FOLIAR NUTRIENT VARIATION IN FOUR SPECIES OF UPLAND OAKS

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ODC 160.21:176.1 *Quercus* spp.

USDA FOREST SERVICE RESEARCH PAPER NE-331
1975

FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
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MANUSCRIPT RECEIVED FOR PUBLICATION 5 APRIL 1975.

ABSTRACT

Sampling of forest tree foliage for nutrient analyses is commonly restricted to specific and often difficult-to-reach locations such as the uppermost sun leaves growing on the south side of the crown. A study of 60-year-old red, white, chestnut, and scarlet oaks growing near Parsons, West Virginia, suggests that the easier-to-reach foliage from the lower crown is equally well suited for nutrient sampling. In this study, 10 individuals of each species were sampled. Foliage samples were taken from the terminal shoot, from each cardinal point in the upper unshaded section of the crown, from each cardinal point in the lower section, and from interior crown positions. Samples were analyzed for N, P, K, Ca, Mg, Mn, and Fe; and variation within trees, among trees of similar species, and between species was determined for each element. Direction of foliage orientation within the crown did not influence nutrient composition. Concentrations of K, Ca, and Mg were generally higher in the lower than in the upper crown, while N, P, Mn and Fe concentrations were unrelated to position. Tree-to-tree variation was approximately the same for all crown positions. Many differences in foliar nutrient composition occurred among species.

PLANT ANALYSIS is a potentially useful technique for diagnosing nutrient deficiencies and predicting fertilizer needs of forest trees. Its reliability for these purposes, however, depends upon careful standardization of sampling procedures.

In deciduous trees, important differences in nutrient composition can be attributed to the location of the foliage in the crown. Differences occur among neighboring trees of equal size, age, and dominance class *(Chandler 1939, Guha and Mitchell 1966, Hoyle 1965, Tamm 1951, and Wallihan 1944)*. Because sampling large trees is expensive and physically difficult, it is essential to have reliable estimates of: (1) within-tree variation, including that associated with different crown positions; and (2) tree-to-tree variation within stands. Having this information, we can begin to develop sampling guidelines so that the desired accuracy of foliar analyses can be attained with a minimum number of samples.

The objective of our study was to obtain information about within-tree, between-tree, and between-species variation in nutrient composition for an even-aged upland oak stand growing on a uniform site in the northern Appalachians.

METHODS

The study was located in a 60-year-old even-aged upland oak stand on the Fernow Experimental Forest near Parsons, West Virginia. Species composition was predominantly of red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), chestnut oak (*Q. prinus* L.), and scarlet oak (*Q. coccinea* Muenchh.), with lesser numbers of black gum (*Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), and sassafras (*Sassafras albidum* Nutt.). The stand had a site index of 66 for upland oaks *(Schnur 1937)* and was tightly closed, averaging 217 stems per acre (531 stems/ha) over 5.0 inches dbh (12.7 cm) with a basal area of 110 square feet per acre (10.2 square meters/ha). The soil was a well-drained Calvin silt loam (Typic Dystrochrept) about 30 inches (76 cm) deep to bedrock and topographically uniform over the entire study site.

Ten dominant-codominant red, white, chestnut, and scarlet oaks (40 trees) located within a 1.5-acre area (0.61 ha) were climbed and sampled during a 12-day period in late August. Foliage from each tree was collected from the terminal shoot, from each cardinal point (north, south, east, west) in the upper unshaded portion of the crown, from cardinal points in the lower crown, and from interior positions. Each foliar sample, except from interior positions and terminal shoots, came from one branch and consisted of 25 mature leaves that were on current-season shoots located near the periphery of the crown. Interior samples of 25 leaves were collected as a composite sample from four smaller branches in the central portion of the inner crown; they represented true shade leaves. The terminal sample consisted of 25 mature leaves from the main terminal leader of the tree.

Leaf-blade samples, with petioles removed, were dried at 70°C, weighed, and ground to pass a 20-mesh screen. Nitrogen was determined by the Kjeldahl procedure. Phosphorus was determined colorimetrically by the vanadomolybdophosphoric yellow method; and K, Ca, Mg, Mn, and Fe were determined by atomic absorption from digests obtained by wet-ashing with nitric and perchloric acids. Nutrient levels were expressed as concentration (percent of dry weight) and also as content (milligrams per leaf). All data were tested for differences at the 5-percent level by using the Scheffé test *(Scheffé 1959)*.

RESULTS AND DISCUSSION

Within-Tree Variation

Positional differences.—Cardinal direction, within either the upper or lower crown, had no consistent effect on foliar dry weight, nutrient concentration, or nutrient content per leaf for any of the species (tables 1 and 2). Therefore, orientation data were pooled by crown position for each tree, and these pooled data were used in all other analyses (unbalanced design considered). Leaf weight and nutrient-concentration levels were often associated with crown position, but nutrient-content levels were less closely related to crown position. Positional differences were greatest for red oak, intermediate for white oak, and least for scarlet oak and chestnut oak (tables 1 and 2).

Leaf dry weight showed a decreasing trend from terminal through interior positions for all species. Differences were greatest for red oak and white oak and minimal for chestnut oak and scarlet oak. White oak leaves from interior positions weighed significantly less than those from other positions. Interior leaves of red oak weighed less than those from terminal and upper positions, and leaves from lower-crown positions weighed less than terminal leaves.

Concentrations of K, Ca, and Mg generally differed among crown positions for most species; but concentrations of N, P, Mn, and Fe were unrelated to position. K concentrations were higher in leaves from interior positions than in leaves from other crown locations; K concentrations were also generally higher in the lower crown than in the upper. Similarly, Ca and Mg concentrations were usually higher for the lower-crown and interior positions than for terminal and upper locations.

These results indicate that, for purposes of comparison, samples that are to be analyzed for weight and concentrations of K, Ca, and Mg must come from specific crown positions; for samples to be analyzed for N, P, Mn, and Fe, it is not necessary to control sampling position.

Nutrient-content data for all species showed no consistent differences due to position for any of the nutrients. However, red, scarlet, and chestnut oaks did have higher K contents in leaves from the interior positions than from terminal, upper, and lower positions. Red oak showed a decreasing trend for content of N, P, Ca, and Mn from terminal through upper, lower, and interior positions.

Species differences.—Differences in foliar weight and nutrient composition among the four species were apparent (appendix, tables 7 and 8). Red oak had the heaviest leaves and consistently had the highest nutrient content for all seven elements. White and scarlet oak foliage weighed least and usually had lower nutrient contents than did red or chestnut oaks. Concentrations of N, P, and Ca differed only slightly among red, chestnut, and white oaks; but these concentrations were significantly higher than values for scarlet oak. K and Mg concentrations were similar for red and chestnut oaks, and these were higher than concentrations occurring in white and scarlet oak foliage. Mn concentrations were significantly higher for red and scarlet oaks than they were for chestnut and white oaks. There were no differences among species for Fe concentrations.

Sampling requirements.—Within-tree variation for leaf weight, nutrient concentration, and nutrient content was usually somewhat less in the upper crown than in the lower (appendix, tables 9 and 10). Differences in variability between upper and lower crown positions were greatest for leaf weight and least for concentration. The higher variance shown by the data for content is the result of additional variation associated with leaf weights. These results show that samples obtained from either the upper or lower crown positions will require foliage from more than one branch for accurately estimating individual tree nutrition, and that a greater sampling intensity is necessary for estimating nutrient content with the same precision level as concentration.

Sample-size requirements for individual trees vary by species, specific nutrients, crown position, and the sampling accuracy that is desired (tables 3 and 4). Sampling the easier-to-reach foliage in the lower crown requires only the collection of leaves from a few more branches than if sampling is done from the

Table. 1.—Dry weight and nutrient concentration of foliage from different crown positions for red, white, chestnut, and scarlet oaks [1]

Species	Terminal foliage	Upper foliage	Lower foliage	Interior foliage	Remarks
		LEAF DRY WEIGHT *(grams)*			
Red oak	0.86a	0.81ab	0.76bc	0.73c	General decrease from terminal through interior.
White oak	.52a	.48a	.47a	.40b	
Chestnut oak	.63a	.64a	.64a	.60a	
Scarlet oak	.52a	.52a	.49a	.48a	
		NITROGEN *(percent)*			
Red oak	2.52a	2.52a	2.48a	2.48a	No appreciable change.
White oak	2.47a	2.56b	2.54ab	2.56b	
Chestnut oak	2.48a	2.45a	2.47a	2.42a	
Scarlet oak	2.26a	2.24a	2.16b	2.21ab	
		PHOSPHOROUS *(percent)*			
Red oak	.14a	.14a	.13a	.14a	No appreciable change.
White oak	.14a	.15ab	.15b	.17c	
Chestnut oak	.14a	.14a	.14a	.14a	
Scarlet oak	.12a	.12a	.12a	.12a	
		POTASSIUM *(percent)*			
Red oak	1.02a	1.04ab	1.07b	1.21c	Increase from terminal through interior; interior significantly higher than other positions.
White oak	.74a	.73a	.76a	.92b	
Chestnut oak	.91a	.90a	.98a	1.16b	
Scarlet oak	.68a	.70a	.73a	.92b	
		CALCIUM *(percent)*			
Red oak	.55a	.55a	.60b	.58ab	Increase from terminal through interior.
White oak	.42a	.47b	.58c	.61c	
Chestnut oak	.55a	.54a	.61b	.62b	
Scarlet oak	.42a	.44ab	.47b	.44ab	
		MAGNESIUM *(percent)*			
Red oak	.13a	.13a	.14b	.14b	Increase from terminal through interior.
White oak	.08a	.09a	.10b	.11c	
Chestnut oak	.11a	.11a	.13b	.13b	
Scarlet oak	.09a	.10a	.10a	.10a	No appreciable change.
		MANGANESE *(percent)*			
Red oak	.18a	.18a	.18a	.16b	No appreciable change.
White oak	.10a	.10ab	.11ab	.11b	
Chestnut oak	.11a	.11a	.12a	.11a	
Scarlet oak	.16a	.17a	.16a	.14b	
		IRON *(ppm)*			
Red oak	94a	95a	99a	101a	No appreciable change.
White oak	79a	82a	89ab	97b	
Chestnut oak	92a	88a	94a	109b	
Scarlet oak	89a	87a	82a	83a	

[1] Terminal and interior values are the averages of 10 samples obtained from 10 different trees. Lower and upper values are the averages of 40 samples (4 samples from each of 10 different trees). Each individual sample contained 25 leaves. Values in each *ROW* followed by the same letter are not significantly different (Scheffé test, $P < .05$).

Table 2.—Nutrient content (milligrams per leaf) of foliage from different crown positions for red, white, chestnut, and scarlet oaks [1]

Species	Terminal foliage	Upper foliage	Lower foliage	Interior foliage	Remarks
			NITROGEN		
Red oak	21.57a	20.29ab	18.97bc	18.12c	Decrease from terminal through interior.
White oak	13.00a	12.40a	12.08a	10.38b	No change due to position.
Chestnut oak	15.56a	15.54a	15.84a	14.52a	
Scarlet oak	11.77a	11.61a	10.69a	10.50a	
			PHOSPHORUS		
Red oak	1.17a	1.10ab	1.02bc	0.99c	Decrease from terminal through interior.
White oak	0.76a	0.72ab	0.72ab	0.67b	No change due to position.
Chestnut oak	0.86a	0.87a	0.91a	0.87a	
Scarlet oak	0.64a	0.64a	0.58a	0.59a	
			POTASSIUM		
Red oak	8.80ab	8.45ab	8.19a	8.89b	No difference between terminal, upper or lower, but interior significantly higher than other 3 crown positions, except for white oak.
White oak	3.92a	3.54a	3.59a	3.71a	
Chestnut oak	5.70a	5.62a	6.27ab	6.96b	
Scarlet oak	3.51a	3.58a	3.62a	4.32b	
			CALCIUM		
Red oak	4.79a	4.49ab	4.56ab	4.27b	No consistent trend.
White oak	2.21a	2.27ac	2.73b	2.50bc	
Chestnut oak	3.44a	2.27a	2.33a	3.77a	No change due to position.
Scarlet oak	2.15a	3.43a	3.85a	3.77a	
			MAGNESIUM		
Red oak	1.09a	1.03a	1.03a	1.01a	No change due to position.
White oak	0.43a	0.42a	0.46a	0.44a	
Chestnut oak	0.68a	0.68a	0.81a	0.81a	
Scarlet oak	0.47a	0.49a	0.48a	0.45a	
			MANGANESE		
Red oak	1.55a	1.45ab	1.36bc	1.21c	Decrease from terminal through interior
White oak	0.54a	0.51ab	0.53ab	0.47b	No change due to position.
Chestnut oak	0.69a	0.69a	0.73a	0.69a	
Scarlet oak	0.80a	0.86a	0.80a	0.68b	
			IRON		
Red oak	0.082a	0.078a	0.079a	0.067a	No change due to position.
White oak	0.041a	0.039a	0.042a	0.400a	
Chestnut oak	0.057a	0.055a	0.060a	0.065a	
Scarlet oak	0.046a	0.045a	0.040a	0.039a	

[1] Terminal and interior values are the averages of 10 samples obtained from 10 different trees. Lower and upper values are the averages of 40 samples (4 samples from each of 10 different trees). Each individual sample contained 25 leaves. Values in each *ROW* followed by the same letter are not significantly different (Scheffé test, $P < .05$).

Table 3.—Number of samples required from individual trees for estimating dry weight and nutrient concentrations at selected standard errors [1]

Species and crown position	Leaf dry weight (grams)			N (% dry wt.)			P (% dry wt.)			K (% dry wt.)			Ca (% dry wt.)			Mg (% dry wt.)			Mn (% dry wt.)			Fe (ppm)		
	.05	.10	.15	.05	.10	.15	.005	.01	.05	.05	.10	.20	.05	.10	.15	.01	.02	.03	.01	.05	.10	4	8	12
Red oak:																								
Upper	13	4	2	15	4	2	9	2	1	5	2	1	5	2	1	3	1	1	9	1	1	20	5	3
Lower	16	4	2	17	5	2	8	2	1	6	2	1	5	2	1	4	1	1	10	1	1	17	5	2
White oak:																								
Upper	5	2	1	22	6	3	9	3	1	2	1	1	6	2	1	3	1	1	8	1	1	45	12	5
Lower	6	2	1	21	6	3	19	5	1	9	3	1	10	3	2	5	2	1	10	1	1	20	5	3
Chestnut oak:																								
Upper	7	2	1	12	3	2	14	4	1	4	1	1	3	1	1	2	1	1	5	1	1	20	5	3
Lower	11	3	2	11	3	2	11	3	1	7	2	1	6	2	1	6	2	1	8	1	1	32	8	4
Scarlet oak:																								
Upper	4	1	1	6	2	1	3	1	1	4	1	1	2	1	1	3	1	1	7	1	1	17	5	2
Lower	5	2	1	12	3	2	7	2	1	7	2	1	3	1	1	3	1	1	7	1	1	19	5	3

[1] 0.95 confidence level, assuming samples of 25 leaves obtained from current-season growth located on periphery of crown; low-vigor branches excluded.

Table 4.—Number of samples required from individual trees for estimating nutrient content (mg/leaf) at selected standard errors[1]

Species and crown position	N			P			K			Ca			Mg			Mn			Fe		
	1	2	3	.05	.10	.20	.4	.8	1.0	.3	.6	1.0	.05	.10	.20	.05	.10	.20	.01	.03	.05
Red oak:																					
Upper	19	5	3	28	7	2	24	6	4	18	5	2	28	7	2	61	16	4	4	1	1
Lower	29	8	4	36	9	3	54	14	9	23	6	3	29	8	2	73	19	5	6	1	1
White oak:																					
Upper	9	3	1	12	3	1	4	1	1	4	1	1	4	1	1	9	3	1	4	1	1
Lower	12	3	2	19	5	2	5	2	1	9	3	1	9	3	1	11	3	1	1	1	1
Chestnut oak:																					
Upper	9	3	1	18	5	2	13	4	3	9	3	1	15	4	1	20	5	2	2	1	1
Lower	17	5	2	30	8	2	16	4	3	15	4	2	22	6	2	27	7	2	4	1	1
Scarlet oak:																					
Upper	5	2	1	6	2	1	3	1	1	3	1	1	6	2	1	20	5	2	2	1	1
Lower	7	2	1	10	3	1	6	2	1	5	2	1	6	2	1	15	4	1	2	1	1

[1] 0.95 confidence level, assuming samples of 25 leaves obtained from current-season growth located on periphery of crown; low-vigor branches excluded.

more difficult-to-reach branches in upper positions. However, only one or two additional branches in the lower crown need be sampled in most cases to achieve the same accuracy obtainable with foliage from upper locations.

Reasonable estimates of tree nutrition are possible if sampling is not limited to foliage located on only one branch. This study showed that a composite sample consisting of four 25-leaf subsamples collected during late August from well-distributed locations anywhere in the tree crown will usually be sufficient for estimating N to within ± 0.10 percent N and P to within ± 0.01 percent P. Also, a composite sample consisting of three 25 leaf subsamples obtained from separate branches in the lower crown or two in the upper crown will allow estimates to be within ± 0.10 percent K, ± 0.10 percent Ca, ± 0.03 percent Mg, and ± 0.1 grams for leaf weight in 95 cases out of 100. Closer estimates of tree nutrition require more intensive sampling (table 3).

Stand Variation

Tree-to-tree variation for leaf weight and foliar-nutrient composition was substantially greater than variation within individual trees. Generally, variation among individual trees of a single species was lowest for N and P, intermediate for K, and highest for leaf weight and the other cations. Tree-to-tree variability was greater for leaf weight and foliar content than it was for nutrient concentrations (appendix, tables 11 and 12).

The number of trees that should be sampled for estimating average stand nutrition varies with species and sampling position in the crown, and varies greatly among the different nutrients (tables 5 and 6). Data from our study show that samples from four trees growing on homogenous sites will generally be enough for estimating foliar N and P concentrations of the stand to within 10 percent of the mean. A much larger sample is necessary for estimating leaf weight, cation concentration, and nutrient content with the same precision.

There does not seem to be any superior sampling position for which nutrient variation remains consistently below other positions for all species. Samples obtained from the lower crown will serve as well as samples from the terminal and upper-crown positions and better than those from the interior.

From these results, we can recommend a suitable standardized sampling procedure for quantifying stand nutrition for upland oaks on homogenous sites. For each tree sampled, four composite samples of 25 leaves should be taken from current-season shoots from each of four well-distributed branches on the exterior part of the lower crown. A minimum of four trees should be sampled for red, white, chestnut, and scarlet oaks. Lower-crown foliage has the advantage of being easier, quicker, less expensive, and less dangerous to obtain. Standardizing the location from which foliar material is obtained will reduce variation and will improve the reliability of foliar-nutrient data for comparative purposes.

CONCLUSIONS

A study of foliar nutrient variation in a 60-year-old even-aged oak stand in West Virginia showed that:

- Samples obtained from lower crown positions satisfy sampling requirements as well as those from terminal and upper locations and better than those from interior positions for estimating tree and stand nutrition.
- Foliar-nutrient composition and leaf weight of individual trees are unaffected by the direction in which branches are oriented within the crown. This means that it is not necessary to restrict foliar sampling to a specific cardinal point.
- For comparative purposes, foliage to be analyzed for weight and K, Ca, and Mg concentrations should come from specific crown positions because these concentrations are dependent upon sampling location; samples for N, P, Mn, and Fe analyses may come from any crown position because concentrations of these nutrients are not position-dependent.
- Foliar-nutrient variation within trees is slightly less in the upper crown than in the lower crown, but for sampling purposes only one or two extra branches from the lower

Table 5.—Number of trees to sample for estimating foliar dry weight and nutrient concentrations (percent dry weight) to within a given percentage of the stand mean (5, 10, and 15 percent), by crown positions [1]

Species and crown position	Dry weight			N			P			K			Ca			Mg			Mn			Fe		
	.05	.10	.15	.05	.10	.15	.05	.10	.15	.05	.10	.15	.05	.10	.15	.05	.10	.15	.05	.10	.15	.05	.10	.15
Red oak:																								
Terminal	81	21	9	8	2	1	4	1	1	25	7	3	39	10	5	45	12	5	33	9	4	26	7	3
Upper	124	31	14	5	1	1	5	1	1	21	5	2	42	10	5	51	13	6	19	5	2	18	5	2
Lower	106	27	12	4	1	1	7	2	1	22	6	3	33	8	4	40	10	5	27	7	3	29	7	3
Interior	56	15	7	3	1	1	6	2	1	21	6	3	58	15	7	30	8	4	56	14	7	62	16	7
White oak:																								
Terminal	137	35	16	8	2	1	13	4	2	37	10	5	92	23	11	25	7	3	170	43	19	90	23	10
Upper	160	40	18	7	2	1	12	3	1	27	7	3	59	15	7	74	18	8	120	30	13	104	26	12
Lower	100	25	11	10	3	1	13	3	2	67	17	7	54	14	6	46	12	5	115	29	13	112	28	13
Interior	66	17	8	6	2	1	8	2	1	44	11	5	41	11	5	49	13	6	114	29	13	150	38	17
Chestnut oak:																								
Terminal	49	13	6	10	3	1	35	9	4	10	3	2	53	14	6	72	18	8	74	19	9	59	15	7
Upper	54	14	6	6	2	1	29	7	3	9	2	1	41	10	5	66	17	7	47	12	5	31	8	3
Lower	14	4	2	7	2	1	35	9	4	11	3	1	74	19	8	40	10	5	74	19	8	29	7	3
Interior	130	33	15	9	3	1	19	5	3	42	11	5	57	15	7	50	13	6	77	20	9	48	12	6
Scarlet oak:																								
Terminal	46	12	6	13	4	2	19	5	3	33	9	4	44	11	5	107	27	12	58	15	7	89	23	10
Upper	53	13	6	10	3	1	11	3	1	38	9	4	41	10	5	99	25	11	34	9	4	51	13	6
Lower	60	15	7	8	2	1	9	2	1	34	9	4	47	12	5	52	13	6	58	14	6	31	8	4
Interior	20	5	3	12	3	2	8	2	1	105	27	12	45	12	5	59	15	7	68	17	8	35	9	4

[1] 0.95 confidence level, assuming that samples from individual trees will be a composite of: (1) 25 leaves for terminal or interior positions and (2) 25 leaves from each of 4 separate branches for upper or lower crown positions.

Table 6.—Number of trees to sample for estimating foliar nutrient content per leaf (mg/leaf) to within a given percentage of the stand mean (5, 10, and 15 percent) by crown positions [1]

Species and crown position	N			P			K			Ca			Mg			Mn			Fe		
	.05	.10	.15	.05	.10	.15	.05	.10	.15	.05	.10	.15	.05	.10	.15	.05	.10	.15	.05	.10	.15
Red oak:																					
Terminal	59	15	7	85	22	10	111	28	13	197	50	22	150	38	17	98	25	11	158	40	18
Upper	108	27	12	135	34	15	154	39	18	242	61	27	211	53	24	100	25	12	206	52	23
Lower	125	32	14	139	35	16	135	34	15	180	45	20	120	30	14	120	30	14	200	50	23
Interior	50	13	6	71	18	8	94	24	11	151	38	17	81	21	9	91	23	11	148	37	17
White oak:																					
Terminal	173	44	20	135	34	15	225	57	25	308	77	35	213	54	24	438	110	49	219	55	25
Upper	223	56	25	172	43	19	217	55	25	230	58	26	231	58	26	339	85	38	213	54	24
Lower	127	32	15	107	27	12	129	33	15	163	41	19	159	40	18	294	74	33	174	44	20
Interior	90	23	10	84	21	10	113	29	13	157	40	18	119	30	14	305	77	34	334	84	38
Chestnut oak:																					
Terminal	59	15	7	86	22	10	58	15	7	62	16	7	156	39	18	70	18	8	85	22	10
Upper	52	13	6	84	21	10	80	20	9	58	15	7	130	33	15	68	17	8	86	22	10
Lower	15	4	2	43	11	5	25	7	3	50	13	6	51	13	6	43	11	5	29	7	4
Interior	138	35	16	150	38	17	151	38	17	349	88	39	174	44	20	305	77	34	186	47	21
Scarlet oak:																					
Terminal	84	21	10	85	22	10	37	10	5	80	20	9	197	50	22	89	23	10	186	47	21
Upper	54	14	6	56	14	7	64	16	8	74	19	9	112	28	13	52	13	6	179	45	20
Lower	67	17	8	62	16	7	98	25	11	109	28	13	65	17	8	89	23	10	125	32	14
Interior	42	11	5	28	7	4	85	22	10	44	11	5	97	25	11	54	14	6	49	13	6

[1] 0.95 confidence level, assuming that samples from individual trees will be a composite of: (1) 25 leaves for terminal or interior positions and (2) 25 leaves from each of 4 separate branches for upper or lower crown positions.

crown need be sampled to offset this variation.

- Variability of nutrient concentrations within the crowns of individual trees is lowest for N and P, intermediate for the cations, and highest for leaf weight. Nutrient content is much more variable than concentration because of added variability from large differences in leaf weight.

- Variation of leaf weight and nutrient composition is much greater among trees of a given species than variation within individual trees.

- In this study, internal nutrient concentrations were generally highest for red oak, lowest for scarlet oak, and variable for white and chestnut oaks, indicating that foliage from more than one species should not be combined for nutrient analyses.

Since this work concerns only one homogenous site, it is important to recognize that further studies of this nature are necessary before any conclusive sampling guidelines for oaks can be formulated on a broader basis. The question whether lower-crown samples will satisfactorily show the effects of stand treatment—such as thinning, fertilization, and irrigation—remains unanswered.

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APPENDIX

Table 7.—Dry weight and nutrient concentration comparisions among species, by crown positions [1]

Crown position	Red oak	White oak	Chestnut oak	Scarlet oak	Remarks
		LEAF DRY WEIGHT *(grams)*			
Terminal	0.86a	0.52b	0.63ab	0.52b	Red oak significantly higher than white and scarlet oaks. No significant difference among chestnut, white, and scarlet oaks.
Upper	.81a	.48b	.64ab	.52b	
Lower	.76a	.47b	.64ab	.49b	
Interior	.73a	.40c	.60ab	.48bc	
All	0.79a	0.47b	0.63ab	0.50b	
		NITROGEN *(percent)*			
Terminal	2.52a	2.47a	2.48a	2.26a	Red, white, and chestnut oaks higher than scarlet oak.
Upper	2.52a	2.56a	2.45a	2.24b	
Lower	2.48a	2.54a	2.47a	2.16b	
Interior	2.48a	2.56a	2.42a	2.21b	
All	2.50a	2.53a	2.46a	2.22b	
		PHOSPHORUS *(percent)*			
Terminal	0.14a	0.14a	0.14a	0.12b	Red, white, and chestnut oaks higher than scarlet oak.
Upper	.14ab	.15a	.14ab	.12b	
Lower	.13ab	.15c	.14bc	.12a	
Interior	.14ab	.17c	.14bc	.12a	
All	0.14ab	0.15c	0.14bc	0.12a	
		POTASSIUM *(percent)*			
Terminal	1.02a	0.74b	0.91a	0.68b	Red and chestnut oaks significantly higher than white and scarlet oaks.
Upper	1.04a	.73b	.90a	.70b	
Lower	1.07a	.76b	.98a	.73b	
Interior	1.21a	.92b	1.16ab	.92b	
All	1.08a	0.79b	0.99a	0.76b	
		CALCIUM *(percent)*			
Terminal	0.55a	0.42b	0.55a	0.42b	Red, white, and chestnut oaks highest; scarlet oak lowest.
Upper	.55a	.47a	.54a	.44b	
Lower	.60a	.58a	.61a	.47b	
Interior	.58a	.61ab	.62b	.44c	
All	0.57a	0.52a	0.58a	0.44b	
		MAGNESIUM *(percent)*			
Terminal	0.13a	0.08b	0.11ab	0.09b	Red oak significantly higher than white and scarlet oaks; chestnut oak intermediate.
Upper	.13a	.09b	.11ab	.10b	
Lower	.14a	.10b	.13a	.10b	
Interior	.14a	.11ab	.13a	.10b	
All	0.14a	0.10b	0.12ab	0.10b	
		MANGANESE *(percent)*			
Terminal	0.18a	0.10b	0.11b	0.16a	Red and scarlet oaks significantly higher than chestnut and white oaks.
Upper	.18a	.10b	.11b	.17a	
Lower	.18a	.11b	.12b	.16a	
Interior	.16a	.11b	.11b	.14a	
All	0.18a	0.10b	0.11b	0.16a	
		IRON *(ppm)*			
Terminal	94a	79a	92a	89a	No significant change.
Upper	95a	82a	88a	87a	
Lower	99a	89a	94a	82a	
Interior	101a	97a	109a	83a	
All	97a	87a	96a	85a	

[1] Terminal and interior values are the averages of 10 samples obtained from 10 different trees. Lower and upper values are the averages of 40 samples (4 samples from each of 10 different trees). Each individual sample contained 25 leaves. Values in each *ROW* followed by the same letter are not significantly different (Scheffé test, $P < .05$).

Table 8.—Nutrient content (mg/leaf) comparisons among species, by crown positions [1]

Crown position	Red oak	White oak	Chestnut oak	Scarlet oak	Remarks
			NITROGEN		
Terminal	21.57a	13.00b	15.56b	11.77b	Red oak significantly higher than white and scarlet oaks. Little difference among chestnut, white, and scarlet oaks.
Upper	20.29a	12.40b	15.54ab	11.61b	
Lower	18.97a	12.08bc	15.84ab	10.69c	
Interior	18.12a	10.38b	14.52ab	10.50b	
All	19.74a	11.96b	15.36ab	11.14b	
			PHOSPHORUS		
Terminal	1.17a	0.76b	0.86b	0.64b	Same as nitrogen.
Upper	1.10a	.72b	.87ab	.64b	
Lower	1.02a	.72bc	.91ab	.58c	
Interior	.99a	.67bc	.87ab	.59c	
All	1.07a	0.72b	0.88ab	0.61b	
			POTASSIUM		
Terminal	8.80a	3.92bc	5.70b	3.51c	Red oak significantly higher than chestnut, scarlet, and white oaks. Chestnut oak generally higher than scarlet and white oaks.
Upper	8.45a	3.54b	5.62b	3.58b	
Lower	8.19a	3.59b	6.27a	3.62b	
Interior	8.89a	3.71b	6.96a	4.32b	
All	8.58a	3.69c	6.14b	3.76c	
			CALCIUM		
Terminal	4.79a	2.21b	3.44ab	2.15b	Red oak generally higher than scarlet, chestnut, and white oaks.
Upper	4.49a	2.27b	2.27b	3.43ab	
Lower	4.56a	2.73c	2.33bc	3.85ab	
Interior	4.27a	2.50b	3.77a	3.77a	
All	4.53a	2.43b	2.95b	3.30b	
			MAGNESIUM		
Terminal	1.09a	0.43b	0.68b	0.47b	Red oak significantly higher than chestnut, scarlet, and white oaks. Chestnut oak generally higher than scarlet and white oaks.
Upper	1.03a	.42b	.68b	.49b	
Lower	1.03a	.46b	.81a	.48b	
Interior	1.01a	.44b	.81a	.45b	
All	1.04a	0.44c	0.74b	0.47bc	
			MANGANESE		
Terminal	1.55a	0.54b	0.69b	0.80b	Red oak significantly higher than chestnut, white, and scarlet oaks, but the latter 3 species were not significantly different.
Upper	1.45a	.51c	.69bc	.86b	
Lower	1.36a	.53b	.73b	.80b	
Interior	1.21a	.47b	.69b	.68b	
All	1.39a	0.51b	0.70b	0.78b	
			IRON		
Terminal	0.082a	0.041b	0.057ab	0.046b	Red oak significantly higher than scarlet and white oaks, but not chestnut oak. Trends were for chestnut oak to be higher than scarlet and white oaks.
Upper	.078a	.039b	.055ab	.045b	
Lower	.079a	.042b	.060ab	.040b	
Interior	.067a	.040b	.065ab	.039c	
All	0.076a	0.040b	0.059ab	0.042b	

[1] Terminal and interior values are the averages of 10 samples obtained from 10 different trees. Lower and upper values are the averages of 40 samples (4 samples from each of 10 different trees). Each individual sample contained 25 leaves. Values in each *ROW* followed by the same letter are not significantly different (Scheffé test, $P < .05$).

Table 9.—Pooled coefficients of variation for leaf dry weight and nutrient concentration (percent dry weight) within individual trees for upper and lower crowns of 4 species of upland oak

Species and crown position	Leaf weight	N	P	K	Ca	Mg	Mn	Fe
				Percent				
Red oak:								
Upper	10	4	4	5	8	6	10	9
Lower	11	4	4	5	8	5	11	12
White oak:								
Upper	10	4	4	4	11	8	24	22
Lower	11	4	6	8	12	10	24	24
Chestnut oak:								
Upper	7	2	2	6	7	6	15	12
Lower	10	4	5	7	9	8	19	11
Scarlet oak:								
Upper	9	3	5	4	4	5	13	16
Lower	12	3	5	6	7	5	17	12

Table 10.—Pooled coefficients of variation for nutrient content (mg/leaf) within individual trees for upper and lower crowns of 4 species of upland oak

Species and crown position	N	P	K	Ca	Mg	Mn	Fe
				Percent			
Red oak:							
Upper	10	11	10	12	11	12	10
Lower	12	13	14	13	12	14	13
White oak:							
Upper	10	10	10	11	12	13	17
Lower	12	13	13	15	13	15	10
Chestnut oak:							
Upper	9	10	9	11	12	14	11
Lower	12	13	11	13	14	16	14
Scarlet oak:							
Upper	8	8	7	9	11	12	12
Lower	12	12	12	12	12	10	16

Table 11.—Pooled coefficients of variation among individual trees for foliar dry weight and nutrient concentration (percent dry weight) by crown position for 4 upland oaks

Species and crown position	Leaf weight	N	P	K	Ca	Mg	Mn	Fe
				Percent				
Red oak:								
Terminal	20	6	4	11	14	15	12	11
Upper	24	5	5	11	14	16	10	9
Lower	23	4	6	10	13	14	11	12
Interior	16	4	5	10	17	12	16	17
White oak:								
Terminal	26	6	8	13	21	21	29	21
Upper	30	6	8	11	17	19	24	22
Lower	22	7	8	18	16	15	24	23
Interior	18	5	6	14	14	19	24	27
Chestnut oak:								
Terminal	15	8	13	7	16	19	19	17
Upper	16	6	12	6	14	18	15	12
Lower	8	6	13	7	19	14	19	12
Interior	25	6	10	14	17	16	19	15
Scarlet oak:								
Terminal	15	8	10	13	15	23	17	21
Upper	16	7	8	14	14	22	13	16
Lower	17	6	7	13	15	16	17	12
Interior	10	8	6	22	15	17	18	13

Table 12.—Pooled coefficients of variation among individual trees for nutrient content (mg/leaf) by crown position for 4 upland oaks

Species and crown position	N	P	K	Ca	Mg	Mn	Fe
				Percent			
Red oak:							
Terminal	17	20	23	31	27	22	28
Upper	23	26	27	34	32	22	32
Lower	25	26	26	30	24	24	31
Interior	16	19	21	27	20	21	27
White oak:							
Terminal	29	26	33	39	32	46	33
Upper	33	29	32	34	34	41	32
Lower	25	23	25	28	28	38	29
Interior	21	20	23	28	24	38	40
Chestnut oak:							
Terminal	17	20	17	17	28	18	20
Upper	16	20	20	17	25	18	20
Lower	8	14	11	16	16	14	12
Interior	26	27	27	41	29	38	30
Scarlet oak:							
Terminal	20	20	13	20	31	21	30
Upper	16	16	18	19	23	16	30
Lower	18	17	22	23	18	21	25
Interior	14	12	20	14	22	16	15