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Aspect Induced Differences in Vegetation, Soil, and Microclimatic Characteristics of an Appalachian Watershed

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ABSTRACT

This study evaluates and quantifies the variation in vegetation, plant nutrients, and microclimate across four topographic aspects in an Appalachian watershed (39°39′43″N, 79°45′28″W). The study found that the north and east aspects were 27–50% more productive than the west and southwest aspects. Species groups that showed strong aspect preference included yellow poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), chestnut oak (*Quercus prinus*), and white oak (*Quercus alba*); the former two being dominant on the north and east aspects while the latter two dominate the west and southwest aspects. Red oak (*Quercus rubra*) and red maple (*Acer rubrum*) showed mild aspect preference indicating their broad ecological amplitude. Although the north and east aspects had greater biomass, the west and southwest aspects had about 23% more stems per hectare.

There were large differences in microclimate among the four aspects. Air temperature during midday period averaged 25.2°C, 24.9°C, 30.5°C, and 29.4°C for the north, east, west and southwest aspects respectively. The maximum temperature difference between the mesic (north and east aspects) and xeric (west and southwest aspects) sites was 5.55°C and was observed at noon. The relative humidity at the xeric site was about 25% lower than that at the mesic site during midday periods. Plant water stress as measured by vapor pressure difference was about 37% higher on west and southwest aspects than on north and east aspects. Plant nutrients only showed minor differences with concentrations being higher on the north and east aspects except for phosphorus, which was higher on the west and southwest aspects.

INTRODUCTION

Growth rates of forest plant species are governed by numerous site factors such as soil moisture, air temperature, light, nutrients, response to competition and predation, and disturbance regime (Fritts 1976, Kramer and Kozlowski 1960, Oliver and Larson 1996, Hicks 1998). Variations in these environmental parameters across a landscape are associated with variations in site productivity, forest growth, and species composition. The spatial variability in these growth-influencing factors is closely tied to attributes of local topography such as aspect, elevation, and slope position and inclination. Differences in site quality, species composition, and forest productivity, due to differences in topographic characteristics have long been recognized by foresters in the eastern United States (Trimble and Weitzman 1956; Doolittle 1957, 1958; Olson and Della-Bianca 1959; Trimble 1964; Phillips 1966; Carmean 1967, 1975; Olson 1969; Lee and Sypolt 1974; Luxmoore et al. 1978; Auchmody and Smith 1979; Spurr and Barnes 1980; Knight 1980; Tajchman and Wiant 1983; Carmean and Kahn 1983; Frank et al. 1984; Hicks and Frank 1984; Boyles and Tajchman 1984; Tajchman and Lacey 1985; McNab 1989, 1993; Hicks 1998).

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As a topographic variable, aspect affects the amount and daily cycle of solar radiation received at different times of the year, and has an influence on the microclimate, especially air temperature, humidity, and soil moisture (Rosenberg et al. 1983). It is generally believed that a southwestern slope is sunnier, hotter, and drier than a northeastern slope because the apex of the solar disk is perpendicular to south facing slopes. However, a study by Lee and Sypolt (1974) showed that, in some years, available soil moisture was not significantly different by aspect in West Virginia. Therefore, an alternative explanation for differential growth rates between forests on north and south-facing slopes relates to differences in energy exchange and thermal regimes rather than differences in soil moisture.

Soil-site studies involve measuring several soil and topographic variables and relating them through multiple regression analysis to site index, height growth, and biomass production. Because of its dissected topography, most soil-site studies in the central Appalachians identify aspect as the influential factor for explaining spatial variability in growth but the amount of variation in vegetation and microclimatic characteristics is not well quantified. The current study specifically examines the extent of variation in site characteristics across four aspects in an Appalachian watershed. In the study area, rainfall is plentiful and even the most xeric aspects could be characterized as moist by southwestern United States standards. However, it is hypothesized that significant differences in site characteristics are expected in response to the fine scale differences in microclimate due to changing topographic aspect. The specific objectives of this study are to examine the spatial variability in vegetation, soil-plant nutrients, and microclimate.

DESCRIPTION OF THE STUDY AREA AND METHODS

Study Area

The study area, Little Laurel Run watershed, is part of Coopers Rock State Forest located approximately 16 km northeast of Morgantown, West Virginia (39°39′43″N, 79°45′28″W). The watershed encompasses approximately 271 ha (670 acres) and is typical of many Appalachian V-shaped valleys with long, steep and rocky slopes. The watershed orientation is from northwest to southeast. The average relief of the watershed is roughly 224 m above sea level (Tajchman and Wiant 1983). The topography of the area is fairly rugged and the average slope inclination is 14° (25%). The average oak site index is 22.6 m (74 ft). The watershed is covered with an even-aged 60–70 year-old mixed hardwood forest of mostly sprout origin. Roughly 62% of the forest is composed of mixed oak cover types. The predominant species in these stands are white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), northern red oak (*Quercus rubra* L.), scarlet oak (*Quercus coccinea* Muench.), and chestnut oak (*Quercus prinus* L.). The remainder, 38% of the forest, is occupied by mesophytic-hardwood stands. These stands occur on the mesic sites and consist primarily of yellow-poplar (*Liriodendron tulipifera* L.), red maple (*Acer rubrum* L.), black cherry (*Prunus serotina* Ehrh.), and northern red oak (Knight 1980).

The soils are characterized as Dekalb series on well-drained hill slopes and ridge tops, deeper Ernest series on concave slopes bordering streams. Annual precipitation averages 51″ (129.4 cm) and is fairly evenly distributed throughout the year. The average annual mean temperature is 9.0°C, although temperatures as low as −33.9°C have been recorded in January (Carvell 1983). The growing season in the study area is approximately May through September and about 47% of the average annual precipitation is received during this critical period of tree growth (Fekedulegn 2001).

The study site has been the center of several soil-site and tree growth related investigations (e.g., Tajchman and Wiant 1983, Boyles and Tajchman 1984, Frank et al. 1984, Hicks and Frank 1984). Since the trees at the study area were commercially logged during the 1930s, no major disturbances by logging, silvicultural treatments, gypsy moth, and fire have been reported till the present time (Carvell 1973).

Vegetation Sampling and Microclimate Data

Following a preliminary survey of the study site (in 1997), a one-hectare super plot was established at each of four topographic aspects of the watershed: north (5°), east (80°), west

(285°), and southwest (240°) facing slopes. The one-hectare super plot at each aspect was then partitioned into 25, 20 m × 20 m square sub-plots. Since 77% of the watershed consists of slopes having inclination from 5° to 20° (Tajchman and Wiant 1983) an effort was made to choose study plots with similar steepness (14° to 18°) and comparable to the average for the site. Plots close to a ridge or drainage line were avoided.

At each aspect, tree data (species, dbh, height and crown class) were collected from every sub-plot for all trees larger than 7 cm diameter at breast height (dbh). The above-ground dry biomass for each tree was then computed according to Brenneman et al. (1978). Using computed individual tree above ground biomass, average biomass value was estimated for each plot. Tree species importance values (Phillips 1959) were computed for each plot and species by summing the relative density, relative basal area, and relative frequency. For each aspect the dominant species was assumed to have the highest importance value that provides a means for comparing species dominance across the four aspects.

Soil pits were dug at five locations within the center sub-plot at each aspect. Soil samples at each pit were taken from three depths: 0–10 cm, 10–20 cm, and 20–30 cm. A total of 60 samples [5 (pits per aspect) × 3 (soil depths) × 4 (aspects)] were taken. The samples were chemically analyzed at the West Virginia soil-testing laboratory to provide estimates of pH, lime requirements, phosphorus, potassium, calcium, and magnesium. Estimates of soil nutrients are total values not available nutrient estimates.

To examine differences in microclimate across the four aspects, air temperature readings were taken at two hour intervals from 6 am to 8 pm using a psychrometer at each aspect during two cloudless days: July 14th and 16th of 1997. Temperature readings within the forest were taken at breast height, 1.4 m above ground. The psychrometer consists of two ventilated thermometers, the dry bulb thermometer measured the air temperature directly, while the wet bulb thermometer measured a temperature lowered by an amount determined by the evaporative cooling caused by the ambient air. These data were then used to provide estimates of relative humidity and vapor pressure deficit (Rosenberg et al. 1983, Burman and Pochop 1994). Vapor pressure deficit (VPD) is an approximate measure of potential evapotranspiration (Et) in that large values of VPD indicate higher rates of evapotranspiration and plant water stress and lower values indicate lower rates.

The relationship between vegetation data and aspect was analyzed using analysis of variance (ANOVA) and nonparametric statistical method (Wilcoxon's test) depending on the distribution of the measures of vegetation.

RESULTS

Relationships of Vegetation with Aspect

Species, Size, and Frequency[†] *Distribution*

Yellow-poplar, black cherry, sugar maple (*Acer saccharum* Marsh.), cucumber tree (*Magnolia acuminata* (L.) L.), and sweet birch (*Betula lenta* L.) occurred most frequently on north-facing slopes. Shagbark hickory (*Carya ovata* (Mill). K. Koch) exhibited maximum frequency on east aspects. Red maple, northern red oak, and chestnut oak occurred most frequently on the west-facing slopes whereas scarlet oak, white oak, black oak, sassafras (*Sassafras albidum* Nutt.), and black gum (*Nyssa sylvatica* Marsh.) were more frequent on southwest aspects.

Among the species recorded in the watershed, red maple, yellow-poplar, and northern red oak accounted for 61% of the trees at the north aspect whereas on the east-facing site these same species made up 73% of the trees. At the southwest aspect 80% of the trees consisted of scarlet oak, red maple, black gum, and northern red oak, while 69% of the trees on the west-facing site were made up of red maple, northern red oak, and chestnut oak. The data show that oak types are more common on west and southwest aspects. On mesic exposures (north and east aspects) oak types are generally replaced by cove hardwood species like yellow-poplar and cucumber

[†] Frequency is the percentage of plots within a stand (aspect) in which individuals of a species are found.

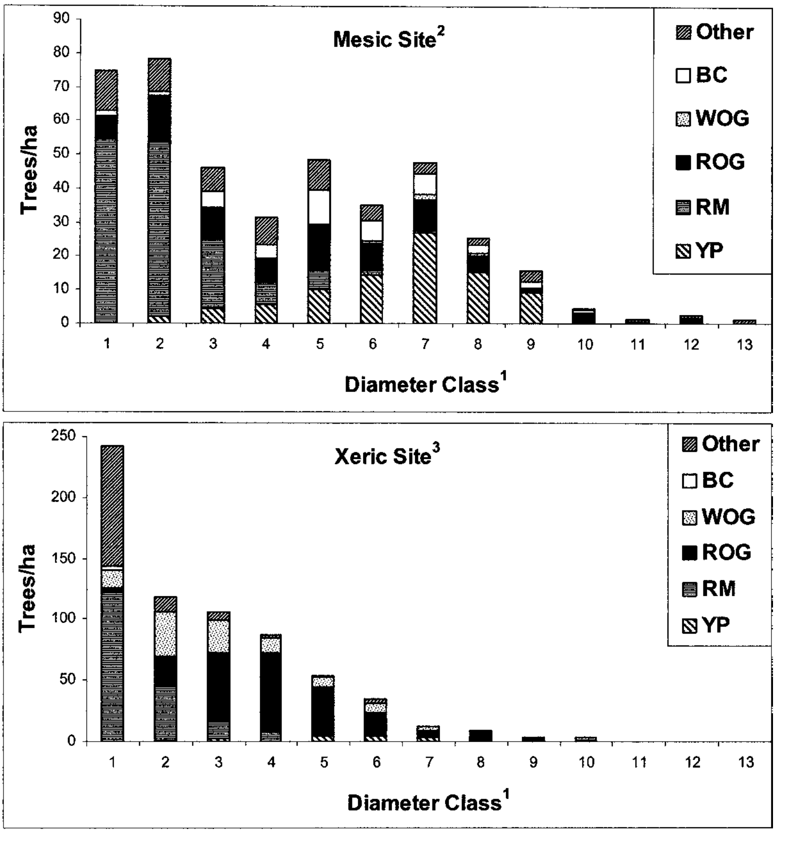

Figure 1. Diameter distribution for the mesic and xeric sites by species groups[4] showing a polymorphic J-shaped structure. [1]Diameter Class: 1 = 7–12.9 cm, 2 = 13–18.9 cm, 3 = 19–24.9 cm, ... , 13 = 79cm +, [2]Mesic Site: (north and east facing slopes), [3]Xeric Site: (west and southwest facing slopes), [4]Species groups: YP (yellow-poplar), BC (black cherry), RM (red maple), WOG (white oak, chestnut oak), ROG (northern red oak, scarlet oak, black oak), Other (sweet birch, shagbark hickory, sugar maple, cucumber tree, black gum, sassafras).

tree. Major tree species that exhibited the greatest variation (>100%) in frequency between the xeric and mesic sites were yellow-poplar, black cherry, sugar maple, white oak, chestnut oak, black oak, and scarlet oak. The data suggest that these species tend to show aspect preference.

The diameter distributions of the stands at the mesic and xeric sites show a polymorphic structure typical of most even-aged stratified, mixed species stands (Figure 1). Yellow-polar, northern red oak, and black cherry combined account for 75 to 83% of trees larger than 31 cm dbh on the mesic site. Red maple accounted for 70% of trees less than 19 cm dbh on both the north and east-facing sites. On the xeric site oaks tend to dominant the higher dbh classes (Figure 1). The red oak group (northern red oak, scarlet oak, and black oak) and the white oak group (white oak and chestnut oak) combined accounted for 80 to 85% of trees larger than 31 cm dbh on the xeric site. Red maple and 'other' species (sweet birch, shagbark hickory, sugar maple, cucumber tree, black gum, sassafras) on the xeric site accounted for 63 to 74% of trees less than 19 cm dbh.

Yellow-poplar and the red oak group had the largest mean dbh at all aspects (Table 1). Red maple and the 'other' species group had the smallest mean dbh at the mesic and xeric site respectively. There were twice as many small (<37 cm) trees on the xeric site. Generally, the number of large trees was much higher on the mesic site. The red oak group growing on the

Table 1. Mean diameter at breast height (±SE) by species and aspect. Means with the same letter are not significantly different between aspects according to ANOVA (alpha = 0.05)

Species Groups[1]	Mesic Site[2]				Xeric Site			
	North Facing		East Facing		West Facing		Southwest Facing	
	Mean DBH(cm)	n	Mean DBH(cm)	n	Mean DBH(cm)	n	Mean DBH(cm)	n
Red maple	17.63 (0.97)[a]	117	16.78 (0.68)[a]	169	13.13 (0.39)[b]	230	12.70 (0.43)[b]	154
Yellow-poplar	44.15 (1.03)[a]	99	41.46 (1.13)[b]	91	37.35 (3.08)[c]	8	33.42 (1.93)[c]	25
Red oak	34.11 (1.94)[a]	56	30.00 (1.63)[b]	88	30.27 (0.95)[b]	126	22.92 (0.93)[c]	68
Chestnut oak[3]	47.50 (—)	1	42.10 (—)	1	25.91 (1.07)[a]	108	19.28 (1.38)[b]	51
Black cherry[3]	32.68 (1.86)[a]	40	39.57 (1.89)[b]	24	12.50 (—)	1	8.20 (—)	5
Red oak group	34.11 (1.91)[a]	57	30.21 (1.56)[b]	96	30.31 (0.76)[b]	182	27.11 (0.55)[c]	257
White oak group[3]	47.15 (—)	4	38.85 (—)	2	27.01 (1.11)[a]	135	23.06 (1.68)[b]	105
Other	31.51 (2.50)[a]	70	26.77 (1.65)[b]	49	12.96 (0.86)[c]	115	10.63 (0.46)[c]	136
Total	31.41 (0.80)	443	27.97 (0.66)	430	22.75 (0.42)	671	20.04 (0.47)	682

[1] Species Groups: Red oak group (northern red oak, scarlet oak, black oak), White oak group (white oak, chestnut oak), Other (sweet birch, shagbark hickory, sugar maple, cucumber tree, black gum, sassafras).
[2] Mesic site: north and east aspects; Xeric site: west and southwest aspects.
[3] Since chestnut oak and the white oak group at the mesic site, and black cherry at the xeric site are the most infrequent species groups, mean comparisons for these species groups were carried out only at those aspects where they are abundant. Mean comparison for black cherry was made between the north and east aspects, and mean comparison for chestnut oak and the white oak group was made between the west and southwest aspects. Mean comparisons for the remaining species groups were made across the four aspects.

mesic site was composed of 95% northern red oak while the red oak group on the xeric site was composed of 44% northern red oak and 52% scarlet oak.

Basal Area and Dry Biomass

The total basal area per hectare at the north (37.9 m^2 ha^{-1}) and east (34.1 m^2 ha^{-1}) aspects is higher than that at the west (31 m^2 ha^{-1}) and southwest (25 m^2 ha^{-1}) aspects (Table 2). The basal area per hectare on the mesic site (36 m^2 ha^{-1}) was 28% higher than that obtained on the xeric site (28 m^2 ha^{-1}). Yellow-poplar and northern red oak accounted for over half of the total basal area on the mesic site (Table 2). On the xeric sites the red oak group and the white oak group accounted for 78% of the total basal area. Red maple basal area was similar across all four aspects (Table 2), ranging from 2.2 m^2 ha^{-1} on the southwest aspect to 4.7 m^2 ha^{-1} on the east-facing site. Red maple made up a smaller percentage of total basal area on mesic sites but represented a larger percentage of basal area than either yellow-poplar or the ‘other’ species group on the xeric site. In general, yellow-poplar is the dominant species in terms of basal area on north and east-facing aspects, and the red oak group dominate the west and southwest aspects. The greater basal area on the mesic site can be attributed to the presence of more trees in the larger (>31 cm) diameter classes.

The total above ground dry biomass at the north (331 t ha^{-1}) and east (276 t ha^{-1}) facing sites were significantly higher ($p < 0.05$) than those at the west (240 t ha^{-1}) and southwest (160 t ha^{-1}) facing slopes (Table 3). Yellow-poplar (126 t ha^{-1} on north, 86 t ha^{-1} on east) and northern red oak (49 t ha^{-1} on north, 65 t ha^{-1} on east) combined account for about 54% of the total above ground dry biomass at the mesic site. The red oak group (109 t ha^{-1} on west, 107 t ha^{-1} on southwest) and white oak group (93 t ha^{-1} on west, 26 t ha^{-1} on southwest) together account for 83% of the dry biomass at the xeric site (Table 3). Scarlet oak alone accounts for over 40% of the dry biomass on the southwest facing site but on the north and east aspects its contribution is less than 1%. The % contribution of red maple to the total above ground dry biomass is similar on all four aspects. However, red maple dry biomass at the mesic site, 28 t ha^{-1}, is about 86% higher than the 15 t/ha measured on the xeric site. This difference was attributed to the larger trees on the mesic sites. On the mesic site 23% of the red maple trees had

Table 2. Basal area (±SE) by species and aspect. Means with the same letter are not significantly different between aspects according to ANOVA (alpha = 0.05)

	Mesic Site				Xeric Site			
	North Facing		East Facing		West Facing		Southwest Facing	
Species Groups[1]	Basal Area (m^2 ha^{-1})	% BA[2]	Basal Area (m^2 ha^{-1})	% BA	Basal Area (m^2 ha^{-1})	% BA	Basal Area (m^2 ha^{-1})	% BA
Red maple	3.85 (0.95)[a]	10.15	4.74 (0.86)[a]	13.94	3.75 (0.38)[a b]	12.07	2.22 (0.32)[b]	8.80
Yellow-poplar	16.05 (2.64)[a]	42.29	11.28 (2.05)[a]	33.19	0.92 (0.42)[b]	2.96	1.86 (0.76)[b]	7.36
Red oak	6.02 (1.25)[a]	15.87	8.13 (1.29)[a]	23.93	10.18 (1.27)[a]	32.81	2.48 (0.39)[b]	9.83
Chestnut oak[3]	0.18 (—)	0.49	0.14 (—)	0.41	6.74 (0.93)[a]	21.70	1.86 (0.39)[b]	7.37
Black cherry[3]	3.50 (0.83)[a]	9.23	5.50 (1.45)[a]	16.18	0.01 (—)	0.04	0.02 (—)	0.09
Red oak group	6.12 (1.25)[a]	16.12	8.74 (1.26)[a]	25.70	14.62 (1.51)[b]	47.10	16.37 (1.12)[b]	64.87
White oak group[3]	0.73 (—)	1.92	0.24 (—)	0.70	9.47 (1.31)[a]	30.51	3.51 (0.90)[b]	13.89
Other	7.70 (1.59)[a]	20.30	3.58 (0.85)[b]	10.52	2.28 (0.63)[b]	7.33	1.26 (0.28)[c]	4.98
Total	37.90 (1.69)	100	34.05 (3.92)	100	31.04 (2.64)	100	25.23 (1.94)	100

[1] Species Groups: Red oak group (northern red oak, scarlet oak, black oak), White oak group (white oak, chestnut oak), Other (sweet birch, shagbark hickory, sugar maple, cucumber tree, black gum, sassafras).
[2] % BA: Percentage of basal area per hectare accounted by each species groups.
[3] Same as in Table 1.

diameters greater than 19 cm as opposed to the xeric site where only 12% of the red maple trees had diameters larger than 19 cm.

The result in Tables 2 and 3 clearly show how aspect affects oak groups. The white oak group (white oak and chestnut oak) contributes less than 2% to the total above ground biomass and basal area at the north and east aspects. However, on the xeric site the white oak group contributes over 30% (west) and 13% (southwest) to both basal area and above ground biomass. On the other hand, black cherry accounts for 14% of the total biomass on the mesic site but on the west and southwest-facing sites it accounts for less than 1% in both basal area and above ground biomass. 'Other' species (sweet birch, shagbark hickory, sugar maple, cucumber tree, black gum, and sassafras) all have greater basal areas and biomass on mesic sites (Tables 2 and 3).

Density

Although the mesic site had greater basal area and above ground biomass, the xeric site had about 54% more trees per hectare (Table 4). The density (stems per hectare) on the north (443 trees/ha) and east (430 trees/ha) aspects was significantly lower than that observed on the west (671 trees/ha) and southwest (682 trees/ha) aspects. Red maple accounted for the largest percentage of stems on all but the southwest aspect where the red oak group dominated (Table 4). Although there were generally more red maple stems present on most aspects, red maple accounted only for a small percentage of the total basal area and above ground biomass (Table 3). This can be attributed to the presence of more red maple trees in the smaller diameter classes; 88 and 77% of the red maple trees had diameters less than 19 cm on the xeric and mesic sites respectively. Yellow-poplar and northern red oak together accounted for about 40% of the trees per hectare on the mesic site (Table 4). On the xeric site, the red oak group and white oak group account for over 50% of the trees per hectare.

Height and Crown Structure

The trees on the north and east-facing sites were taller than trees on the west and southwest aspects (Table 5) indicating a higher site index for the former. All dominant and codominant trees on the mesic site, north and east aspects, were significantly taller ($p < 0.05$) than those on the west and southwest aspects (Table 6). Most dominant and codominant species

Table 3. **Above ground dry biomass (±SE) by species and aspect. Means with the same letter are not significantly different between aspects according to Wilcoxon's test (alpha = 0.05)**

	Mesic Site				Xeric Site			
	North Facing		East Facing		West Facing		Southwest Facing	
Species Groups[1]	Dry Biomass ($t\ ha^{-1}$)	% BIO[2]	Dry Biomass ($t\ ha^{-1}$)	%BIO	Dry Biomass ($t\ ha^{-1}$)	%BIO	Dry Biomass ($t\ ha^{-1}$)	%BIO
Red maple	25.77 (9.07)[a]	7.79	30.02 (8.6)[a]	10.9	19.09 (2.32)[b]	7.94	10.23 (1.79)[c]	6.39
Yellow-poplar	126.47 (20.89)[a]	38.22	85.76 (15.6)[b]	31.1	6.39 (3.06)[c]	2.66	11.79 (5.10)[d]	7.37
Red oak	48.99 (11.12)[a]	14.80	65.22 (11.05)[b]	23.7	76.11 (10.48)[c]	31.67	15.35 (2.52)[d]	9.60
Chestnut oak[3]	2.15 (—)	0.65	1.49 (—)	0.54	63.47 (10.69)[a]	26.41	11.83 (2.81)[b]	7.40
Black cherry[3]	30.85 (7.66)[a]	9.32	52.87 (14.02)[b]	19.1	0.05 (—)	0.02	0.07 (—)	0.05
Red oak group	49.66 (11.09)[a]	15.00	69.99 (10.92)[b]	25.4	108.80 (12.33)[c]	45.28	107.07 (7.94)[c]	66.95
White oak group[3]	7.90 (—)	2.39	2.35 (—)	0.85	92.69 (16.01)[a]	38.57	25.70 (8.98)[b]	16.07
Other	90.27 (21.61)[a]	27.29	34.75 (8.74)[b]	12.6	13.27 (4.21)[c]	5.52	5.07 (1.38)[d]	3.17
Total	330.92 (17.85)	100	275.73 (33.63)	100	240.30 (23.77)	100	159.92 (14.34)	100

[1] Species Groups: Red oak group (northern red oak, scarlet oak, black oak), White oak group (white oak, chestnut oak), Other (sweet birch, shagbark hickory, sugar maple, cucumber tree, black gum, sassafras).

[2] % BIO: Percentage of above ground biomass per hectare accounted by each species groups.

[3] Same as in Table 1.

on the north and east-facing sites had similar mean heights except yellow-poplar which was significantly taller (Table 6). On the west and southwest aspects, however, mean height of dominant and codominant yellow-poplar trees was not significantly taller than the trees in the red oak group. The stands on the mesic and xeric sites had two distinct strata, an overstory stratum (>24 m tall) dominated by shade-intolerant species and an understory stratum (<14 m tall) dominated by shade-tolerant species (Figure 2). The understory stratum (trees <12 to 14 m tall) on the north and east aspects is mostly composed of red maple (63%). On the west and southwest aspects red maple (46%) and 'other' species (42%) make up 88% of the understory vegetation. On the north and east-facing sites, most of the dominant and codominant trees in the overstory stratum were greater than 25 m tall. However, there were considerably few trees taller than 25 m on the west and southwest aspects and most of the codominant trees were between 17 and 25 m tall. Yellow-poplar (40%) and the red oak group (20%) make up 60% of the dominant and codominant trees in the north and east aspects whereas on the west and southwest aspects the red oak group (64%) and the white oak group (22%) together account for 86% of the trees in the overstory stratum (>25 m tall).

Species Importance Values

Species importance values (summation of relative density, relative basal area, and relative frequency) was highest for yellow-poplar, red maple, and northern red oak in that order on the north-facing site (Figure 3). On the east facing aspect red maple followed by northern red oak and yellow-poplar had the highest species importance values. On the west and southeast aspects northern red oak, red maple and chestnut oak were most prevalent in terms of dominance, density, and frequency combined. The graph showing species importance values by aspect (Figure 3) clearly shows species that are specialists and generalists with respect to aspect. Northern red oak and red maple yield above average species importance values at all

Table 4. Trees per hectare (±SE) by species and aspect. Means with the same letter are not significantly different between aspects according to ANOVA (alpha = 0.05)

	Mesic Site				Xeric Site			
	North Facing		East Facing		West Facing		Southwest Facing	
Species Groups[1]	Trees/ha (No. Stems ha^{-1})	% TPH[2]	Trees/ha (No. Stems ha^{-1})	%TPH	Trees/ha (No. Stems ha^{-1})	%TPH	Trees/ha (No. Stems ha^{-1})	%TPH
Red maple	116.67 (11.33)[a]	26.28	168.97 (10.72)[b]	39.3	230.01 (12.99)[c]	34.28	154.01 (18.86)[b]	22.58
Yellow-poplar	98.96 (16.31)[a]	22.29	90.52 (14.65)[a]	21.1	8.12 (3.14)[b]	1.19	25.28 (8.54)[c]	3.67
Red oak	56.25 (9.90)[a]	12.67	87.93 (8.83)[b]	20.4	126.00 (11.04)[c]	18.78	68.08 (12.21)[a]	9.97
Chestnut oak[3]	1.04 (—)	0.23	0.86 (—)	0.2	108.00 (13.90)[a]	16.10	51.11 (11.04)[b]	7.48
Black cherry[3]	39.58 (8.50)[a]	8.92	24.14 (9.96)[b]	5.6	1.00 (—)	0.15	5.42 (—)	0.73
Red oak group	57.29 (9.81)[a]	12.90	95.69 (8.42)[b]	22.3	182.12 (16.49)[c]	27.12	257.02 (23.16)[d]	37.68
White oak group[3]	4.17 (—)	0.93	1.72 (—)	0.4	135.03 (13.77)[a]	20.12	105.03 (11.81)[b]	15.40
Other	69.79 (21.61)[a]	15.72	49.14 (10.27)[b]	11.4	115.12 (16.20)[c]	17.14	136.05 (17.45)[c]	19.94
Total	443.75 (18.91)	100	430.17 (24.98)	100	671.40 (23.08)	100	682.81 (33.74)	100

[1] Species Groups: Red oak group (northern red oak, scarlet oak, black oak), White oak group (white oak, chestnut oak), Other (sweet birch, shagbark hickory, sugar maple, cucumber tree, black gum, sassafras).
[2] % TPH: % of trees per hectare.
[3] Same as in Table 1.

four aspects, and this reflects the rather broad ecological amplitudes of these species. On the other hand, yellow-poplar, chestnut oak, and black cherry seem to be specialists with respect to aspect in that yellow-poplar and black cherry occur primarily on the mesic slope (north and east aspects), and chestnut oak dominate the west and southwest aspects.

Relationship of Soil Characteristics with Aspect

In Table 7, the averages for soil chemical properties indicate that soils in the study area were acidic with pH <4.5 at all aspects. The soils at the study area contain substantial quantities of potassium but major plant nutrient elements (calcium, phosphorus, and magnesium) were generally quite low relative to potassium. In the shallower surface layer, the lowest pH (3.9) and hence, the highest lime requirement was observed at the southwest facing site (Table 7). Phosphorus and magnesium had the least variation with aspect; phosphorus concentration in the surface layer ranged from 10.8 ppm at the southwest aspect to 11.5 ppm at the east facing site while magnesium varied from 18.8 ppm at the west to 23.4 ppm at the north aspect. Calcium concentration was highest at the mesic site (10.35 ppm) and lowest on the xeric site (6.95 ppm). Generally, potassium (Standard deviation [SD] = 4.34) followed by calcium (SD = 2.25) showed relatively higher aspect related variation than did phosphorus (SD = 0.3) and magnesium (1.89). Although differences were not large in magnitude, the plant nutrients exhibited consistently higher concentrations on the mesic site than on the xeric site.

Aspect related variation in phosphorus concentration in the subsoil layers (SD = 2.2), although minimal, was higher than that in the surface layers but unlike the surface layer the relationship is reversed; the west and southwest aspects had 3–4 ppm more phosphorus than the north and east aspects. Calcium (SD = 1.73), magnesium (SD = 2.1), and phosphorus showed the least aspect related variation in the subsoil; magnesium ranged from 18.8 ppm at

Table 5. **Mean total height (±SE) by species and aspect. Means with the same letter are not significantly different between aspects according to ANOVA (alpha = 0.05)**

	Mesic Site				Xeric Site			
	North Facing		East Facing		West Facing		Southwest Facing	
Species Groups[1]	Mean Height (m)	n	Mean Height (m)	n	Mean Height (m)	n	Mean Height (m)	n
Red maple	14.76 (0.56)[a]	117	13.12 (0.41)[a b]	169	12.16 (0.28)[b]	230	14.00 (0.41)[a]	154
Yellow-poplar	30.32 (0.51)[a]	99	28.08 (0.60)[a]	91	23.94 (1.35)[b]	8	23.32 (1.20)[c]	25
Red oak	23.45 (0.86)[a]	56	20.03 (0.76)[b]	88	21.03 (0.38)[b]	126	21.08 (0.57)[b]	68
Chestnut oak	26.5 (—)	1	25.60 (—)	1	19.94 (0.41)[a]	108	19.43 (0.87)[a]	51
Black cherry	24.46 (1.02)[a]	40	24.34 (0.90)[a]	24	11.30 (—)	1	9.81 (—)	5
Red oak group	23.39 (0.84)[a]	57	20.08 (0.72)[b]	96	21.14 (0.30)[b]	182	23.29 (0.31)[a]	257
White oak group	28.96 (—)	4	23.16 (—)	2	20.01 (0.39)[a]	135	18.88 (0.63)[a]	105
Other	20.57 (0.95)[a]	70	19.84 (1.01)[a]	49	10.11 (0.53)[b]	115	10.18 (0.39)[b]	136
Average	22.28 (0.41)	443	19.36 (0.35)	430	17.14 (0.21)	671	17.91 (0.29)	682

[1] Species Groups: Red oak group (northern red oak, scarlet oak, black oak), White oak group (white oak, chestnut oak), Other (sweet birch, shagbark hickory, sugar maple, cucumber tree, black gum, sassafras).

the northeast aspect to 15.5 ppm at the southwest aspect while calcium varied from 10.4 to 6.9 ppm between the northeast and southwest aspects. Potassium concentration, however, showed considerable variation with aspect.

The subsoil had a 3–5 ppm higher phosphorus concentration than surface layer on the west and southwest aspects, but differences are negligible on the north and east facing sites. Generally, nutrient concentrations, except phosphorus, are higher in the surface layer than the subsoil at all aspects with the north and southwest aspects showing the largest differences. Regardless of aspect, soil nutrient concentration at the study site was low for phosphorus and magnesium, medium for potassium, and very low for calcium (Ghazi et al. 1978). The pH in the surface layer is generally lower than the subsoil and relative differences are larger on the west and southwest aspects. Estimates of pH for the two layers on the north and east aspects were identical. Conversely, the lime requirement for the surface layers is higher than those recommended for the subsoil, and the difference in lime requirements between the two layers is highest on the west and southwest aspects.

Relationships of Air Temperature and Vapor Pressure Deficit with Aspect

Figures 4 and 5 show the diurnal variation of air temperature, relative humidity, and vapor pressure deficit at breast height (1.4 m above ground) during two observation periods (July 14th and 16th of 1997). Each plotted point represents an average for two days. At breast height, air temperature on the west and southwest aspects were lower early in the morning and much higher during midday and in the afternoon than the corresponding temperature on the north and east facing slopes. During early morning, from 7 to 11 am, air temperature at the north and east aspects were about 2.74°C higher than those of the west and southwest facing sites. However, during midday period, from 12 to 4 pm, west and southwest aspects had air temperature about 4.86°C higher than those at the north and east aspects. The maximum temperature difference between the xeric and mesic site was 5.55°C and was observed at noon (Figure 4). During the two observation periods air temperature ranged from 15 to 25.6°C on the north and east aspects, and from 13 to 30.8°C on the west and southwest aspects.

The amount of water vapor present in the air was represented in terms of relative humidity. The relative humidity at the west and southwest aspects was about 25% lower than that at the north and east aspects during midday periods (Figure 4). The maximum difference in relative humidity between the two sites was observed during noon to 3 pm. The pattern of vapor pressure deficit (VPD) follows that of air temperature (Figure 5). Vapor pressure deficit is an approximate measure of potential evapotranspiration in that large values of VPD indicate

Table 6. Mean height in meters (±SE) of dominant and codominant trees by species and site. Means with the same letter are not significantly different within each site according to ANOVA (alpha = 0.05)

	Species Group					
Site	Red Maple	Yellow-poplar	Black Cherry	Red Oak Group	White Oak Group	Other
Mesic site	26.26 (0.50)[a]	30.91 (0.29)[b]	28.49 (0.47)[a]	27.67 (0.39)[a]	—	26.63 (0.30)[a]
Xeric site	22.33 (0.59)[a]	25.8 (1.23)[b]	—	23.92 (0.35)[b]	24.75 (0.53)[b]	20.43 (1.03)[a]

higher rates of evapotranspiration and plant water stress and lower values indicate lower rates of evapotranspiration. The data in Figure 5 shows that evapotranspiration rates on the west and southwest aspects begin slower in the morning, reaching maximum rates at noon and remain higher throughout the afternoon than those on the north and east aspects. Plant water stress as measured by vapor pressure difference is about 37% higher on west and southwest aspects during midday periods than on north and east aspects. Both relative humidity and vapor pressure deficit depend on the air temperature; as temperatures increase vapor pressure differences between the surrounding air and leaves increases, and the relative humidity decreases. For example, at 50% relative humidity, the vapor pressure difference doubles when the canopy temperature increases from 25°C to 32°C and this effect is less at lower relative humidity and greater at higher relative humidity (Lee and Sypolt 1974).

DISCUSSION

Vegetation

Forest types on the west and southwest aspects are upland oak types, primarily white oak, chestnut oak, northern red oak, and black oak. The north and east aspects were dominated primarily by yellow-poplar and northern red oak. Red maple was a substantial component across all aspects, especially in terms of density (stems/ha). Species groups that exhibited the greatest variation in occurrence between the mesic and xeric aspects were chestnut oak, black cherry, yellow-poplar, and the red oak and white oak groups. The data show that chestnut oak and white oak were uncommon on north and east exposures, and black cherry occurred infrequently on west and southwest exposures. Yellow-poplar was about six-times more frequent on mesic aspects whereas the red oak group was about three times more frequent on the west and southwest aspects.

The mean DBH (29.69 cm), total height (20.82 m), and basal area (35.97 m^2 ha^{-1}) were all higher for the stands on mesic aspects. The diameter, height, and basal area averaged 8.3 cm, 3.3 m, and 7.84 m^2 higher respectively on the mesic aspects. An earlier study at the WVU forest by Lee and Sypolt (1974) showed that at age 40 the stands on the north facing sites had 5.1 cm, 5.4 m, and 3 m^2 ha^{-1} larger diameter, total height, and basal area, respectively, than stands growing on south facing slopes, thus the magnitude of the difference appears to be increasing over time. For the watershed, basal area and dry biomass data collected on 100 plots from trees >7 cm dbh, averaged approximately 32 m^2 ha^{-1} and 252 t ha^{-1} respectively. The southwest aspect was 21% (in basal area) and 36% (in dry biomass) below the overall average for the site. The north and east facing aspects were 50% (in dry biomass) and 27% (in basal area) more productive than the west and southwest aspects. Spurr and Barnes (1980) cite a much smaller difference between the northeast and the southwest aspects. They indicated that in the mixed upland oak forests of the Appalachian Mountains, northeast aspects were 15% more productive than the south and west aspects.

Tree density on the xeric site was 54% higher than that observed on the moist exposures; the west and southwest aspects had 240 more stems per hectare than the north and east aspects. This is consistent with findings of Lee and Sypolt (1974) who reported that at age 40 the

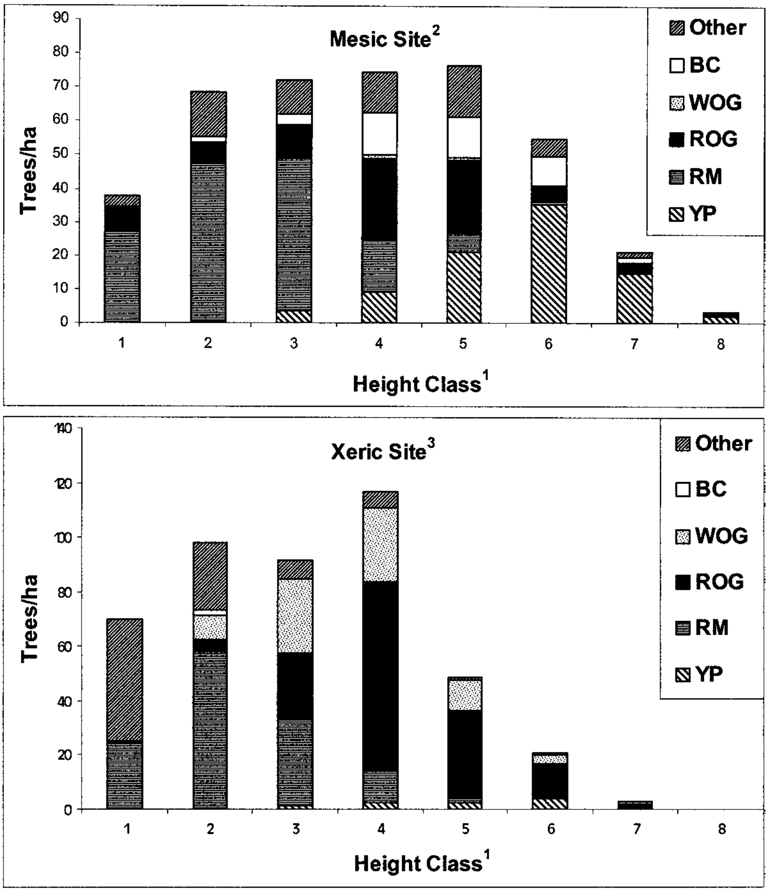

Figure 2. Trees per hectare by height class and species groups[4] for the mesic and xeric sites. [1]Height Class: 1 = 4–8.9 m, 2 = 9–13.9 m, 3 = 14–18.9 m, . . . , 8 = 39 m +, [2]Mesic Site: (north and east facing slopes), [3]Xeric Site: (west and southwest facing slopes), [4]Species groups:YP (yellow-poplar), BC (black cherry), RM (red maple), WOG (white oak, chestnut oak), ROG (northern red oak, scarlet oak, black oak), Other (sweet birch, shagbark hickory, sugar maple, cucumber tree, black gum, sassafras).

stands at the south facing site at the West Virginia University forest had 24% or 140 more trees per hectare than the stands at the north facing site. The higher tree density on the xeric site could primarily be due to the presence of more stress-tolerant species capable of competing on poorer sites. The presence of more stems per hectare on the west and southwest exposures may also be due to the more open conditions of the crown canopy, and the greater amount of light reaching the lower strata favoring the growth of shade tolerant species such as red maple. More stems, lower basal area, and smaller average stem diameter on the xeric site compared to the mesic site can also be explained in terms of natural mortality. Natural mortality due to competition occurs on both sites. The mesic site exhibits faster growth, faster reduction in number of stems, and faster increase in average stem diameter compared to the xeric site. This can be thought of as an accelerated stand development, thus the mesic site exhibits characteristics of an "older" stand compared to that on the xeric site. These same conditions will occur on the xeric site, but they will occur at a later date. Generally, on stressed sites, more energy is devoted to below ground growth in order to collect soil nutrients and water. This results in a lower degree of canopy closure and canopy density, and consequently, more, and higher quality photosynthetically active radiation hits the forest floor. On moist exposures, slow growing species could have been smothered quickly by the dense cover of other fast growing

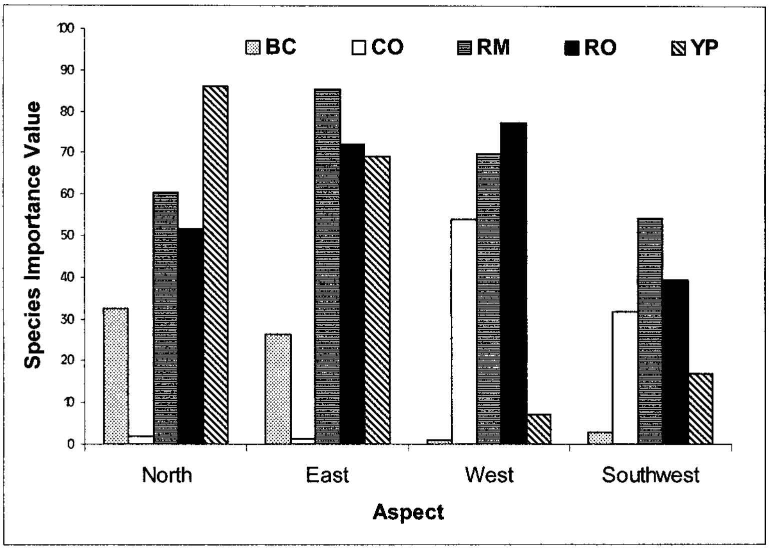

Figure 3. Species importance values by aspect for five species. Yellow-poplar and black cherry show highest values at the mesic (north and east aspects) site and chestnut oak tend to dominate the drier sites (west and southwest aspects). Species groups: YP (yellow-poplar), RO (northern red oak), RM (red maple), CO (chestnut oak), BC (black cherry).

species such as yellow-poplar. Generally, trees on the north and east aspects attain greater diameter and therefore wider crowns. These crowns fill up the available growing space with fewer trees. Inclusion of small trees with dbh of 7 to 10 cm may have exaggerated the difference in density between the mesic and xeric sites. When only trees with dbh ≥10 cm were considered, density averaged 425 trees/ha at the mesic site and 522 trees/ha at the xeric site.

Microclimate

Higher radiant energy inputs results in higher midday temperatures, lower relative humidity, and higher vapor pressure deficits on west and southwest aspects (Figures 4 and 5). A study by Lee and Sypolt (1974) at the West Virginia University forest demonstrated that the net radiation (difference between the total upward and downward radiation fluxes) on south facing slopes exceeded that on north-facing slope by 24%. The importance of net radiation is that it is the fundamental quantity of energy available at the earth's surface to drive the processes of evaporation, air and soil heating, as well as other smaller-energy consuming processes such as photosynthesis. At the study site the large differences in temperature, relative humidity and vapor pressure deficits on the xeric and moist sites can therefore be attributed to differences in the amount of net radiation received at each aspect. The data in Figures 4 and 5 show that the breast height air temperature during midday period averaged 25.2°C, 24.9°C, 30.5°C, and 29.4°C for the north, east, west, and southwest aspects, respectively. For relative humidities of 30 to 40%, vapor pressure differences were 22.1 mb for north and east aspects and 30.2 mb for the west and southwest aspects. Evapotranspiration during midday period was about 36% greater on the west and southwest aspects.

Higher midday temperatures and vapor pressure deficits at the xeric site result in a depression of net assimilation rates (Kramer and Kozlowski 1960, Delvin and Baker 1971, Lee and Sypolt 1974) because of an exponential increase in respiration rates with increasing temperatures (Rosenberg et al. 1983). Stomatal closure and increased mesophyll resistance to CO_2 diffusion induced by leaf water deficits also contribute to reduced net assimilation (Delvin 1975). Lower dry biomass at the west and southwest exposures could be associated with higher respiration rates and earlier and longer stomatal closure in response to plant water deficits.

Table 7. Average values for soil properties by aspect, soil horizon and soil depth

		Mesic Site		Dry Site	
Soil Property	Depth	North Facing	East Facing	West Facing	Southwest Facing
PH	0–10 cm	4.2	4.2	4.1	3.9
	10–20 cm	4.3	4.4	4.3	4.3
	20–30 cm	4.1	4.3	4.3	4.5
	10–30 cm	4.2	4.2	4.3	4.4
Lime Requirement (t/ac)	0–10 cm	9.8	10.5	11.4	15.2
	10–20 cm	8.7	23.4	8.8	9.3
	20–30 cm	11.9	8.5	9.8	5.0
	10–30 cm	10.4	10.4	9.3	7.15
Phosphorus (ppm)	0–10 cm	11.1	11.5	11.4	10.8
	10–20 cm	11.6	12.6	11.8	15.6
	20–30 cm	10.6	13.0	16.6	15.6
	10–30 cm	10.4	11.3	14.2	15.6
Potassium (ppm)	0–10 cm	63.7	56.9	61.5	54.1
	10–20 cm	46.9	53.9	53.9	54.6
	20–30 cm	54.6	54.7	48.5	38.0
	10–30 cm	50.7	53.8	51.2	46.3
Calcium (ppm)	0–10 cm	11.7	9.0	7.0	6.9
	10–20 cm	7.1	5.8	6.9	3.8
	20–30 cm	7.1	5.3	5.9	4.2
	10–30 cm	7.1	8.1	6.4	4.0
Magnesium (ppm)	0–10 cm	23.4	20.7	18.8	21.4
	10–20 cm	16.0	15.6	16.9	14.9
	20–30 cm	20.3	14.0	15.2	14.8
	10–30 cm	18.2	19.4	16.1	14.9

Simply put, the high vapor pressure gradient between the surrounding air and the plant canopies on the west and southwest aspects induces higher transpiration rates, and in response to these higher transpiration demands plants tend to close their stomata. This reduces the influx of CO_2 into plant leaves that consequently depresses the rate of photosynthesis. Delvin (1975) and Spurr (1964) indicate that the optimum net assimilation temperature for forest species in the middle latitudes is about 25°C. Air temperature (at dbh) for the xeric and mesic sites both reached 25°C around midday (11 am for the xeric, and 12 pm for the mesic), however, air temperatures at the xeric sites remained above 25°C for a much longer time interval (nine hours versus two hours, respectively), with a consequent greater reduction in time of photosynthesis and net assimilation.

Soil Nutrients and Site Productivity

The pH of soils (surface layer) on the north and east facing slopes was slightly higher, probably because the northeast aspects had more calcium than the west and southwest aspects. On the north-facing slope, potassium and calcium contents were the highest in the surface layer. Nutrient concentrations at the study site were higher in the surface layer, except for phosphorus, irrespective of aspect. Also, average nutrient concentration for north and east aspects, except for phosphorus, were higher than average nutrient concentrations for the west and southwest aspects in both horizons. Nutrient concentrations in soil are dependent on inputs from weathering, precipitation, and litter fall. Hicks and Frank (1984) explain that the higher nutrient concentrations in the surface soils compared to sub-soils is likely a function of recycling. The greater concentration of nutrient elements at the mesic aspects could be due to greater leaf area index and thus greater litter production, more rapid weathering, and the more rapid decomposition rate of litter at these sites.

In the present study differences in site productivity (soil-plant nutrients and dry biomass)

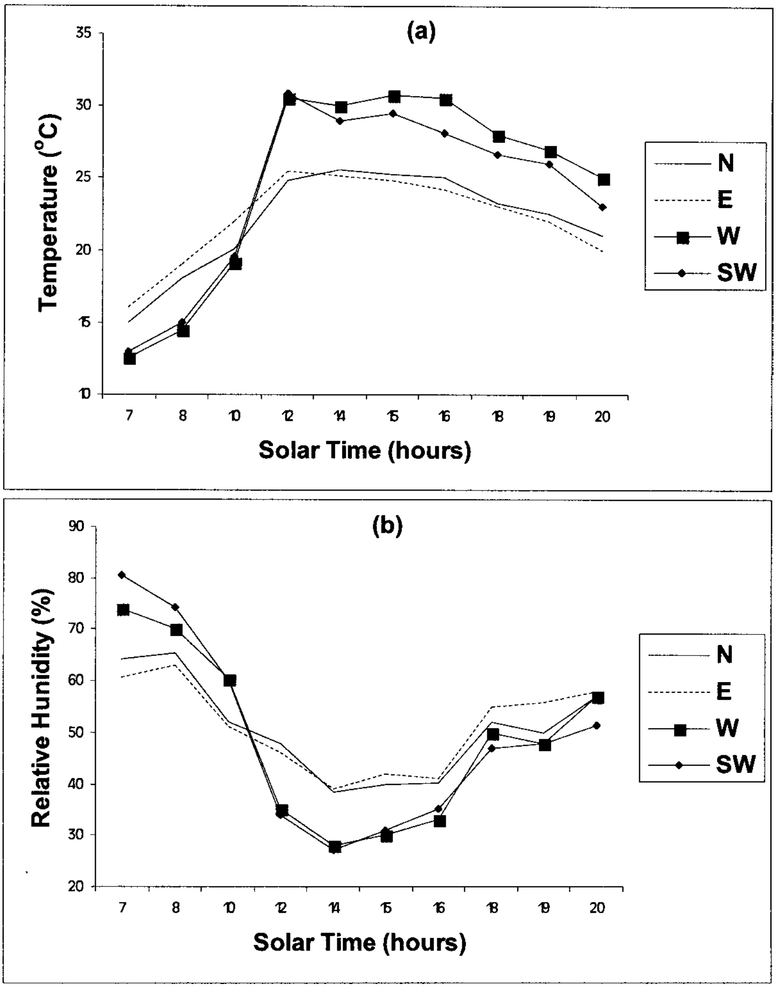

Figure 4. The diurnal pattern of air temperature (a) and estimated relative humidity (b) across the four aspects during two growing season days (July 14th and 16th of 1997).

associated with aspect can in part be explained in terms of aspect-induced differences in microclimate. The larger energy input increases evapotranspiration on west and southwest aspects making them much warmer and dryer than the north and east facing slopes. The moist conditions at north and east aspects affords much better living conditions for soil fauna than at the southwest aspect and this facilitates a more rapid incorporation of organic matter in to the mineral soil through decomposition of litter. Humus being highly colloidal, has the ability to adsorb and retain for future plant use many of the ions such as calcium, magnesium, potassium, phosphates and ammonia which might be leached from the soil and lost in drainage (Brady 1974). Therefore, the mesic aspects (north and east facing slopes) have microclimatic advantages that favors more litter fall on the forest floor and its consequent rapid decomposition compared to xeric sites.

Increased net radiation on west and southwest aspects is the primary microclimatic difference relative to north and east aspects. The microclimatic data from two summer days (Figures 4 and 5) show the effects of increased radiation. The litter layer on west and southwest aspects frequently becomes drier due to higher evapotranspiration, and this results in slower decomposition and deeper accumulation of litter on these aspects. Dry litter decomposes slower

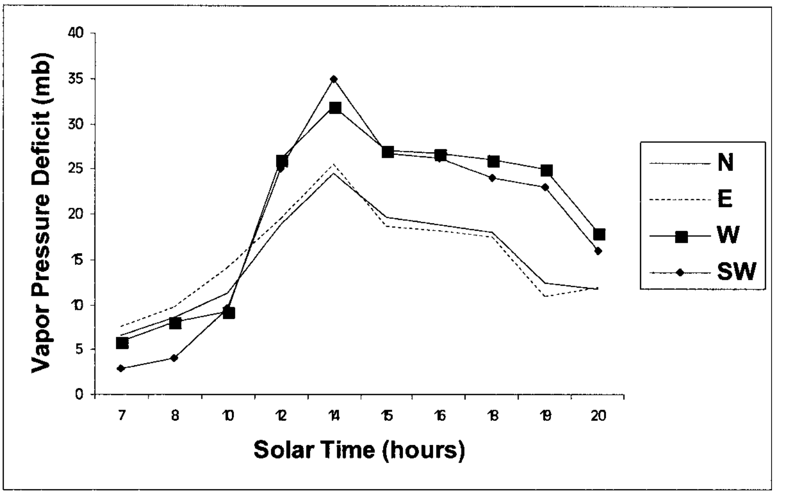

Figure 5. The diurnal pattern of estimated vapor pressure deficit (VPD) across the four aspects during two growing season days (July 14th and 16th of 1997). VPD is a measure of the demand for evapotranspiration.

and provides a less favorable environment to soil flora and fauna, further slowing decomposition. The lower soil nutrient concentrations and dry biomass on these aspects can in part be attributed to these effects. In the present study the relationships between species composition and aspect in terms of basal area and dry biomass and species importance values indicate that oaks dominate the west and southwest aspects. A study by Lang and Orndorf (1983) attributed deeper litter layers on the south and west facing slopes to the slower decomposition rate characteristics of oak litter, which predominates these sites. This is in agreement with Melillo et al. (1982) who reported that oak leaves have high lignin content and decompose slowly.

Sample Size Requirements

The coefficient of variation (CV) of dry biomass at the east-facing site (33.4%) of the watershed was significantly higher ($p < 0.01$) than those at the north (26.7%), west (31%), and southwest (29.4%) aspects. A related study at the Fernow Experimental Forest (Tajchman et al. 1995) attributed a higher coefficient of variation of plot biomass on the east facing slope (29.9%) and a lower coefficient (25.3%) on the west aspects to complexity and uniformity of the topography respectively. The coefficient of variation of dry biomass has practical importance since it affects the determination of appropriate sample size required for biomass studies. The magnitude of the coefficient of variation is in direct proportion to the size and number of plots required to determine estimates of above ground biomass within certain error limits. Larger coefficients of variation require larger number and/or size of plots. In the present study, in order to determine how the magnitude of CV changes with number of plots, the coefficient of variation of dry biomass was computed by varying the number of plots from 1 to 25. The coefficient of variation decreased with increasing number of plots but did not reach a steady value. This suggests that aspect related biomass studies at the watershed may require more number of plots than currently used ($n = 25$) or that the plot size should be increased for $n = 25$.

Conclusions

The study shows that aspect has a profound effect on species composition, size class distribution, dry biomass, basal area, air temperature, relative humidity and evapotranspiration. The relationship of these parameters with aspect in the present study were stronger than commonly reported (Hicks and Frank 1984, Tajchman et al. 1995) because the study plots were chosen to represent the two extremes, rather than cover a wide range of aspects.

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