% of the years; but when rainfall is 3 inches less, growth is less in 70% of the years. These data are brought together in table III-A.

TABLE III-A

Relation between correlations of growth and rainfall in years when rainfall is conspicuously greater than the previous year and similar correlations when rainfall is conspicuously less than the preceding year.

Rainfall Changes	Pereentage of years showing eorrelation. Average for all tree specimens	
	When rainfall is more than previous year	When rainfall is less than previous pear
Annual rainfall differs from previous year by 10 inches or more	50	62
November-October rainfall differs from previous year by 10 inches or more	67	82
May-August rainfall differs from previous year by 5 inches or more	70	74
June-August rainfall differs from previous year by 5 inches or more	59	72
June rainfall differs from previous year by 3 inches or more	72	70

Table IV shows the percentage of individual trees which showed increased growth in years when there was conspicuous increase in rainfall over the preceding year. It will be seen that except for the years 1909, 1919 and 1929, high percentages of the trees showed increased growth in years which were characterized by conspicuous increases in rainfall. These three years stand out conspicuously for the small percentage of individual trees which responded to increased rainfall by increased growth. The rainfall in both 1909 and 1919 for the periods under study was unusually high and followed corresponding periods of normal or only little below normal rainfall

TABLE IV

Correlation between growth and rainfall for years when rainfall is conspieuonsly more than the preceding year. Figures are the percentages of trees showing greater growth than the preceding year.

Rainfall Change	Years	Percentage of Trees Showing Greater Growth than Preceding Year Q. b. maxima	Q. alba	F. americana
Annual rainfall 10 inches more than previous year	1909	30	50	34
	1916	60	75	68
	1926	96	100	84
	1929	12	0	17
Nov.-Oct. 10 inches more than previous year	1916	60	75	68
	1919	42	25	34
	1926	100	100	84
	1935	78	100	100
May-Aug. 5 inches more than previous year	1912	78	100	50
	1919	42	25	34
	1926	94	100	84
	1935	78	100	100
June-Aug. 5 inches more than previous year	1909	30	50	34
	1912	78	100	50
	1919	42	25	34
	1926	94	100	84
Jnne 3 inches more than previous year	1911	90	100	84
	1916	60	75	68
	1924	66	100	100
	1937	84	100	84

for the preceding year. Annual rainfall was 32.41 inches for 1908 and 44.01 inches for 1909 while the normal for this area is about 34 inches. The June-August period of 1909, which likewise showed little correlation between increased rainfall and increased growtb, showed 6.84 inches for 1908 and 13.02 inches for 1909 with the normal about 10 inches. Annual rainfall was 34.42 inches for 1918 and 40.09 inches for 1919. The May-August rainfall was 10.18 inches for 1918 and 17.16 inches for 1919 with the normal about 13 inches. The June-August rainfall was 5.62 inches for 1918 and 11.46 for 1919 with normal about 10 inches. While in this last period there was greater departure from the normal in the preceding year, the month preceding the beginning of the period (i. e. May, 1918) was above normal bringing available water during the growing period

TABLE V.

Correlation between growth and rainfall for years when rainfall is conspicuously less than the preceding year. Figures are percentages of trees showing less growth than preceding year.

Rainfall Change	Year	Percentage of Trees Showing less, Growth than Preeeding Year Q. b. maxima	Q. alba	F. americana
Annual rainfall 10 inches less than previous year	1910	60	100	100
	1917	73	100	100
	1922	6	0	34
	1928	42	75	51
	1930	60	100	84
	1934	72	100	100
Nov.-Oct. 10 inches less than previous year	1917	78	100	100
	1934	72	100	100
May-Aug. 5 inches less than previous year	1910	60	100	100
	1913	78	75	50
	1917	78	100	100
	1922	6	0	17
	1925	100	100	100
	1934	72	100	100
	1936	66	75	100
June-Aug. 5 inches less than previous year	1908	42	25	50
	1910	60	100	100
	1913	84	75	50
	1925	100	100	100
June 3 inches less than previous year	1910	60	100	100
	1912	24	0	50
	1917	78	100	100
	1925	100	100	100

in 1918 sufficiently near the optimum that its deficiency was not felt. These data support the conclusion that increased rainfall affects growth relatively little when the increase is imposed upon a previous amount already near the normal.

The reason for the low percentage of trees showing increased growth in 1929 as compared to 1928, even though there were over 10 inches more of rainfall in the latter year, is to be found in a different set of conditions from those that pertain in the years 1909 and 1919. Annual rainfall was 27.55 in 1928 and 38.68 in 1929 while the normal is about 34. During these same years, however, the rainfall during the growing season (June-August) was 12.69 inches in

1928 (the year with total reduced rainfall) and 11.06 inches in 1929. It is thus seen that June-August rainfall was above normal in both 1928 and 1929 and since that for 1928 was higher, increased growth could hardly be expected in 1929.

Table V shows the percentage of individual trees which showed decreased growth in years which showed conspicuous decreases for the various rainfall periods. It will be seen that the percentages are high for all periods for nearly all years. Conspicuous lack of correlation is found for the year 1922. A careful analysis of the conditions pertaining in 1921, 1922 and 1923 shows that rainfall effects may carry over from one year to the next. Rainfall for 1921 was much above normal from August on, but 1922 was below normal and 1923 above normal. Growth in 1922 increased over 1921 in spite of a 10-inch decrease in rainfall while in 1923 growth decreased over 1922 in spite of an increase of 8.1 inches in rainfall. Thus a period of above normal rainfall was reflected in increased growth the following year during which rainfall was over 10 inches less and almost as far below normal as the previous year was above normal, while the period of below normal rainfall (1922) was in turn reflected in decreased growth during the year following it when rainfall increased to above normal. The rainfall for the calendar years 1921, 1922 and 1923 was 40.89, 30.34 and 38.44 inches respectively. If the rainfall is calculated from August of one year to July of the following year we find a complete reversal of the rainfall curve and a complete correlation of it with the growth curve. The rainfall thus computed for 1920-21, 1921-22 and 1922-23 was 27.22, 42.44 and 31.24 inches respectively.

Tables VI-VIII show the amounts of rainfall change for each rainfall period when 90% of the specimens of *Quercus borealis maxima* (table VI), and 100% of the specimens of *Q. alba* (table VII) and 100% of the specimens of *Fraxinus americana* (table VIII) show either increased or decreased growth over the preceding year. It will be seen that in all cases except 1922, 1923 and 1931 increases in growth are correlated with increases in rainfall for all or nearly all of the month-combinations and decreases in growth are correlated with decreases in rainfall. Except for these years, rainfall for June-August always shows an increase over the same period of the preceding year when there is 90-100% agreement amongst the specimens from the standpoint of increase in growth and a decrease in rainfall when there is a decrease in growth. The exceptions for 1922 and 1923 have been discussed above. That for 1931 is due to essentially the same factors. Total rainfall for 1930 and 1931 was 28.60 and 36.32 inches respectively while rainfall for the August-July combination of months for 1929-30 and 1930-31 was 35.01 and 27.32 inches respectively. It is thus seen that the rainfall for the latter month-combinations is the reverse for these years from that pertaining for the calendar year.

TABLE VI

Quercus borealis maxima. Correlation between growth and rainfall showing amount of rainfall change as compared to preceding year when 90% or more of the trees showed increase or decrease in amount of growth as compared to preceding year.

	Rainfall Change as Compared with Preceding Year				
Years	Annual	Nov.-Oct.	May-Aug.	June-Aug.	June
Growth Increase in inches					
1911	9	2	1.5	3.5	4.8
1915	0.29	−2	2.1	1.9	1.7
1922	−10	−2.8	−4.4	−4.6	−0.47
1926	15	13.7	9.2	5.6	2.5
1935	8.2	13.2	7.9	1.1	1.4
1937	2.3	4.7	3.6	4	4.1
Growth Decrease in inches					
1913	−3.3	−4.9	−6.7	−7	−0.15
1914	−5.7	−4.1	0.5	0.5	1.5
1918	6.4	−1.5	−2.3	−3.2	−0.01
1925	−7.3	−6.7	−7.9	−6.2	−5.3
1929	11	−0.8	−1	−1.6	−0.1

TABLE VII

Quercus alba. Correlation between growth and rainfall showing amount of rainfall change as compared to preceding year when 100% of trees showed increase or decrease in amount of growth as compared to preceding year.

	Rainfall Change as Compared with Preceding Year				
Years	Annual	Nov.-Oct.	May-Aug.	June-Aug.	June
Growth Increase in inches					
1902			16.3	11.8	−8.5
1907	4.4	5.8	2.5	2.6	−0.6
1911	8.4	2.2	1.6	3.5	4.8
1912	1.9	6.2	8.8	6	−3.4
1922	−10	−2.8	−4.8	−4.6	−0.4
1924	−6.2	−3.7	−0.8	0.4	4.3
1926	15	13.7	9.2	5.2	2.5

TABLE VII—(Continued)

Years	Annual	Rainfall Change as Compared with Preceding Year Nov.-Oct.	May-Aug.	June-Aug.	June
1932	1.3	2.1	1.3	2.8	–2
1935	8.2	13.2	7.9	1.1	1.4
1937	2.3	4.7	3.6	4	4.1
Growth Decrease in inches					
1901	–3.7	–2.6	–9.8	–7.1	–1.3
1910	–14.1	–8.1	–4.8	–6.3	–3.7
1914	–5.7	–4.1	0.5	0.5	1.5
1917	–16	–12	–8.9	–4.3	–6.8
1918	6.4	–1.5	–2.3	–3.2	–0.01
1923	8.1	3.2	4.1	3.8	–0.4
1925	–7.3	–6.7	–7.9	–6.3	–5.3
1929	11	–0.8	–1	–1.6	–0.1
1930	–10	–7.9	–3.9	–4	–1.5
1931	7.7	6.1	4.5	2.3	1.9
1933	2.4	7.1	–0.2	–3.9	–0.7
1934	–11	–2	–6.3	–0.1	0.6

TABLE VIII

Fraxinus americana. Correlation between growth and rainfall showing amount of rainfall change as compared to preceding year when 100% of trees showed increase or decrease in amount of growth as compared to preceding year.

Years	Annual	Rainfall Change as Compared to Previous Year Nov.-Oct.	May-Aug.	June-Aug.	June
Growth Increase in inches					
1911	9	2	1.5	3.5	4.8
1915	0.29	–2	2.1	1.9	–1.7
1924	–6.2	–3.7	–0.8	0.4	4.3
1932	1.3	2.1	1.3	2.8	–2
1935	8.2	13.2	7.9	1.1	1.4
Growth Decrease in inches					
1910	–14.1	–8.1	–4.8	–6.3	–3.7
1917	–16	–12	–8.9	–4.3	–6.8
1925	–7.3	–6.7	–7.9	–6.3	–5.3
1934	–11	–20	–6.3	–0.12	0.6
1936	–5	–5.1	–8	–3.4	–2.3

DISCUSSION

From the foregoing data it is clear that there is no simple relationship between growth and rainfall for any conceivable combination of months. The data will support the conclusion that rainfall shows the highest degree of correlation when it becomes a limiting factor.

It is obvious that the important condition is that the plant have water available to it when it is needed and in amounts sufficient for these needs. During a growing season when evaporation demands are lower a higher percentage of available water is left for growing purposes. An increased rainfall imposed upon a previous rainfall already adequate will not be reflected in increased growth, but an increased rainfall imposed upon a previous year of deficiency will be likely to be reflected in growth increase. In a similar manner a decrease following a year of excessive rainfall will not necessarily show a decrease in growth but if the decrease follows a year when available water is already a limiting factor, decrease in growth is to be expected. It is entirely possible that light due to number of cloudless hours may become the limiting factor in years of excessive rainfall if the excess comes during the growing season. While rainfall occurring during the period June-August more often shows a correlation with growth in this study, it does not always do so. In some years an accumulated deficit prior to June may not be sufficiently offset by an excessive rainfall during these months and hence a great increase in this period over the corresponding period of the previous year will still show a decrease in growth over the preceding year. Conversely an accumulated excess prior to the growing period may carry the plants through a growing season receiving deficient rainfall.

It is obvious that much also depends upon the condition of the soil when the rain falls. High rainfall during some winters may be of much less value than during others. There will be a tremendous difference between frozen and unfrozen soil from the standpoint of the amount of water that can be absorbed and the percentage of the rain that must run off. This means that the time of year when the rains come will be a vital factor. The distribution of the rains over the year from the standpoint of frequency and severity also becomes a vital factor.

SUMMARY AND CONCLUSIONS

1. Correlation between width of annual rings and rainfall is studied in stump and stem sections from 17 specimens of *Quercus borealis maxima*, 4 of *Q. alba*, 6 of *Fraxinus americana*, 2 of *Acer saccharum* and 1 each of *Carya cordiformis* and *Liriodendron tulipifera* from Marshall county, Indiana.

2. The highest percentage of correlation for most specimens was with rainfall for either June-August or the single month of June but individual exceptions are found in which the highest correlation is with other rainfall periods. In the case of *Quercus alba* a slightly higher percentage of correlation occurs with the rainfall in the period November-October in 3 of the 4 specimens studied.

3. When rainfall for one year or a particular period of that year is conspicuously greater than for the preceding year, growth is also greater in from 50 to 72% of the years; but when the rainfall for corresponding periods is conspicuously less than for the preceding year, growth is also less in from 62 to 82% of the years.

4. When rainfall for one year or a particular period of that year is conspicuously greater or conspicuously less than for the preceding year, growth is greater or less respectively in a large percentage of the individual trees; but some years are found in which the percentage of individual trees showing such correlation is very small. This lack of correlation is due to the distribution of rainfall failing to coincide with the vegetative year.

5. In years when there is 90-100% agreement amongst the individual trees, increase in growth is correlated with increase in rainfall and decrease in growth with decrease in rainfall for nearly all month-combinations. The correlation is perfect for June-August rainfall except for 1922, 1923, and 1931 during which years the rainfall for the month-combinations August to July of the following year forms perfect correlation.

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