SEASONAL VARIATION IN THE NUTRIENT COMPOSITION OF YELLOW-POPLAR LEAVES

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ABSTRACT

In 10-year-old planted yellow-poplar trees on the Cumberland Plateau in Tennessee, leaf dry weight (mg/cm^2) increased about 20% as the growing season progressed; moisture content (% DW) decreased after an early July maximum. Whether foliar nutrient composition was expressed as concentration (% DW) or content ($\mu g/cm^2$), seasonal trends for each element were similar. Nitrogen concentration decreased during the season; N content remained constant through mid-August, then decreased. Phosphorus composition was relatively stable, and K and Mg composition gradually increased. Calcium composition increased rapidly in early summer, decreased in mid-September, and reached a seasonal high before leaf abscission. Since nutrient element levels were relatively stable during the first half of August, this period is considered an appropriate time to sample the foliage of young yellow-poplar trees.

INTRODUCTION

Foliar analysis has been widely used to assess the nutrient status of forest stands; however, the technique is not without difficulties. Meaningful analyses must take into account variations arising from seasonal changes, position in the crown, and leaf age. In deciduous broadleaf trees, the nutrient composition of leaves varies appreciably during the year because of leaching of nutrients by rainfall, transport within the plant, and changes due to maturation (Tamm 1951, Kramer and Kozlowski 1960, Guha and Mitchell 1966, Leaf 1973). McHargue and Roy's (1932) work in Kentucky represents the single study of seasonal variation in nutrient composition of yellow-poplar (*Liriodendron tulipifera* L.). They sampled only in May, August and September; and they expressed nutrient elements in terms of concentration (percent of dry weight). There are no published data on seasonal changes in yellow-poplar leaf dry weight or nutrient contents (weight per leaf or weight per area of leaf surface).

The present study sought to determine the pattern of change in leaf mass, nutrient concentration, and nutrient content of leaves of 10-year-old yellow-poplar from two seed sources growing on the Cumberland Plateau in Tennessee. These data are needed before diagnostic fertilizer experiments can begin.

Both nutrient concentration and content were examined because researchers disagree on which is more reliable. As leaves mature and accumulate cellulose and lignin, leaf mass increases. Thus, if nutrient composition is expressed as a percentage of dry weight, the accumulation of carbon compounds in mature leaves alters the basis of comparison. On the other hand, nutrient content per leaf is of questionable value because the large variation among species in leaf mass makes comparisons difficult. Since leaf area remains fairly constant after initial expansion, nutrient content per unit of leaf area may be a more useful measurement (Woodwell 1974).

SITE AND PLANTATION DESCRIPTION

The study area was located at an elevation of 1,850 feet on an east-facing slope with a 4% gradient. The soil was a Hartsells fine sandy loam (fine-loamy, siliceous, thermic, typic Hapludult), a common forest soil.

The plantation was established during the winter of 1960-61 at a 5- x 5-foot spacing with 1-0 seedlings from two geographic sources--Sewanee, Tennessee and Birmingham, Alabama. The two sources represented a difference of 2° in latitude and 1,200 feet in elevation. There were no significant (0.05 level) differences in average tree height or d.b.h. between the two sources at age 10 (Table 1).

Table 1. Plantation conditions at age 10 years after two thinnings.

Attribute[1/]	Seed Source	
	Sewanee, Tennessee	Birmingham, Alabama
Number of trees per acre		
Average	536	526
Range	475 - 576	504 - 562
Basal area - sq. ft. per acre		
Average	17.2	17.5
Range	14.1 - 20.2	13.1 - 24.4
Total tree height - feet		
Average	22	23
Range	10 - 35	9 - 41
Diameter breast height - inches		
Average	2.4	2.5
Range	0.7 - 4.2	0.5 - 4.5

[1/] The value of each attribute is the mean of four plots.

METHODS

Thinning had left the trees widely spaced with most crowns exposed on at least three sides; live crown ranged from 1/3 to 1/2 of total tree height. However, tree crowns were not large enough to sample repeatedly from just one portion of the crown--the normal procedure. Therefore, foliage samples were obtained from throughout the crown.

The 10 tallest trees per plot were selected (about 1/3 to 1/4 of the trees). On each selected tree, 12 branches were identified and numbered. Number one was the uppermost branch formed during the 1969 growing season, number two was the next branch below, and so on proceeding basipetally. Branches formed in 1970 were excluded because, on taller trees, it was impossible to reach them. The 12 branches on each tree were randomly assigned one of 12 sampling dates.

On each sampling date, leaves originating at the base of the current (1971) year's twig growth were obtained from the preselected branches in the following manner. Starting at the branch terminal and proceeding toward the main stem, pairs of leaves were detached from each twig until 20 leaves, or about 40 grams fresh weight, were obtained. If designated leaves were missing or multilated, the next younger leaves of the current year's growth were picked. This selection scheme compensated to a large extent for differences in nutrient composition associated with different stages of physiological development among leaves on a branch (Mitchell 1936, Wallihan 1944, Cain 1959). Leaves were placed in plastic bags, sealed, and stored at 5° C until processed.

After sampling, petioles were clipped from the blades; blades were ovendried at 70° C, weighed, and ground to pass a 20-mesh screen. One-gram samples were dry-ashed at 450° C for 4 hours, and the ash was taken up in 2N HCl. Phosphorus was determined by the vanado-molybdophosphoric yellow procedure (Olsen and Dean 1965), K by flame emission, and Ca and Mg by atomic absorption. Total N was determined by the micro-Kjeldahl analysis (Bremner 1965). Blade area was determined by area/weight ratios developed from 2.0 cm^2 disks punched from each leaf.

Only seven of the 12 planned collections were made. The first collection was made on 17 June and the seventh on 27 September. The first signs of fall leaf coloration appeared in early September; and by the middle of the month the older leaves had changed color, particularly those on lower branches. By 27 September leaf fall was well underway and the lower branches on most trees were nearly bare.

Physical characteristics and foliar composition of leaves from the two seed sources did not differ significantly; therefore, data on both sources were combined for analysis.

Since branch number actually denoted crown position, any differences in nutrient composition due to crown position were confounded with sampling

date. Simple linear regressions of leaf variables on branch number (crown position) were calculated for each of the sampling dates. Leaf blade weight, blade area, moisture content, and nutrient contents were significantly related to crown position; but nutrient concentrations were not significantly related. However, r^2 values of significant regressions averaged 0.13 and did not exceed 0.35. Therefore, it was concluded that crown position had not unduly influenced foliage characteristics and would not invalidate the analyses of seasonal trends.

RESULTS

Leaf Weight and Moisture Content

There was a small but steady increase in the weight per unit area throughout the season (Fig 1). Mass increased about 20% from 5.97 mg/cm^2 on 17 June to a high of 7.11 mg/cm^2 on 27 September. Surface area of sampled leaves averaged 100 cm^2.

Moisture content reached a maximum of 239% on 1 July and then decreased gradually to a low of 183% on 27 September just before abscission (Fig 2).

Nutrient Composition

Seasonal trend for each of the five elements was fairly similar whether expressed in relative or absolute units (Figs 1 and 2). Nitrogen concentration decreased steadily from a high of 2.18% on 17 June to a low of 1.35% on 27 September. Nitrogen content was nearly constant at 130 μg/cm^2 through mid-August and then decreased steadily to 96 μg/cm^2 in late September.

Calcium concentration and content increased rapidly from 1.38% and 82 μg/cm^2 on 17 June to a temporary high of 2.30% and 156 μg/cm^2 in mid-August. A slight reduction occurred in late August and early September. The seasonal high of 2.50% and 178 μg/cm^2 was recorded on the last sampling date.

Phosphorus concentration declined from 0.12 to 0.10% early in the summer and remained stable until the last sampling when it declined to 0.08%. Phosphorus content varied from 6.7 to 7.2 μg/cm^2 during most of the season before dropping to 5.8 μg/cm^2 prior to leaf abscission.

Both concentration and content of K, after reductions in late June, increased steadily from 0.99% and 60 μg/cm^2 to seasonal highs of 1.19% and 79 μg/cm^2. Potassium concentration decreased slightly on the last sampling date.

Magnesium increased from mid-June to mid-July, remained stable at 0.34% and 23 μg/cm^2 for about 45 days, and decreased in mid-September before reaching seasonal highs of 0.35% and 25 μg/cm^2 on 27 September.

Coefficients of variation of the physical and chemical properties of the leaves sampled on a particular date were less than 30%; most were 20% or less.

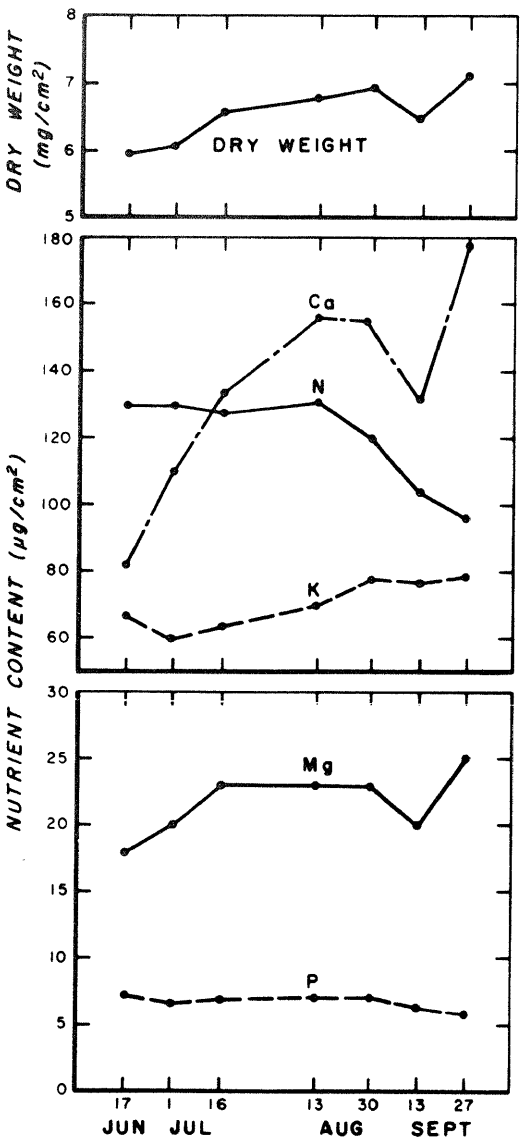

Figure 1. Dry weight and nutrient content of yellow-poplar leaves in relation to season. Each point represents the mean of 80 sample trees.

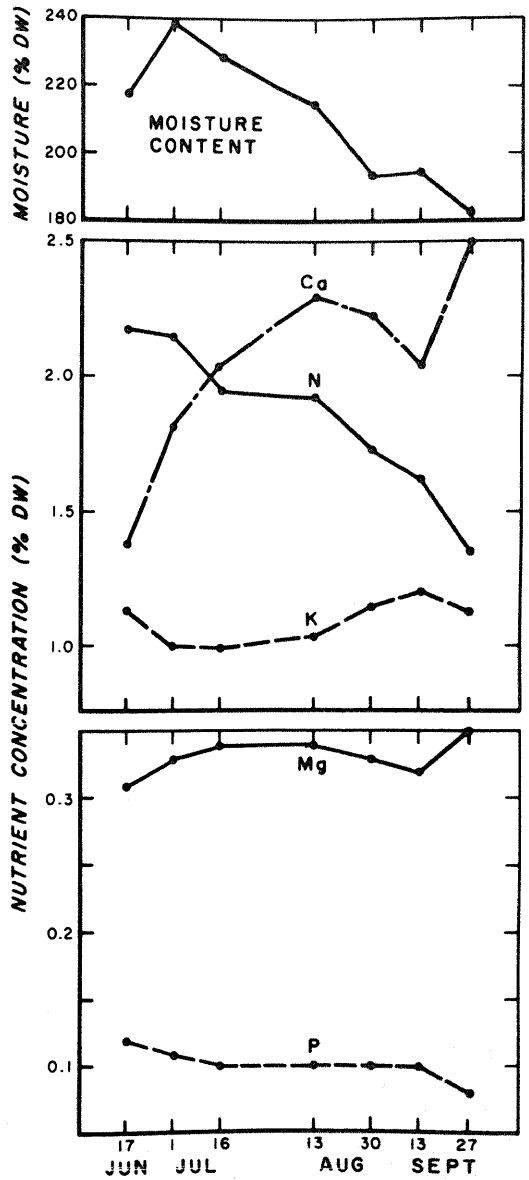

Figure 2. Moisture content and nutrient concentration of yellow-poplar leaves in relation to season. Each point represents the mean of 80 sample trees.

DISCUSSION

The 20% increase in mass per unit of leaf area was less than the 51 and 29% increases reported for white oak (Quercus alba L.) and scarlet oak (Q. coccinea Muenchh.) in the Brookhaven forest (Woodwell 1974). Since leaf area is nearly constant after initial expansion, trends in leaf mass per unit area can be compared with changes expressed as mass per leaf. Thus, the steady increase in leaf mass with season observed in the current study agrees with trends reported by Mitchell (1936) and Chandler (1939). However, Hoyle (1965) and Leaf (1973) reported late summer to early fall losses in leaf weight. Cottonwood (Populus deltoides Bartr. var. deltoides) leaves lose as much as 50% of their dry weight between August and November.[1/] Such a trend may have been undetected in my study because of the sampling procedure. Some leaves sampled on 13 September had started to change color and weighed less than the previous sample. On 27 September many of the older leaves had abscissed, and the sample contained younger leaves that had not begun to lose weight. These leaves were the heaviest ones sampled all season.

The concentrations of P were less than, while those of N, K, Ca, and Mg were comparable to reported values for many deciduous species (Alway et al. 1934, Mitchell 1936, McVickar 1949, Hoyle 1965, Guha and Mitchell 1966, and Leaf 1973). However, N, P, K and Ca concentrations disclosed by this study were less than those reported by McHargue and Roy (1932) for yellow-poplar. Differences could be due, in part, to soil. Their trees were growing in limestone-derived soils; mine were growing in soil from sandstone. Also, McHargue and Roy's foliage samples included leaves of all ages, which would tend to raise the mean concentrations.

On the average, element contents ($\mu g/cm^2$) of yellow-poplar leaves in this study were several times greater than those of white and scarlet oaks (Woodwell 1974).

For the most part, the mobile elements, N and P, displayed seasonal patterns similar to many published accounts. The constancy of N content through mid-August while N concentration was decreasing indicated that the rate of dry weight increase exceeded the rate of N flow into the leaves. Woodwell (1974) indicated an early rapid increase in N content; and Mitchell (1936), Tamm (1951), Hoyle (1965), and Leaf (1973) reported early rapid decreases in N concentration. No such changes were evident in this study because they probably occurred before 17 June when sampled leaves were about 2 months old. The stable P concentration from mid-summer to near the time of abscission was consistent with the findings of several researchers (Mitchell 1936, Tamm 1951, Hoyle 1965, Guha and Mitchell 1966, and Leaf 1973). The constancy of P content in yellow-poplar leaves was in sharp contrast to the fluctuating contents reported for white and scarlet oaks (Woodwell 1974).

[1/] Blackmon, B. G. Personal communication. Southern Forest Experiment Station, U.S. Forest Service, Stoneville, MS.

Twenty-six percent of N content was lost between mid-August and September; 17% of P content was lost in September. These losses may be due to leaching or reabsorption into other tree parts. Whether nutrients are reabsorbed before abscission (Miller 1938) cannot be answered by this type of study. If the losses are caused by reabsorption, then movement in these yellow-poplar trees, particularly of N, occurs over a longer time period than is normally associated with this process (Hoyle 1965, Woodwell 1974).

The increase in K concentration during August and September was unexpected since K is both mobile and highly soluble. The usual pattern is a steady decrease most of the season, occasionally with a more rapid decrease before abscission (McHargue and Roy 1932, Alway et al. 1934, Mitchell 1936, McVickar 1949, Tamm 1951, Guha and Mitchell 1966, and Leaf 1973). Woodwell (1974) reported constant or slowly increasing K contents in oaks followed by a rapid decrease after mid-September.

Except for the mid-September reduction, Ca and Mg compositions displayed well-documented patterns (McHargue and Roy 1932, Alway et al. 1934, Mitchell 1936, Chandler 1939, McVickar 1949, Tamm 1951, Hoyle 1965, Guha and Mitchell 1966, Leaf 1973, and Woodwell 1974). Possibly the interaction of leaf maturation and the sampling procedure was responsible for the mid-September reduction.

The ratios of N:P:K were nearly constant at 19:1:9 through mid-August. With the onset of fall coloration, the N ratio value decreased and the K ratio value increased slightly. The ratio of Ca:Mg in late June was 4.6:1 and increased slowly to 7.1:1 before leaf abscission. These reasonably stable ratios indicate that foliar analyses can be useful for determining the nutrient status of young yellow-poplar plantations.

The period before autumn coloration has been widely used as the time to sample foliage for plant analysis because of the relative stability of nutrient element levels in the foliage. Leaf (1973) questioned the biological justification for an autumnal collection time for foliage. Analysis of foliage at this time does not measure element levels during their physiological important use period. However, there are practical limitations in sampling large numbers of trees during a period of rapid change in element levels. The period from mid-July to mid-August seems acceptable for comparing percentages of P, K and Mg. Contents of P and Mg are stable from mid-July through August. Sampling for absolute amounts of N should be done before mid-August. Percentages of N and Ca and absolute amounts of K and Ca displayed no stable period. Therefore, the first half of August is proposed as the sampling period for future studies of nutrient-growth relationships.

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Glendon W. Smalley received a B.S. in forestry in 1952 and a M.S. in forest ecology in 1956 from Michigan State University, and a Ph.D. in plant and soil science from the University of Tennessee at Knoxville in 1975. He worked as a junior forester on the Sam Houston National Forest in Texas and as an assistant district ranger on the Ouachita National Forest in Arkansas from 1953-1956. In 1957, he joined the Southern Forest Experiment Station at Birmingham, Alabama. He transferred to the Silviculture Laboratory at Sewanee, Tennessee in 1963, and is currently Principal Soil Scientist for research on the Silviculture of Cumberland Plateau and Highland Rim Forests. He is the author or coauthor of 19 publications in the fields of silviculture, evaluation of forest site quality, and growth and yield.

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