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Description of the Fork Mountain Long-Term Soil Productivity Study: Site Characterization

Mary Beth Adams
James Burger
Lucian Zelazny
John Baumgras

Abstract

The effects of air pollution and timber harvesting on soil resources continue to be an important issue in eastern hardwood forests. This publication describes the Fork Mountain Long-term Soil Productivity Study (LTSP), located on the Fernow Experimental Forest, WV, and the pretreatment stand, soil and climatic conditions. Extensive vegetation surveys, biomass determinations, site characterization, and analyses of soil physical and chemical characteristics are described herein. The Fork Mountain LTSP site is, based on most metrics, a highly productive site with vegetative diversity typical of most second growth Appalachian hardwood forests. Other than relatively low soil nutrient levels, site characteristics suggest few problems with regeneration. Based on soil characteristics, the site may be susceptible to leaching of base cations as a result of high levels of acidic deposition. Productivity and nutrient characteristics, particularly calcium, varied across the site spatially, but are accommodated in the experimental design. We continue to monitor the response of this ecosystem to these treatments.

The Authors

MARY BETH ADAMS, Project Leader and soil scientist with the USDA Forest Service, Northeastern Research Station, Parsons, WV.

JAMES BURGER, Professor of forestry and soil science, Virginia Tech University, School of Forest Resources, Blacksburg, VA.

LUCIAN ZELAZNY, Thomas B. Hutcheson Professor of soil science, Virginia Tech University, Department of Crop and Environmental Science, Blacksburg, VA.

JOHN BAUMGRAS, forest products technologist (retired), Northeastern Research Station, Morgantown, WV.

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Introduction

The forests of the central Appalachian region provide recreational opportunities, valuable timber commodities, wildlife habitat, and important ecosystem services. These forests also are threatened by invasive plants, insects and diseases, urban encroachment and development, strip mining, wildfire, air pollution, and unregulated recreational use. Forest decline has not yet been documented in the central Appalachian region, but the sustainable productivity, biodiversity, and health of central Appalachian forest ecosystems are of increasing concern. One hypothesized agent of decline that has received significant attention of late is base cation depletion of poorly buffered soils via forest harvesting and atmospheric inputs of nitrogen (N) and sulfur (S) (Adams 1999). Declines in soil base levels, particularly calcium (Ca) and magnesium (Mg), with intensive harvesting of forest products, have been documented in a few instances in the United States (Fuller et al. 1987). Because timber harvesting is expected to increase substantially in the eastern United States (National Research Council 1998), and because the shift in forest utilization is toward more intensive fiber production and removal of more organic matter, nutrient removal in biomass could contribute significantly to base cation loss from some forested sites. Possible base cation depletion resulting from timber harvesting on public lands managed by the USDA Forest Service has already been questioned in timber sale appeals and identified as an important issue in National Forest Management Plans.

The central Appalachian region receives some of the largest inputs of acidic deposition in the United States (Adams et al. 1994). Although S deposition has decreased in some areas of the eastern United States, nitrogen emissions are predicted to increase (Galloway et al. 1995). Nitrogen in excess of what the biota can assimilate leads to N saturation. Symptoms of N saturation have been documented for many ecosystems (Fenn et al. 1998), and research from the Fernow Experimental Forest (Adams et al. 1997, Peterjohn et al. 1996, Gilliam et al. 1996) suggests that some central Appalachian forested sites have reached or are nearing N saturation. One symptom of N saturation is accelerated leaching of base cations from the soil; this raises concerns about long-term soil nutrient levels. Sensitive soils are those with a low cation exchange capacity, intermediate base saturation, low pH, low amounts of bases released via weathering, low sulfate absorption capacities, and shallow depth (Adams et al. 2000). A large percentage of soils in the Appalachian region exhibit these characteristics. Because increased timber harvesting is expected along with continued high levels of N deposition in the central Appalachians, base cation depletion and complications from N saturation are major concerns for long-term productivity, biodiversity, and sustainability of forest ecosystems.

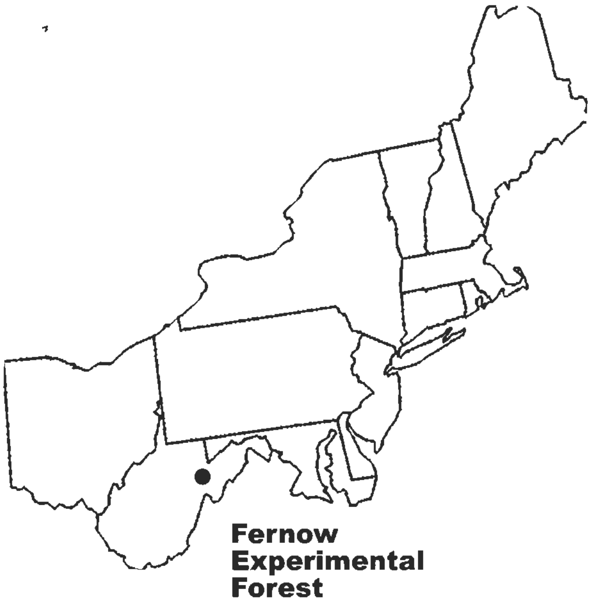

Figure 1.—Location of Fernow Experimental Forest, site of Fork Mountain Long-Term Soil Productivity Study.

To address these concerns, a study was initiated in 1996 on the Fernow Experimental Forest (Fig. 1). This study is affiliated with the National Long-term Soil Productivity (LTSP) Study (Tiarks et al. 1997), to evaluate timber management impacts on long-term soil productivity and evaluate the sustainability of managed stands. Our objective is to evaluate the interaction of forest management and air quality on long-term soil productivity. Specifically, we are studying the influence of nutrient removals on long-term forest productivity through examination of biomass production and nutrient cycling over time. We will focus on key processes, particularly those related to base cation retention and supply, nitrogen saturation, and soil buffering. We also will evaluate how soil changes affect forest communities in central Appalachian hardwood forests, including vegetative species composition, structure, diversity, and productivity.

Our goals for this study include:

1. Characterize the productivity, diversity and biogeochemistry of a forest system hypothesized to be sensitive to base cation removal through harvest removals and continuing inputs of nitrogen and sulfur.

2. Determine the response of this forest community to base cation removal.

3. Create new and modify existing vegetation/ nutrient/hydrologic models to describe and simulate forest change in response to base removals, nitrogen and sulfur inputs, and mitigating base additions.

This publication addresses goal 1, provides a description of the Fork Mountain LTSP site prior to implementation of the experiment, and briefly discusses site variability.

Methods

Location of Experiment

This experiment is located on the Fernow Experimental Forest in Tucker County, West Virginia (latitude 39° 04' N, longitude 79° 41' W) on Fork Mountain, and was established in 1996. The Fernow is located in the Allegheny Mountain subsection of the Appalachian Physiographic Province. The site has a southeast aspect, with slopes ranging from 15 to 31 percent. Elevation ranges from 798 m to 847 m. At the initiation of this study, trees on this mostly undisturbed forested site were about 85 years old and were typical of a relatively high productivity (red oak site index$_{50}$ = 80) central Appalachian mixed hardwood forest. This site was last harvested around 1910.

Description of Experiment

This experiment is designed to address the long-term (one rotation or ~80 years) effects of base cation removals on forest productivity, measured as aboveground biomass, and to allow repeated measures of many important parameters and processes. It is designed with four replications of four treatments, and is blocked by slope position (i.e. each row of four plots is one block; see Fig. 2). The treatments are an uncut, untreated control (CTRL); whole-tree harvesting (removal of all aboveground biomass; WT); whole-tree harvesting + ammonium sulfate fertilizer additions (WT+NS); whole-tree harvesting + ammonium sulfate fertilizer + addition of dolomitic lime (LIME). The ammonium sulfate treatment is designed to accelerate base cation leaching from the soil, and is based on other research (Adams et al. 1997) which demonstrated a significant increase in leaching of Ca and Mg in response to fertilization at rates equal to twice ambient N and S deposition rates. Ambient rates of deposition in throughfall are ~15 kg N/ ha/yr and 17 kg S/ha/yr (Helvey and Kunkle 1986). Fertilizer treatments are applied three times per year (March, July, November) to mimic natural deposition patterns. Treatment of one-fourth of the treatment plots with dolomitic lime will test whether relatively simple amelioration techniques can be used to mitigate base cation losses. Dolomitic lime is applied at a rate twice that of the export rate of Ca from a nearby reference watershed. Stream water export is approximately 11.25 kg Ca/ha/yr and 5.83 kg Mg/ha/yr (Adams et al. 1997). Control plots will provide an untreated reference. (See Fig. 2 for treatment assignments to plots.) On all harvested plots, the vegetation will be allowed to regenerate naturally.

Each growth plot is 0.2 ha in size (45.7 m on a side, corrected for slope), and is bordered by a buffer strip (7.6 m wide) on each side, for a total treatment plot area of 0.4047 ha (Fig. 3).

Sampling and Measurements — Productivity

Productivity indicators include tree growth rates over time and aboveground production, both in terms of biomass and economic (timber) value. Therefore, the vegetation was intensively sampled to determine initial

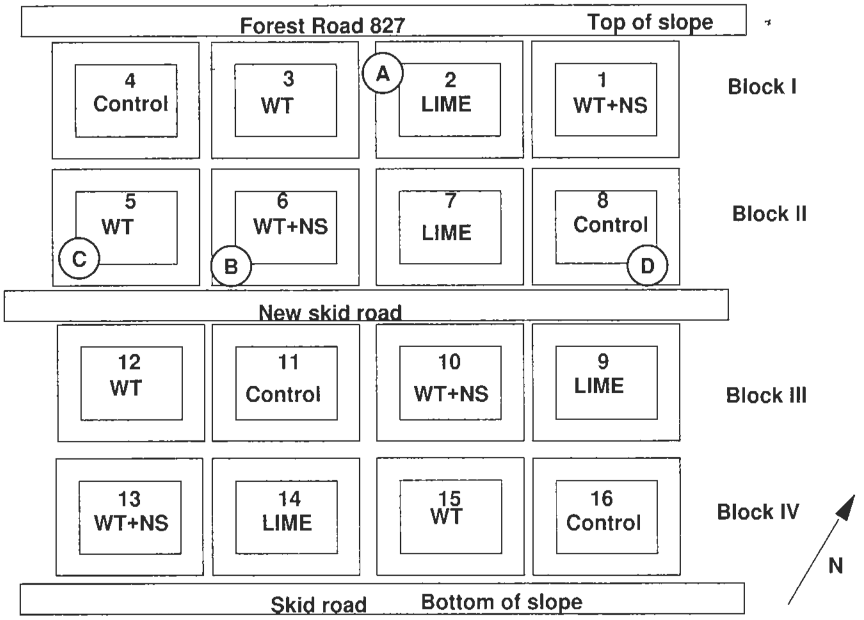

Figure 2.—Plot layout and treatment assignments, Fork Mountain Long-Term Soil Productivity Study. Letters within circles indicate location of characterization soil pits. See Appendix Table 19 for descriptions.

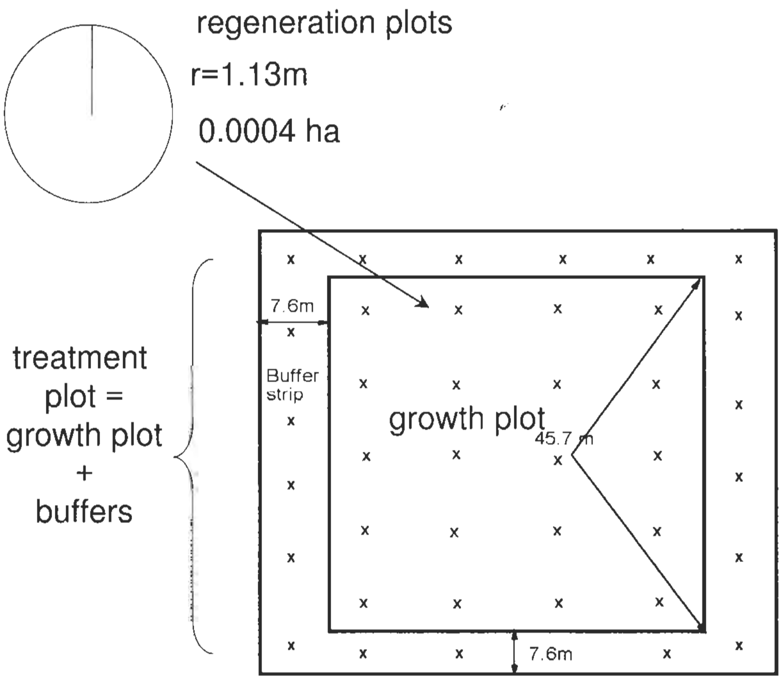

Figure 3.—Diagram of a treatment plot, growth plot and regeneration plot on the Fork Mountain Long-Term Soil Productivity Study.

conditions of volume, basal area and density of tree species, abundance of shrubs and herbs, and total aboveground biomass. Also, an important component of future productivity is reproductive capability, so regeneration was evaluated in terms of existing tree seedlings and sprouts and the regeneration potential of stored seed in the forest floor (seed bed potential).

Overstory vegetation: Height and diameter at breast height (dbh) of all trees greater than 2.54 cm diameter were measured on each growth plot in the spring of 1996. Standing dead trees also were tallied. On the untreated (control) growth plots, all trees greater than 2.54 cm diameter were tagged with permanent metal tags so growth could be followed over time. In addition to dbh and total height, height to 10 cm diameter top (merchantable height), number of logs, crown class, and condition also were recorded for all trees greater than 2.54 cm dbh. Basal area and density (stems/ha) were calculated for each plot by species.

Pretreatment aboveground biomass also was determined for each growth plot. Unbiased estimates of the green whole-tree biomass weights of all trees greater than 12.7 cm dbh on each growth plot were obtained using the first stage of the probability proportional to size (PPS) method described by Valentine et al. (1987). The PPS method provides a randomized approach to selecting sample trees to be weighed, where the probability of selecting a tree to be weighed is determined by the estimated weight of that tree as a proportion of the sum of the estimated weights of all trees on the sample plot. Estimates of the green weight of each tree with a dbh greater than 12.7 cm were obtained using the regression equations developed for Appalachian hardwood tree species by Brenneman and Daniels (1982). These equations estimate whole-tree green weight, minus foliage, as a function of tree dbh and height to a 10 cm top diameter outside bark. The unbiased estimates of plot weights are obtained by adjusting the original total of estimated tree weights using the relationships between the estimated and actual weights of the sampled trees.

The number of trees weighed on each growth plot, as a percentage of the total number of trees with a dbh greater than 12.7 cm, averaged 15.1 percent and ranged from 12 to 20 percent. Because the larger, heavier trees were more likely to be sampled using PPS, the proportion of total plot weight represented by sample trees exceeded the proportion of tree numbers sampled. Accordingly, the total weight of the trees sampled averaged 35 percent of the estimated total plot weight, ranging from 23 to 46 percent.

The biomass estimates for trees greater than 12.7 cm dbh do not include foliage weight. Tree weights were sampled from March through November 1996. As a result, all trees were not weighed without foliage. For trees weighed with leaves on, green weight minus foliage was estimated by deducting 4 percent of the total weight. Keays (1975) and Young et al. (1979) reported that foliage accounts for approximately 4 percent of the total green weight of hardwood trees.

The dry-weight estimates were calculated by multiplying the treatment plot green-weight estimates by a green-weight-to-dry-weight conversion factor (GDCF). The GDCF was derived for each plot by dividing the sum of the estimated dry weights for all trees on the plot greater than 12 cm dbh by the sum of the estimated green weights of these same trees. These tree weights were estimated using both the green and dry biomass equations developed by Brenneman et al. (1978) for Appalachian hardwood tree species, such that the GDCF obtained for each treatment plot reflects both the species composition and diameter distribution unique to that plot. For the 12 treatment plots, GDCF values were relatively consistent, ranging from 0.559 to 0.609. A similar process was used for the small trees, but equations were derived from a sample of 127 small trees harvested on Fork Mountain and elsewhere on the Fernow.

Because trees were not cut on the four control plots, it was not possible to estimate biomass using the same PPS methods applied to the treated plots. However, tree weight data collected from the adjacent treatment plots was incorporated into the estimates of control plot biomass. The estimated and actual weights of trees sampled from the treatment plots were used to develop conversion factors for each tree species or species group. These conversion factors then were applied to the regression equation estimates of tree weights on the four control plots to estimate total plot biomass. The approach to converting green weight to dry weight applied to the treatment plots also was applied to the four control plots.

Trees between 2.54 and 12.7 cm dbh were cut at the ground and mass determined on site, using a scale mounted on a logging crane. All woody vegetation smaller than 2.54 cm dbh and greater than 0.3 m also was removed and weighed for each growth plot.

Regeneration, shrubs, and herb layer: Twenty 0.0004-ha circular regeneration plots were established on each growth plot (Fig. 3), and the center marked with a metal stake (radius =1.13 m). Each of these regeneration plots was visited in late June/early July 1996. At each regeneration plot, woody regeneration was counted by species, height class, and origin (seedling vs. sprout). The percentage surface cover was estimated for woody regeneration and competing vegetation and the presence of deer browse, slash, stoniness, and other characteristics also were noted. All herbs and shrubs were then tallied on one-fourth of each regeneration plot. An additional 20 regeneration plots were established in the buffer area around each measurement plot and woody regeneration, herbs and shrubs tallied on these plots. On five of these buffer regeneration plots, one-fourth of each plot served as a clip plot, where all aboveground vegetation (herbs and shrubs, < 2.54 cm diameter, and < 1 m height) was clipped at the ground line, placed in paper bags, oven-dried, and weighed.

Seed bed potential: Because regeneration occurs naturally from seeds and/or sprouts, we characterized the seedbed to account for possible differences in species composition of regeneration after treatments began. Methods similar to those of Wendel (1987) were used. In March 1996, five 30 cm X 30 cm X 10 cm deep samples of the forest floor were collected from each of the treatment plots. Four samples were collected from the buffer areas along with one sample from the interior of the growth plots. The samples were placed on newspaper (to prevent soil loss during transport) in wooden trays with hardware cloth bottoms. Each tray was labeled as to sampling location and transported to the greenhouse. Trays were watered regularly, and allowed to germinate over the growing season. Regeneration was tallied in each tray twice during the growing season: in July and September. The counts were averaged per plot and densities calculated. Only the September data are presented here.

Leaf area index: Leaf area index was determined using a LICOR LAI 2000 (Licor, Inc., Lincoln, NE). Measurements were made in August 1996 at each treatment plot corner for each of the 16 plots, using an open sky as calibration; a mean of the four measurements determined the leaf area index.

Litterfall biomass: Freshly fallen leaf litter samples were collected in autumn 1996 from the control plots, using 0.9 m X 0.9 m collectors. One collector was placed in the center of each control plot, the litter collected on a weekly basis during the time of leaf fall, and samples were dried and weighed.

Coarse woody debris: All down woody debris larger than 10 cm diameter and longer than 30 cm, and all stumps less than 1.4 m tall (snags were captured in tree tally) were measured on each growth plot. Two diameters (large end and small end; on very long pieces, several diameters, to capture taper) and length of each piece of down wood were recorded along with species and decay class (See Adams and Owens 2001 for a description of the decay classes; generally, Class I is the least decayed, and Class III the most decayed). Samples also were collected for nutrient analyses by species. Volume of down wood was calculated using Smalian's equation (Husch et al. 1972) for log volume:

$$\mathbf{V = ((B+S)/2)L}$$

where B = cross sectional area at butt end, S = cross sectional area at small end, and L=length. Biomass was calculated using published specific gravity values for each species and decay class (Adams and Owens 2001). Biomass of standing dead trees was estimated from diameters and heights, and density values for Class II dead wood from Adams and Owens (2001) for the appropriate species.

Forest productivity will be measured using biomass estimates from destructive sampling during the first 5 years, and thereafter estimated by equations. When the stand reaches approximately 15 years of age, trees greater than 2.54 cm dbh will be permanently tagged and growth measured every 5 years. Vegetation indices (species composition, density, frequencies, etc.) also will be surveyed periodically.

Sampling and Measurements — Diversity

Species richness and diversity were estimated from measurements described above. Richness is defined as the total number of tree or plant species recorded on the growth plots. Tree inventory data were used to calculate relative density (RD), relative basal area (RBA), and an importance value (IV) for each overstory species on each growth plot, and overall, where importance value = (RD+RBA)/2 (Jenkins and Parker 1997). Relative importance values also were calculated for herbs and shrubs (based on number of plants/species relative to total number). The Shannon Diversity Index (H') and evenness also were calculated (Magurran 1988).

Sampling and Measurements — Biogeochemistry

Measurements were made of vegetation and soil nutrient pool sizes and solution chemistry. All tissue nutrient analyses were conducted at the University of Maine Soil and Plant Testing Laboratory, using protocols described by Adams et al. (1995). Soil samples were analyzed at Virginia Polytechnic Institute and State University (Lusk 1998), and solution samples were analyzed at the USDA Forest Service Timber and Watershed Laboratory in Parsons, WV (Edwards and Wood 1993).

Foliar chemistry: Foliage was collected from dominant/codominant trees of four species (yellow-poplar, black cherry, red maple, and sweet birch) per treatment plot during August 1996. Samples were collected from the upper crown of two trees/species/treatment plot, where present. Samples were dried and ground (1mm mesh) and analyzed for N, Ca, K, Mg, P Al, B, Cu, Fe, Mn, and Zn.

During the assessment of buffer regeneration plots, all herb species, except violets (*Viola* spp), on one-fourth of each regeneration plot were removed at the ground line and placed in paper bags for drying and weighing. Violets were placed in a separate bag for drying and weighing, to be used as a bioindicator of site nutrient status. *Viola* was selected because it is ubiquitous, and was found to be a sensitive indicator of nitrogen differences in the soils (Gilliam and Turrill 1993).

Soil physical and chemical properties: In March and April of 1996, soils were sampled from three randomly located quantitative pits per treatment plot. A 30.5 cm X 30.5 cm square template was placed on the soil surface, and the surface litter layers were collected from within the template, by cutting around the edge with a knife (Oi and Oe+Oa layers, separated), and placed in paper bags. Then the top mineral soil layer (0-15 cm) was removed within the same 30.5 X 30.5 cm area, gravels and cobble-sized materials were removed, and all components weighed separately. Then the hole was lined with a plastic bag and backfilled with sand of a known density, level with the soil surface, and the weight (and thus volume) of the sand determined (Grossman and Reisch 2002). This allowed bulk density to be calculated for the surface horizon. A bulk density core was collected from the 15-30 cm horizon using an AMC (Art, Manufacturing and Supply, Inc., American Falls, ID) soil core bulk density sampler. The soil was removed from the 15-30 cm horizon, subsampled, and the process repeated for the 30-45 cm layer. These depths approximately correspond with soil horizons (A, AB or BA, Bw or BC) determined from the soil reconnaissance (See Appendix Table 19 for soil profile descriptions). Soils were subsampled by horizon for nutrient determination and the remaining soil returned to the soil pits in the appropriate layered order. Soil samples were air-dried, passed through a 2 mm (#10) sieve and stored in plastic bags at room temperature. Coarse fragments (all materials > 2 mm) and roots not passing through the sieve were washed and their presence recorded as a percentage of total bulk mass. Each soil sample was then analyzed in duplicate for physical and chemical characteristics as described in Lusk (1998): particle size; organic C; pH in water, 1N KCl, and 0.1 M $CaCl_2$, exchangeable base cations; exchangeable acidity; total acidity; and cation exchange capacity (CEC).

N cycling in the soil: Nitrogen mineralization and nitrification were assessed using techniques described by Gilliam et al. (1996). On each of four subplots within a treatment plot, the surface litter layer was removed from a small area, and soil samples collected to a depth of 10 cm and placed in plastic bags. One bag was returned to the soil to incubate *in situ* for a month, and the other was returned to the laboratory. All samples were stored on ice for transport and until processing. Rocks and twigs were removed and samples gently sieved, and ~15 g subsamples weighed into plastic jars. To each 15 g sample, 150 mL 1N KCl was added, the sample shaken for 30 seconds, then filtered after 24 hours. Net mineralization and net nitrification were determined from the change in nitrate and ammonium pools over the one-month incubation period and averaged across subplots. An additional 10 g sample was used to determine moisture content and organic matter content (loss on ignition).

Soil solution chemistry: Suction lysimeters were installed on the growth plots on May 6 and 8, 1996. Three lysimeters per growth plot were installed to a depth of 1 m at approximately a 45-degree angle. Lysimeters were placed to capture the variability of each growth plot. Samples were collected approximately monthly when sufficient solution was available. Soil solution was analyzed for ammonia (NH_3), nitrate (NO_3), Ca, Mg, Na, K, Cl, SO_4, pH, and alkalinity, using methods and QA/QC protocols detailed in Edwards and Wood (1993).

Other Measurements

Soil reconnaissance: Soils were described by Don Flegel, USDA Natural Resources Conservation Service soil scientist, from four pits distributed across the study area (See Fig. 2). Descriptions are provided in Appendix (Table 19). Based on these descriptions, soils are classified as Calvin, Berks, or Hazleton series (loamy-skeletal, mixed mesic Typic Dystrochrepts).

Meteorological measurements: The hydrometeorological network of the Fernow has been described by Adams et al. (1994). Data on rainfall volume and chemistry, air temperature, and relative humidity are collected routinely and provide data for most of Fork Mountain, including the LTSP study site. In addition, Wind Mark Wind sensors (Climatronics Corporation, Bohemia, NY) were used to measure wind speed (miles/hour), wind direction (degrees), standard deviation of wind direction (degrees), solar radiation (watt/m^2), and quantum radiation (μ/s/m^2). The sensors are connected to a Campbell Scientific CR10x data logger (Campbell Scientific Inc., Logan, UT), recording readings every second, averaged every 15 minutes, and reported as hourly averages. The sensors are located on a 9 m tower, approximately 1.6 km east of the study site on the Fork Mountain ridge at approximately the same elevation as the study plots.

Here,we present data for November 1995 through October 1997, beginning the year prior to treatment, and incorporating the initial operation for the FM-LTSP weather station, with supplemental information from other Fernow monitoring stations and programs.

HOBO data loggers® (Onset Computer Corporation, Bourne, MA) were used to monitor soil temperature in four treatment plots: two control plots and two harvested plots (WT). In each of the four treatment plots, four HOBOs were placed at the 10 cm depth and left for 3-6 months, recording soil temperature every 4 hours, before being returned to the lab for data retrieval. HOBOs were placed in the soil in June 1996 prior to treatment, removed during logging (beginning in August 1996), then returned to the soil after logging treatments were completed (May 1997).

Site characteristics: Various surface properties were assessed at each of the regeneration plots: evidence of deer browsing, presence of slash taller than 4 feet, presence of soil disturbance, soil compaction, surface stoniness (defined as > 35% surface stone), and surface wetness. These parameters were classified according to whether they might interfere with tree regeneration. For each growth plot, the presence or absence of these parameters was recorded at each regeneration plot, and values expressed as percentage of regeneration plots with these characteristics.

Statistical Analyses

For descriptive and characterization purposes, means and standard deviations were calculated by plot and by block, and ranges are provided for some variables. To analyze for spatial variability, the data were analyzed using SAS GLM program (SAS Institute, Cary, NC), with the following model: VARIABLE= block treatment block*treatment. Results were evaluated at the 95 percent probability level to determine statistical significance.

Results and Discussion

Goal 1 objectives were to thoroughly characterize this site prior to treatment and describe in detail the conditions we observed. To this end, we describe the overall site characteristics, but also will evaluate variability among

Table 1.—Surface characteristics of growth plots on Fork Mountain LTSP site, with block and treatment assignments.

			Percentage of regeneration plots					
Growth plot	Block	Treatment	Browsed	Slash	Surface disturbance	Compacted soil	Stony surface	Surface wetness
1	I	WT+NS	20	5	0	0	35	0
2	I	LIME	10	0	10	10	20	10
3	I	WT	5	5	0	0	15	0
4	I	CONTROL	15	0	0	0	0	0
5	II	WT	20	0	15	0	0	0
6	II	WT+NS	5	0	5	0	10	0
7	II	LIME	0	10	5	5	5	0
8	II	CONTROL	0	5	5	0	15	0
9	III	LIME	10	10	0	0	50	0
10	III	WT+NS	50	0	5	0	15	0
11	III	CONTROL	5	10	5	0	0	0
12	III	WT	15	5	15	0	10	0
13	IV	WT+NS	35	20	0	0	0	0
14	IV	LIME	45	10	20	20	25	0
15	IV	WT	20	10	0	0	20	0
16	IV	CONTROL	40	0	15	0	35	5
Average			18	6	6	2	16	1

the four blocks, as appropriate. See Figure 2 or Table 1 for block and treatment assignments.

Growth plot characteristics: Plot surface characteristics are shown in Table 1. Eighteen percent of the regeneration plots showed evidence of browsing by deer. This measurement indicated the presence or absence of browsing on the regeneration plots; we have little information on the extent of browsing. Only four growth plots had evidence of deer browsing on more than 20 percent of the regeneration plots. No growth plots had more than 50 percent of the regeneration plots browsed. This suggests densities of approximately 6 deer/km^2; which are slightly lower than other areas in West Virginia and western Pennsylvania[1]. Eight deer/ km^2 is the density at which deer interfere with establishment of regeneration (McWilliams et al. 2003). Ninety-four percent of the regeneration plots had no slash cover, and 5 percent had slash cover which was less than 4 feet tall; and what slash was present generally covered less than 5 percent of the surface area. Ninety-four percent of the regeneration plots showed no disturbance of the forest floor, whereas about 3 percent showed disturbance of less than 50 percent of the plot's surface area. Surface compaction was observed on only three growth plots. These three measurements suggest that this second-growth stand had not been disturbed recently. Sixteen percent of the regeneration plots were characterized as stony (defined as greater than 35% surface cover in stone). On four growth plots (1, 9, 14, 16), 25 percent or more of the regeneration plots were recorded as stony: On growth plot 9, 50 percent of the regeneration plots were described as stony, and on growth plots 1 and 16, 35 percent of the regeneration plots were described as stony. On growth plot 14, 25 percent of the regeneration plots were described as stony. Surface wetness was observed on only two growth plots. We conclude that other than deer browsing, which was relatively low, these plots experienced little recent disturbance. Also, relatively

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[1] W.M.Ford, 2004. Personal communication. Timber and Watershed Laboratory, Parsons WV 26241

Table 2.—Tree (> 2.54 cm dbh) density, basal area and importance value by species for growth plots.

Species	Density (stems/ha)	Basal area (m^2/ha)	Importance value
Sugar maple[a]	248	4.79	31.4
Northern red oak	24	4.94	12.6
Striped maple	133	0.15	11.7
Black cherry	26	3.90	10.5
Red maple	47	2.15	8.6
Yellow-poplar	18	3.42	8.8
Fraser magnolia	14	0.50	2.3
White ash	10	0.96	2.9
Cucumber magnolia	9	0.55	2.0
Chestnut oak	5	0.58	1.6
Sweet birch	8	0.32	1.4
American beech	11	0.04	1.1
Bitternut hickory	3	0.32	0.9
Basswood	5	0.21	0.8
Black locust	3	0.25	0.8
White oak	1	0.28	0.7
Others:			
Common serviceberry, Spice bush, Sourwood, American Chestnut, Scarlet oak, American hornbeam, Blackgum, Alternate-leafed dogwood, Witch hazel	< 5 each	<0.10 each	<0.1 each
Total	584	23.54	

[a] See Appendix Table 20 for scientific names

high concentrations of large surface stones represented the only physical impediment to successful regeneration, but these were not evenly distributed across the site.

Productivity: Nineteen commercial tree species, four noncommercial tree species and three shrub species were recorded in the overstory (Table 2; a complete list of all plant species recorded, with scientific names can be found in the Appendix, Table 20). Basal area for the site was 23.54 m^2/ ha, with a density of 584 stems/ha. The highest stem densities were recorded for the maples, with sugar maple being the most abundant, followed by striped maple and red maple. Northern red oak, black cherry, and yellow-poplar also were relatively abundant. However, the greatest basal area was found in sugar maple, red oak, black cherry, and yellow-poplar (Table 2). With the exception of sugar maple, these species were not among the most abundant, indicating relatively few, but fairly large red oak, black cherry and yellow-poplar trees. Based on importance values, four species comprise approximately two-thirds of the stand: sugar maple, northern red oak, striped maple, black cherry.

Twenty-two species of standing dead trees were identified (Table 3). Sugar maple was the most abundant standing dead tree on the site, averaging 22 dead trees/ha, followed by black locust. Black locust represented the largest basal area of standing dead, followed by black cherry, red oak, and white ash, suggesting the dead trees of these species were fairly large, while there were many small diameter dead sugar maple trees. Total basal area of standing dead trees on the 16 growth plots was 2.5 m^2/ ha, which represents about 10 percent of total stand live basal area, with a density of 88 standing dead trees/ha.

Table 3.—Standing dead trees by species, on growth plots.

Species	Density (no./ha)	total basal area (m^2/ha)	Importance value
Black locust	16	0.55	20.2
Sugar maple	22	0.13	14.6
Black cherry	9	0.26	10.3
Northern red oak	6	0.26	8.3
White ash	3	0.21	6.0
Sourwood	3	0.19	5.8
Striped maple	9	0.03	5.6
Red maple	6	0.09	5.0
Yellow-poplar	1	0.16	3.9
Sweet birch	3	0.11	3.6
Chestnut oak	2	0.11	3.5
Fraser magnolia	3	0.07	3.1
Bitternut hickory	1	0.10	2.6
Sassafras	1	0.08	2.1
Cucumber magnolia	1	0.05	1.5
Shagbark hickory, Eastern hophornbeam, Yellow birch, Flowering dogwood, Witch hazel, White oak, American chestnut	<1 each	<0.05 each	3.74 combined
Total	88	2.46	

Analysis of existing woody regeneration identified 19 commercial tree species (Table 4), three noncommercial tree species, and 12 shrub species (Table 5). The regeneration consisted of 86 percent seedlings, with the remainder root sprouts and stump sprouts. The most abundant regeneration was from three species: black cherry (26,933 stems/ha), striped maple (11,058 stems/ha) and yellow-poplar (4,609 stems /ha). Each of these species was found on all 16 growth plots, as were sugar maple (4,594 stems/ha), red maple (3,428 stems/ha) and northern red oak (2,401 stems/ha). White ash also was relatively abundant and was found on 15 plots. Among the shrubs and competing vegetation, greenbrier was most abundant and found on all growth plots (5,212 stems/ha).

In the herb layer, 75 plant species were identified (Table 6; see Appendix Table 20 for a complete listing), including 20 woody tree species. *Viola* spp. was the most abundant herb and was found on all growth plots, at an average density of 221,491 plants/ha, with stinging nettle being next most common (93,280 plants/ha). Although there were many plant species recorded, eight species accounted for 75 percent of those recorded in the herb layer survey: *Viola* spp., stinging nettle, black cherry seedlings, Christmas fern, grapevine, Indian cucumber root, New York fern, and yellow-poplar seedlings. The Shannon Index of diversity based on the herb layer/ regeneration plots survey was 3.95 and evenness was calculated as 0.908. This H′ value is slightly higher than those reported by Eliott et al. (2002) in the southern Appalachians for undisturbed forest and forest disturbed by Hurricane Opal and salvage logging. Species richness (r) for the Fernow herb layer also was greater than that reported for the southern Appalachian site.

In the survey of seed bed potential, 10 tree species were identified: sweet birch, yellow-poplar, sassafras, black cherry, black locust, sugar maple, red maple and chestnut oak, fire cherry, and striped maple. We estimated ~183,000 potential tree seedlings/ha in these plots. Sweet

Table 4.—Woody regeneration of commercial tree species, from regeneration plots.

Species	No./ha	Importance value
Black cherry	26,933	47.2
Striped maple	11,057	19.4
Yellow-poplar	4,609	8.1
Sugar maple	4,594	8.1
Red maple	3,428	6.0
Northern red oak	2,401	4.2
White ash	2,726	4.8
Sweet birch	416	0.7
Fraser magnolia	309	0.5
Eastern hophornbeam	216	0.4
Cucumber magnolia	154	0.3
Black locust	85	0.1
Chestnut oak	54	0.1
Bitternut hickory, shagbark hickory, American beech, sassafras, blackgum, yellow birch	< 35 each	0.1
Total	57,017	

Table 5.—Woody regeneration of noncommercial tree species and shrub species, from regeneration plots.

Species	No./ha	Importance value
Greenbrier	5,212	41.0
Grapevine	3,219	25.3
Rubus spp.	3,004	23.6
Mapleleaf viburnum	548	4.3
American hornbeam	31	0.2
Flowering dogwood	23	0.2
Deciduous holly	209	1.6
Dutchman's pipe	163	1.3
Alternate leaf dogwood	93	0.7
Downy serviceberry	85	0.7
Spicebush	31	0.2
Azalea, mountain laurel, fire cherry	7 each	< 0.1
Total	12,710	

Table 6.—Herb species density and importance value, determined during regeneration survey.

Species	No./ha	Importance value
Viola	221,490	38.94
Stinging nettle	93,280	16.40
Black cherry	45,340	7.97
Christmas fern	17,450	3.07
Grapevine	15,470	2.72
Indian cucumber root	14,520	2.55
New York fern	14,080	2.48
Yellow-poplar	12,760	2.24
Twisted stalk	12,720	2.23
Indian turnip	12,480	2.19
Striped maple	12,170	2.14
unknown	11,800	2.07
Rubus	9,790	1.72
Greenbrier	9,670	1.70
Sedum	8,960	1.58
Deertongue grass	7,540	1.32
Sugar maple	6,020	1.06
White ash, black cohosh, grass, red maple, bedstraw, upright smilax, wild licorice	2,000 - 5,000 each	4.3 total
Touch-me-not, blue cohosh, trillium, slender toothwort, white snakeroot, *Lycopodium,* false Solomon's seal, mapleleaf viburnum	500 - 2,000 each	3.3 total
All others	<500 each	2.1
Total	569,460	

birch and yellow-poplar were the most numerous tree seedlings followed by fire cherry and sassafras (Fig. 4). The most numerous of the 24 semiwoody and shrub competitors were *Rubus* spp., and grapevine. Wendel (1987) evaluated abundance and distribution of vegetation under four hardwood stands ranging in site index from 64 to 80, using similar methods. On Wendel's sites, abundance ranged from 75,000 to 250,000 seedlings/ha. Wendel also found species composition similar to what we reported: sweet birch was consistently the most abundant of the regenerating tree species that were common to all areas, and yellow-poplar usually was ranked second in abundance. It is noteworthy that on the Fork Mountain LTSP site, oak seedlings, which were nearly absent in the regeneration layer of this second-growth stand on Fork Mountain, despite their presence in the overstory, also were nearly absent in the seedbed survey. Because many oaks have infrequent heavy mast years, this relatively low abundance of oak seedlings could be due to low acorn production or to high predation of acorns. Overall, the lighter seeded species were most abundant in the seedbed on the Fork Mountain site.

Biomass: Estimates of total aboveground plant biomass (dry mass) ranged from 243 metric tons (T)/ ha to 385 T/ha, with the average of 312 T/ha (Table 7). Most of the biomass was comprised of overstory trees larger than 12.7 cm dbh, with values ranging from 238 to 381 T/ha. This is considerably greater than the 94 T/ha estimated by Patric and Smith (1975) for 70-year-old trees on the Fernow, and is also greater than values reported for most hardwood forests in the eastern United States (see Adams et al. [2000] for comparisons). The stand on Fork

Table 7.—Aboveground vegetative biomass. Estimated tree mass does not include foliage.

Plot	Trees > 12.7 cm dbh	Trees 2.54 -12.7 cm dbh	Trees < 2.54 cm dbh	Herbs	Total
	- - - - - - -	- - - - - - -	Metric ton/ha	- - - - - - -	- - - - - - -
1	296	3.95	0.67	0.32	301
2	347	4.55	0.74	0.09	352
3	340	3.58	0.99	0.24	345
4	381	3.06	0.81	0.28	385
5	308	1.96	1.70	0.18	312
6	362	2.60	0.99	0.17	366
7	320	4.59	1.43	0.09	326
8	238	3.51	1.37	0.14	243
9	262	7.92	1.06	0.03	271
10	299	5.32	1.70	0.07	306
11	302	3.45	1.55	0.14	307
12	312	4.50	1.91	0.08	319
13	305	6.28	1.95	0.11	314
14	285	5.17	1.32	0.05	291
15	274	4.66	1.17	0.07	280
16	261	5.75	1.48	0.13	269
Mean (std.dev)	306 (38.3)	4.43 (1.48)	1.30 (0.40)	0.14 (0.08)	312 (37.5)

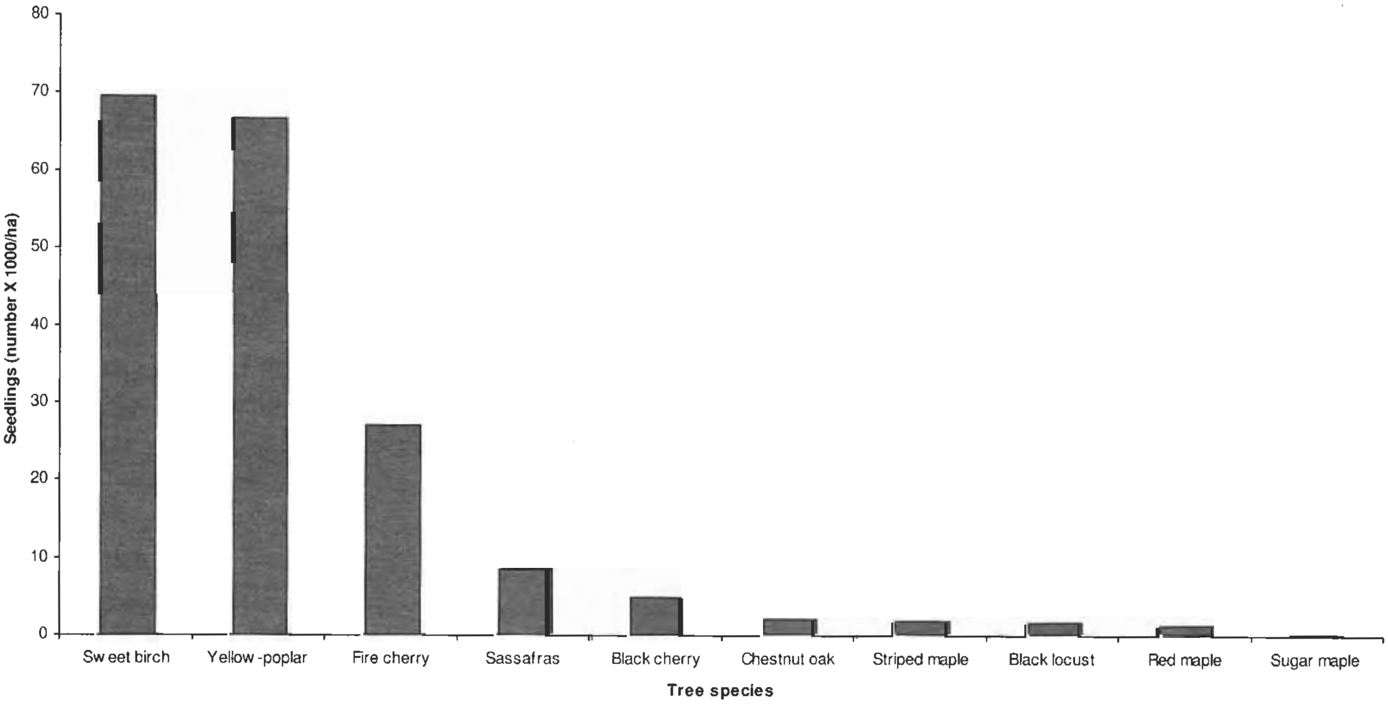

Figure 4.—Number of seedlings of most common tree species found in seedbed potential survey.

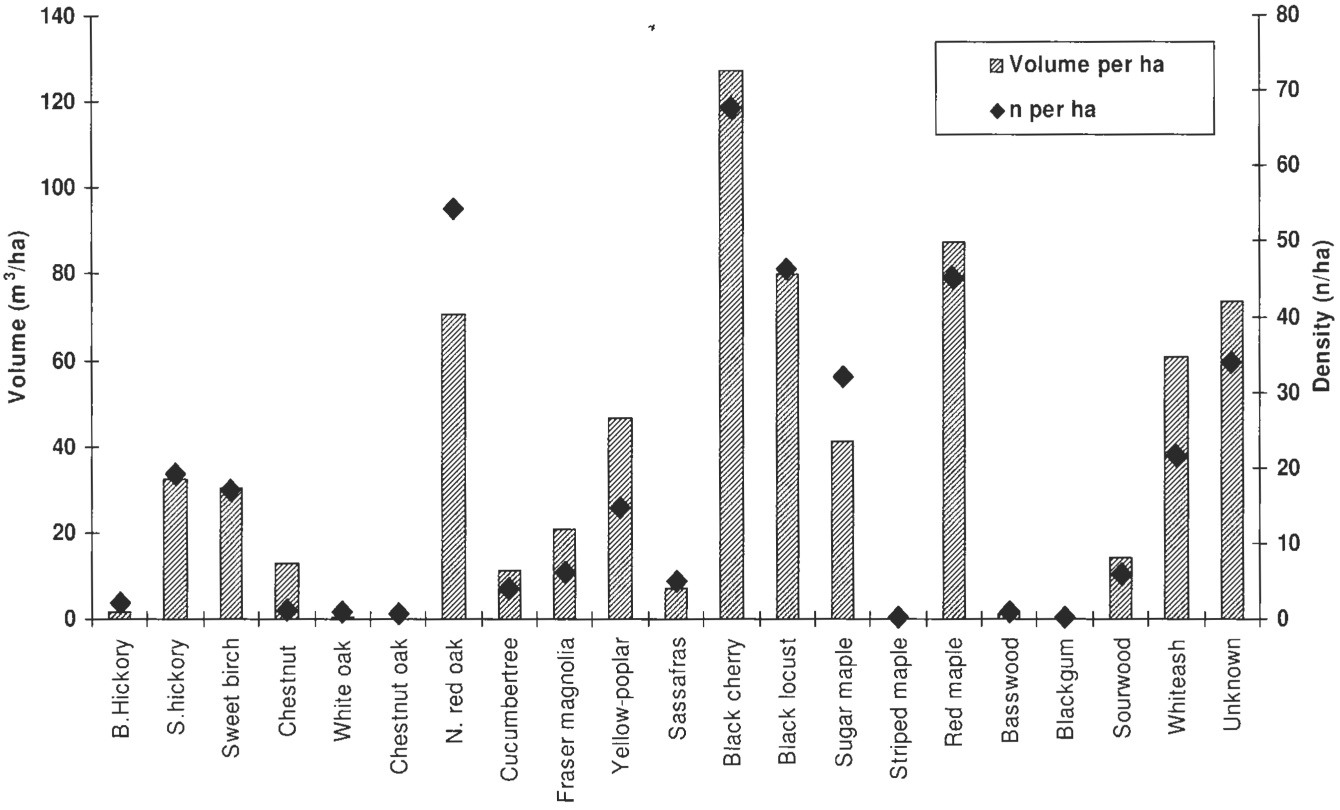

Figure 5.—Down dead wood on Fork Mountain Long-Term Soil Productivity Study, pretreatment volume and density, by species. See Appendix, Table 20 for scientific names of tree species.

Mountain was approximately 90 years old at the time of measurement and on a high productivity site. Although basal area on this site was average for sites on the Fernow, the high biomass may be attributed partly to the tall trees: average height of the trees sampled was 29.3 m. Litterfall production for 1996 was 3.80 T/ha, and leaf area index averaged 4.5 across the site, both of which are indicators of the high productivity of the Fork Mountain site.

Average down woody debris (DWD) volume (exclusive of stumps, and across decay classes) was 44.9 m³/ha (Table 8). This is comparable to other published values for mixed hardwood forests, but less than reported for Watershed 4, a reference watershed on the Fernow, located about 1 km from the Fork Mountain LTSP site (Adams et al. 2003). DWD volume on Watershed 4 was estimated as 69.7 m³/ha, and American chestnut was the dominant species of down dead wood. American chestnut DWD was nearly nonexistent on the Fork Mountain LTSP site. Across all the plots on the Fork Mountain LTSP research site, black cherry was the most commonly encountered and represented the greatest volume of DWD, followed by red maple, black locust and northern red oak (Fig. 5). Note that density and volume of DWD are well correlated on this site. Average down wood biomass per plot was 17.3 T/ha (Table 8). Eighty-four percent of the DWD was in wood decay Class III, the most decayed. Presence as DWD may reflect presence in the living stand or durability (decay resistance) of the wood. Black locust is very decay resistant, but is not very abundant in the overstory (Table 2). Black cherry is both abundant and relatively decay resistant. There were approximately 52 stumps/ha, with black cherry the most common, followed by northern red oak, and most of the stumps were in wood decay Class II or III. (Table 9). Stumps added an additional deadwood volume of 0.384 m³/ha, and stump mass was estimated at 168 kg/ha. An average of 90 standing dead trees were recorded per hectare, with an average basal area of 2.46 m²/ha (Table 10). Standing dead mass was estimated as 7.4 T/ha, for a total deadwood mass (DWD+stumps +standing dead) of 24.9 T/ha. This represents less than 10 percent of the total aboveground biomass.

Table 8.—Down woody debris mass and volume.

Plot	Dominant species, by volume	volume (m^3/ha)	mass (T/ha)
1	sweet birch, yellow-poplar	42.8	14.9
2	white ash	23.1	11.5
3	black cherry, black locust	25.4	10.5
4	northern red oak, black cherry	65.4	25.5
5	white ash	49.4	20.0
6	white ash, black locust	56.9	22.5
7	black locust, unknown	79.0	24.5
8	Fraser magnolia	39.3	13.4
9	yellow-poplar	38.1	14.4
10	yellow-poplar, red maple	47.9	19.0
11	sassafras	31.6	15.9
12	black locust	51.4	23.8
13	chestnut	53.2	18.9
14	sugar maple, black cherry	41.0	14.2
15	cucumber magnolia	46.4	21.3
16	red maple, yellow-poplar	28.5	6.9
Mean (std. dev.)		44.9 (16.7)	17.3 (5.44)

Table 9.—Number of stumps by species and decay class. See Adams and Owens (2001) for details on decay classification.

	Wood decay class				
Species	I	II	III	Total	No./ha
Black cherry	6	25	43	74	23
Northern red oak	5	16	16	37	11
Red maple	1	10	3	14	4
Black locust	9	1	1	11	3
Sugar maple	3	0	3	6	2
Sweet birch	1	1	2	4	1
Yellow-poplar	1	2	1	4	1
Shagbark hickory	0	2	1	3	1
Sour wood	1	1	1	3	1
American chestnut	0	1	1	2	1
White ash	0	0	2	2	1
Fraser magnolia	1	1	0	2	1
Unknown	0	4	3	7	2
Total	28	64	77	169	52
% of total	17	38	45		

Soil characteristics: Soil physical characteristics are displayed in Table 11. Coarse fragment content, both at the surface and to depth, ranged from as low as 8 percent to nearly 70 percent, with the greatest average coarse fragment content in the 0-15 cm depth. Although classified as loams, these soils contain appreciable amounts of sand and porosity can be quite high. The coarse fragment content also is high in all three depths and these soils are considered well drained.

Soil chemical data are presented in Tables 12 and 13. These soils are acidic, with mean pH in water of 4.24, 4.45 and 4.42 for the 0-15, 15-30, 30-45 cm depths, respectively, and low base saturation values in all horizons. Base cation concentrations are relatively low and reflect the acidic sandstone and/or shale of the parent material bedrock. Carbon concentration is greatest in the upper horizon, as is true for most chemical values, averaging 7 percent. The forest floor (litter) is relatively rich in most nutrients, but with some differences between layers. The mass of Oe+Oa is greater than the Oi layer, with greater concentrations of N and P. Aluminum concentration in the Oe+Oa layer is approximately 6.5 times that of the Oi layer. Note also there are large differences in mean Fe concentrations between the forest floor layers.

Biogeochemistry: Foliar nutrient concentrations in the four tree species sampled are shown in Table 14. These means fall within the range reported by Adams et al. (1995) for sites nearby on the Fernow. As expected, foliar nutrient concentrations varied among the species, with yellow-poplar containing the highest levels of N, P and Ca. Aluminum concentration also was highest in yellow-poplar foliage. Given the reported sensitivity of yellow-poplar to Al, this suggests further examination of the nutrient relationships of this species are needed. Zinc concentrations were elevated in sweet birch by almost a factor of 10 relative to the other three species, while Mn concentrations in yellow-poplar and black cherry were considerably greater than for sweet birch or red maple. These levels are not believed to be indicative of nutrient deficiency or toxicity, due to the absences of visible symptoms, although published critical values are not available for most hardwood tree species. Mean values for N, Ca, and Mg concentrations in birch, black cherry and red maple foliage fell within the range of values observed across the northeastern United States for these species (Northeastern Ecosystem Research Cooperative foliar chemistry database 2004). Foliar P concentrations in black cherry, however, were at the lower end of the range reported for the northeastern United States in the foliar chemistry database for black cherry. The P concentrations reported here are similar to those found elsewhere on the Fernow[2], and may suggest the potential for P limitation on this site. Additional data from this and other nearby sites[3] lend support to this hypothesis, and open additional research topics.

Table 10.—Basal area and density of standing dead trees.

Plot	Basal area (m²/ha)	Density (stems/ha)
1	1.58	59
2	2.08	119
3	1.29	44
4	2.08	30
5	3.51	54
6	2.52	54
7	2.28	64
8	2.03	158
9	3.81	153
10	1.73	104
11	2.67	128
12	2.67	79
13	3.56	104
14	3.91	188
15	2.52	69
16	1.09	35
Mean (std. dev)	2.46 (0.87)	90 (48)

Mass and nutrient content of all vegetative and soil components are shown in Table 15. The majority of K, Ca, and Mg are found aboveground, while most of the N

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[2] M.B. Adams. Unpublished data. Timber and Watershed Laboratory, Parsons WV 26241

[3] W.T. Peterjohn. Unpublished data. West Virginia University, Morgantown WV. 26506

Table 11.—Mean soil physical properties plus range in values

	0-15 cm (n=48)			15-30 cm (n=48)			30-45 cm (n=48)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
% Sand	57.9	46	69	46.6	20	63	43.1	29	54
% Clay	13.6	8	18	19	9	28	29.4	23	39
% Silt	28.6	18	36	34.6	21	59	27.4	22	32
% Coarse fragment[a]	54.7	26	69.7	31.1	15.4	61.8	26.7	8.3	55.8
Bulk density (fine earth fraction)[b]	0.7	0.5	1.3	1.0	0.5	1.3	1.3	1.0	1.6
Bulk density (whole soil)	1.2	0.9	1.7	1.2	0.9	1.4	1.5	1.3	1.6
% porosity				55.1	47	64	42.6	39	49
% capillary porosity				36.9	32	42	33	29	40
Noncapillary porosity				18.4	11	27	9.4	1	21

[a] coarse fragment % (mass basis) in 15-30 cm and 30-45 cm depth do not include large gravels or cobbles

[b] fine earth fraction: fine earth= soil with coarse fragments (>2 mm) removed; bulk density estimates in 15-30 cm and 30-45 cm depths do not include large gravels or cobbles.

Table 12.—Mass and nutrient concentrations of forest floor layers.

	Oi layer (n=48)			Oe+Oa layer (n=48)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Mass (kg/ha)	6289	2014	13838	8801	247	70855
N (%)	1.26	0.87	1.70	1.63	1.12	2.16
C (%)	48.12	39.88	50.05	41.94	0	93.73
Ca (mg/kg)	8860	5130	13600	7869	2130	15400
K (mg/kg)	819	467	1290	985	699	1590
Mg (mg/kg)	734	455	1040	882	483	1420
P (mg/kg)	515	299	744	822	611	1110
Al (mg/kg)	548	172	2720	3501	741	8840
B (mg/kg)	20.3	11.9	27.9	19.9	14.1	29.9
Cu (mg/kg)	23.45	4.44	731.00	10.06	6.27	16.60
Fe (mg/kg)	408	134	3470	3155	518	10500
Mn (mg/kg)	2134	860	3730	2712	698	4490
Zn (mg/kg)	34.8	21.2	93.7	52.6	34.6	153.0

Table 13.—Mean soil chemical characteristics, plus range in values.

	0-15 cm (n=48)			15-30 cm (n=48)			30-45 cm (n=48)		
Variable	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
% C	6.58	3.34	16.29	2.71	1.25	8.39	1.12	0.45	3.80
pH$_{water}$	4.24	3.81	4.97	4.45	4.15	5.02	4.42	3.83	4.96
Total N (%)	0.42	0.22	0.85	0.22	0.12	0.42	0.14	0.09	0.26
Ca (cmol$^+$/kg)	0.54	0.19	2.80	0.17	0.05	0.76	0.13	0.04	0.13
Mg (cmol$^+$/kg)	0.18	0.04	0.48	0.07	0.02	0.19	0.04	0.02	0.14
K (cmol$^+$/kg)	0.33	0	0.69	0.34	0.06	9.09	0.12	0.03	0.24
Al (cmol$^+$/kg)	3.52	0.93	6.63	3.43	0.74	6.02	3.92	0.93	8.16
Exch. acidity (cmol$^+$/kg)	5.30	2.42	10.23	4.12	2.31	6.82	4.68	1.98	10.78
Total acidity (cmol$^+$/kg)	27.65	12.36	48.20	18.51	6.49	49.41	13.25	5.66	40.78
CEC(cmol$^+$/kg)	28.70	13.27	49.76	19.09	6.86	50.12	13.55	5.92	41.39
% BS	3.67	1.09	9.11	2.99	1.04	38.31	1.61	0.70	3.73

Table 14.—Mean (std. dev.) nutrient concentrations in foliage.

	Sweet birch (n=8)	Yellow-poplar (n=20)	Black cherry (n=19)	Red maple (n=13)
N (%)	2.53 (0.17)	2.92 (0.22)	2.61 (0.26)	1.96 (0.15)
P (mg/kg)	1245 (128)	1569 (79)	1332 (143)	1165 (130)
K (mg/kg)	12800 (1538)	14157 (2310)	14446 (2444)	7996 (1971)
Ca (mg/kg)	10292 (1865)	12120 (3429)	9955 (1928)	6870 (1146)
Mg (mg/kg)	1891 (376)	2589 (435)	2817 (222)	962 (172)
Al (mg/kg)	62.48 (5.74)	265.5 (46.92)	128.74 (315.78)	33.76 (2.94)
Cu (mg/kg)	9.42 (0.72)	11.01 (0.77)	8.01 (0.94)	7.79 (1.09)
B (mg/kg)	41.24 (5.47)	31.39 (4.62)	27.53 (4.66)	28.68 (3.45)
Fe (mg/kg)	81.15 (9.62)	64.06 (6.75)	66.59 (4.36)	57.07 (5.43)
Mn (mg/kg)	4841 (1061)	17977 (1002)	18617 (772)	1955 (530)
Zn (mg/kg)	229 (63.2)	24.3 (3.0)	20.05 (3.6)	35.1 (6.6)

Table 15.—Mass and nutrient content. There are no data available for soil phosphorus.

	Mass	N	P	K	Ca	Mg
	Kg/ha					
Trees>12.7 cm dbh (w/o foliage)	305,800	625	40	282	1,446	61
Small trees (w/o foliage)	198	9	<1	5	18	1
Foliage	3,300	83	4	41	33	7
Herb layer	134	<1	<1	<1	<1	<1
CWD	24,868	48	2	10	42	4
Total aboveground biomass	334,300	766	48	339	1,540	74
Forest floor	15,091	219	10	14	1,121	11
Soil						
0-15 cm	1,818,700	3,324		100	87	18
15-30 cm	1,771,900	2,656		78	38	12
30-45 cm	2,296,900	2,367		77	41	9
Total		9,332		608	2,827	124

is in the soil. However, these soil values represent exchangeable base cation pools only. We have no estimates of total cations for these soils, but contributions from other pools are not expected to be very large. Total Ca in other West Virginia soils derived from variably acid sandstone and shale ranged from 400 to 1,096 kg/ha, for example (Jenkins 2002). Nearly equivalent amounts of Ca are found in the forest floor and in the vegetation, while less than 175 kg/ha is available in the soil as exchangeable Ca. Approximately half of the aboveground Ca can be found in the boles of trees, with a nearly equivalent amount in tops and branches (Adams et al. 1995). Managing base cations, particularly Ca, in these soils requires balancing nutrient removals in forest biomass (Adams 1999).

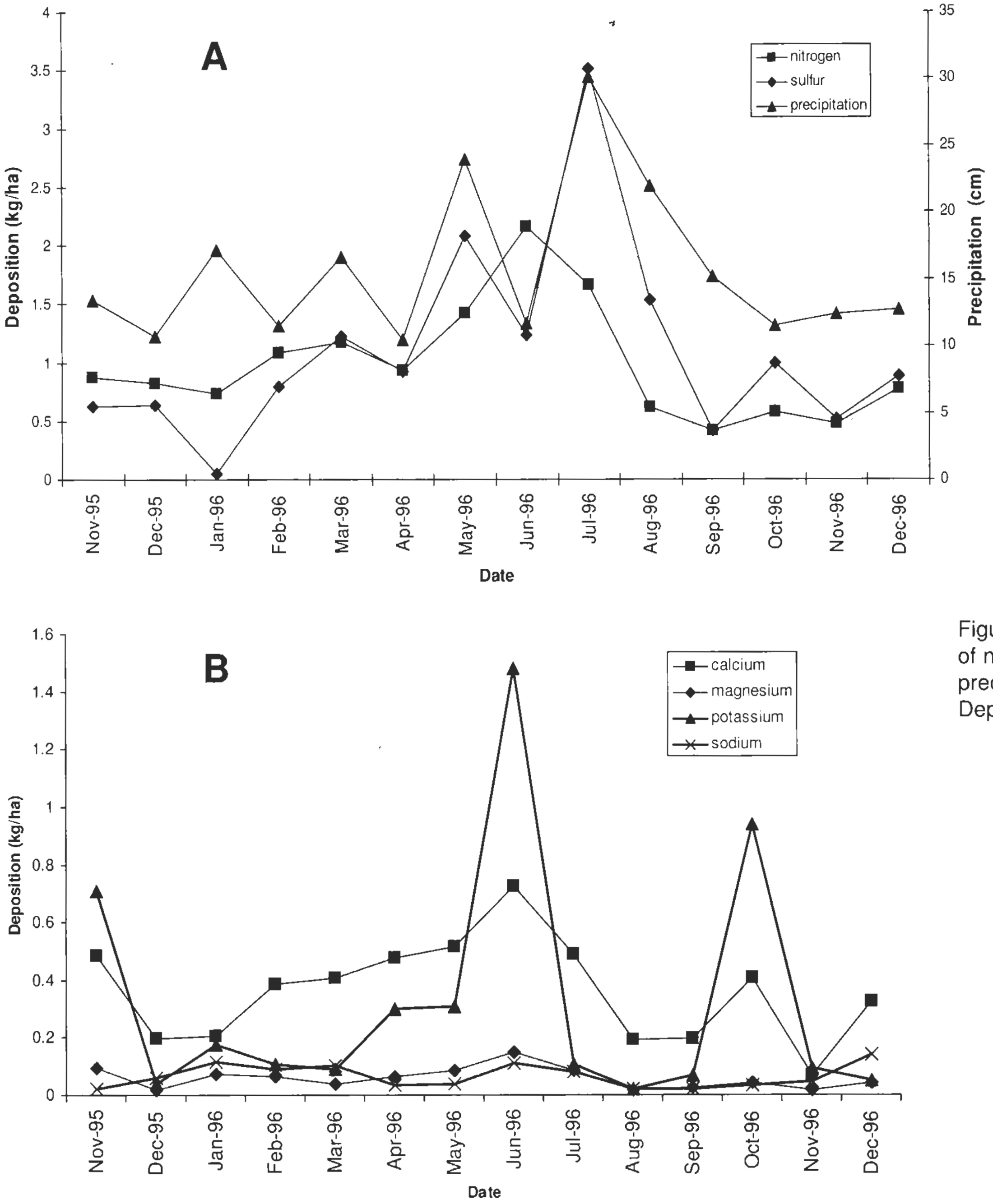

Figure 6.—(A) Wet deposition of nitrogen and sulfur and precipitation amount; (B) Deposition of cations.

Deposition chemistry for the pretreatment period is shown in Figures 6A and 6B. Deposition of sulfate and nitrate are typically higher during the growing season (Adams et al. 1994). The same is usually true for other atmospheric constituents, and trends in deposition of all constituents over time generally follow trends in precipitation amounts. Most (> 60%) of the nitrogen in deposition comes from nitrate. N deposition ranged from 0.5 to 2 kg/ha/mo. Total N deposition for 1995 and 1996 was 8.6 and 12.1 kg/ha, respectively.

Net N mineralization rates of the surface soil ranged from less than 0.5 g/m^2/mo to approximately 6 g/m^2/mo, with the greatest rates in July and August (Fig. 7). Net nitrification exhibited a similar pattern and rates. Mean monthly (growing season) rates of net mineralization and net nitrification ranged from 4-6 g N/m^2 and 3-4 g N/m^2, respectively (Gilliam and Adams 1999). These are relatively high rates of processing compared with other sites in the northeastern United States (Peterjohn et al. 1996), but are comparable to other published Fernow

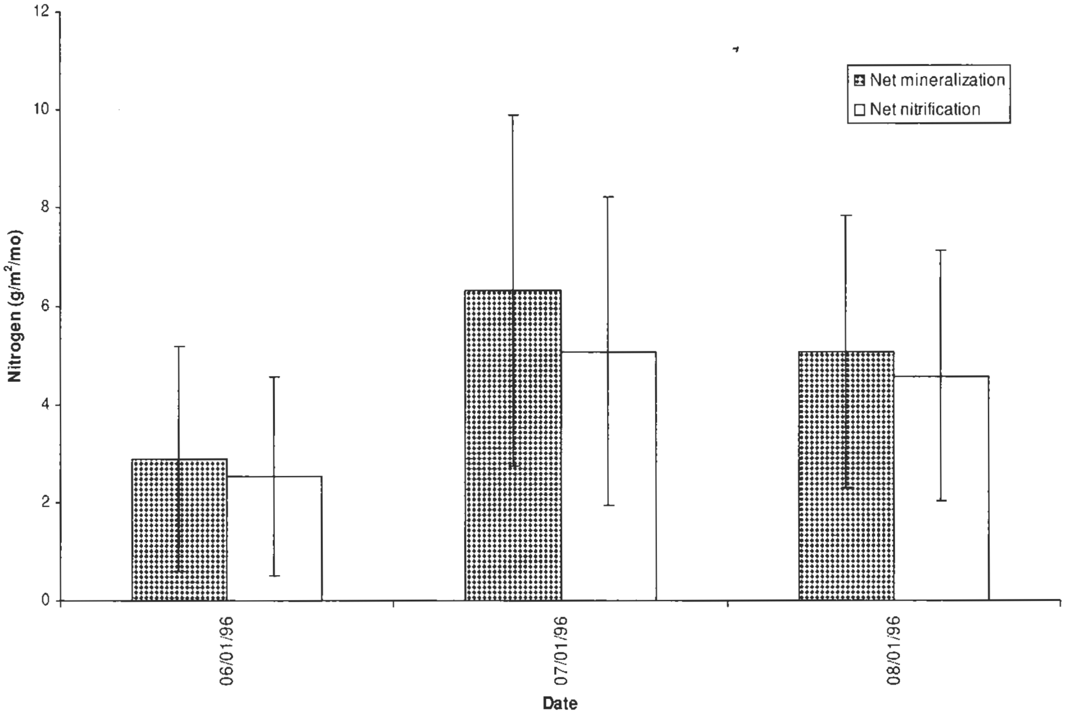

Figure 7.—Net nitrogen mineralization and net nitrification in soils (0-10 cm), summer 1996. Vertical bars represent ± 1 standard deviation.

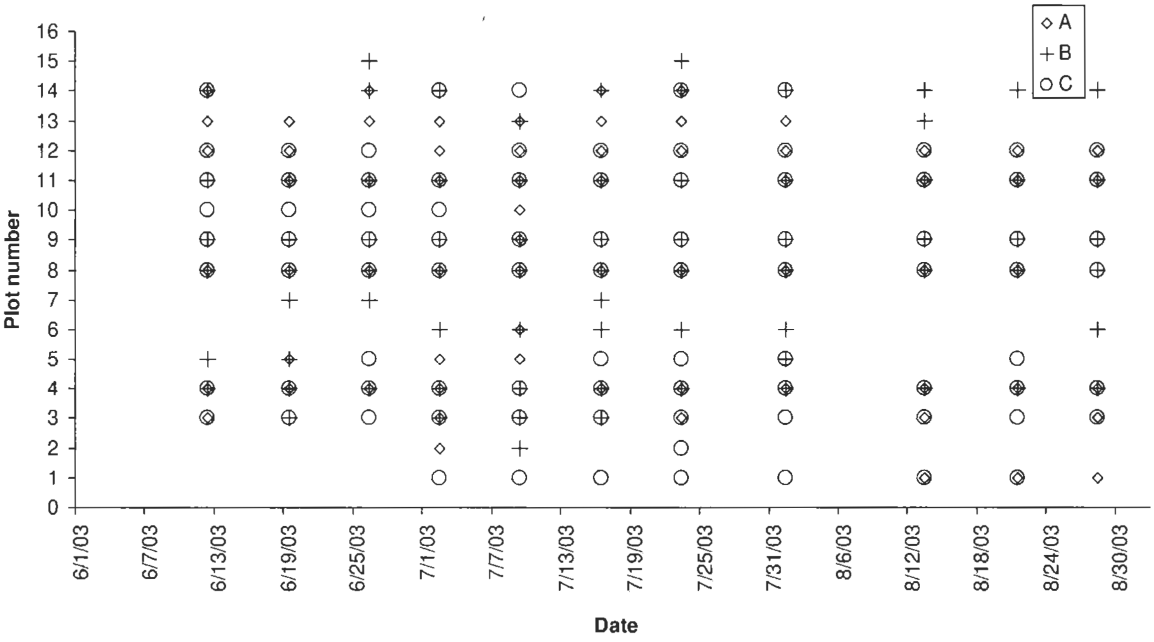

Figure 8.—Capture of soil solution by tension lysimeters, summer 1996. A, B, and C represent different lysimeters within each growth plot.

values (Gilliam et al. 1996). High rates of nitrogen cycling in the soil are symptomatic of nitrogen saturation, a condition that has been well described elsewhere on the Fernow (Peterjohn et al. 1996). It is not unreasonable to assume that as the Fork Mountain site has some of the same symptoms, it may also be nitrogen saturated.

During the pretreatment period, soil solution captured by the lysimeters varied over space and time (Fig. 8), with lysimeters in some plots capturing very little or no soil solution. For purposes of describing the site, concentrations were averaged by month and plot, and also across plots. Monthly mean concentrations of most

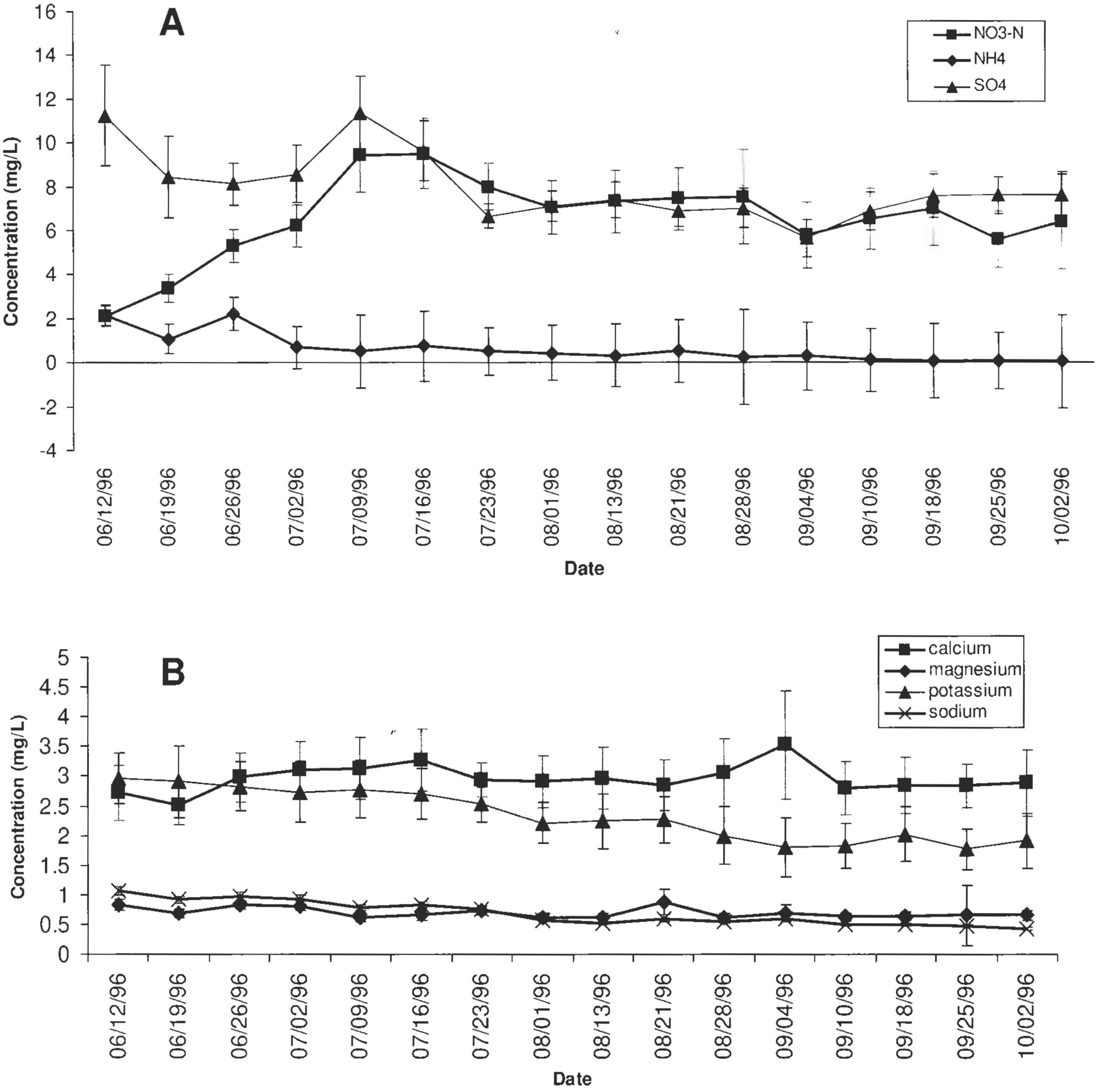

Figure 9.—(A) Soil solution concentrations of nitrate, ammonium, and sulfate;
(B) Soil solution concentrations of cations. Vertical bars represent ± 1 standard deviation.

analytes did not vary greatly over the summer (Fig. 9A-B). The notable exception was NO_3-N (Fig. 9a), which exhibited an increase in concentration during the first month of data collection, about 3 months after installation. Thereafter, concentrations leveled off around 6-7 mg/L. Soil solution concentrations did not appear related to precipitation amount. Mean solution pH from all lysimeters decreased during the summer and fall of 1996 from about 5.8 to about 5.3.

Meteorology and Air Quality: Precipitation varied somewhat from the long-term averages described by Adams et al. (1994) (Fig. 10A), with 1996 being wetter than the long-term mean and 1997 being drier. Monthly mean temperatures did not vary greatly from the long-term mean (Fig. 10B). Note the frigid minimum temperatures recorded in February 1996 and January 1997. Other meteorological data (wind speed and direction, solar radiation, and relative humidity) are

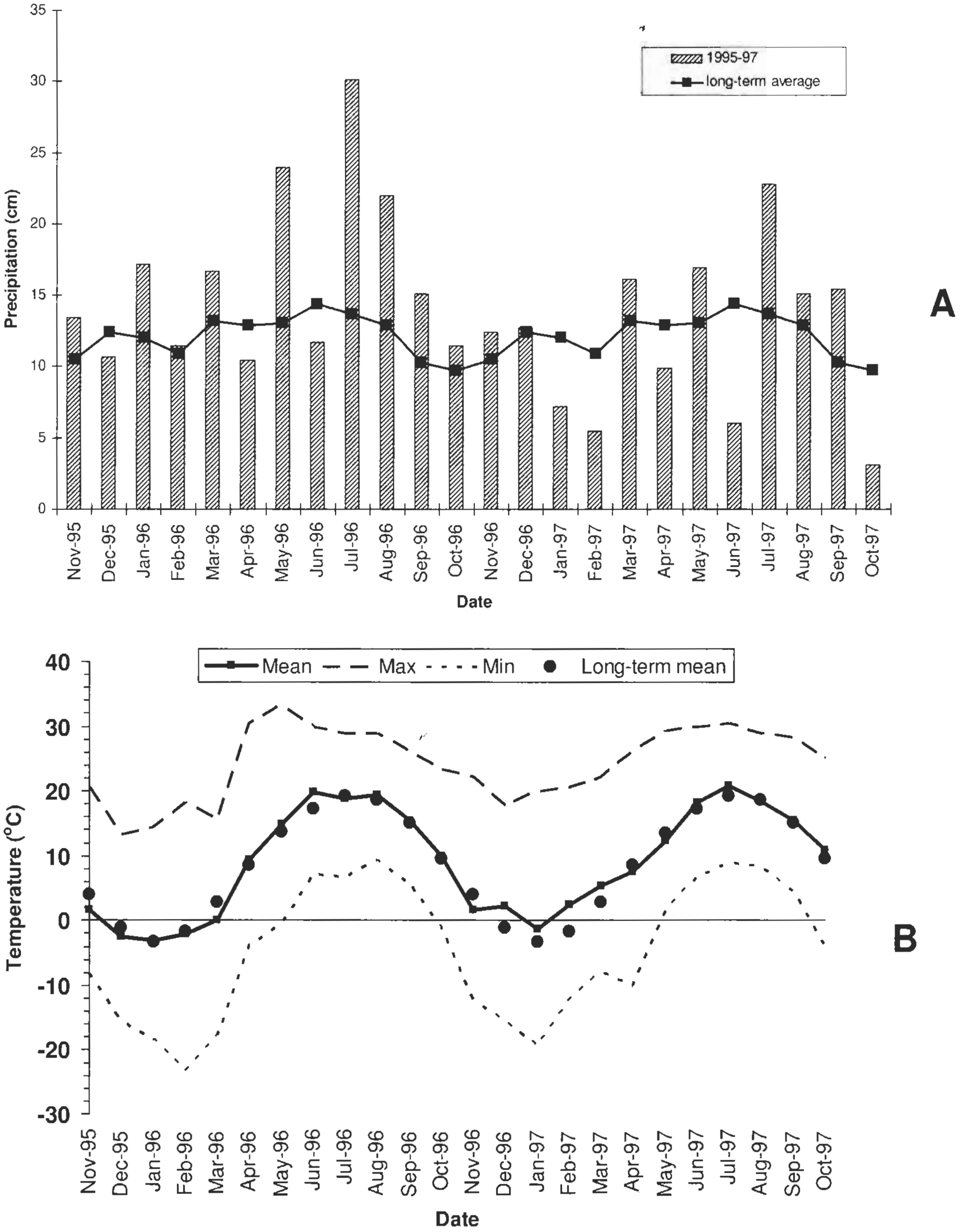

Figure 10.—(A) Mean monthly precipitation amounts 1995 -1997, compared with 30-year average monthly precipitation; (B) Monthly mean, long-term mean, and minimum and maximum air temperature.

shown in Table 16. Low values for mean monthly rainfall pH (Fig. 11A), and high ozone concentrations (Fig. 11B) attest to potential air-quality related problems.

During the summer months soil temperature ranged from 12 to 18 °C at 10 cm depth. There were no significant differences among the four HOBOs in each plot or among the plots; daily means, minimums, maximums are shown in Figure 12. Average soil temperature during the summer of 1996 was around 16 °C, but can change quickly in response to changes in air temperature and particularly, precipitation.

Table 16.—Meteorological data, monthly average values, Fork Mountain weather station, 1996-1997.

Date	Wind speed miles/hr	Wind direction degrees	Solar radiation watts/m^2	Relative humidity %
1995 Nov	2.28	252	60.8	77.0
Dec	2.82	274	58.9	73.4
1996 Jan	2.99	230	59.3	73.8
Feb	2.99	249	87.6	71.0
Mar	2.69	246	127.1	81.6
Apr	2.87	255	172.1	76.9
May	2.20	220	177.1	81.7
Jun	1.56	210	240.7	71.2
Jul	1.61	211	204.8	75.7
Aug	1.33	193	220.0	77.3
Sep	1.87	203	140.1	78.3
Oct	1.86	233	107.7	74.8
Nov	3.85	193	48.7	72.6
Dec	4.91	202	50.3	76.1
1997 Jan	6.04	205	72.4	66.8
Feb	5.25	198	86.6	71.1
Mar	5.42	195	129.8	69.0
Apr	4.37	198	198.8	63.8
May	5.09	195	212.6	66.0
Jun	3.40	174	245.2	72.1
Jul	2.64	199	260.9	74.5
Aug	1.03	213	200.4	79.5
Sep	2.39	200	179.6	79.9
Oct	3.14	189	140.04	78.2

Spatial Variability

A top-to-bottom of slope gradient was expected for variables related to soil moisture and nutrients, including productivity, because of the vast body of literature describing increases in productivity in "cove" and other depositional sites. This was the rationale for the block design, blocking across the slope. On Fork Mountain, total aboveground biomass was highest in Block I (Fig. 13A), reflecting the greatest mass of trees greater than 12.7 cm dbh, and decreased down the slope. However, these differences were not statistically significant for total aboveground biomass or for biomass of trees larger than 12.7 cm dbh (Table 17). Block effects were statistically significant for the following biomass variables: small trees (2.54-12.7 cm dbh), those trees with dbh less than 2.54 cm, and for herb biomass and standing dead wood mass, although the patterns differed from that of the large trees. The trend of decreasing mass downhill was consistent for the mass of herbs (Fig. 13B), but not for the other variables.

Other variables that might be related to soil moisture include physical properties, such as coarse fragment content, and nutrient concentrations in soil and some plant tissues. No significant differences in coarse fragment content were detected for the upper horizon (Table 17), but there was a significant effect for the 15-30 and 30-45 cm depth, with significantly greater coarse fragment content in Blocks I and II relative to Blocks III and IV (Fig. 14). Block is a statistically significant effect for some variables related to nutrients: foliar Ca

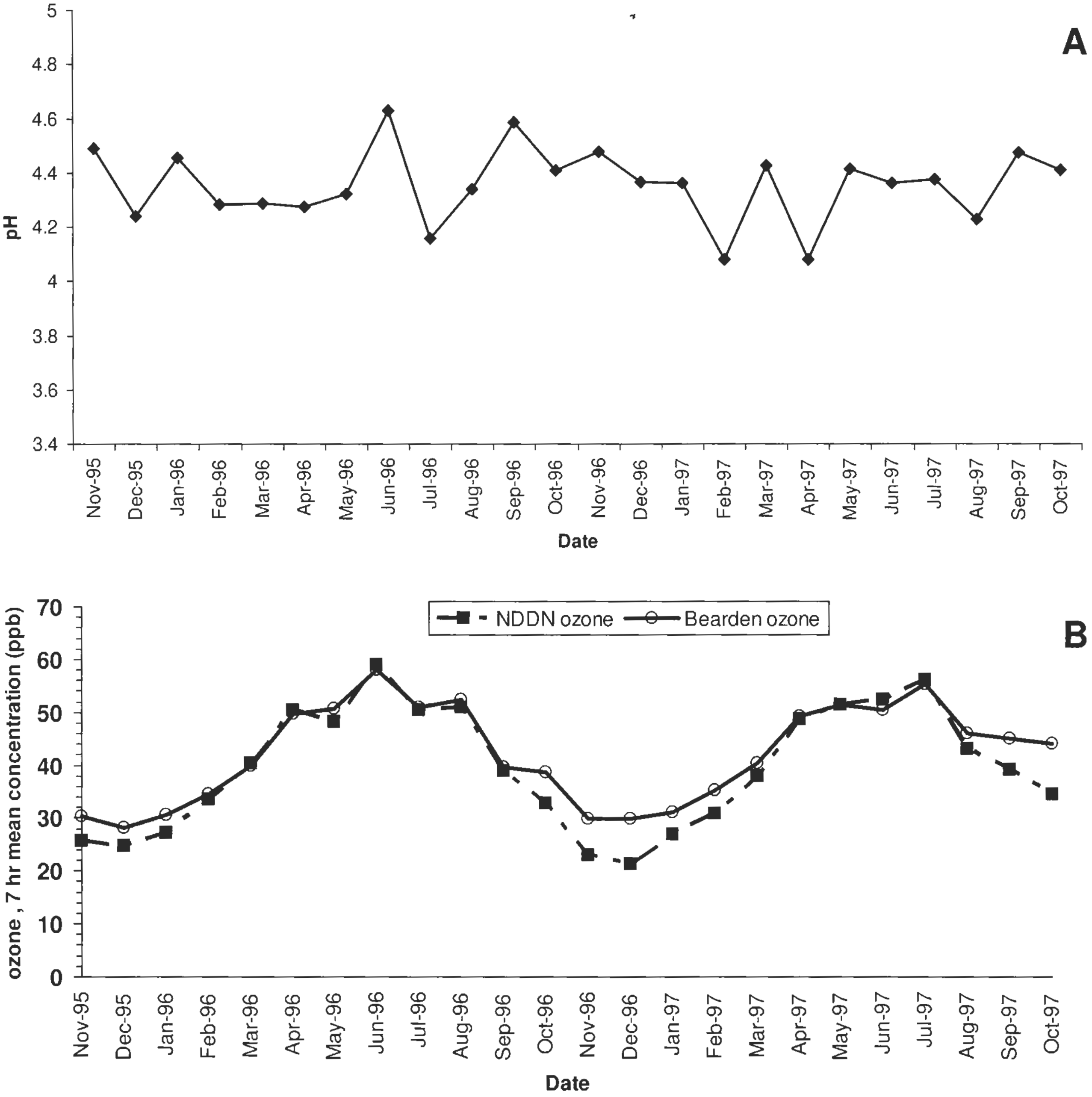

Figure 11.—(A) Mean monthly precipitation pH; (B) Atmospheric ozone concentrations at two ozone-monitoring sites near Fork Mountain Long-Term Soil Productivity Study. See text for details of locations.

concentrations in yellow-poplar, foliar N concentrations in red maple; forest floor Oi layer C content; forest floor Oi layer Ca, P, Mn concentrations; Oe + Oa layer Ca and Mg concentrations; and soil base cation concentrations. For most of these, nutrient concentrations are greatest in Block I and decrease down slope, though not always linearly. Generally, the upper row of plots (Block I) was the richest in terms of soil nutrient concentrations. This was particularly true for Ca, which may be explained by particularly high Ca values for plots 1 and 4, perhaps due to the presence of the gravel road approximately 10 m above the top boundary of those plots. Soil Ca concentrations in the 0-15 cm depth decreased down slope (Fig. 15), as did total base cation concentrations, foliar Ca in yellow-poplar, and forest floor Ca concentrations. Therefore, while these nutrient data do not appear to support the idea of nutrient enrichment down the slope, they do provide support for the blocking

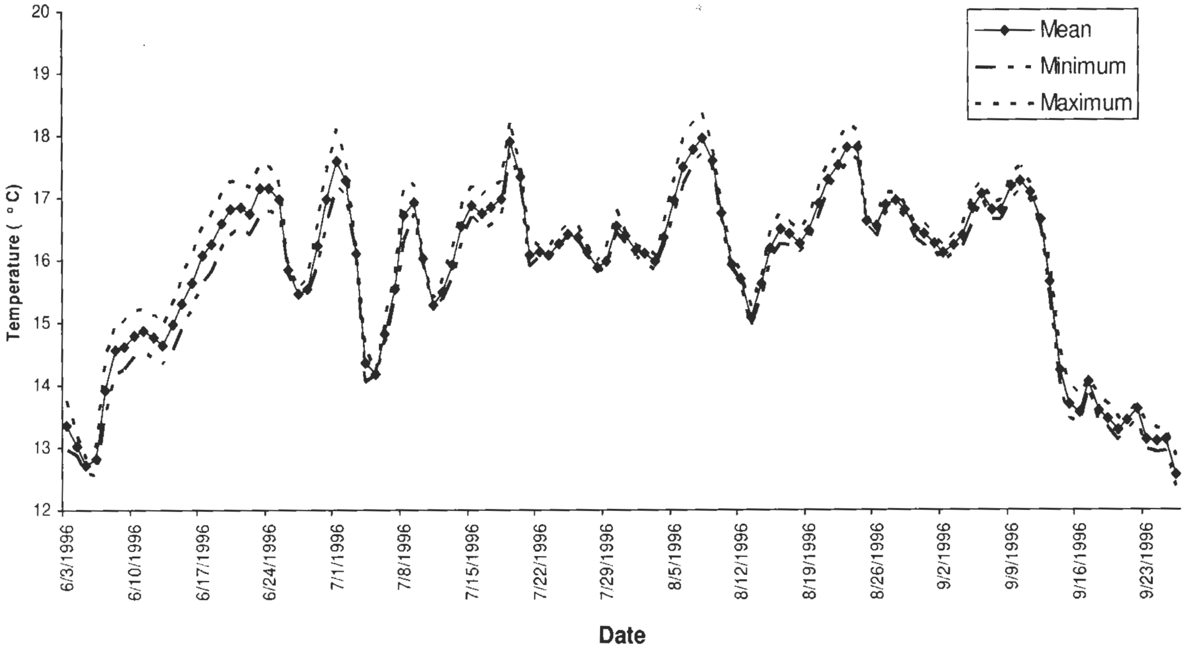

Figure 12.—Daily mean, minimum and maximum soil temperature at 10 cm depth.

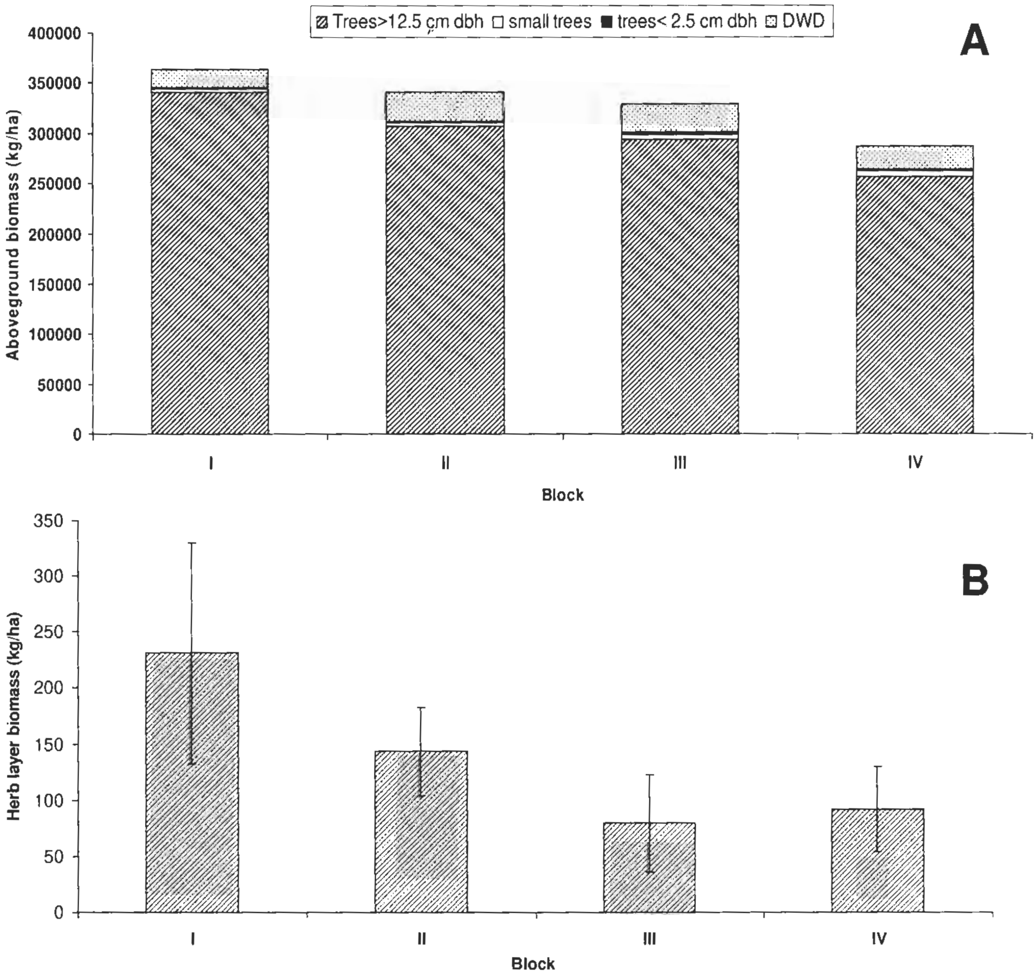

Figure 13.—(A). Total aboveground biomass, by component and block;
(B) Herb layer biomass, by block. Vertical bars represent ± 1 standard deviation.

Table 17.—Pretreatment analysis of variance results for Fork Mountain LTSP.

Variable	Block	Treatment
Biomass		
Trees >12.7 cm dbh	NS	NS
Trees 2.5 -12.7 cm dbh	0.019**	.086*
Trees <2.54 cm dbh	0.028**	NS
Herbs	0.0017**	.0140**
Forest Floor -Oi	NS	NS
Forest Floor-Oe+Oa	NS	NS
Forest Floor -total mass	NS	NS
Down woody debris	NS	NS
Stumps	NS	NS
Deadwood standing	0.085*	0.095*
Deadwood total	NS	NS
Total biomass	NS	NS
Nutrients - Foliage		
Sweet birch -N conc.	NS	NS
Sweet birch - P conc.	NS	0.0481**
Sweet birch K conc.	NS	NS
Swwet birch Ca conc.	NS	0.0349**
Sweet birch Mg conc.	NS	NS
Yellow-poplar -N conc.	NS	NS
Yellow-poplar -P conc.	NS	NS
Yellow-poplar -K conc.	NS	NS
Yellow-poplar -Ca conc.	0.0331**	NS
Yellow-poplar -Mg conc.	NS	NS
Black cherry N-conc.	NS	NS
Black cherry P-conc.	NS	NS
Black cherry K-conc.	NS	NS
Black cherry Ca-conc.	NS	NS
Black cherry Mgconc.	NS	NS
Red maple -N conc.	0.0136**	0.0544**
Red maple -P conc.	NS	NS
Red maple -K conc.	NS	NS
Red maple -Ca conc.	NS	NS
Red maple -Mgconc.	NS	NS
Coarse fragments in soil		
0-15 cm	NS	NS
15-30 cm	0.023**	NS
30-45 cm	0.07*	NS
Nutrients - Forest Floor		
Oi Nitrogen content	NS	NS
Oi Carbon content	0.0930*	NS
Oi Ca conc.	.0589*	NS
Oi P Conc.	0.0670*	NS
Oi Mn conc.	0.0046**	NS
Oe+Oa Nitrogen content	NS	NS

Continued

Table 17.—continued

Variable	Block	Treatment
Oe+Oa Carbon content	NS	NS
Oe+Oa Ca conc.	0.0030**	NS
Oe+oa Mg conc	0.0416**	NS
Nutrients in Soil		
Ca conc. - 0-15 cm	0.0161**	NS
Ca conc - 15-30 cm	0.0073**	NS
Ca conc - 30-45 cm	0.0380**	NS
Mg conc - 0-15 cm	0.0920*	NS
Mg conc - 15-30 cm	0.0010**	0.0390**
Mg conc - 30-45 cm	NS	NS
K conc - 0-15 cm	NS	NS
K conc - 15-30 cm	0.0975*	NS
K conc - 30-45 cm	0.0445**	NS
Total bases- 0-15 cm	0.0113**	NS
Total bases - 15-30 cm	0.0014**	NS
Total bases - 30-45 cm	0.0204**	NS

* Significant at p<.10

** Significant at p<.05

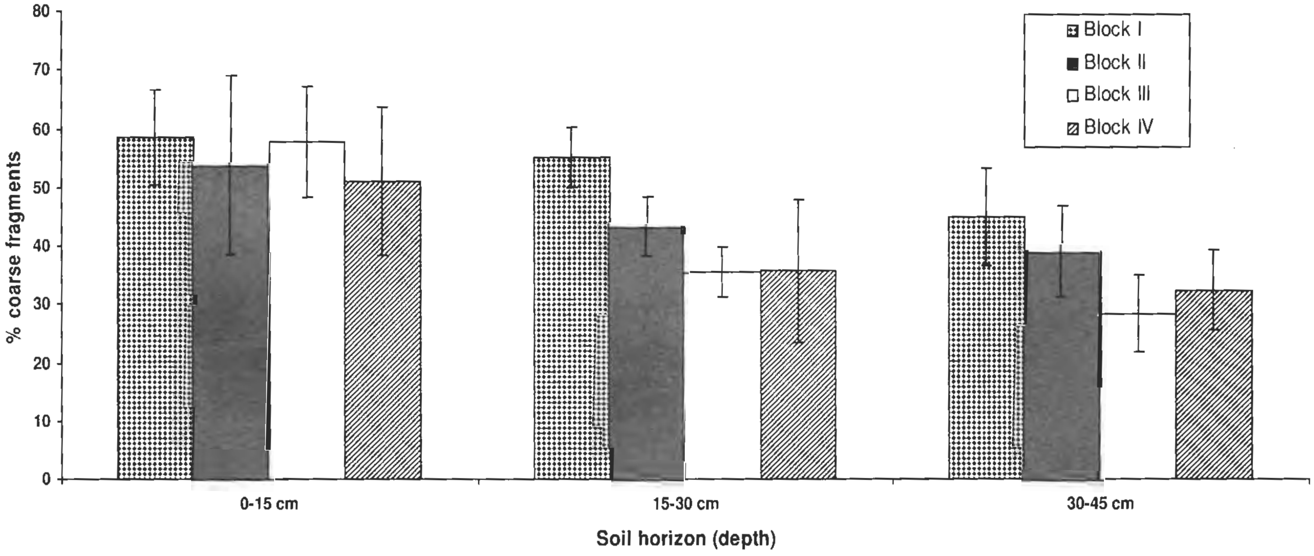

Figure 14.—Percentage coarse fragment content in soil by horizon and block. Vertical bars represent ± 1 standard deviation.

rationale: that variability down the length of the slope is significant enough to capture by blocking.

Another way to evaluate spatial variability is by evaluating plot means in relation to their location within blocks (Fig. 16). When aboveground biomass is displayed this way, in addition a slight down-slope trend, a trend from the west to east side of the plots is evident. Note that the upper northwest corner of the study area (plots 3, 4, 5, 6, 12) are similar in aboveground productivity, as

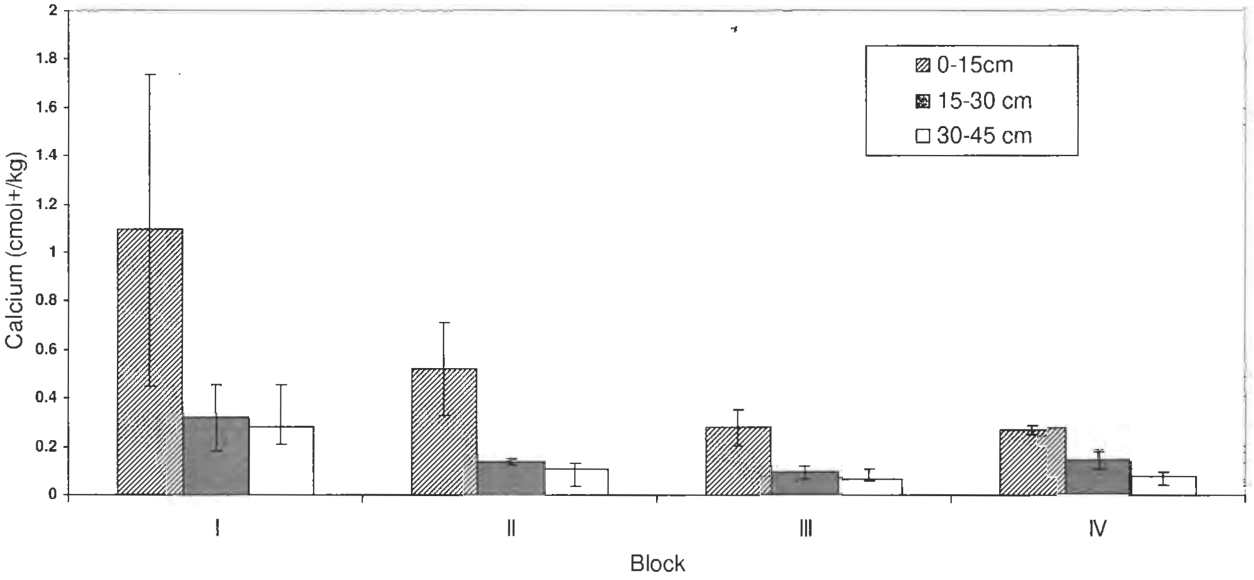

Figure 15.—Mean soil Ca concentration, in three horizons by block. Vertical bars represent ± 1 standard deviation.

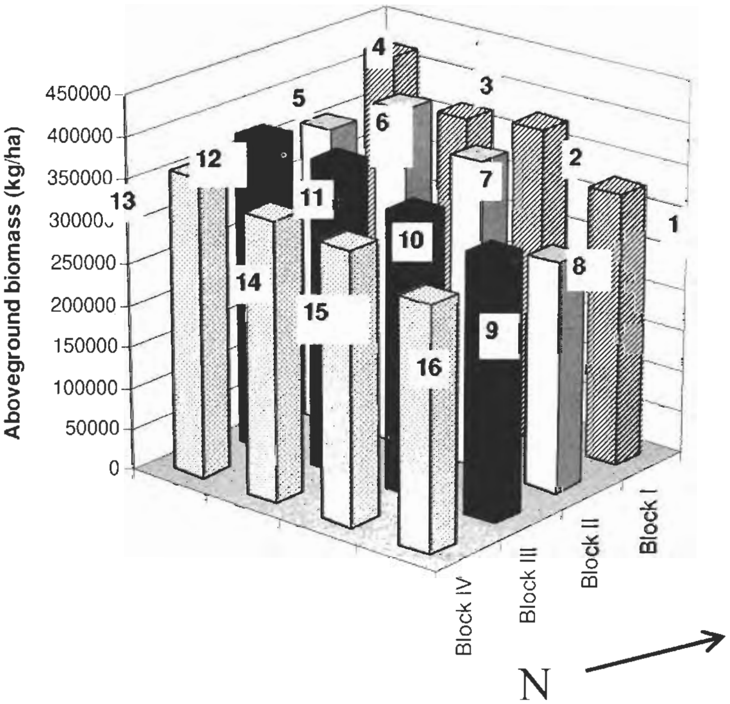

Figure 16.—Spatial arrangement of total aboveground biomass by plot and block. Numbers on the bars are growth plot numbers.

measured by aboveground biomass, and those in the lower, southeast corner (8,9,16) show some of the lowest productivity.

Tree species and herb layer richness for each plot are displayed similarly in Figures 17 and 18. The plots below the midslope logging road (plots 9 through 16) exhibited greater tree species richness than those above the road, as well as a higher stem density. However, herb species richness was greater on the upper two blocks of plots. Tree species richness, diversity and evenness increased down slope, while herb layer r and H' exhibited a nearly

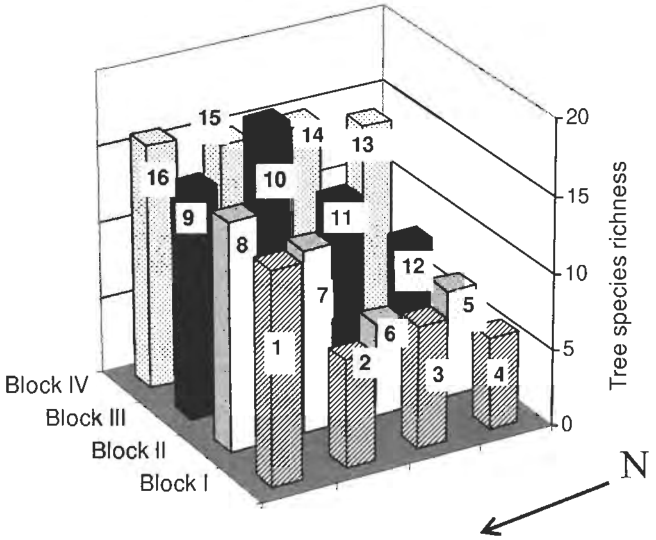

Figure 17.—Spatial arrangement of tree species richness by plot and block. Note this graph is rotated from Figure 16 for ease of viewing. Numbers on the bars are growth plot numbers.

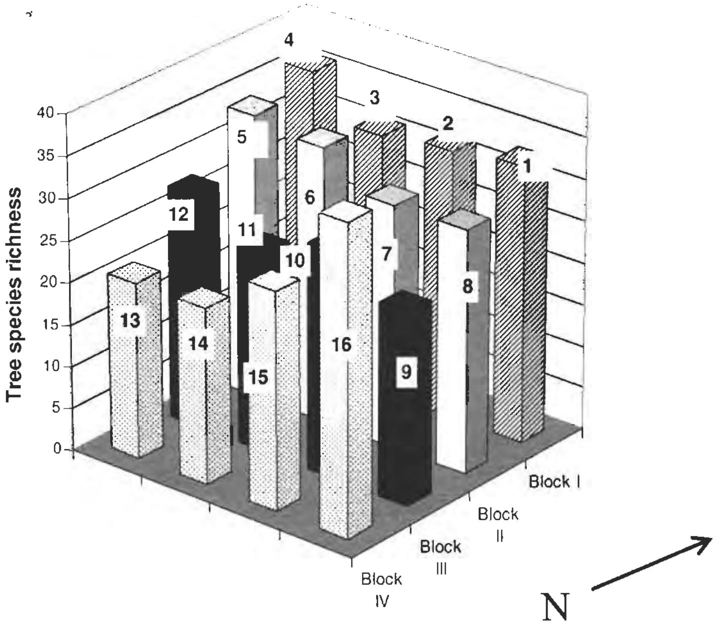

Figure 18.—Spatial arrangement of herb species richness by plot and block. Numbers on the bars are growth plot numbers.

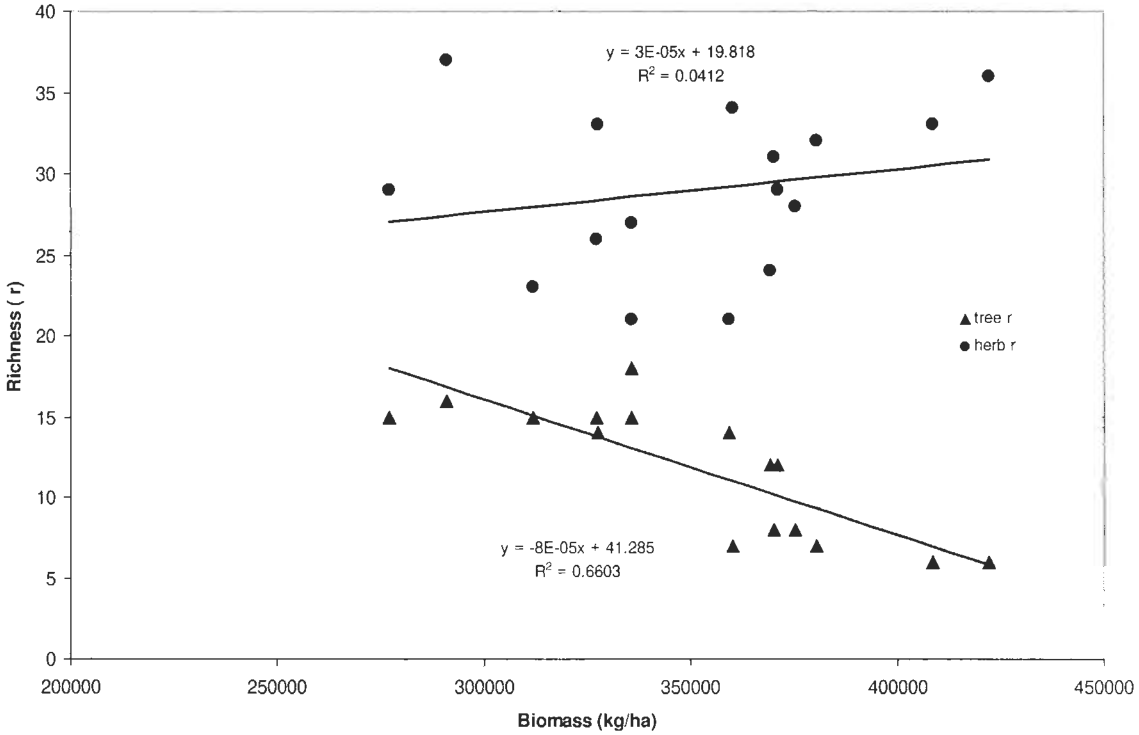

Figure 19.—Linear regression of growth plot aboveground biomass vs. plot species richness for trees (triangles) and herb layer vegetation (circles).

Table 18.—Diversity measures, by block, Fork Mountain LTSP study site

Block	Trees			Herbs		
	Species richness (r)	Shannon Index of Diversity (H′)	Evenness	Species richness (r)	Shannon Index of Diversity (H′)	Evenness
I	16	2.63	0.948	55	3.85	0.962
II	17	2.69	0.949	49	3.75	0.964
III	20	2.89	0.965	41	3.55	0.957
IV	23	3.01	0.960	49	3.73	0.958
All	26	3.95		76	3.95	0.908

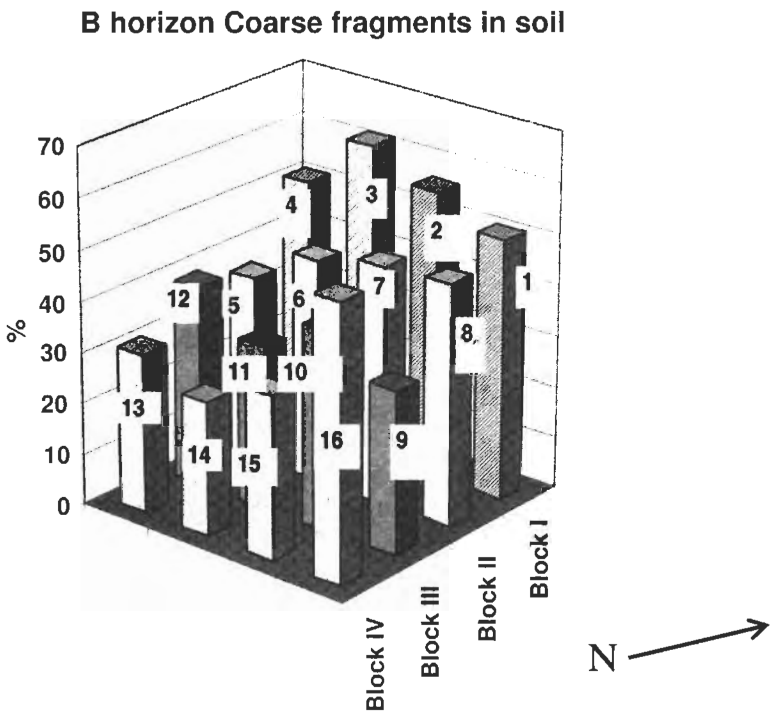

Figure 20.—Spatial arrangement of percentage soil coarse fragment content in 15 - 30 cm horizon by block and plot. Numbers on the bars are the growth plot numbers.

opposite pattern (Table 18). The spatial pattern of tree species richness by plot is nearly opposite that for productivity, including the west to east gradient. Those plots (3, 4, 5, 6, 12) with the greatest aboveground biomass had the lowest tree species richness and generally, with some exceptions, the greatest herb layer diversity. These relationships are shown in Figure 19. The inverse relationship between tree species richness and aboveground biomass is reasonably robust. The complex trends across the site are also reflected in the 15-30 cm horizon coarse fragments, where the down-slope trend is apparent, but the across-slope gradient is less pronounced. (Fig. 20).

Summary

We have learned a great deal about this particular site. Based on most metrics, the Fork Mountain LTSP site is a highly productivity site, with vegetative diversity typical of most second-growth Appalachian hardwood forests. Except for relatively low soil nutrient levels, the site characteristics suggest few problems with regeneration. Based on soil properties, the site may be susceptible to leaching of base cations as a result of high levels of acidic deposition. The trends in productivity and nutrients, particularly Ca, were somewhat unexpected but are accommodated within the experimental design. Monitoring the response of this ecosystem to these treatments continues.

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APPENDIX

Table 19.—Characterization soil profiles, described by Natural Resources Conservation Service, 1996. See Figure 2 for location of pits.

Identification: A
Location: 35' at SE 45° from boundary stake GP2/GP3
Parent material: sandstone colluvium over McCrady shale residue
Slope: 16%
Aspect: SE facing

Layers	Description
Oa	0-1"
A	1-8", 20% coarse fragments, 6.4 YR 3/1, loam, very friable, many very fine to coarse roots, clear, wavy boundary
BA	8-13", 25% coarse fragments, 7.5 YR 3/3, loam, friable, many very fine to coarse roots, wavy, boundary
Bw1	13-24", 30% coarse fragments, 5 YR 5/4, silt loam, firm consistence, common very fine to medium roots, gradual, wavy boundary
Bw2	24-36", 35% coarse fragments, 5 YR 4/3, silt loam, firm consistence, few very fine and fine roots, clear wavy boundary
2C	36-53", 45% coarse fragments, 2.4 YR 4/3, silty clay, massive structure, firm consistence, rare very fine to fine roots, clear wavy boundary
2Cr	53-55", 2.5 YR 3/3, and 2.5 YR 5/6, firm consistence
R	> 55"

Identification: B
Location: Buffer strip between 6 & 5, 25' from stake corner 4, GP5
Parent Material: Sandstone residuum
Slope: 8%
Aspect: SE facing

Layers	Description
Oa	0-0.5"
A1	0.5-2.5", 45% coarse fragments, 7.5 YR 2.5/1, loam, very friable, many very fine to coarse roots, wavy boundary
A2	2.5-6.5", 35% coarse fragments, 7.5 YR 3/3, loam, very friable, many very fine to coarse roots, clear wavy boundary
BA	6.5-9", 30% coarse fragments, 10YR 4/4, silt loam, friable, many very fine to coarse roots, clear wavy boundary
Bw1	9-20", 35% coarse fragments, 10 YR 4/6, silt loam, friable, common very fine to coarse roots, gradual, wavy boundary
Bw2	20-30", 40% coarse fragments, 10 YR 5/6, silt loam, friable, common very fine to coarse roots, clear, wavy boundary
Bw3	30-43%, coarse fragments, 10 YR 5/6, loam, friable, few very fine and fine roots, gradual, wavy boundary
C	43-55", 70% coarse fragments, 10 YR 5/8, loam, firm consistence, few fine roots

Continued

Table 19.—continued

Identification: C
Location: at end of plot 5 (buffer stake #5)
Parent material: Sandstone residuum
Slope: 8%
Aspect: SE

Layers	Description
Oa	0-0.5"
A	0.5-3", 20% coarse fragments, 2.5 YR 3/2, loam, very friable, many very fine to coarse roots, clear, wavy boundary
BA	3-7", 20% coarse fragments, 10 YR ¾, loam, very friable, many very fine to coarse roots, clear wavy boundary
Bw1	7-17", 25% coarse fragments, 10 YR 6/6, silt loam, friable, common very fine to coarse roots, gradual wavy boundary
Bw2	17-20", 30% coarse fragments, 10 YR 6/6, loam, friable, few very fine and medium rots, clear, wavy boundary
BC	28-34", 40% coarse fragments, 10 YR 6/6, loam, firm consistence, very few fine and fine roots, gradual wavy boundary
2C	34-45", 55% coarse fragments, 10 YR 6/8 (with inclusions of 10 YR 5/3, 10 YR 5/2), loam, firm consistence, clear wavy boundary
R	> 45"

Identification: D
Location: Buffer stake # 7-8, 15' east on road
Parent material: weathered shale
Slope:
Aspect: SE

Layers	Description
Oa	0-1",
A	1-5", 20% coarse fragments, 10 YR 3/1, loam friable, many very fine to coarse roots, clear wavy boundary
BA	5-9", 25% coarse fragments, 2.5 yr 4/3, loam, friable, many very fine to coarse roots, clear wavy boundary
Bw1	9-29", 35% coarse fragments, 10 YR 5/6, silt loam, friable, common very fine to coarse roots, gradual wavy boundary
Bw2	29-44", 65% coarse fragments, 10 YR 5/4 (with 10 YR 7/2 colors and 6.5 YR 5/6), loam, very firm consistence, few very fine and fine roots, clear wavy boundary
C	44-63", coarse fragments, 7.5 YR 5/6, loam with silt loam pockets, massive structure, firm consistence, no roots, clear wavy boundary
CR	63-74", 2.5 YR 6/6 with red coatings (7.5 YR 5/6)

Table 20.—Plant species found on Fork Mountain LTSP plots[a]

Trees	
Red maple	*Acer rubrum* L.
Sugar maple	*Acer saccharum* Marsh.
Common serviceberry	*Amelanchier arborea* (Michx. f.) Fernald
Sweet birch	*Betula lenta* L.
Yellow birch	*Betula lutea* Michx.
American hornbeam	*Carpinus caroliniana* Walt.
Bitternut hickory	*Carya cordiformis* (Wang) K. Koch
Shagbark hickory	*Carya ovata* K. Koch
American chestnut	*Castanea dentata* (Marsh.) Borkh.
Alternate-leaved dogwood	*Cornus alternifolia* L.
Flowering dogwood	*Cornus florida* L.
American beech	*Fagus grandifolia* Ehrh.
White ash	*Fraxinus americana* L.
Yellow-poplar	*Liriodendron tulipifera* L.
Cucumber magnolia	*Magnolia acuminata* L.
Fraser magnolia	*Magnolia fraseri* Walt.
Blackgum	*Nyssa sylvatica* Marsh.
Eastern hophornbeam	*Ostrya virginiana* (Mill.) K. Koch
Sourwood	*Oxydendrum arboreum* (L.) D.C.
Fire cherry	*Prunus pennsylvanica* L.
Black cherry	*Prunus serotina* Ehrh.
Chestnut oak	*Quercus montana* Willd.
Northern red oak	*Quercus rubra* L.
Black locust	*Robinia pseudo-acacia* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees.
American basswood	*Tilia americana* L.
Shrubs	
Striped maple	*Acer pennsylvanicum* L.
Deciduous holly	*Ilex* sp.*
Mountain laurel	*Kalmia latifolia* L.
Spicebush	*Lindera benzoin* (L.) Blume
Azalea sp.	*Rhododendron* sp.
Common elderberry	*Sambucus canadensis* L.
Mapleleaf viburnum	*Viburnum acerifolium* L.
Witch hazel	*Hamamelis virginiana* L.
Woody Vines	
Dutchman's pipe	*Aristolochia durior* Hill.
Virginia creeper	*Parthenocissus quinquefolia* (L.) Planch.
Blackberry sp.	*Rubus* sp.
Grape sp.	*Vitis* sp.

Continued

Table 20.—Continued

Ferns and Allies	
Clubmoss	*Lycopodium* sp.
Hayscented fern	*Dennstaedtia punctiloba* (Michx.) Moore
New York fern	*Dryopteris noveboracensis* (L.) Gray
Beech fern	*Dryopteris* sp.
Christmas fern	*Polystichum acrostichoides* (Michx.) Schott.
Flowering Herbs	
White baneberry	*Actaea alba* L.
Mountain anemone	*Anemone lancifolia* Pursh.
Indian turnip	*Arisaema triphyllum* (L.) Schott.
Aster sp.	*Aster* sp.
False nettle	*Boehmeria cylindrica* (L.) Sw.
Sedge sp.	*Carex* sp.
Blue cohosh	*Caulophyllum thalictroides* (L.) Michx.
Black cohosh	*Cimicfuga racemosa* (L.) Nutt.
Slender toothwort	*Dentaria heterophylla* Nutt.
White snakeroot	*Eupatorium rugosum* Houtt.
Wild licorice	*Gallium circaezans* Michx.
Bedstraw sp.	*Gallium* sp.
Wild geranium	*Geranium maculatum* L.
St. Johnswort	*Hypericum* sp.
Touch-me-not	*Impatiens* sp.
Red henbit	*Lamium purpureum* L.
Indian cucumber-root	*Medeola virginiana* L.
Partridgeberry	*Mitchella repens* L.
Basil balm	*Monarda clinopoda* L.
Indian pipe	*Monotropa uniflora* L.
Sweet cicely	*Osmorhiza claytoni* (Michx.) Clarke
Ginseng	*Panax quinquefolius* L.
Deertongue grass	*Panicum* sp.
Pokeweed	*Phytolacca americana* L.
Mayapple	*Podophyllum peltatum* L.
Common cinquefoil	*Potentilla simplex* Michx.
Lion's foot	*Prenanthes trifoliata* (Cass.) Fernald
Mountain mint	*Pycnantheum* sp.
Buttercup	*Ranunculus* sp.
Black snakeroot	*Sanicula canadensis* L.
Sedum	*Sedum ternatum* Michx.
False Solomon's seal	*Smilacina racemosa* (L.) Desf.
Upright smilax	*Smilax ecirrhata* (Engelm.) S. Wats.
Greenbrier	*Smilax* sp.
Twisted stalk	*Streptopus roseus* Michx.

Continued

Table 20.—Continued

Cliff meadow rue	*Thalictrum* sp. *
Virginia knotweed	*Tovara virginiana* (L.) Raf.
Trillium	*Trillium* sp.
Stinging nettle	*Urtica dioica* L.
Violet	*Viola* sp.
Orchid sp.	
Grass sp.	
Wild parsley*	

[a] All plant names according to Strausbaugh and Core (1952)

*not listed in Strausbaugh and Core

Adams, Mary Beth; Burger, James; Zelazny, Lucian; Baumgras, John. 2004. **Description of the Fork Mountain long-term soil productivity study: site characterization.** Gen. Tech. Rep. NE-323. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 40 p.

The effects of air pollution and timber harvesting on soil resources continue to be an important issue in eastern hardwood forests. This publication describes the Fork Mountain Long-term Soil Productivity Study (LTSP), located on the Fernow Experimental Forest, WV, and the pretreatment stand, soil and climatic conditions. Extensive vegetation surveys, biomass determinations, site characterization, and analyses of soil physical and chemical characteristics are described herein. The Fork Mountain LTSP site is, based on most metrics, a highly productive site with vegetative diversity typical of most second growth Appalachian hardwood forests. Other than relatively low soil nutrient levels, site characteristics suggest few problems with regeneration. Based on soil characteristics, the site may be susceptible to leaching of base cations as a result of high levels of acidic deposition. Productivity and nutrient characteristics, particularly calcium, varied across the site spatially, but are accommodated in the experimental design. We continue to monitor the response of this ecosystem to these treatments.

Keywords: diversity, acidic deposition, eastern hardwoods Appalachian forests

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