EFFECTS OF FERTILIZATION AND ASPECT ON LEAF BIOMASS, LEAF SIZE, AND LEAF AREA INDEX IN CENTRAL APPALACHIAN HARDWOOD STANDS

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Abstract.--Leaf biomass production and leaf area indexes (LAI) were determined on four small hardwood-forested watersheds in the Central Appalachian Mountains of West Virginia. Leaf area predictive equations were developed from leaf parameters for red oak, chestnut oak, red maple, and sugar maple. Two of the watersheds had southern exposures and two had northwestern exposures. One of each watershed pair was fertilized with 336 kilograms nitrogen/hectare and 224 kilograms phosphorous/hectare. Results showed that leaf biomass production was not significantly related to fertilization or watershed aspect, but there was a significant difference among years. The best predictor of leaf area was the product of maximum width and maximum leaf length with R^2 values between 0.87 and 0.93. R^2 values for the correlation between leaf area and leaf weight ranged from 0.61 to 0.79. LAI for the watersheds averaged 4.91 and was not significantly correlated with watershed aspect or fertilization. Average leaf weight for each species differed significantly among watersheds, but the differences were small and of little practical importance. Leaf area for each species, except chestnut oak, did not differ significantly among watersheds. Significant differences in streamflow were not detected among watersheds nor were annual differences in leaf biomass production related to annual or growing season precipitation.

Keywords: Leaf biomass, leaf area index, fertilization. *Quercus rubra* L., *Quercus prinus* L., *Acer rubra* L., *Acer saccharum* Marsh.

INTRODUCTION

Several indexes commonly used to characterize site occupancy and vigor of a forested area include basal area, total biomass, leaf biomass, and leaf area index (LAI)--the ratio of total leaf surface area measured on one side of the leaves to ground area. Leaf biomass and leaf area index are directly correlated with evapotranspiration and inversely correlated with

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water yield from a catchment. For example, Douglass and Swank (1975) found that annual water yield decreased about 200mm 16 years after a watershed in the southern Appalachians was converted from mixed hardwoods to eastern white pine. They attributed the water yield change to a much greater LAI of the pines. Also, Swank and Helvey (1970) concluded that water yield changes during hardwood regrowth were a function of LAI (or leaf biomass) on the watershed. Hibbert (1969) found an excellent correlation between water yield and the amount of dried vegetation on a grass-covered watershed. Grass yield was manipulated by fertilizer application.

Forest fertilization of mixed hardwoods may change LAI and leaf biomass and thus decrease water yields, but no such studies in the Central Appalachians have been reported. In 1974, a study was started to test the effects of forest fertilization on growth rate, leaf biomass, LAI, water yield, and water chemistry. The effects of the treatment on basal area growth have been reported (Lamson 1980). This article reports on changes in leaf biomass and LAI as a result of fertilization on opposing north and south slopes. Also, because leaf area is a difficult measurement, we describe some simple measurements as predictors of leaf area.

THE STUDY AREA

The study was conducted on the Fernow Experimental Forest in the Central Appalachian Mountains near Parsons, West Virginia. Four watersheds ranging from 2.6 to 3.8 hectares were studied. Two of them face south and two have northwest exposures. The soil is classified as Calvin channery silt loam, which is well-drained, very strongly acid with moderate permeability. Slopes are steep, averaging between 30 and 40 percent.

Vegetation is dominated by second growth hardwoods with a scattering of older trees that were left after the early logging between 1900 and 1910. Annual precipitation is evenly distributed between the dormant and growing seasons, averaging 1447mm on a nearby control watershed for a 29-year period. Annual runoff from the control watershed for the same period of record averaged 635mm; 152mm during the growing season and 483mm during the dormant season. Potential evapotranspiration on the Fernow Experimental Forest was estimated to be 559mm per year (Patric and Goswami 1968).

The most abundant species on the northwest-facing watersheds were beech (*Fagus grandifolia* Ehrh.), red oak (*Quercus rubra* L.), sugar maple (*Acer saccharum* Marsh.), sweet birch (*Betula lenta* L.) and red maple (*Acer rubra* L.). On the south watersheds, red oak, chestnut oak (*Quercus prinus* L.), red maple, white oak (*Quercus alba* L.), sugar maple, and sweet birch were most abundant. Basal area of all trees larger than 13cm dbh was about 24 m^2/ha on the south-facing watersheds, and it was about 23 m^2/ha on the northwest-facing watersheds. Volume on the 4 areas ranged from 123 to 190 m^3/ha and averaged 161 m^3/ha (Table 1).

METHODS

A 120° or 90° V-notch weir was installed on each watershed to monitor streamflow. In April 1976, one member of each watershed pair was fertilized with 336 kilograms N/ha as ammonium nitrate and 224 kilograms P/ha as P_2O_5.

Table 1. Number of trees, basal area and volume of the forests on the study watersheds

Watershed	dbh class 14-28 cm		dbh class > 28 cm		Volume	Area
	trees/ha	m^2/ha	trees/ha	m^2/ha	m^3/ha	hectares
South fertilized	110	8	55	14	144	3.2
South control	108	8	56	20	190	3.8
North fertilized	58	4	51	21	186	2.6
North control	85	6	41	16	123	2.6

Sixteen litter traps, each measuring 46 x 91 x 10 centimeters deep, were spaced at intervals of 15 meters on transects in each watershed. The traps were placed at the same locations in mid-September each year of the study and left in place until canopies were bare, usually in mid-November. Leaf biomass was collected in the fall of 1975, 1976, 1977, and 1978.

Leaves from each trap were collected weekly. A 10 percent aqueous solution of chlorox was added to each bag to curtail decomposition and to make the leaves pliable enough to handle without damage. The bags were sealed and stored in a refrigerator for 24 hours to permit the leaves to become thoroughly dampened.

In the laboratory, each bag was emptied on a table and regardless of size the first 10 whole leaves for red maple, sugar maple, red oak, and chestnut oak were selected and dried in a plant press for later determination of leaf area and leaf weight. Leaves with holes were not used. Near the end of leaf fall period, fewer than 10 leaves were often sampled for area and weight determinations. The remaining leaves in the weekly collections were ovendried and later used to determine total ovendry foliage production for each year.

The area of each pressed sample leaf was determined to the closest $0.01cm^2$ with a Denko Hayashi, Model AAM-5, automatic area meter.[2/] Maximum leaf length and maximum leaf width were also recorded for each leaf. The sample leaves were dried to a constant weight at 105°C and weighed to the closest 0.1mg, and this weight was added to the total ovendry weight for the sampling period. About 23,000 leaves of the four species were measured and weighed during this study.

An analysis of variance was used to test for differences in leaf biomass and LAI in relation to treatment (fertilized vs control), aspect, and years. The 5-percent probability level was used for accepting or rejecting the null hypotheses. Regression analysis was used to test some simple measurements of individual leaves (length, width, length multiplied by width, and weight) as predictors of surface area. Both linear and curvilinear models were tested for each species as well as a single regression for all species combined.

RESULTS

Leaf Biomass

For all watersheds, leaf fall biomass averaged 4.23 mt/ha/year (Table 2). There was no significant effect ($p > .05$) of fertilization or aspect, but there was a significant difference in leaf production among years. In 1976, leaf production averaged 4.68 mt/ha compared to 3.94, 4.19, and 4.12 mt/ha for years 1975, 1977, and 1978 respectively.

Although the greatest leaf biomass was observed in 1976, the same year that fertilizer was applied to two of the watersheds, leaf biomass was not significantly different among watersheds for that year.

In general, the south-facing watersheds produced slightly more leaf biomass than the north-facing areas. This was probably due to the greater abundance of oak leaves, which are heavy, on the south-facing watersheds.

No significant change in water yields was detected during the 3 years after fertilization although leaf biomass production was significantly different among years. It was thought that yearly differences in leaf biomass might be related to precipitation. However, we did not detect any significant relationship between annual leaf biomass production and growing season or total annual precipitation.

[2/] Manufactured by Yen Enterprises, Incorporated. The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Table 2.--Annual leaf production from four small forested watersheds in north central West Virginia

Year	North		South		Average
	Control	Fertilized	Control	Fertilized	
	-------mt per hectare ± one standard deviation----------				
1975	3.85±0.38	3.96±0.38	4.03±0.47	3.92±0.29	3.94
1976	4.73±0.60	4.35±0.52	4.73±0.54	4.91±0.54	4.68
1977	4.17±0.43	4.08±0.45	4.30±0.45	4.08±0.27	4.19
1978	3.90±0.49	3.54±0.36	4.62±0.40	4.39±0.29	4.12
Average	4.19	3.99	4.44	4.35	4.23

Leaf Weight

Although there was a significant difference in average leaf weight for each species among watersheds, the magnitude of the differences are small and of little practical significance (Fig. 1). The means were statistically significant because of the large number of observations, > 4,500, rendering the tests very powerful and making it possible to detect small differences.

Average leaf weight varied among years and was not related to watershed. For red maple and sugar maple, the lowest average leaf weight occurred in 1976, for red oak in 1978, and for chestnut oak in 1977.

Leaf Area

For each species except chestnut oak, average leaf area did not differ significantly among watersheds (Fig. 2). Chestnut oak average leaf area was significantly smaller on the north-fertilized watershed than on the other three.

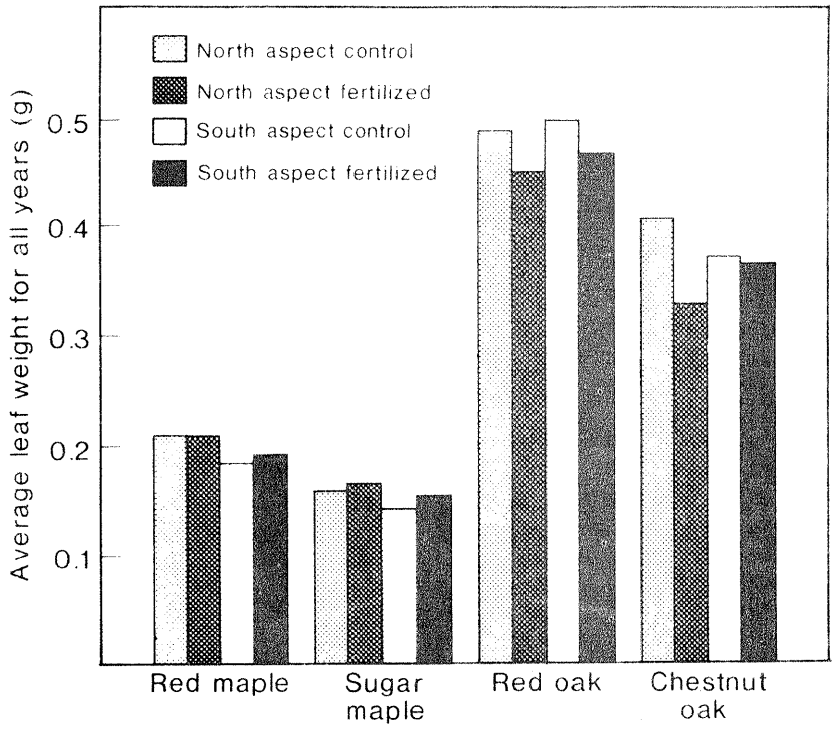

Figure 1.--Average leaf weight by watershed and species for all years.

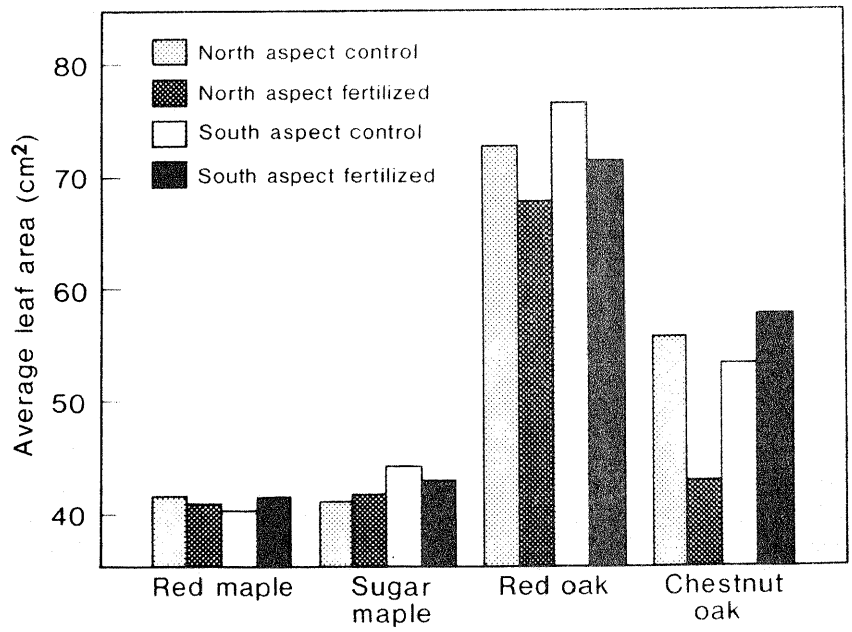

Figure 2.--Average leaf area by watershed and species for all years.

Leaf Area Index (LAI)

The parameter used to estimate LAI was total ovendry leaf biomass/hectare on each watershed. The pooled equation for all species (Table 3) using ovendry leaf weight as the independent variable was used to calculate total leaf area on each watershed:

$$Y = 17.93 + 115.83X$$

where: Y = leaf area in cm^2

X = ovendry leaf weight grams including petiole.

The ovendry leaf biomass/hectare values from Table 2 were converted to grams and entered in the equation to yield total leaf area, cm^2, on each watershed. LAI was calculated by dividing the area represented by leaf biomass/hectare by an equivalent unit of ground area, in this instance, 1 hectare.

Average LAI for all watersheds ranged from 4.6 in 1975 to 5.4 in 1976. The differences were not significant ($p > .05$) among watersheds or years. The average LAI for all years and watersheds was 4.9 calculated from the average leaf biomass of 4.23 mt/ha (Table 2).

Indexes of Leaf Area

Indexes used to estimate leaf area were maximum leaf length, maximum leaf width, the product of length times width, and weight. The product of length and width accounted for 87 to 96 percent of the variation in the regression of y on x with standard error of estimates ranging from 5.58 to 12.89cm^2 (Table 3). Maximum width was the next best predictor except for red oak where length was better.

The poorest estimator of leaf area was leaf ovendry weight. This variable accounted for 61 to 79 percent of the variation in leaf area for the species sampled. The relationship was considerably better for the oaks than for the maples. The pooled equation accounted for 73 percent of variation in leaf area associated with average leaf weight. The curvilinear model generally yielded slightly higher R^2 values, but the coefficients of the quadratic terms were not significant.

Average Weight/Unit Area

The four species were common on all watersheds and represent a wide range in leaf size and weight. Oak leaves were largest and heaviest, and maples were smallest and lightest. Red and sugar maple leaves averaged 0.0048 g/cm^2 and 0.0038 g/cm^2, respectively, while red and chestnut oak averaged 0.0066 g/cm^2 and 0.0071 g/cm^2, respectively.

Table 3.--Coefficients derived from 4 years of data (1975-1978) on all the watersheds for determining leaf area in cm^2 for the equation having the form Y = a + bx

Species	Independent variable[1/] (x)	Number of observations (n)	a	b	Coefficients of determination (r^2)	Standard error (cm^2)
Red maple	Wt	5143	12.16	148.04	.67	12.85
	L	5143	-35.94	9.97	.80	9.94
	W	5143	-28.84	8.52	.84	8.92
	LxW	5143	.59	.60	.91	6.64
Sugar maple	Wt	6713	15.51	168.23	.61	13.58
	L	6713	-35.95	10.22	.83	8.97
	W	6713	-32.73	8.28	.87	7.75
	LxW	6713	.57	.57	.93	5.58
Red oak	Wt	6407	13.60	123.63	.75	18.25
	L	6407	-66.57	10.14	.82	15.26
	W	6407	-47.52	11.58	.76	17.81
	LxW	6407	1.29	.48	.87	12.89
Chestnut oak	Wt	4517	9.33	116.13	.79	13.82
	L	4517	-46.54	7.80	.79	13.82
	W	4517	-28.36	14.02	.86	11.34
	LxW	4517	2.14	.64	.96	6.24
All species	Wt	22780	17.93	115.83	.73	16.15
	L	22780	-17.01	6.70	.70	16.98
	W	22780	-18.66	8.30	.60	19.76
	LxW	22780	7.18	.48	.88	10.77

[1/] Wt = ovendry leaf weight (g) including petiole.

L = length measured from base of leaf along the midrib to the longest tip (cm) excluding petiole.

W = width measured perpendicular to midrib at widest point (cm).

LxW = product of length times width.

n = number of individual leaves measured.

DISCUSSION AND SUMMARY

Single-side leaf area was best estimated by the product of maximum leaf length and maximum leaf width. For individual small trees with few leaves, the required measurements would be practical and would provide a good estimate of leaf area/tree. In fact, Wargo (1978) used these parameters for determining leaf area of small black oak, white oak, and sugar maple trees in New England. For determining leaf area of individual large trees, the weight equations, though less accurate, would probably have to be used. For estimating leaf surface area of our stands in this study, we used the ovendry weight/leaf area relationships developed from measurements on about 23,000 red oak, chestnut oak, red maple, and sugar maple leaves subsampled from leaf trap collections over a period of 4 years. Although only the four major species occurring on the watersheds were sampled, the pooled weight equation, when used in conjunction with leaf trap data, should provide more than adequate estimates of LAI for Central Appalachian hardwood stands.

We were not able to detect any significant differences in leaf biomass production or individual species weight from fertilization. In contrast, Auchmoody and Smith (1977) reported an increase in yellow-poplar and red oak leaf weights from fertilized trees in similar Central Appalachian hardwood stands. Although Lamson (1980) reported diameter and basal area growth response in red oak and black cherry during the 4 years after fertilization on the same watersheds, we did not detect any increase in leaf weight.

We had speculated that fertilization might also reduce streamflow by increasing tree growth and leaf size with a resultant increase in evapotranspiration, but we were unable to detect any significant changes in water yield between the control and fertilized watersheds.

Our average annual leaf production of 4.23 mt/ha for the four watersheds was slightly less than the 4.66 mt/ha reported for a 265 year-old oak forest in the piedmont of New Jersey (Lang 1974). Although our stands contained a high percentage of oaks, mixed with a sugar maple, red maple, and sweet birch component, the New Jersey forest was composed primarily of oaks which have generally heavier leaves than the maples and sweet birch. In general, our values were higher than those reported for oak-hickory and mesophytic cover types in eastern Tennessee, (Grigal and Grizzard 1975) and the general figure compiled for deciduous angiosperm forests in the northern hemisphere by Bray and Gorham (1964). In our study the highest amount of leaf litter biomass occurred in 1976 which was significantly higher than the other three years of record. Lang (1974) also reported annual differences in the 265 year-old oak forest in New Jersey. However, Bray and Gorham (1964) compiled data from several deciduous angiosperm forests in which the ratio of maximum to minimum total litter fall for several years varied from 1.1 to 1.8. For our study areas during the four years the ratio of maximum to minimum annual leaf biomass was 1.3 for the north and south watersheds. Among the important variables cited as affecting annual variation in leaf biomass or total litter fall, were environmental factors such as storms, depth of species rooting, and temperature and moisture regimes during the growing and dormant seasons (Bray and Gorham 1964).

We did not address the problem of leaf weight loss due to consumption by insects and diseases or retranslocation. Thus, our values for leaf weights are probably low. Monk et al. (1970) reported that 1.6 to 8.7 percent of the net primary annual production in a Georgia Piedmont oak-hickory forest was consumed by organisms.

The data presented on LAI provides useful estimates of this parameter for Central Appalachian hardwood forests. Our calculated LAI value of 4.91 for all watersheds is about midway of the 4 to 6 range reported for many fully stocked deciduous forests (Whittaker and Woodwell 1967). Apparently, LAI does not vary greatly within a region for different stand structures and densities. For all practical purposes, the stands on these watersheds were considered fully stocked, and we were not able to detect any differences in LAI among treatments.

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