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PRECIPITATION AND THE GROWTH OF OAKS AT COLUMBIA, MISSOURI

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Precipitation and the Growth of Oaks at Columbia, Missouri

William J. Robbins

In the winter of 1919-20 while examining the stumps of oaks cut during that same season near Columbia, Missouri, it was noticed that the last seven annual rings were comparatively narrow while the previous 13 were comparatively broad with an unusually broad ring for the year 1902. A cursory examination of several stumps showed that this condition was true for all of the stumps examined. Other similarities between the rings of the same age of different stumps aroused sufficient interest to induce more careful measurements of the width of the annual rings.

Two methods were followed in making the measurements. In one, a sheet of white paper was laid on the stump and ink marks, indicating the limit of each year's growth, were made along the edge of the paper. Three such records perpendicular to one another were made on each stump. The record sheets secured were then taken to the laboratory where measurements were made when convenient. Later the measurements were made on the stumps themselves. A ruler was laid on the stump along the radius of the circles made by the annual rings, and the width of each ring was noted and recorded. In the absence of a metric rule of sufficient degree of fineness, an architect's boxwood rule graduated to fiftieths of an inch was used. A watch-maker's magnifier with a power of about 5 diameters aided in reading the fine subdivisions. In this case also measurements were made along three radii as nearly as possible perpendicular to one another and particular care was used to check the rings measured on each radius to make sure that no ring was inadvertently overlooked.

The species of oaks measured could not be determined in all cases because of the fact that the tops had been cut and removed some months previously. Most of the stumps measured were those of *Quercus rubra L.*, a few *Quercus imbricaria Michx.*

All the stumps measured with the exceptions noted below were located within a circle having a diameter of about one-half mile on the floor and sides of a small flat valley through which runs a small stream, dry during a considerable part of the summer. The trees in this valley are isolated rising from a sparse undergrowth of shrubs or from meadow. No definite information as to how long this condition has existed could be gained. The trees still standing do not have the widely branched habit of those which have always grown in the open but are free from limbs for 20 feet or more at their bases. If the stand was originally more dense as seems probable, the stumps which might indicate that fact have disappeared.

The stumps measured were of trees about 100 years old and the measurements were made in each case as far back as the rings could be clearly distinguished. The averages for 16 individual trees are given in Table I and are represented graphically in figure 1. The table represents the average of over 3,500 measurements of individual rings. A complete set of measurements could not be

TABLE I. AVERAGE WIDTH OF THE ANNUAL RINGS OF 16 OAK TREES IN 1/50 INCH.

	0	1	2	3	4	5	6	7	8	9
1910	10.6	5.8	9.5	5.9	3.6	5.2	4.9	5.4	4.3	5.6
1900	5.0	5.3	13.5	10.5	12.4	10.8	7.8	10.7	10.3	11.8
1890	5.5	6.7	7.5	7.1	4.7	8.5	8.2	8.5	6.9	6.2
1880	6.0	5.6	6.4	7.8	7.4	7.3	5.5	5.2	5.2	7.5
1870	4.7	6.2	6.6	5.2	4.2	5.5	6.2	4.4	5.5	5.7
1860	2.6	4.1	3.9	3.7	3.5	4.6	4.0	4.4	4.1	6.4
1850	3.3	3.7	2.9	3.1	3.1	3.1	2.9	2.9	3.8	3.8
1840	1.9	1.8	2.7	2.2	2.5	2.4	2.3	1.7	2.8	3.3
1830	2.6	2.7	2.8	1.4	1.6	2.3	2.3	3.1	2.3	2.7

obtained for each tree. From 1859-1919 inclusive the figures given in Table I represent the averages for the 16 trees; but for 1858 of only 15 trees, for 1853-57 of 14, 1851-52 of 13, 1850 of 11, 1849 of 9, 1848 of 8, 1847 of 7, 1839-46 of 6, 1835-38 of 5, and 1830-34 of 4 trees.

The data in Table I and figure 1 indicate that for these trees the general tendency of the annual rings has been to increase in width with increasing age of the tree to a maximum during the years 1902-1913. This period corresponds to an age of about 100 years for the trees measured. The maximum width for the average of the 16 trees was 13.5 fiftieths of an inch or 0.27 inch for the year 1902. The average annual increment for the rings and trees measured was about 0.104 inch. During the first thirty years, from 1830-1859, the aver-

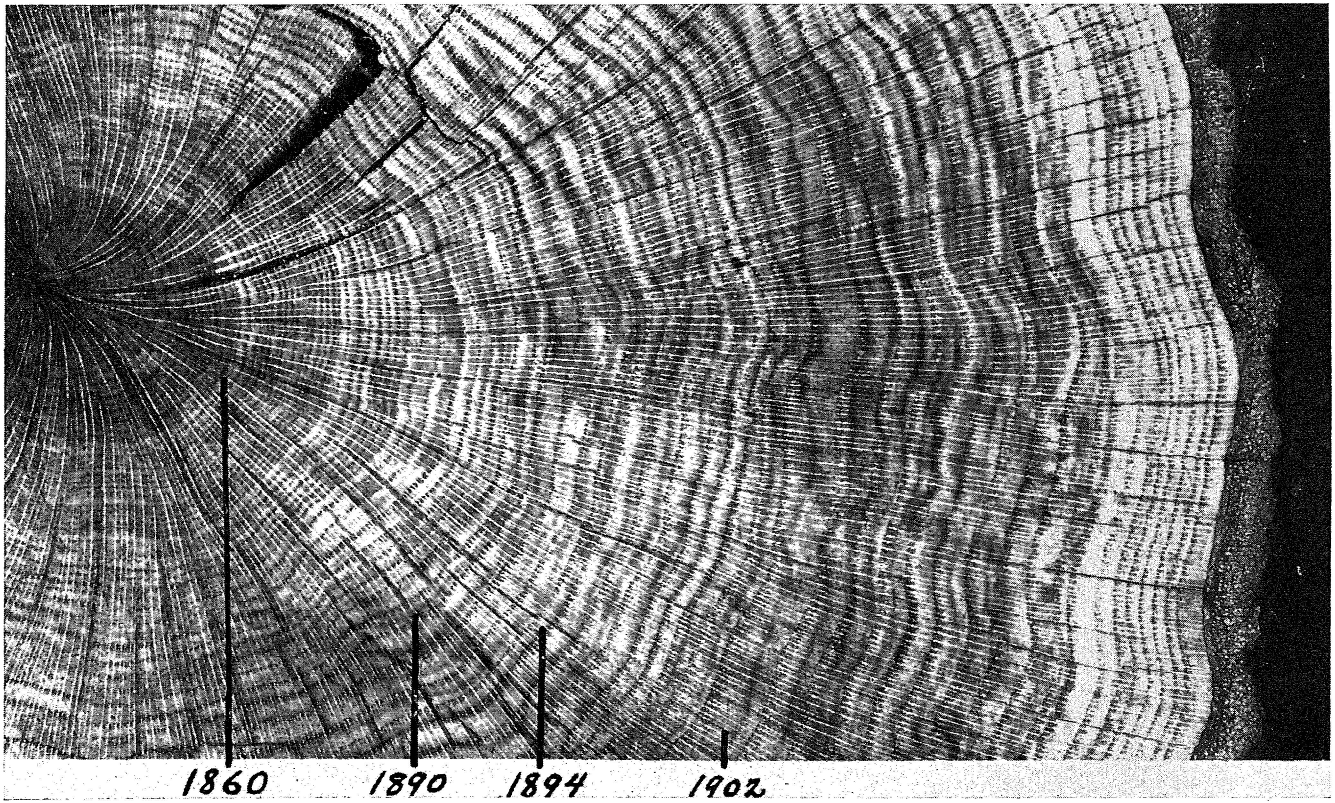

Plate I.—Photograph of a typical oak stump from a tree cut in the winter of 1919-20. The last ring is, therefore, that formed in 1919. The broad ring is that of 1902. The narrow rings for 1860, 1890 and 1894 are evident.

age annual increment was 0.052 inch; from 1860-1889, 0.106; and from 1890-1919, 0.152 inch. These figures show the gradually increasing width of the rings with age of the trees.

The rate of growth in diameter of a tree is the resultant of a large number of factors both internal and external. While the maximum annual ring width in the group of oaks under consideration occurred at about the age of 100 years it would not be possible to state definitely that the internal factors included in the term age were the cause of this maximum. We cannot estimate with the incomplete data at hand how far objective factors such as shade, water supply, evaporation, temperature, and changing edaphic conditions affected the diam-

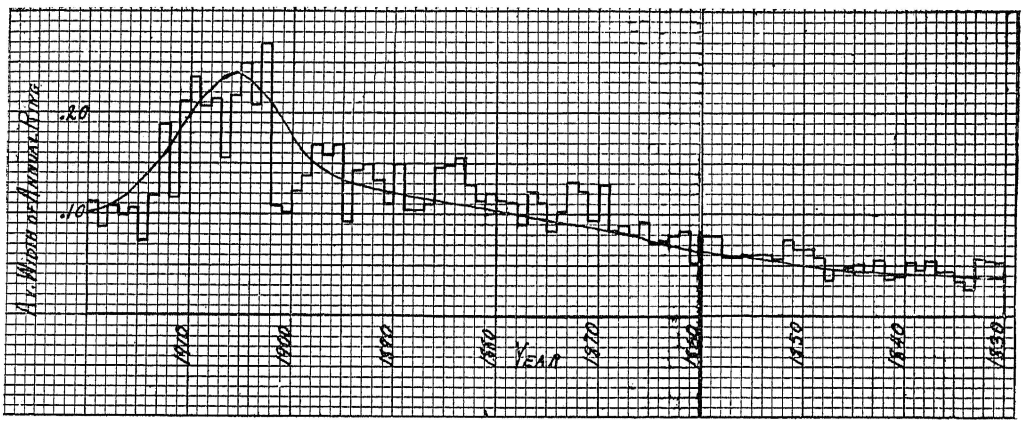

Figure 1.—Annual ring width of oaks at Columbia, Missouri, from 1830 to 1919.

eter increase. Huntington (1912) and Douglass (1919) state that in sequoia the rate of growth decreases with age. Conrad (1918) cites cases in Ohio where the maximum growth in oak of the same species occurred at ages varying from 18-20 years to 90-100 years. Shreve (1917) gives figures on yellow pine in Arizona which indicate that the rate of growth may increase or decrease up to 100-200 years depending upon the altitude.

The second striking fact which can be noted from these data is the frequent occurrence of narrow rings alternating with one or several relatively broader rings. This is shown very clearly in figure 1 by the gaps which occur in the diagram when the amount of growth was decidedly less than that of a preceding or following year. Examining figure 1, the years which are clearly marked as years of small growth relative to the amount which occurred in the years which precede or follow them are 1833 and 34, 1838, 1840 and 41, 1847, 1860, 1870, 1874, 1877, 1886, 87 and 88, 1890, 1894, 1900, and 01, 1903, 1906, 1911, 1914, and 1918.

Temperature, precipitation, defoliation from insects or other causes, light, soil conditions and solar activity have all been correlated with the amount of annual growth in trees.

Lutz (1895) removed the buds and leaves of six to ten-year old trees of *Fagus silvatica.* Trees were defoliated March 20, May 20, June 15, July 1, 15, 30, and August 28 and kept in that condition during the summer. No radial growth took place in those trees defoliated March 20. About 4 to 30 percent of the normal radial growth occurred in the tree defoliated May 20. The amount of radial growth increased in each case until in the tree defoliated August 28 the amount of growth was normal.

Bogue (1905) determined the average width of the annual rings for 42 trees near Lansing, Michigan, for the years 1892-1904. He found a correlation between precipitation and width of annual rings and states that an abnormally large or small annual precipitation is evidenced by the tree growth the following year.

Stewart (1913) compared the width of the annual rings of an oak stump at York, New York, with weather records at Rochester, N. Y., 25 miles north. Greater correspondence was found between variations in rainfall during June and July and ring width than between rainfall for the entire growing season and ring width. No conclusion was reached on the relation of temperature to growth.

Brown (1915) working with *Pinus strobus L.* at Ithaca, N. Y., states that the rapidity of growth is dependent upon three factors, moisture, available food (reserve), and temperature. The first two are at an optimum in the spring; the amount of growth therefore is directly proportional to the prevailing temperature.

Brewster (1918) failed to find a correlation in a five-year period between growth in height of larch in northern Idaho and the rainfall in April, May, June, and July.

Conrad (1918) reports that attempts to find a relation between the rate of growth of oaks at Grinnell, Iowa, and wet and dry seasons proved futile.

Pearson (1918) compared the annual height growth of yellow pine saplings and the precipitation for various periods. He found no apparent correlation between height growth and annual precipitation, summer precipitation, or winter precipitation. The spring precipitation (April and May) was apparently the controlling factor. Factors reflecting the atmospheric conditions including evaporation showed a close though not consistent relation to height growth. The height growth varied inversely with the temperature probably because of the influence of temperature on transpiration and therefore on the relative water supply.

Douglass (1909, 1914, 1919) working in Arizona with an annual rainfall of 22 inches found the correlations between tree growth as shown by the annual rings and rainfall records for 8 or 10 years to be, in the dry climate groups, in the neighborhood of 70 percent. The closest agreement between growth and precipitation in the case of yellow pine, *Pinus ponderosa*, was found when the annual rainfall was calculated from November 1st, at Flagstaff and from September 1st, at Prescott. He also correlated crop failures and freshets recorded by Bancroft for settlements in Arizona and New Mexico with the tree record, notably the flood in the Rio Grande in 1680, famines between 1680 and 1690, and droughts in Arizona in 1748, 1780, and 1820-23. In northern Europe an equal exactness in following the rainfall was not found, but a direct correlation between solar activity and tree growth was evident.

The Columbia station of the Weather Bureau of the U. S. Department of Agriculture, located about 1 mile from the trees under consideration, has complete weather records from the year 1890. Attempts to correlate variations in the width of the annual rings with the length of the growing season, the dates of the last killing frost in the spring or the first killing frost in the fall met with little success.

A comparison of mean monthly temperatures (Table IV) with the annual growth seemed to show that the temperatures for May and June vary inversely with the annual ring width. In figure 2 the sums of the mean temperatures of May and June are plotted against the annual ring width for the same year. A comparison of the two curves shows that in general the temperature of these two months varies inversely with ring width. This is particularly evident in the periods 1890-1894 and 1910-1919.

The annual precipitation figured as is customary from January to January showed that in some years a drop in the annual rainfall was correlated with a drop in the wood formation. This was true for 1894, 1901, 1903, 1906, and 1914. However 1896, 1910 and 1917 are years with decided decreases in annual precipitation with no corresponding decreases in wood growth. In some cases a low annual precipitation apparently shows its effect in the following year, as the small rainfall in 1910 and decreased ring width in 1911, and the low precipitation in 1917 appearing as a gap in the ring widths in 1918. Failures in the correlation between January to January precipitation and ring width would not be unexpected as that precipitation corresponds to no physiological period in the tree's growth.

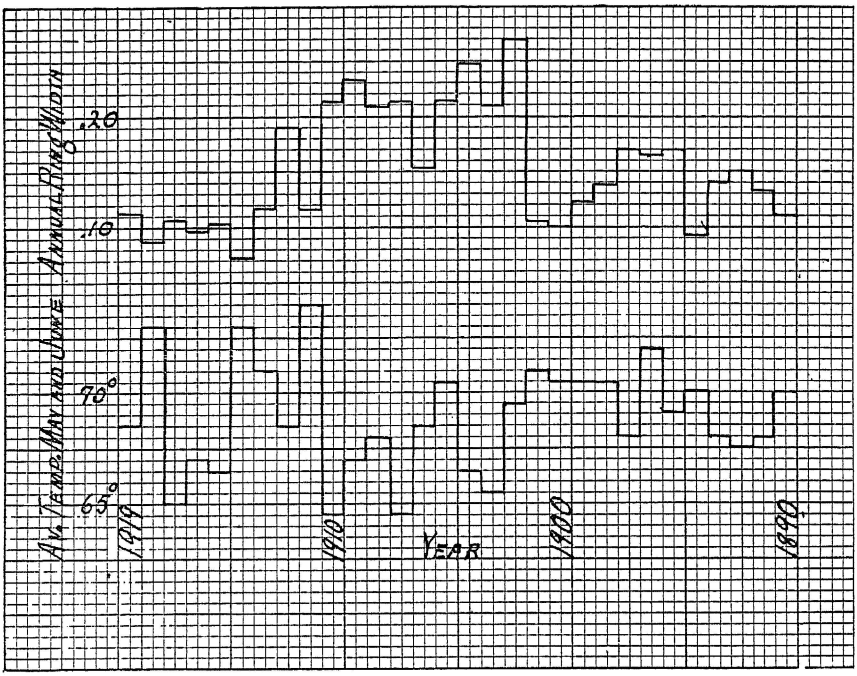

Figure 2.—Annual ring width of oaks from 1890-1919 and sum of the mean monthly temperatures for May and June.

When monthly precipitations (Table V) or the precipitation of groups of months are considered the best correlation is found between the total rainfall in the months of March, April, May, and June and the annual ring width. Fairly good correlation exists between the precipitation in March, April, and May and ring width. The other combinations of months considered were January to September; October to October; October to April; April to October; April and May; May and June; April, May and June; and March and April.

Beginning with the year 1890 (Figure 3) an increase or decrease in annual ring width is correlated with an increase or decrease in rainfall in March, April, May, and June in each one of the 30 years except 1893, 1898, 1901, and 1908. The average rainfall for March, April, May, and June was 16.34 inches and the average increase in annual ring width was 0.152 of an inch. There were 14 years of more than average growth and 13 years of more than average rainfall. Nine of the 14 years of more than average growth occur in years of

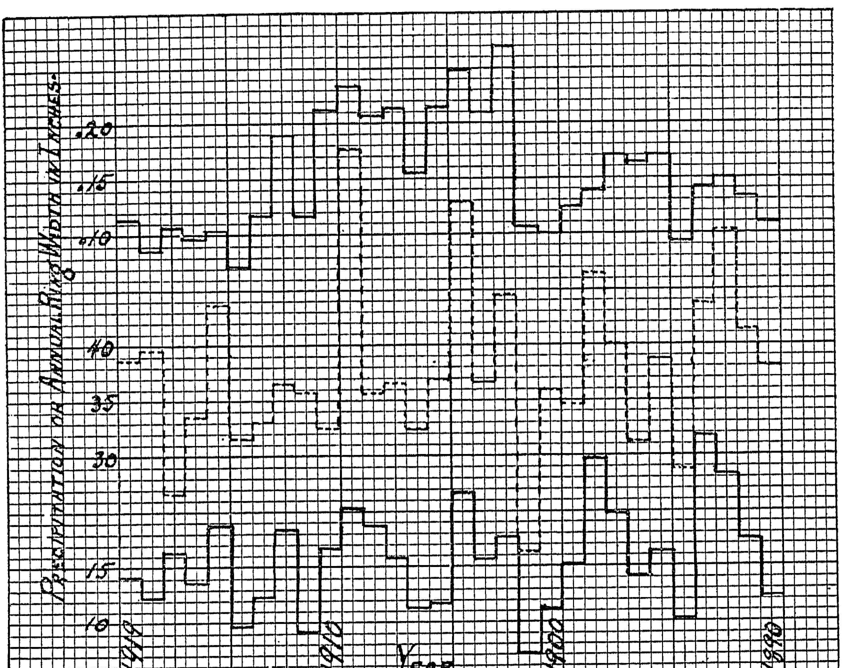

Figure 3.—Annual ring width of oaks from 1890-1919 and precipitation. Upper curve is ring width, dotted curve is the annual precipitation from January to January, lower curve is the sum of the rainfalls for March, April, May, and June.

more than average rainfall, the exceptions being the years 1896, 1903, 1905, 1906, and 1907. A precipitation of 12 inches or less occurred in 1890, 1894, 1900, 1901, 1905, 1906, 1911, 1913, 1914, and 1918. These years are correlated with the gaps in ring width of 1890, 1894, 1900, 1901, 1906, 1911, 1914, and 1918.

From the data in figure 3, it can also be noted that the precipitation of one year does not show its effect the following year. The heavy precipitation of 1893 had no noticeable effect in modifying the effects of the low rainfall of 1894. The dry spring of a given year shows its effect in that year's growth and not in the following year.

Since the ring width varies directly with the spring precipitation and inversely with the temperature for May and June we should expect, if precipitation and temperature were alone the determiners of variations in the annual ring width in the trees concerned, that growth (ring width) would equal a constant multiplied by the quotient of precipitation over temperature, $G=C \times \frac{P}{T}$. In Table II, columns 2 and 3 respectively, the sum of the rainfalls for March, April, May, and June and the sum of the mean monthly temperatures for May and June of each year are given. In column 4 the quotient of the precipitation divided by the temperature is given. The constant in this case which must be used to bring the quotient of P/T to the same magnitude as the observed ring width is 100. Comparing the quotient of 100P/T with the growth as actually determined, column 5, it will be noted that fairly good agreement between the calculated and observed values occurs from 1890-1894 and from 1914-1919. Between these periods the observed values diverge farther and farther from the calculated as we proceed toward the years 1905-1906. The discrepancy between the observed and calculated values can be clearly seen when the sum of the calculated values for the 30 years, 3.459 inches, is compared with the sum of the observed values for the same period, 4.574 inches. The calculated width is about 29 percent less than the observed.

By inspection, however, a factor can be introduced which brings the calculated values more closely into agreement with the observed. This factor for the years 1890-1894 is 1, for 1895-1900 is 1.5, for 1901-1906 is 2.0, for 1907-1913 is 1.5, and for 1914-1919 is 1. Calculating the growth by employing the factor mentioned, $G=f \times \frac{100P}{T}$ we obtain the figures given in column 6. In this case the agreement between the calculated and the observed values is in general much closer than before, the greatest difference being for the year 1898 where the calculated is almost twice the observed. The average difference is 2.3 hundreths of an inch or 15 percent of the average growth. Almost half of this is due to the four years 1893, 1897, 1898, and 1904, all years with springs of high rainfall. The sum of the widths for the 30 years as calculated by this means is 4.866 inches about 6 percent greater than actually found, most of which difference is again due to the difference between the calculated and observed ring widths of the four years of high spring rainfall noted above.

The factor used in the above calculations is probably an approximate expression of the normal growth tendency of the oaks under consideration. This fact is made probable by considering the growth

TABLE II. ANNUAL RING WIDTH AND ITS RELATION TO THE RAINFALL OF MARCH, APRIL, MAY, AND JUNE AND THE TEMPERATURE FOR MAY AND JUNE. FOR 1890-94 F=1; 1895-1900 F=1.5; 1901-1906 F=2; 1907-1913 F=1.5; 1914-1919 F=1.

Year	Precipitation (P) March, April, May, June inches	Sum of Av. Temp (T)—May, June °F	$\frac{100P}{T}$	Annual ring width (G) observed .01 inch	$\frac{f100P}{T}$	f′	$\frac{f'100\,P}{12\ \ T}$
1890	12.29	140	8.8	11.0	8.8	12.2	9.0
1891	17.38	136	12.7	13.4	12.7	12.4	13.1
1892	23.28	135	17.3	15.0	17.3	12.7	18.2
1893	26.95	136	19.8	14.2	19.8	13.0	21.5
1894	11.23	140	8.0	9.4	8.0	13.2	8.8
1895	16.32	138	11.8	17.0	17.7	13.5	13.2
1896	14.15	144	9.8	16.4	14.7	14.2	11.6
1897	19.94	136	14.6	17.0	21.9	15.0	18.2
1898	24.58	141	17.6	13.8	26.4	15.5	22.6
1899	15.16	141	10.3	12.4	15.4	16.7	14.4
1900	11.30	141	8.0	10.0	12.0	18.5	12.4
1901	7.21	142	5.1	10.6	10.2	20.0	8.5
1902	17.89	139	12.9	27.0	25.8	21.7	23.2
1903	15.54	131	11.8	21.0	23.6	22.8	22.4
1904	21.99	133	16.5	24.8	33.0	23.5	32.4
1905	11.93	141	8.5	21.6	17.0	24.0	17.0
1906	11.73	137	8.6	15.6	17.2	23.5	16.8
1907	15.93	129	12.4	21.4	18.6	22.7	23.5
1908	18.74	136	13.8	20.6	20.7	22.0	25.3
1909	20.68	134	15.4	23.6	23.1	21.0	27.0
1910	16.95	129	13.1	21.2	19.6	19.5	21.2
1911	9.05	148	6.1	11.6	9.2	17.5	8.9
1912	18.32	137	13.4	19.0	20.1	16.0	17.8
1913	12.17	142	8.5	11.8	12.7	14.9	10.6
1914	9.61	146	6.6	7.2	6.6	13.5	7.4
1915	18.62	133	13.9	10.4	13.9	12.2	14.1
1916	13.46	134	10.0	9.8	10.0	11.7	9.8
1917	15.71	130	12.0	10.8	12.0	11.2	11.2
1918	12.34	146	8.4	8.6	8.4	10.5	7.4
1919	14.31	137	10.2	11.2	10.2	10.0	8.6
Total	----	---	345.9	457.4	486.6	---	476.1

curve in figure 1. A smooth line curve has been constructed which would represent the growth of the oaks with yearly variations eliminated. This curve might be taken to represent the growth of the oaks under normal conditions of temperature and precipitation. From this curve the "normal" growth for each year can be determined by measuring the length of the abscissa for each year concerned. This has been done in Table II, column 7 which is headed f'. When we calculate growth (annual ring width) by means of the formula $G = \frac{100f'}{12} \times \frac{P}{T}$ the values of column 8 are obtained which agree with those actually observed much as those of column 6 calculated by means of the arbitrary factor f. In this case the constant, determined by inspection, which is necessary to bring the product of $f' \times \frac{P}{T}$ into agreement with the observed ring width is 100/12. The greatest divergence in this series is for the year 1898 which is 63 percent. The average difference is 2.6 hundredths of an inch or 17 percent of the average yearly ring width. The sums of the observed and calculated values for the 30 years differ by less than 5 percent.

From the above it would appear evident that the average ring width in these oaks for the last 30 years had been largely determined by three variables, a gradually changing factor which may be age, the rainfall for March, April, May, and June, and the temperature for May and June. Variations in annual ring width from year to year have been largely determined by variations in two factors, the rainfall and the temperature of the months indicated above. The yearly variations depend inversely upon the temperature and directly upon the rainfall.

Other factors are of course operative. Light, mineral salt and nitrogen supply, hours of sunshine and intensity of evaporation might be suggested. We also probably do not have the most satisfactory expression possible of the two factors precipitation and temperature. Total rainfall without considering the daily distribution, the run-off and the seepage, and temperature without considering daily variations, are somewhat unsatisfactory. Determination of soil moisture would probably be better than precipitation and of intensity of evaporation than temperature [Fuller (1914), Livingston (1916), Pearson (1918)]

Douglass has called attention to the appearance of characteristic rings or groups of rings and has cited a case in which he has been able to name the year (20 years before) when a tree was felled from the determination of known charactertistic rings. In the oaks in this vicinity the rings most easily identified are those of 1860, 1890, 1894, and 1902. These charactertistic rings can be seen on the photograph of one of the stumps measured which is shown in Plate I. The combination of factors in 1860 was evidently very poor for the elaboration of xylem tissue. The ring for 1860 is a narrow ring standing between two wide ones on each side; the ring for 1890 is narrow; for 1894 is narrow with 3 wide rings on each side; and for 1902 is unusually broad. Other characteristic rings or group of rings could no doubt be found. No difficulty was found in rapidly determining the time that had elapsed since trees were cut by the identification of the rings indicated above.

The narrowness of the ring for 1860 is of particular interest with reference to the question of rainfall and ring width. No weather records are available back of 1890 (except 1888 and fragmentary records for 1887 and 89) at Columbia. Three weather stations in northern Missouri however have records which extend back to 1860 or beyond. One of these, Oregon, Holt County, is in the extreme northwestern part of the state about 160 miles from Columbia; another, Miami, Saline county, is about 50 miles northwest of Columbia in the north central part of the state; the third, Edina, Knox County, is 85 miles directly north of Columbia. An examination of the weather data from these stations shows that 1860 at all three stations had the lowest annual rainfall recorded. The rainfall during the months of March and April was particularly low being one inch or less in the two months. The annual precipitation in 1860, the mean annual precipitation and the precipitation in March, April, May, and June for these three stations are given in Table III.

It is very probable that Columbia also suffered in that year an extremely dry spring and the results are preserved in the scanty

TABLE III. PRECIPITATION IN 1860 AT THREE STATIONS IN NORTHERN MISSOURI.

	Annual precipitation 1860	Mean annual precipitation	Precipitation March, April 1860	Precipitation March, April, May, June 1860	Mean precipitation March, April, May, June
	inches	inches	inch	inches	inches
Edina	20.88	7 yrs. 31.28	0.37	6.49	12.63
Oregon	23.12	62 yrs. 36.03	1.1	8.65	14.92
Miami	15.73	55 yrs. 36.60	0.37	4.52	14.87

wood growth shown by the narrow and meager annual ring for that year. Local variations in rainfall make it impossible to apply the weather data from these stations to the annual ring width of other years.

If we are correct in assuming that a dry spring is associated with decreased wood formation that same year we are probably also correct in assuming that the springs of 1833 and 34, 1838, 1840 and 41, 1843, 1847, 1860, 1870, 1874, 1877, 1886, 87 and 1888 were also dry springs at Columbia and probably received 12 inches or less of rainfall in the months of March, April, May, and June.

Why the water supply of the spring and the temperature of May and June should influence xylem formation and how this influence is exerted might be explained in the absence of experimental proof as follows:

Xylem formation in deciduous trees takes place in the spring and early summer. Th. Hartig (1857) as quoted by Grossenbacher (1915) found that new radial growth had not begun by April 15 in the oak but was evident by May 15. By August 19 radial growth had ceased on all above-ground parts of broad-leaved trees. Jost (1892) measured the diameter increase of a number of trees and found most of the growth in diameter of *Quercus Cerris, Q. Dalechampi, and Q. coccinea* to occur in June and July. In 1 and 2-year-old twigs of *Q. pedunculata.* increase in diameter took place in April, May and June. Hastings (1900) found that no increase in thickness took place in broad-leaved trees until the buds had opened and the first leaves expanded. Bogue (1905) found in a number of fruit trees and in *Acer saccharinum* that most of the diameter increase occurred in May, June and July. Knudson (1913) by histological methods found in the larch that xylem formation began the latter part of May, a month later than leaf formation, and ended early in July. Knudson (1916) found xylem growth in the grape to begin about May 29, three weeks after the buds swell, and to cease before August 9. In the peach it began about the time the buds opened May 8. In the apple xylem formation began about May 15 when the trees were in full bloom and was completed by July 19.

The xylem formed is largely formed at the expense of food manufactured during the current season and not from reserve material from the previous year. The reserve material is chiefly used in the exfoliation of leaves and the formation of flowers where they occur before leaves are formed. Hartig (1891) states that the beginning and continuation of growth activity of the cambium mantle depends on the one hand, on the temperature and on the other hand, on the presence of active building material. This building material he believes comes almost entirely from the assimilatory activity of the leaves and not from reserve material. Wieler (1896) covered 3 to 4-year-old trees of *Quercus sessilflora* before leaf development in the spring with boxes lined with black paper and compared their diameter increase with that of trees left in the light. He found that the diameter increase of the covered oaks was slight. He concludes that the reserve material plays little part in the diameter increase of the oak. Knudson (1913) states from observations made over a 2-year period with a considerable number of trees that in general growth in diameter does not begin until the leaves have been full developed and have been sufficiently active in food making to supply the requirements of rapid cell formation. The reserve foods stored up in the fall are probably largely utilized in leaf and in blossom formation, when the latter precede the formation of leaves.

The total amount of synthesized food available for a given tree depends upon the leaf area, the rate of photosynthesis per unit of leaf area, and the time during which photosynthesis is carried on. The close relation which exists between turgidity and growth makes it very probable that in seasons of insufficient water supply the total leaf area of a tree is decidedly reduced. Schimper (1903) states that with decreasing water in the soil the height of trees and the surface of foliage generally diminish. Thoday (1910) has also found that the rate of photosynthesis in turgid leaves is more rapid than in partially or completely flaccid leaves. Turgidity, dependent upon water supply on the one hand and water loss (transpiration) on the other, would limit the total amount of food synthesized by a tree due to its effect upon the leaf area of the tree and its effect upon the rate of photosynthesis. The period when water supply would be particularly important for xylem formation would therefore be during the period of exfoliation; i. e., during the latter part of April and early part of May, and during the remainder of the period of xylem formation. The rainfall during March, April, May, and June determines the supply of water available during this critical period. We should expect increased growth with increased temperature as the average temperatures for May and June (66.5 to 74°F) would hardly appear to be above the optimum for the fundamental processes, including photosynthesis, and for growth. However, increase in temperature would mean increase in transpiration which would have the same ultimate effect as a decreased water supply. High temperature due to its effect upon transpiration would, where water supply is a limiting factor, intensify the effect of low rainfall and partially nullify the beneficial effect of high rainfall. The temperature of May and June is concerned because May and June are the months during which exfoliation takes place and most of the food material is synthesized from which xylem is formed. It would appear, therefore, reasonable to assume that the water supply in the spring and the temperature of May and June influence the amount of xylem formed chiefly because of their effect upon the leaf area of the tree and upon the rate of photosynthesis which together determine the amount of material available for building xylem tissue.

Although considerable investigations have been carried out on the saturation deficit of the leaves of herbs and shrubs no observations have been published on the daily or seasonal saturation deficits of the leaves of trees. Neither have there been published, so far as the writer's knowledge extends, studies on the relation of precipitation and temperature to the leaf area of trees. The relation of leaf area and of the saturation deficit in leaves to the process of photosynthesis and the fundamental relation of this process to the growth and reproduction of trees would seem to make studies of the above type of considerable importance. It would appear advisable to investigate the relation of precipitation and temperature to the leaf area of trees and to the saturation deficit of the leaves of trees.

SUMMARY

1. The average annual ring width for oaks at Columbia, Mo. has been determined from 1830-1919 by measuring the width of the rings on stumps.

2. The annual ring width tends to increase to a maximum during the years 1902-1910 corresponding to an age of about 100 years for the oaks measured.

3. Yearly variations in the width of the annual rings for 1890-1919 are correlated inversely with the mean monthly temperatures of May and June.

4. Yearly variations in the width of the annual rings for 1890-1919 are correlated directly with the precipitation of March, April, May, and June.

5. A decided drop in the width of an annual ring during the last 30 years is correlated with a precipitation of 12 inches or less in March, April, May, and June.

6. Characteristic rings are those of 1860, 1890, 1894, and 1902.

7. The narrow ring of 1860 is correlated with a low spring rainfall in northern Missouri.

8. Sharp drops in the annual ring width occur in 1833 and 34, 1838, 1840 and 41, 1843, 1847, 1860, 1870, 1874, 1877, 1886, 87, and 1888 and probably indicate dry springs in those years at Columbia.

9. The annual ring width for the last 30 years has been calculated by means of a formula $G=Cf \times \frac{P}{T}$ where C=a constant, P=the precipitation for March, April, May, and June in inches, T=the sum of the mean monthly temperatures for May and June and f=a gradually changing factor.

10. The value of the factor, f, for 1890-94 is approximately 1, for 1895-1900, 1.5, for 1901-1906, 2, for 1907-1913, 1.5, and for 1914-1919, 1.0.

11. From the smoothed curve of the annual ring width the factor f is apparently a factor expressing the normal growth tendency of the oaks considered.

12. The average difference between the calculated and determined annual ring width is 17 percent, and for the 30 years the difference between the calculated and determined ring width about 5 percent.

TABLE IV. MEAN MONTHLY TEMPERATURES, COLUMBIA, MO., FROM 1890-1920. TAKEN FROM THE RECORDS OF THE COLUMBIA STATION OF THE WEATHER BUREAU OF THE UNITED STATES DEPARTMENT OF AGRICULTURE.

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1890	36	38	37	57	63	77	79	72	64	56	47	37
1891	36	35	37	57	62	74	72	73	72	56	41	42
1892	25	40	40	53	61	74	75	75	67	58	40	30
1893	23	28	42	55	63	73	77	74	72	59	42	36
1894	32	30	50	57	64	76	77	79	70	59	42	38
1895	25	24	43	59	65	73	74	76	73	52	43	35
1896	33	36	40	64	71	73	77	78	67	55	43	39
1897	29	35	45	55	63	73	79	74	76	64	44	29
1898	34	36	45	52	65	76	76	77	72	54	40	28
1899	30	20	37	54	67	74	75	79	67	63	50	29
1900	34	26	40	56	67	74	77	81	71	62	43	35
1901	35	27	42	53	64	78	85	79	69	60	42	27
1902	29	22	44	53	69	70	77	74	62	60	51	30
1903	31	29	46	55	65	66	77	74	66	57	40	28
1904	26	28	44	48	63	70	74	73	69	57	46	32
1905	21	20	50	54	65	76	73	77	69	54	45	33
1906	34	32	32	58	66	71	75	76	72	55	40	35
1907	34	32	52	47	59	70	77	75	69	55	42	36
1908	32	33	48	55	65	71	75	75	70	56	46	36
1909	31	37	42	53	62	72	75	79	67	56	53	23
1910	30	28	56	54	59	70	76	74	68	58	41	30
1911	34	36	45	52	69	79	78	76	73	55	38	35
1912	17	27	33	55	68	69	79	76	68	58	45	36
1913	31	28	40	55	66	76	80	83	70	54	52	38
1914	28	26	42	54	67	79	80	78	69	59	48	25
1915	27	39	35	62	63	70	74	68	70	59	49	33
1916	31	30	45	53	65	69	81	79	67	58	46	30
1917	31	28	44	52	59	71	78	72	68	49	45	24
1918	15	34	51	49	69	77	77	82	61	60	45	40
1919	34	35	47	55	62	75	79	75	71	58	42	27
1920	27	33										

TABLE V. MEAN MONTHLY PRECIPITATION, COLUMBIA, MO., FROM 1890-1919. TAKEN FROM THE RECORDS OF THE COLUMBIA STATION OF THE WEATHER BUREAU OF THE UNITED STATES DEPARTMENT OF AGRICULTURE.

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec
1890	4.02	2.34	2.80	2.17	3.92	3.40	4.97	5.47	3.97	2.10	2.34	0.38
1891	0.97	2.63	3.43	4.97	4.29	4.69	3.74	5.52	0.46	1.51	3.90	1.04
1892	2.27	6.80	3.50	5.60	10.58	3.60	7.62	3.56	4.50	1.87	2.44	2.28
1893	0.39	1.97	2.82	11.30	6.00	6.83	6.63	0.94	3.45	0.59	1.16	0.55
1894	2.46	1.35	1.84	2.02	4.33	3.04	1.20	1.29	7.57	0.98	1.60	1.20
1895	1.23	0.31	3.41	1.04	6.09	5.78	4.93	2.30	1.48	0.25	4.19	7.82
1896	1.03	1.58	1.13	3.08	5.61	4.33	3.79	1.85	3.61	2.45	1.61	1.11
1897	6.87	1.22	5.33	4.83	3.19	6.59	4.28	1.89	0.51	0.69	2.55	2.20
1898	3.37	1.84	4.41	2.76	8.39	9.02	4.60	0.47	5.43	2.61	2.29	1.42
1899	0.71	2.19	2.71	2.61	4.89	4.95	3.75	3.21	3.55	2.73	1.22	2.29
1900	1.46	3.76	1.51	3.02	1.75	5.02	2.94	4.05	3.14	7.73	1.24	0.38
1901	2.32	1.79	3.25	2.38	0.35	1.23	2.74	1.67	1.37	1.16	0.80	2.29
1902	1.04	0.90	3.58	3.42	4.33	6.56	7.66	6.64	2.60	2.52	2.89	2.20
1903	1.90	2.66	3.46	4.66	5.26	2.16	2.36	5.09	5.24	2.41	0.71	0.87
1904	2.09	1.01	3.69	7.35	5.39	5.56	2.42	6.17	15.79	1.36	0.28	1.96
1905	1.97	1.91	0.92	2.65	4.53	3.83	4.05	6.91	1.54	6.33	1.40	0.99
1906	3.94	2.56	2.83	1.96	2.73	4.21	1.33	2.94	4.80	0.40	2.93	1.60
1907	5.65	0.57	2.99	3.85	4.05	5.04	5.49	3.48	1.01	2.16	1.19	1.26
1908	1.13	4.06	1.79	4.26	6.17	6.52	2.97	4.74	2.99	0.91	3.80	1.23
1909	2.48	2.87	1.67	3.35	6.44	9.22	4.78	0.06	13.09	4.70	5.36	3.60
1910	2.36	1.09	0.64	3.82	6.82	5.67	5.25	4.40	0.36	0.67	0.33	0.81
1911	0.96	3.04	1.54	5.65	1.27	0.59	3.03	1.86	8.87	3.87	2.49	2.94
1912	0.25	1.74	6.23	5.34	3.25	3.50	1.88	4.91	3.55	4.07	1.33	0.40
1913	2.57	2.37	4.95	3.39	1.43	2.40	3.38	0.77	4.40	2.40	3.24	1.74
1914	0.55	2.51	3.36	1.74	1.37	3.14	1.70	7.35	2.56	5.14	0.32	1.86
1915	2.10	2.14	1.15	2.04	6.32	9.11	3.55	4.29	6.89	1.37	3.02	1.67
1916	6.80	0.81	1.93	2.68	5.21	3.64	0.67	2.04	4.43	1.55	2.21	1.66
1917	1.05	0.25	3.52	4.64	4.89	2.66	0.93	5.27	2.38	0.72	0.10	0.44
1918	1.00	1.30	0.64	5.07	3.95	2.68	0.73	7.83	9.69	1.99	2.47	2.30
1919	0.07	1.73	1.30	2.84	6.21	3.96	2.52	5.37	3.31	7.68	2.84	0.55

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