A PRELIMINARY REPORT ON NUTRIENT CONCENTRATIONS IN SUN AND SHADE LEAVES OF NINE HARDWOOD TREE SPECIES IN SOUTHWESTERN ILLINOIS

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Abstract.--The relative proportions of seven mineral nutrients in foliage, for most trees sampled were (descending order): Ca, K, Mg, Mn, Fe, Zn and Cu. Whether the concentration of a given nutrient was higher in sun or shade leaves was dependent upon the individual tree. Differences in concentrations between sun and shade leaves were significant ($p \leq .10$) for only 2 nutrients for *Carya glabra* (Mill.) Sweet (Cu, Zn), *Acer saccharum* Marsh. (Mn, K) and *Liriodendron tulipifera* L. (Fe, K). Differences were significant for concentrations of 6 nutrients (Ca, K, Mg, Mn, Zn, and Cu) for *Fagus grandifolia* Ehrh. and *Quercus alba* L. Although interactions between species and foliage type were significant for all nutrients except Fe, the principal source of variation in nutrient concentrations was species. Foliage type and the interaction component accounted for less than 9% of the variation in nutrient concentration.

Additional keywords: Illinois Ozarks, nutrient concentrations, sun and shade leaves, hardwoods, sampling scheme.

INTRODUCTION

Foliage is an important sink for nutrients in forest ecosystems and has been studied extensively in nutrient analysis work. Obtaining representative samples for estimating mean conditions and nutrient standing crops is difficult and has received considerable study (van den Burg 1976). Variation in foliar nutrient concentrations may occur among species, branches on single trees, leaves of different ages, positions within tree crown, times of sampling, morphological types, and degrees of exposure to sunlight (Auchmoody and Greweling 1979). Unfortunately, these variations in nutrient concentrations are often inconsistent (Wallihan 1944, McVickar 1948, Guha and Mitchell 1966, Thomas 1969, Johnson and Risser 1974, Ellis 1975, Rochow 1975). Therefore, prior knowledge of the sources of variation, and the relative importance of each, is required for devising sampling schemes intended to characterize foliar nutrient contents.

In this paper we report the variations in the concentrations of seven foliar nutrients which are attributable to species differences and foliage type (sun and shade leaves) for nine hardwoods important in forests of the Illinois Ozarks. The results have proven useful for planning studies of mineral standing crops in these forests.

STUDY AREA

The forests of the Southern Section of the Ozark Hills (Schwegman 1973) where the study was conducted include both mixed mesophytic and oak-hickory

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communities. These Hills are at the eastern most edge of the Ozark Plateau Province (Thornbury 1965) and are included within the Western Mesophytic Forest Region (Braun 1950). Basal area and density average 24.2 $m^2 \cdot ha^{-1}$ and and 868 $stems \cdot ha^{-1}$, respectively, (J. Rosson unpublished data) in the watershed. The nine taxa sampled in this study comprise 82% of the total basal area with the following distributions; 28% Quercus alba L., 27% Q. velutina Lam., 6% Q. rubra L., 8% Carya glabra (Mill.) Sweet. (includes C. ovalis (Wang.) Sarg.), 3% Sassafras albidum (Nutt.) Nees., 2% Lirodendron tulipifera L., 2% Fagus grandifolia Ehrh., 2% Acer saccharum and 2% Liquidambar styraciflua L. Five of these species (Quercus alba, Q. velutina, Q. rubra, Carya glabra (includes C. ovalis) and Liriodendron tulipifera) have a total above-ground biomass of 151 $mt \cdot ha^{-1}$ (Jones 1980).

The watershed itself is located in the Trail-of-Tears State Forest in Union County. Maximum local relief is 60 m and steep, with finely dissected slopes prevailing. Soils of the Alford series, (fine-silty, mixed, mesic) Typic Hapludalf, which is formed in deep loess occupies most ridges and upper slopes. The Goss series, (clayey-skeletal, mixed, mesic) Typic Paleudalf, which forms in a mixture of cherty residuum and loess is common on mid-and lower slopes. Elsah soils, (loamy-skeletal, mixed, non-acid, mesic) Typic Udifluvent, formed in relatively shallow silty and cherty materials, occupy larger ravine bottoms. Precipitation averages about 108 $cm \cdot yr^{-1}$ (Page 1949) but moisture deficits may occur during mid-and late summer.

METHODS

Foliage samples were collected in late August and September, 1978, prior to yellowing. During this period, within tree foliage nutrient concentrations are more stable than at other times during the growing season (van den Burg 1976). Only trees in dominant and codominant canopy positions were sampled. Sixteen grab samples were taken from one tree of each species. Eight of the samples were shade leaves collected from 1 or 2 of the lower branches and the remaining were sun leaves which were collected from 1 or 2 branches in the upper one-half of the crown.

Samples were oven dried at 70°C for at least 24 hours, then ground in a Wiley Mill with stainless steel knives and a 2mm mesh stainless steel screen. Milled samples were redried to a constant weight for digestion. Samples of between 0.5 and 0.75g and weighed to the nearest 0.1mg were digested using nitric and perchloric acids with sodium chromate added as a catalyst and safety indicator as described by Smith (1953). Nutrient concentrations for Ca, K, Mg, Mn, Fe, Zn, and Cu were measured by flame atomic absorption spectrophotometry. Calcium and Mg were determined by a nitrous oxide flame. Interferences associated with Ca were minimized by adding a 5% lanthanum solution to samples at a ratio of 5ml lanthanum per 95ml sample solution (Perkin-Elmer 1976). Samples were stored at 3°C in linear polyethylene bottles.

The data were analyzed using the t-test for correlated samples (Roscoe, 1975) to test differences between mean nutrient concentrations at the 0.10 level of significance. Also, major sources of variation in nutrient concentration were determined through analysis of variance. All analyses were conducted using the Statistical Package for the Social Sciences (Nie et al. 1975).

RESULTS

Species, foliage type, and the interaction of species and foliage type each were significantly related ($P \leq 0.10$) to variations in nutrient concentrations of foliage from the nine hardwoods, with only a few exceptions (Table 1). Species accounted for 75% or more of the total variation for most nutrients. The only exception was Fe, for which species differences accounted for about 43% of the variance. For this element 50% of the variance was unexplained by the effects tested, compared to 20% or less of unexplained variance in the other elements. Variance in nutrient concentrations attributal to foliage type and the interaction of species x foliage type differed among the elements but was less than 5% for each source in all cases.

Differences in concentrations of nutrients between foliage types(sun and shade) leaves did not have a consistent pattern, but varied according to species and element. Sun leaf-shade leaf differences were significant for 31 of the possible 63 cases and that most often shade leaf concentrations were greater (Fig. 1). Only eight cases were found where sun leaves had the greater concentration, and five of these were for Mn. Concentration differences between foliage types, when significant, averaged about 25%, but the range was from 7-59%. Among nutrients, differences were greatest for Cu ($\bar{x}$=28%) and Ca ($\bar{x}$=26%) and least for Fe ($\bar{x}$=19%). Species with greatest differences between foliage types were *Liquidambar styraciflua* ($\bar{x}$=30%) and *Fagus grandifolia* and *Sassafras albidum* ($\bar{x}$=26%); least differences were in *Acer saccharum* and *Liriodendron tulipifera* ($\bar{x}$=14%).

Differences in concentrations between foliage types were significant ($P \leq .10$) for two nutrients for *Carya glabra* (Cu, Zn), *Acer saccharum* (Mn, K) and *Liriodendron tulipifera* (Fe, K). Differences were significant for 6 nutrients (Ca, K, Mg, Mn, Zn, Cu) for *Fagus grandifolia* and *Quercus alba*. The remaining 4 species had either 3 or 4 significant nutrient concentration differences.

Comparison of nutrient concentrations in Figure 1 shows that none of the species had either universally high or low nutrient concentrations. Some species such as *Liriodendron tulipifera* and *Quercus velutina* had the highest concentrations for one or two elements but the lowest for others. For most elements minimum and maximum concentrations between species differed by factors of 4 to 5 times. The relative concentrations of mineral nutrients in foliage, for most species, regardless of foliage type were (in descending order): Ca, K, Mg, Mn, Fe, Zn and Cu. Exceptions to this sequence were Mn and Mg for *Quercus alba*, *Q. velutina*, and *Fagus grandifolia*.

DISCUSSION

Nutrient values from one individual of a species population seldom, if ever, represents the true population mean. However, the concentrations in the present study are generally in good agreement with mean concentrations (N=10) found by Jones (1980) for the same species populations which were sampled irrespective of foliage type. Also, intraspecies variability was relatively small for all nutrients (SE of the mean less than 10%); while minimum and maximum concentrations between species differed by factors ranging from 0.5 (Cu) to 5.5 (Zn) times and averaged 2.6 times (Jones 1980).

Table 1.--R^2 values (x 100) for sources of variation for concentrations of seven nutrients in tree foliage.

		Element													
		Ca		Mg		K		Mn		Fe		Zn		Cu	
Source of Variation	df	R^2	F	R^2	F	R^2	F	R^2	F	R^2	F	R^2	F	R^2	F
Species	8	89.2	193.93[c]	90.2	238.36[c]	74.9	73.53[c]	88.1	203.06[c]	42.6	13.54[c]	93.7	313.65[c]	75.3	61.81[c]
Foliage Type	1	0.8	13.07[c]	0.3	5.83[b]	4.9	38.30[c]	0.1	20.74[c]	3.2	8.22[c]	0.5	13.69[c]	3.9	25.15[c]
Species x Foliage Type	8	1.5	3.6[c]	3.1	8.17[c]	4.0	3.91[c]	3.1	7.08[c]	4.6	1.45[ns]	1.2	4.06[c]	2.4	1.99[a]
Residual	126	7.4		6.1		16.4		6.9		50.3		4.8		19.6	

[a]denotes $P \leq 0.10$

[b]denotes $P \leq 0.05$

[c]denotes $P \leq 0.01$

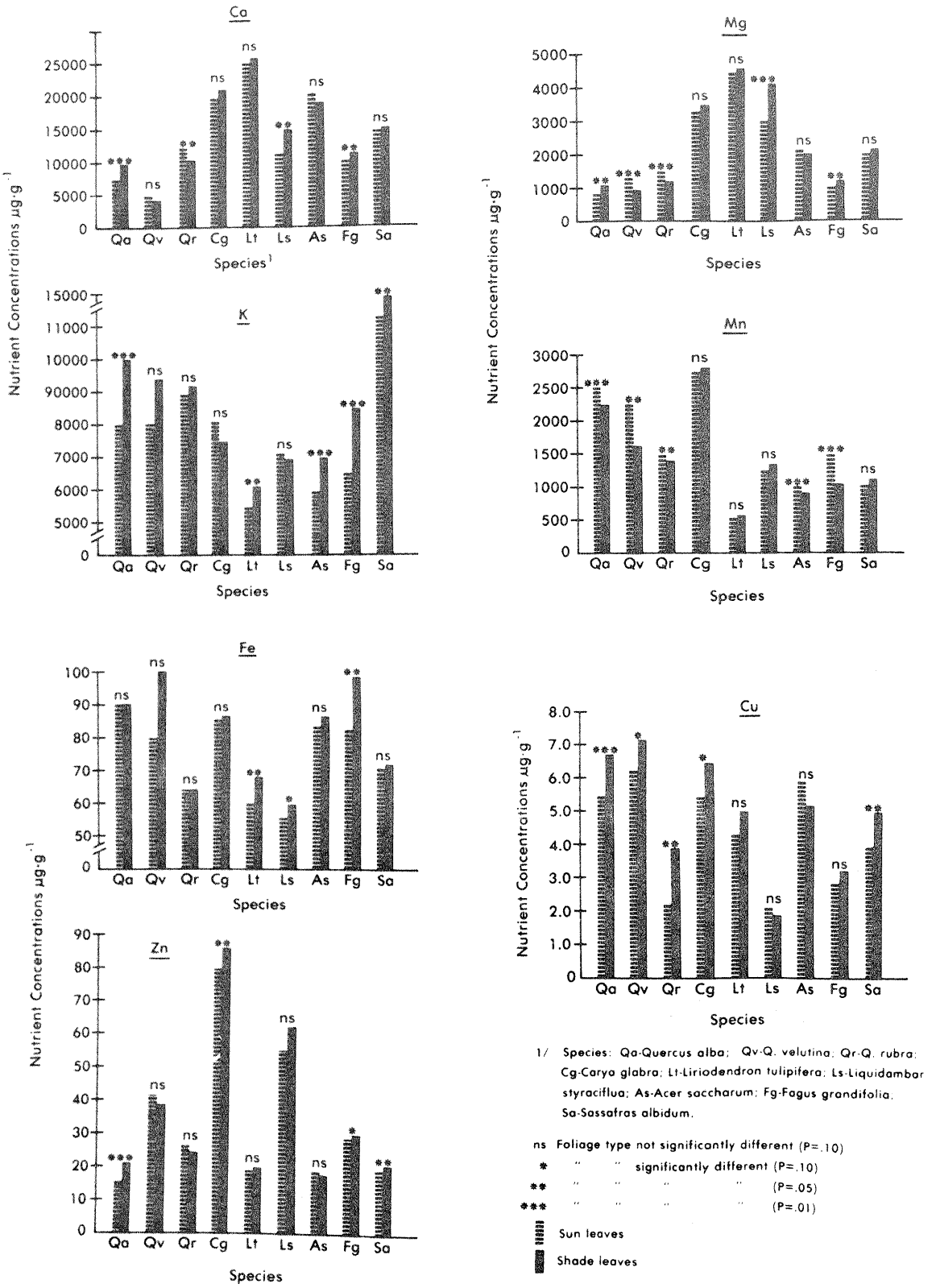

Figure 1.--Concentrations of seven nutrients in sun- and shade-leaves of nine hardwood tree species.

The sequence of nutrients, according to relative concentrations and the wide range in amount of each, is typical of the foliage of many hardwood trees (Wallihan 1944, Guha and Mitchell 1966, Ellis 1975, Woodwell et al. 1975, Whittaker et al. 1979). The effects tested in this study, particularly species differences, accounted for a relatively large proportion of these variations for all nutrients except Fe. The narrow range of concentrations of Fe among species may partially explain the relatively low R^2 for this element. The factors associated with the magnitude of differences for specific nutrients in these species are unclear but may include local environmental conditions and nutritional differences among species in addition to respective roles of nutrients in photosynthesis. For example, ranges of concentrations were small for some photosynthetic (Fe) and nonphotosynthetic (K) elements, but were large for other elements from these respective groups (Mg, Mn vs. Ca).

None of the species can be classified as nutrient "rich" or "poor" in the sense that concentrations of all nutrients are either high or low, relative to other species. Each species has a unique nutrient profile (sensu Woodwell et al. 1975) based on the deviation of each nutrient from the mean concentration for all species. This indicates that the contribution of these species to the standing crop pool of each element will vary.

There is no universal pattern which describes the relationship of nutrient contents to foliage type for these particular species and nutrients. The most common pattern of greater concentration in shade leaves seems to reflect structural rather than photosynthetic differences between foliage types. While maximum photosynthetic rates and foliage dry weight per unit area are greater for sun leaves, actual chlorophyll content may differ very little between types (Wassink et al. 1956, Logan 1970, Woodman 1971). For most nutrients any increased concentration associated with higher photosynthetic rates of sun leaves apparently is offset by greater dry weight per unit area. This has led to the recommendation that nutrient content per unit area might be more useful for comparing nutrient differences because leaf area remains fairly constant after initial expansion (Woodwell 1974).

The greater concentration of Mn in sun leaves of several species is unique among the nutrients studied. Other "reversals" occurred but in each case the most common pattern also characterized one or more species. Also, a taxonomic relationship is suggested since all members of the Fagaceae sampled displayed this pattern for Mn. Possible nutritional differences at the generic and/or family levels are indicated.

CONCLUSIONS

It has been shown that nutrient concentration differences do occur between foliage types for certain species and nutrients, but the relative proportion of total variance accounted for is small ($R^2 < 5\%$). Since the number of samples in any study of nutrient levels must of necessity be limited, a researcher faces decisions as to what variable should be emphasized in the sampling process. The results of this study suggest that accurate representation of the population will be achieved better through broad sampling of species populations than by concentrating on foliage types. The general pattern was greater nutrient concentrations in shade leaves which seems to suggest structural rather than photosynthetic differences between foliage types.

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