STEM GROWTH AND PHENOLOGY OF A DOMINANT WHITE OAK[1/]

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Stem circumference growth was observed continuously for four years in a dominant white oak tree (Quercus alba L.) while phenological data on reproductive and vegetative events were recorded for two years. Stem growth was divided in five phases: (1) an initial period limited by freezing temperatures, (2) a period of very rapid growth, (3) a period of maximum flower, leaf and branch growth when stem growth was reduced, (4) a period of moderate growth rates when leaves were fully developed and (5) a soil moisture limited phase of either no growth or net stem shrinkage. Phenological variation in both vegetative and reproductive events was not only noted between dogwood (Cornus florida L.), sugar maple (Acer saccharum Marsh.) and white oak but also within the white oak crown.

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INTRODUCTION

Phenological descriptions of growth in deciduous forest types have been limited either to the study of vegetation and reproductive events in one species (Hoffman 1972; Taylor 1972; Longman and Coutts 1974) or to the study of one growth process in one or more species (Taylor 1972; Reader 1975). An important step in modeling eco-physiological processes

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in an oak-hickory forest is a description of the timing and duration of various growth processes in the major species. The purpose of this paper is to examine the seasonal course of stem circumference growth in a dominant white oak tree (Quercus alba L.) in relationship to phenological changes and certain environmental factors. In addition, phenological events in the overstory white oak will be compared with those in two understory species, sugar maple (Acer saccharum Marsh.) and dogwood (Cornus florida L.).

METHODS AND MATERIALS

Site Description

Research was conducted in a second growth oak-hickory forest at the Ashland Wildlife Area in southeastern Boone County, Missouri (38° 45′ N. lat., 92° 12′ W. long.). The study stand, site meteorology, and soil characteristics have been previously described (Garrett and Cox 1973; Hinckley and Bruckerhoff 1975).

Study Species

A 57 year old, 19.1 m tall, dominant white oak tree 38.8 cm in diameter at breast height, a 3.3 m sugar maple sapling, and a 2.0 m dogwood sapling were chosen for study. All study trees were within 2 m of each other.

Stem Circumference Growth Study

Four electromechanical tree ring bands were placed on the stem of the dominant white oak on June 2, 1972 and stem circumference was continuously recorded using procedures described by Hinckley and Bruckerhoff (1975). Data analysis is restricted to the band located 7.7 m above the ground and just below major branching. This band was previously shown to be the most sensitive to both growth and hydrostatic changes in stem circumference (Bruckerhoff 1975).

Between June 1 and October 15, additional plant and environmental data were collected (20 days in 1972, 5 days in 1973, 7 days in 1974 and 5 days in 1975) to describe diurnal variation in not only stem circumference but also xylem pressure potential, solar radiation, air temperature and vapor pressure deficit. A complete description of data collection is provided by Bruckerhoff (1975) and Hinckley and Bruckerhoff (1975).

Phenology Study

Phenological data on leaf expansion, shoot elongation, flower and fruit formation, and leaf production, senescence, and fall were recorded weekly in 1974 (April 1 to December 10) for white oak and dogwood, and biweekly in 1975 (March 25 to December 11) for white oak, sugar maple

and dogwood. Five branches in both dogwood and sugar maple were characterized throughout the study. The mature oak was divided into sections representative of the lower, middle and upper crown. Five branches from each section were tagged and numbered for observation. On each branch, the activity of the central terminal, one side terminal, and one lateral bud were examined. Bud condition and size, bud burst, shoot elongation, number of leaves, and width and length of each leaf were measured. Similarly, flower burst, bud size, bract size, fruit production and acorn size were determined.

Leaf area index was estimated by hanging a weighted 20 m length of cord through a 25 m^2 area surrounding the white oak tree and measuring at 1 m intervals leaves which touched the cord. After randomly repeating this procedure fifteen times, the leaf area index was calculated from the mean.

Air temperature was continuously recorded by a thermograph located under the forest canopy 15 m from the study trees. Rainfall was measured with a U.S. Weather Bureau rain gauge placed in a clearing 60 m from the study area. Concomitant with phenological measurements, a Nuclear Chicago P19 depth probe and a Model 2800 A scaler were used to determine soil moisture in two access wells located within 0.5 m of the study trees. Measurements were made every 15 cm to a depth of 120 cm and converted to percentage soil moisture on a volumetric basis. This conversion was based upon a calibration between neutron probe and gravimetric readings in a nearby calibration soil pit.

When mature leaves were present, base (i.e., pre-sunrise) xylem pressure potential (BP) was measured with a pressure chamber using procedures outlined by Ritchie and Hinckley (1975). Measurements were taken on petioles of four leaves taken between 12 to 15 m in the white oak crown and on stems of two sugar maple and two dogwood branches. Relationships between BP and soil moisture content (SMC) at each depth and averaged for several depths were determined by regression analysis. The least squares best fit equations between BP and average SMC for the top 30 cm (highest coefficients of determination) for dogwood, sugar maple and white oak respectively, are as follows:

$$\ln BP = 13.199 - 3.778 \ln SMC;\ R^2 = 0.95\ (n = 28),$$
$$\ln BP = 8.545 - 2.335 \ln SMC;\ R^2 = 0.93\ (n = 5),$$
$$\ln BP = 10.253 - 2.875 \ln SMC;\ R^2 = 0.94\ (n = 25).$$

According to an analysis of variance, there was no statistical difference (.05 level) between the sugar maple and the white oak while there was between these species and dogwood.

RESULTS AND DISCUSSION

White Oak Stem Circumference Growth: Seasonal Patterns

The seasonal pattern of the 0700 hour (true solar time) stem circumference was observed in the white oak from June 2, 1972 (Year Day 154) through September 27, 1975 (270) (Fig 1). The 0700 hour value was used

because it most consistently represented maximum diurnal stem expansion in late spring, summer and early fall (Fritts 1958, Leikola 1969, Hinckley and Bruckerhoff 1975). The general pattern of stem growth consisted of an initial lag phase, a period of very rapid growth, a summer period of either no cell enlargement or net stem shrinkage, and a fall recovery period which also exhibited some growth. The discussion in this section will concentrate on patterns of stem growth, duration of each pattern and environmental (or plant) factors which might cause the shift from one pattern to the next.

The period between March 1 (60) and early April was characterized by increasing temperatures, high levels of soil moisture and an occasional period of sub-freezing temperatures. When minimum temperatures dropped below -5.0°C, rapid decreases in stem circumference of up to 1.28 mm resulted. Similar abrupt decreases in stem size have been observed in American Beech (Fagus grandifolia Ehrh.) (Fritts 1958) and in eastern hemlock (Tsuga canadensis (L.) Carr.) (Turner and DeRoo 1974) with sub-freezing temperatures. Towards the end of growth phase 1, positive increases in stem size were noted when both rehydration of tissues and growth occurred (Fritts 1958, Monk 1959). Consequently, stem circumference returned to its previous fall level or increased slightly. During 1973 and 1974, some stem growth was observed (Table 1). In contrast, no growth was observed during the same period in 1975, a year characterized by lower than normal March and early April temperatures (-2.4°C).

The second phase of growth usually began in mid-April (Fig 1, Table 1). There were either no leaves or very few small leaves on the tree during this time and soil moisture was high. Thus, daily growth was assumed to be related to stored food reserves (Kozlowski 1971). Variation in growth rates within this phase appeared sensitive to temperature changes. Fritts (1958) did not observe rapid rates of stem growth before leaf emergence in American beech in 1954 and 1955 in Ohio as were noted in this study. A combination of cold April and early May temperatures in Ohio, and lack of stored reserves within the tree because of the 1952 drought might explain this difference.

Phase 3 was typically initiated in early May. During this phase, growth in circumference was reduced considerably as branch, leaf and flower growth were taking place. Leaf emergence and major leaf and branch growth were observed on April 24 and May 6, 1974 and on April 22 and May 1, 1975, respectively. The reduced daily circumference growth during this period probably was not limited by soil moisture or temperature, but rather by competition for stored and new photosynthate by more

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Figure 1. Stem circumference growth for 1972, 1973, 1974 and 1975 from day 80 (early March) through day 270 (late September) in the dominant white oak. Plots of growth for each year are staggered to minimize overlap; that is, they do not originate at "0" on the Y-axis. Each phase (P) is indicated on the graph and the average growth rate during each growth phase is presented in mm/day. Absolute stem size for each year is given in Table 2.

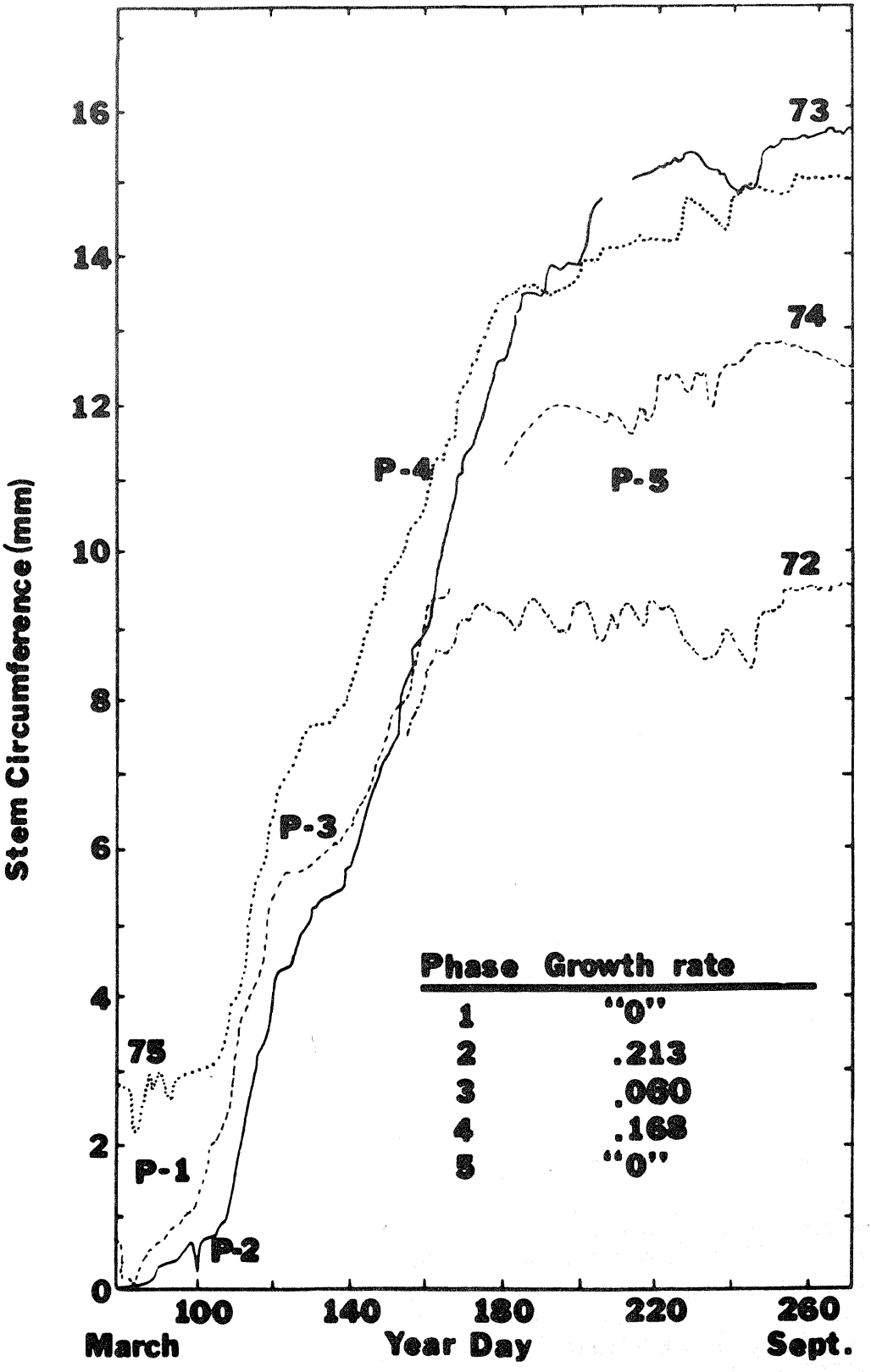

Stem Circumference (mm)
0
2
4
6
8
10
12
14
16
100
140
180
220
260
March
Year Day
Sept.
73
74
72
75
P-1
P-2
P-3
P-4
P-5
Phase Growth rate
1 "0"
2 .213
3 .060
4 .168
5 "0"

Table 1. Comparison of the date of initiation (Year Day), the duration of and rate of white oak stem circumference growth during four growth phases over a five year period (see Fig 1). Data from 1976 are included for comparative purposes, but are not discussed in the text.

	Growth Phase 1				Growth Phase 2		
Year	Date Initiated	Duration (Days)	Rate (mm/day)	Year	Date Initiated	Duration (Days)	Rate (mm/day)
1972	*	*	*	1972	*	*	*
1973	3-27 (86)	20	0.036	1973	4-15 (105)	17	0.213
1974	4-3 (93)	7	0.043	1974	4-10 (100)	23	0.196
1975	-	0	0.000	1975	4-17 (107)	16	0.230
1976	3-25 (85)	8	0.088	1976	4-2 (93)	19	0.206

	Growth Phase 3				Growth Phase 4		
Year	Date Initiated	Duration (Days)	Rate (mm/day)	Year	Date Initiated	Duration (Days)	Rate (mm/day)
1972	*	*	*	1972	*	*	0.153
1973	5-2 (122)	16	0.065	1973	5-18 (138)	**	0.171
1974	5-3 (123)	18	0.040	1974	5-21 (141)	**	0.155
1975	5-5 (125)	13	0.070	1975	5-18 (138)	**	0.136
1976	4-21 (112)	26	0.028	1976	5-17 (138)	**	0.112

* Factor was not measured.
** The fourth phase ended as soil moisture fell below 27.6% or BP fell below -2.3 ± 0.7 bars.

active sinks in other parts of the tree. The rate of growth was lowest in 1974 probably because of the abundance of reproductive structures.

By May 20, 1974 and May 16, 1975, 90% of leaf and branch growth had been completed. Growth phase 4 began in mid-May (Fig 1, Table 1). Growth rates during this period appeared to be more variable and a function of a number of complex factors. Large foliar surface coupled with increased atmospheric evaporative demand on warm, clear days resulted in mid-day stem shrinkage, thereby restricting cell enlargement to the night (Fig 2). Also, during this growth phase, stem growth probably did not depend upon stored food reserves, but rather upon currently produced photosynthates. Optimum days for photosynthesis were not always optimum days for growth. The fourth phase ended as soil moisture fell below 27.6% or BP fell below -2.3 ± 0.7 bars. The progression of day-to-day stem shrinkage was related to soil moisture and hence BP (Hinckley and Bruckerhoff 1975). The mathematical relationship between stem deviation (SD, -mm) from the zero stress (or fully turgid condition) line and BP (-bars) is: $SD = 0.084 + 0.054\ BP$, $R^2 = 0.93$ ($n = 24$). After light thunderstorms, stem circumference recovered to a level either equal to or less than the previous maximum. However, with heavier rains which allowed soil moisture to recover to 31.5% or greater and allowed BP to increase to -1.6 ± 0.5 bars or greater, stem circumference not only recovered but actually increased. This indicated that some cell division had occurred during the drought and that these cells were still capable of expanding. Dobbs (1966) noted that cambial activity (i.e., cell division) continued under summer drought conditions in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) even though stem circumference was shrinking. Full recovery of tree water content usually coincided with September rains.

Observations on progressive seasonal shrinkage of plant tissues have been extensively documented in broadleaf trees (Fritts 1958, Kozlowski and Winget 1964, Hinckley and Bruckerhoff 1975), in conifers (Haasis 1934, Kozlowski and Winget 1964, Dobbs 1966, Leikola 1969) and in herbaceous plants (Klepper et al. 1973). It appears that tissues shrink as transpiration exceeds absorption and these tissues act as a supplementary resevoir of water in addition to that in the soil (Hinckley and Bruckerhoff 1975).

Total seasonal stem growth was greatest during 1973 (Table 2) when (1) soil moisture remained high into late June, (2) early July thunderstorms (13.5 cm of rain) resulted in complete recharge of soil water throughout the soil profile, (3) the August drought was not severe (BP decreased to -10.4 bars), and (4) there were heavy rains in the first ten days of September (9.1 cm total). The least amount of total stem growth was noted in 1972 (Table 2) which was a year when soil moisture stayed below 27.6% from June 24 (176) to September 7 (251). During this prolonged drought, BP reached -19.2 bars on August 31 (244). Stem growth during 1974 and 1975 was comparable but the drought of 1975 was more severe. Base P declined to -11.5 bars in an adjacent white oak reference tree located some 4 m upslope from the study tree. Beginning on July 13, 1975 (194), the white oak study tree was periodically irrigated and BP remained near -2.3 bars and thus the stem neither shrank nor grew. Two large rains on August 14 (266, 3.4 cm) and on August 25 (237, 9.7 cm) caused an appreciable increase in stem size (Fig 1).

Maximum yearly stem circumferences were observed from September to November (Table 2). Differences in the day on which maximums occurred appeared to be related to (1) early September cold periods which accelerated senescence, (2) fall droughts and (3) the timing of leaf fall. Stem circumference after these dates decreased an average of 0.27 ± 0.06 mm by mid-November as the tree dehydrated and became dormant. Though temperatures below freezing would accelerate these decreases, most of the reduction in stem size occurred when temperatures were greater than freezing.

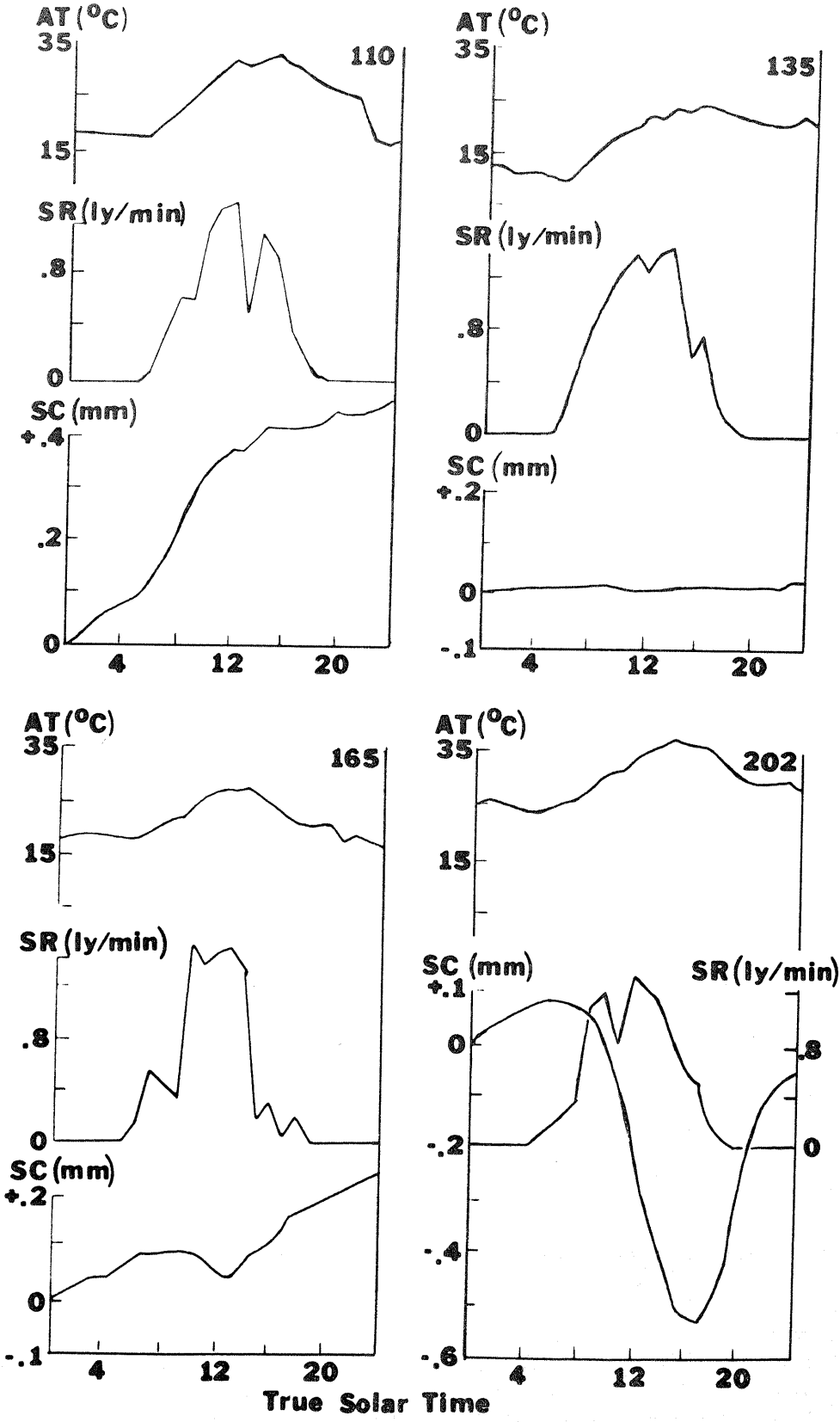
Table 2. Initial growth season and maximum stem circumference of a dominant white oak. Both the date and year day of this observation are given.

Year	Initial Growth Season Stem Circumference		Final Maximum Stem Circumference		Total Stem Growth
	Date	Size (cm)	Date	Size (cm)	(cm)
1972	6-2 (154)	75.148	11-2 (307)	75.406	0.258
1973	3-22 (81)	75.501	10-4 (277)	77.074	1.573
1974	4-3 (93)	77.070	9-7 (250)	78.265	1.195
1975	4-17 (107)	78.263	9-21 (264)	79.440	1.177

White Oak Stem Circumference Growth: Diurnal Patterns

Seasonal fluctuations in stem size are considered a result of the accumulation of those factors which cause diurnal dimensional changes (Haasis 1934). In order to more fully understand the seasonal patterns just discussed, four days in 1974 were chosen to depict the diurnal trends in stem circumference in relationship to certain environmental and plant factors (Fig 2). Soil moisture on day 110 (April 20, growth phase 2) was 42.1% and a high rate of stem growth was recorded. On day 135 (May 15, growth phase 3) soil moisture was high (42.4%), but changes in stem size were minimal. Growth conditions on day 165 (June 14, growth phase 4) were characterized by high soil moisture (40.2%), high BP (-0.8 bars) and moderate atmospheric evaporative demand. On day 202 (July 21, growth phase 5), growth conditions were characterized by low soil moisture (18.3%), relatively low BP (-6.6 bars) and high atmospheric evaporative demand.

Figure 2. Diurnal patterns of air temperature (AT), solar radiation (SR) and stem circumference (SC: set at 0 mm for 0000 hours) for days 110 (April 20), 135 (May 15), 165 (June 14) and 202 (July 21) in 1974 are shown for white oak. Year day is shown in the upper right section.


AT (°C)
35
15
110
SR (ly/min)
.8
0
SC (mm)
+.4
.2
0
4
12
20
AT (°C)
35
15
135
SR (ly/min)
.8
0
SC (mm)
+.2
0
-.1
4
12
20
AT (°C)
35
15
165
SR (ly/min)
.8
0
SC (mm)
+.2
0
-.1
4
12
20
AT (°C)
35
15
202
SC (mm)
+.1
0
-.2
-.4
-.6
SR (ly/min)
.8
0
4
12
20
True Solar Time

As discussed earlier, stem growth rates during phase 2 were the most rapid (Fig 1, Table 1). Stem circumference increased a total of 0.46 mm on day 110, a clear day during which air temperature ranged from an early morning minimum of 15.5°C to a high of 31.1°C and a low by midnight of 14.5°C (Fig 2). Diurnal stem growth was sigmoidal with a plateau in the late afternoon or early evening. Examination of stem growth and meteorological factors during several days in 1973 and 1974 during growth phase 2 suggested that four environmental factors influenced growth. These were: (1) minimum temperature near or less than freezing resulted in little or no growth, (2) low minimum temperatures caused a delay in the initiation of daily growth, (3) high daily maximum temperatures increased growth and (4) high evening temperatures reduced the length of time before a second burst of growth would occur. In contrast to the findings of Fritts (1958, 1959) in American beech, white oak and sugar maple, maximum temperatures during this growth phase did not affect stem growth as much as low morning and/or evening temperatures did.

Very little stem growth was observed on day 135 (May 15, 1974), during a phase in which major leaf and branch growth were occurring (Fig 2 and 3a). In contrast, major stem growth was noted on day 165 during phase 4; however, there was diurnal shrinkage of the stem which did not occur during phase 2 (Fig 2). The amount of shrinkage during growth phase 4 was related to atmospheric evaporative demand and will be discussed later in this section. As long as soil moisture was greater than 39% (BP $\geqslant$ -1.0 bars), recovery of stem circumference was completed before or at sunset and growth resumed. During this phase, high daytime temperatures and hence high vapor pressure deficits did not favor rapid rates of growth while high night temperatures did.

Day 202 was during a drought in 1974 and net day-to-day stem shrinkage had been observed from day 197 (July 16). Approximately 0.62 mm of shrinkage was noted between the daily maximum at 0700 hours and the daily minimum at 1700 hours. Similar patterns have been described in detail for the summer of 1972 for this tree by Hinckley and Bruckerhoff (1975).

Environmental and plant factors which might influence the amount of stem shrinkage on any day during either growth phase 4 or 5 were found by using a stepwise regression analysis on a number of environmental and plant variables and their interactions. The least squares best fit multiple variable equation where the F value for variable exclusion was set at the 5% level was:

$$\text{Stem Deviation} = 0.0223 - 0.0070\ (\text{Avg. DP*BP}) - 0.0029(\text{BP})^2 - 0.3397\ (\overline{R}_s)^2;$$
$$R^2 = .83.$$

where the units for stem deviation are -mm, for BP are -bars, for the depression in P(DP) are bars[2/] and for average solar radiation ($\overline{R}_s$) are

[2/]The terms DP and BP are defined by Ritchie and Hinckley (1975). At anytime, P = BP + DP where BP is assumed a function of soil moisture and DP the lag between transpiration and absorption.

ly/min. Obviously, stem deviation was affected by both decreasing BP, an indication of a drying soil, and increasing DP, an estimate of increasing daily plant water deficits.

Phenology Study

Figures 3a and 3b illustrate 1974 and 1975 vegetative and reproductive events in white oak (at three locations within the crown), sugar maple and dogwood. Leaf area index is also shown in order to illustrate the general vertical distribution of foliage in this stand.

Bud Burst and Leaf Emergence: Bud burst first occurred in central terminal buds of dogwood on April 1, 1974 and March 25, 1975 (Fig 3a). In 1975, side terminal buds burst four days after central terminal buds while laterals burst twelve days later. In contrast to 1975, the lateral buds in 1974 opened only seven days after the central terminal bud had burst. All tagged central terminals, 80% of the side terminals, and 40% of the laterals developed leaves and an expanding shoot in 1975.

Leaf emergence and expansion in the dogwood began simultaneously in all terminal buds and was identical for both years. Both leaf and flower development started earlier and proceeded faster in 1974 than in 1975. This may have been related to the above average temperatures in March and April of 1974 (+2.3°C difference between actual and long term daily averages) as compared to the below average temperatures in March and April of 1975 (-1.2°C).

Bud burst in the white oak and sugar maple was noted three weeks after bud burst in dogwood. In 1975, bud burst in white oak occurred almost simultaneously in central and side terminals, and in lateral buds in all three crown positions of the white oak. Approximately 75% of the lateral buds which finally opened burst at the same time as the terminal buds. The remaining lateral buds burst within the next week. However, about 20% of the lateral buds never opened. Most of the buds which failed to open were located in the lower crown section. In 1974, white oak terminal buds opened first in the lower, one week later in the middle, and two weeks later in the upper crown. Lateral buds did not open until one to two weeks after terminal bud burst. Bud swell in white oak in both years occurred about one week before bud burst.

Leaf and Shoot Growth: Leaves appeared in dogwood approximately two weeks after bud burst. Expansion of these leaves was 55% complete before the shoot began to elongate (about 20 days after the leaves first emerged). Shoot elongation continued for the next three weeks and then stopped while the leaves continued to mature. At the end of this first flush, three pairs of leaves were noted on most terminal shoots. As few as one leaf (the other aborted) was observed on lateral shoots indicating a much higher leaf mortality on these branches. About a week later, shoots from terminal buds began to elongate again, usually producing a new pair of leaves. Recurrent flushing was observed several times each

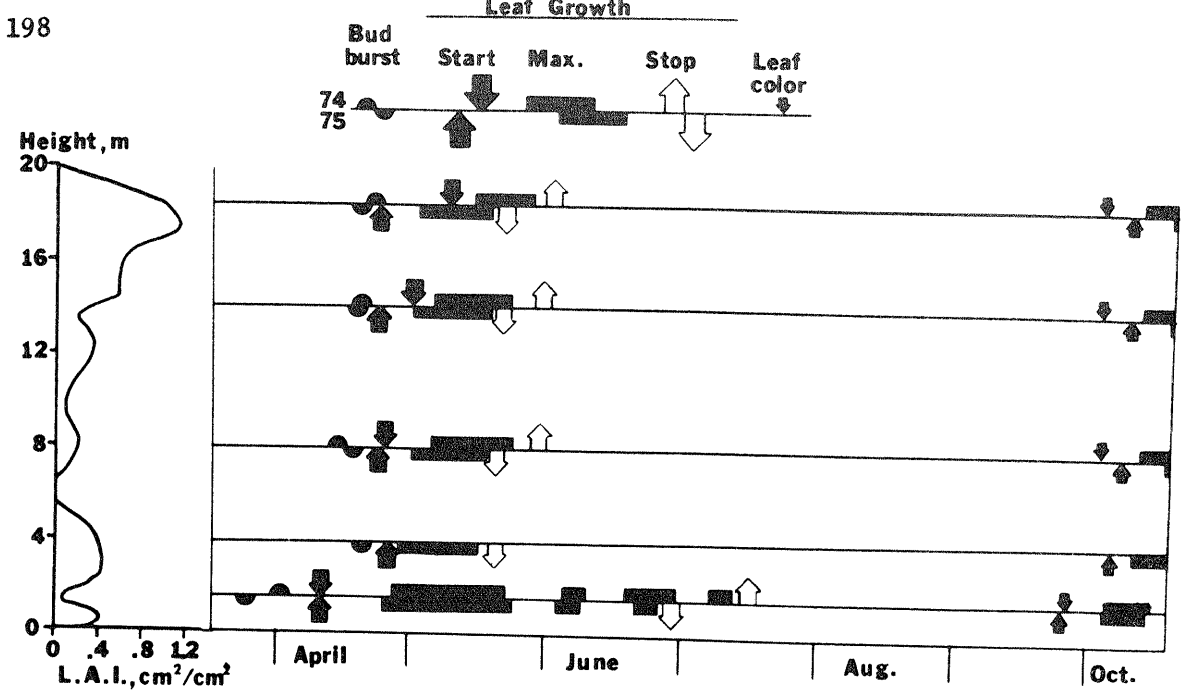


Figure 3a. Vegetative events in dogwood (first line from bottom), sugar maple (second line from bottom), and white oak (bottom, middle and top crown sections, top three lines respectively) for 1974 (top of each line) and 1975 (bottom) from March to October. Leaf area index (L.A.I.) is also given. A legend is provided.

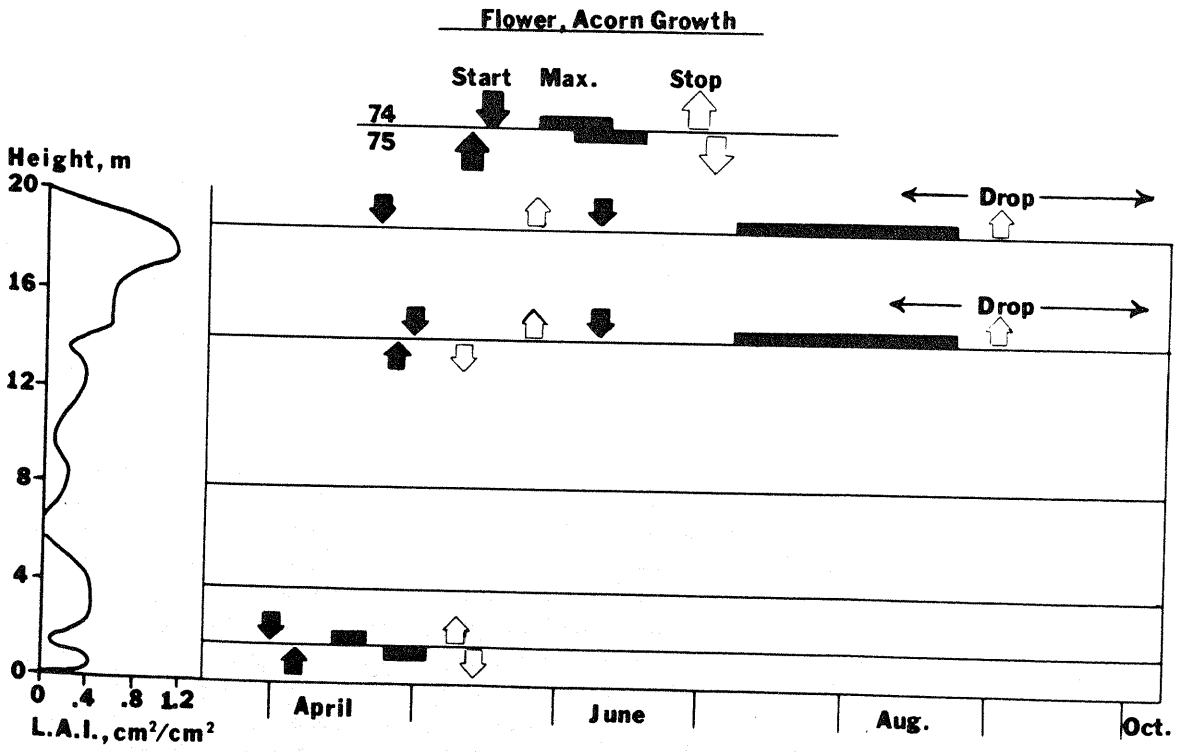


Figure 3b. Reproductive events for dogwood, sugar maple and white oak.

year with the last flushes usually restricted to the dominant terminal bud. Averages of 7, 5 and 2 leaves were recorded on the central terminal, side terminal and lateral shoots, respectively. Insect damage was prevalent in subsequent flushes. More flushes were observed in 1974 than in 1975. In both years, flushing was terminated as soil moisture approached 25% and BP decreased below -2 bars (July 13, 1974 and June 28, 1975). Leaf flushes appeared to occur (1) when soil moisture conditions improved to the extent that BP became greater than -1 bar or (2) after approximately one week as long as soil moisture remained above 25%.

Shoot growth was similar in sugar maple and white oak as it (1) started about 3 to 5 days after bud burst, (2) ended some 2.5 or 3.5 weeks after it started (white oak and sugar maple, respectively) and (3) did not flush again. In both species, leaves were initiated while the shoot continued to elongate. Leaves were fully expanded 6 to 8 days after shoot elongation had stopped. The average numbers of leaves on the sugar maple were 5, 3 and 4 for the central terminal, side terminal and lateral branches, respectively. There were 6, 5 and 1 for the lower, 7, 5 and 2 for the middle, and 4, 6 and 7 for the top crown sections of the white oak, respectively. In addition, there were differences between 1974 and 1975 white oak phenology attributed to a wasp infestation that caused deformity and aborted leaves especially in the middle crown section.

Reproductive Growth: Dogwood flower buds burst several days earlier than vegetative buds in 1974, a year with a warmer than normal March (+3.7°C). In contrast, flower bud activity in 1975 was approximately one week later than vegetative bud activity (Fig 3b). March was colder than normal in 1975 (-2.0°C) (Nat. Ocean. & Atmos. Admin. 1975). The major period of bract development occurred two weeks later and flowers were noted about three weeks after the initial bud burst. No reproductive buds were observed in the sugar maple or the lower crown zone of the white oak.

In 1974, male and female flowers appeared in the upper crown of the white oak at the same time vegetative buds were bursting in this section. About a week later reproductive buds burst in the middle crown. Male flowers exhibited faster growth rates than female flowers. The peak period of pollen dissemination was noted about three weeks after the male flowers had first appeared. Both male and female flowers dropped from the upper crown 32 days after burst and from the middle crown 25 days after burst. In 1975, no reproductive buds were observed on any of the tagged branches in any crown location. A few male flowers were found in the middle crown section; however, they never matured and had fallen from the tree within 14 days after first appearing.

In 1974, acorns were first observed in early June (Fig 3b). Major acorn growth occurred during a 48 day period beginning in early July. Acorns had matured and began changing color by the first week of September. Acorns which fell earlier were found in large clusters of 3 to 4. Acorns from smaller clusters did not seem to abort as frequently.

No acorns were noted on the study white oak tree and few on other white oak trees at the Ashland Wildlife Area in 1975.

Previous observations of acorn production in this tree described a moderate mast crop in 1972 and none in 1973. Johnson (1975) explained the excellent white oak mast production in 1974, as compared to 1973, in central Illinois using an hypothesis originally stated by Sharp and Sprague (1967). They hypothesized that an April warm period promoted the development of staminate flowers and was followed by a ten day cool period in early May which delayed pollen dispersal to coincide with pistillate flower development. A similar temperature pattern was noted at the Ashland Wildlife Area in 1974, but not at Ashland or in central Illinois in 1973. However, very few reproductive structures were noted in the study white oak in 1973, probably as a result of the extensive and severe drought of the previous summer (Hinckley and Bruckerhoff 1975).

Senescence and Leaf Fall: In dogwood, leaf coloring and observable senescence were first noted on September 25, 1974 and on September 23, 1975 (Fig 3b). Dogwood leaf fall started on October 5 in 1974, and on October 4 in 1975, lasting from 7 to 14 days in both years. In sugar maple, leaf color changes in 1975 were first observed on October 2. Leaf fall began on October 9 and lasted approximately two weeks. White oak leaves began to turn from green to brown around October 1, 1974 and five days later in 1975. In 1974, leaf fall began on October 12 while, in 1975, it did not begin until October 21. In both years, leaf fall lasted between ten and fifteen days for white oak.

CONCLUSIONS

Observations were made of phenological events for two years in a dominant white oak, an understory sugar maple and dogwood and on stem circumference growth for four years in the dominant white oak. It was found that for these trees in mid-Missouri:

(1) Five discernable stem growth phases seemed evident in white oak. The greatest amount of growth was noted during the second phase which ended when major leaf and branch growth began. The least amount of growth was observed during phase 1, when sub-freezing temperatures limited growth and during phase 5 when soil moisture was limiting.

(2) Within the white oak crown, temporal differences in bud burst, leaf emergence and growth (bottom, middle and then the top crown section) and flower emergence (top and then middle) were noted in 1974, but not in 1975. A tremendous mast production was observed in 1974 while none was found in 1975.

(3) Cooler March and early April weather in 1975 delayed both leaf and flower development in dogwood, but not in white oak. These cooler temperature averages did affect stem growth in white oak.

(4) Both vegetative and reproductive buds burst approximately three weeks earlier in dogwood than in either white oak or sugar maple.

(5) Recurrent flushing was observed only in dogwood and seemed to be controlled by soil moisture levels.

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