Analysis of Pre-treatment Woody Vegetation and Environmental Data for the Missouri Ozark Forest Ecosystem Project

John M. Kabrick[1], David R. Larsen[1], and Stephen R. Shifley[2]

Abstract.—We conducted a study to identify pre-treatment trends in woody species density, diameter, and basal area among MOFEP sites, blocks, and treatment areas; relate woody species differences among sites, blocks, and treatment areas to differences in environmental conditions; and identify potential treatment response differences based upon our findings. Sites 2 through 5 had greater numbers of species per unit area. Sites 7 and 8 had fewer trees ≥ 4 cm diameter, less white oak, and more scarlet oak. Block 3 had fewer trees ≥ 11 cm, less overall basal area, and less white oak. Block 2 had less black oak. There were no treatment-level woody vegetation differences. Greater numbers of species per acre, greater abundance of white oak, and lesser abundance of scarlet oak were associated with sites and blocks that have a greater proportion of base-rich geological strata and a greater proportion of soils classified as Alfisols. We hypothesize: (1) no-harvest (NH) and uneven-aged management (UAM) treatment responses will be more variable and more difficult to interpret than even-aged management treatment responses (EAM) because NH and UAM treatments were delegated to more contrasting sites and (2) EAM treatment areas will have greater growth rates because these treatments were delegated to sites having siltier surface soil textures and a greater proportion of base-rich parent materials. The designated blocks were effective in grouping sites with similar vegetational characteristics. However, based on an examination of environmental characteristics, blocks that combined sites 1, 7, and 8; sites 3, 4, and 5; and sites 2, 6, and 9 may improve blocking effectiveness.

The Missouri Ozark Forest Ecosystem Project (MOFEP) is a long-term, large-scale study of responses of a broad range of ecological attributes to silvicultural treatments (Brookshire *et al.* 1997, Brookshire and Hauser 1993). One facet of the study is to compare woody vegetation responses among even-aged management, uneven-aged management, and no-harvest treatments. Identifying differences in woody vegetation pre-treatment conditions and potential differences in treatment response is critical for interpreting treatment responses over the course of the MOFEP study.

Our study had four objectives. The first was to identify pre-treatment trends in woody species density, diameter, and basal area among the nine MOFEP sites, the three blocks, and the three treatment areas. The second objective was to relate woody species differences among sites, blocks, and treatments to differences in environmental conditions (e.g., soil, geology, and landform) and land-use history. Our third objective was to identify potential differences in treatment responses. Our final objective was to evaluate blocking effectiveness based upon the findings of objectives one and two.

METHODS

The MOFEP study is described in detail by Brookshire *et al.* (1997), Brookshire and Hauser

[1] Postdoctoral Fellow and Assistant Professor, respectively, School of Natural Resources, 1-31 Agriculture, University of Missouri, Columbia, MO 65211.
[2] Research Forester, USDA Forest Service, North Central Forest Experiment Station, 1-26 Agriculture Building, University of Missouri, Columbia, MO 65211.

(1993), and Kurzejeski *et al.* (1993). The study consists of nine sites (or compartments) that range in size from 657 ac (266 ha) to 1,302 ac (527 ha). Sites were grouped into three blocks, each containing three sites. The three treatments—even-aged management (EAM), uneven-aged management (UAM), and no-harvest (NH)—were randomly assigned to the three sites in each block, yielding three replicates of each treatment (Sheriff and He 1997). The site, block, and treatment groupings are summarized in table 1, and their spatial arrangement is illustrated in figure 1 of Brookshire *et al.* (1997).

Data Sources

In 1991-1992, prior to any experimental treatments, a total of 645 half-acre (0.2-ha) sample plots were established across the nine MOFEP sites. Plots were distributed to ensure that at least one plot was located within each identified stand, and plot placement within each stand was random. Live and dead trees ≥ 4.5 in. (11 cm) d.b.h. were sampled in each 0.5-ac (0.2-ha) circular plot. Characteristics recorded for each tree included species, d.b.h., and status (i.e., live or dead). Trees between 1.5 in. (4 cm) and 4.5 in. (11 cm) d.b.h. were measured on four 0.05-ac (0.02-ha) circular subplots within the main plot. Live trees at least 3 ft (1 m) tall and less than 1.5 in. (4 cm) d.b.h. were tallied by species and size class in four 0.01-ac (0.004-ha) subplots. Subplots were combined to obtain a plot average for trees by size class. All values were converted to an acre basis for analysis. Additional details regarding data collection can be found in Brookshire *et al.* (1997).

Soils, geology, and landform information was also collected at each 0.5-ac (0.2-ha) vegetation plot (Meinert *et al.* 1997). Soils were described in small excavations at the center of each plot. Horizon presence and thickness, texture class, stoniness, soil parent materials, location in geologic strata, and soil classification were estimated from samples at each excavation. Elevation, slope, landform, slope shape normal and parallel to slope, and aspect were also estimated. Variation in soil properties and landform characteristics was also noted.

Attributes and Analyses

We evaluated pre-treatment data for the MOFEP sites and tested for block and treatment unit differences in:

1. number of species per plot,
2. trees per acre,
3. basal area per acre, and
4. quadratic mean d.b.h.

Analyses were conducted by size classes corresponding to the sampling thresholds for vegetation plots and subplots: trees ≥ 3 ft (1m) tall, trees ≥ 1.5 in. (4 cm) d.b.h. and trees ≥ 4.5 in. (11 cm) d.b.h. We also tested for differences in items 2 through 4 for the key timber species: white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), scarlet oak (*Quercus coccinea* Muenchh.), and shortleaf pine (*Pinus echinata* Mill). Quadratic mean diameter and basal area were calculated for trees ≥ 1.5 in. (4 cm) d.b.h. using standard methods (Husch *et al.* 1982).

Table 1.—*Assignment of blocks and treatments by site (compartment) for the MOFEP study. Treatments were uneven-aged management (UAM), even-aged management (EAM), and no harvest (NH). Numbers of 0.5-ac (0.2 ha) plots by site, block, and treatment are shown in parentheses.*

Site	Block assignment	Treatment	
1 (73 plots)	1 (218 total plots)	NH	(214 total plots)
2 (73 plots)	1	UAM	(218 total plots)
3 (72 plots)	1	EAM	(213 total plots)
4 (74 plots)	2 (215 total plots)	UAM	
5 (70 plots)	2	EAM	
6 (71 plots)	2	NH	
7 (71 plots)	3 (212 total plots)	UAM	
8 (70 plots)	3	NH	
9 (71 plots)	3	EAM	

Analysis of variance was used to evaluate differences among blocks and treatment units (before treatment implementation) with the fixed effects model:

$$Y_{ij} = \mu + \text{block}_i + \text{treatment}_j + \varepsilon_{ij} \quad [1]$$

where μ is the overall mean of the attribute, block_i is the effect of each of the three blocks, treatment_j is the effect of each of the three treatment areas in each block, and ε_{ij} is the error effect, $N(0,\sigma^2)$. Blocks and treatments each receive 2 degrees of freedom, leaving 4 degrees of freedom for error.

Several environmental variables were also evaluated to identify site-, block-, and treatment-level differences (table 2). These variables were selected because of their potential to affect energy, water, and nutrient distributions.

Most variables in the MOFEP environmental dataset were categorical and were observed by plot. To analyze these data, we transformed each variable to represent its proportional occurrence by plot within each site. For example, Roubidoux geology occurred in 24 out of 76 plots in site 1. The proportional occurrence relative to other plots within site 1 was:

$$\frac{24}{76} = 0.32.$$

Thus, we inferred that 32 percent of site 1 contained Roubidoux geology. We ranked sites by their proportions of key environmental variables to identify site-level differences. We also used principal components analysis (Gauch 1986, Webster and Oliver 1990) to summarize important site-level differences in environmental variables.

Confidence Interval Interpretations

The MOFEP study design prohibited a rigorous statistical analysis of site-level differences in woody vegetation. Specifically, there was no true replication of each site. To identify differences among sites, we constructed boxplots with confidence intervals. Medians and confidence intervals were generated using plot-level information within each site. This provided a less statistically rigorous but useful visual

Table 2.—*Environmental variables used in analyses.*

Variable	Type	Indicator of:
Slope	continuous	moisture, soil thickness
Aspect	continuous	available moisture
Landform	categorical	strata, moisture gradient
Geology	categorical	strata, materials, texture, base saturation
Profile description, A-horizon		
horizon thickness	continuous	carbon, herbaceous rooting
modifier	categorical	moisture/nutrients, gravel content
texture class	categorical	moisture, nutrient supply
Profile description, E-horizon		
horizon thickness	continuous	herbaceous and seedling rooting
texture modifier	categorical	moisture/nutrients, gravel content
texture class	categorical	moisture, nutrient supply
Profile description, B-horizon		
horizon thickness	continuous	tree rooting
texture modifier	categorical	moisture/nutrients, gravel content
texture class	categorical	moisture, nutrient supply
Depth to clay	categ/continous	major texture discontinuities
Classification	categorical	
subgroup	categorical	key properties: fragic, mollic, lithic
order	categorical	alfic/ultic break
Variable bedrock	categorical	shallow soils
Outcrop, % class	categorical	area percentage of outcrop
Stoniness, % class	categorical	percent of stones, boulders

method for comparing within-site variation and differences among sites. Non-overlapping confidence intervals generated for sample means or medians provide evidence of statistical differences.

RESULTS

Site-Level Differences in Woody Vegetation

Sites 2 through 5 generally had a greater median number of species per plot than site 1 and sites 6 through 9 (fig. 1). Median differences were small in magnitude (e.g., 13 vs. 18 species per plot), but the upper range of data for sites 2 through 5 also exceeded that of the remaining sites. All sites had roughly similar means and ranges for total trees per acre (table 3). Sites 7 and 8 had fewer trees at the 1.5 in. (4 cm) d.b.h. threshold and had relatively large quadratic mean diameters compared to the other sites (figs. 2a, 2b). Basal area was similar in mean and range among sites (table 3). Although the quadratic mean diameter of white oaks ≥ 1.5 in. (4 cm) d.b.h. at sites 7 and 8 was roughly the same as at the other sites (fig. 2d), the number and basal area of white oak at sites 7 and 8 was nearly half the magnitude of that at other sites (figs. 2c, 2g). In contrast, scarlet oak was slightly more abundant and greater in diameter and basal area at sites 7 and 8 (figs. 2e, 2f, 2h). No notable among-site differences in abundance, diameter, and basal area were observed for black oak or shortleaf pine (table 3).

Treatment- and Block-Level Differences in Woody Vegetation

There were no significant treatment-level differences in species numbers, trees per acre, quadratic mean diameter, or basal area for all trees or for important timber species (white oak, black oak, scarlet oak, and shortleaf pine)

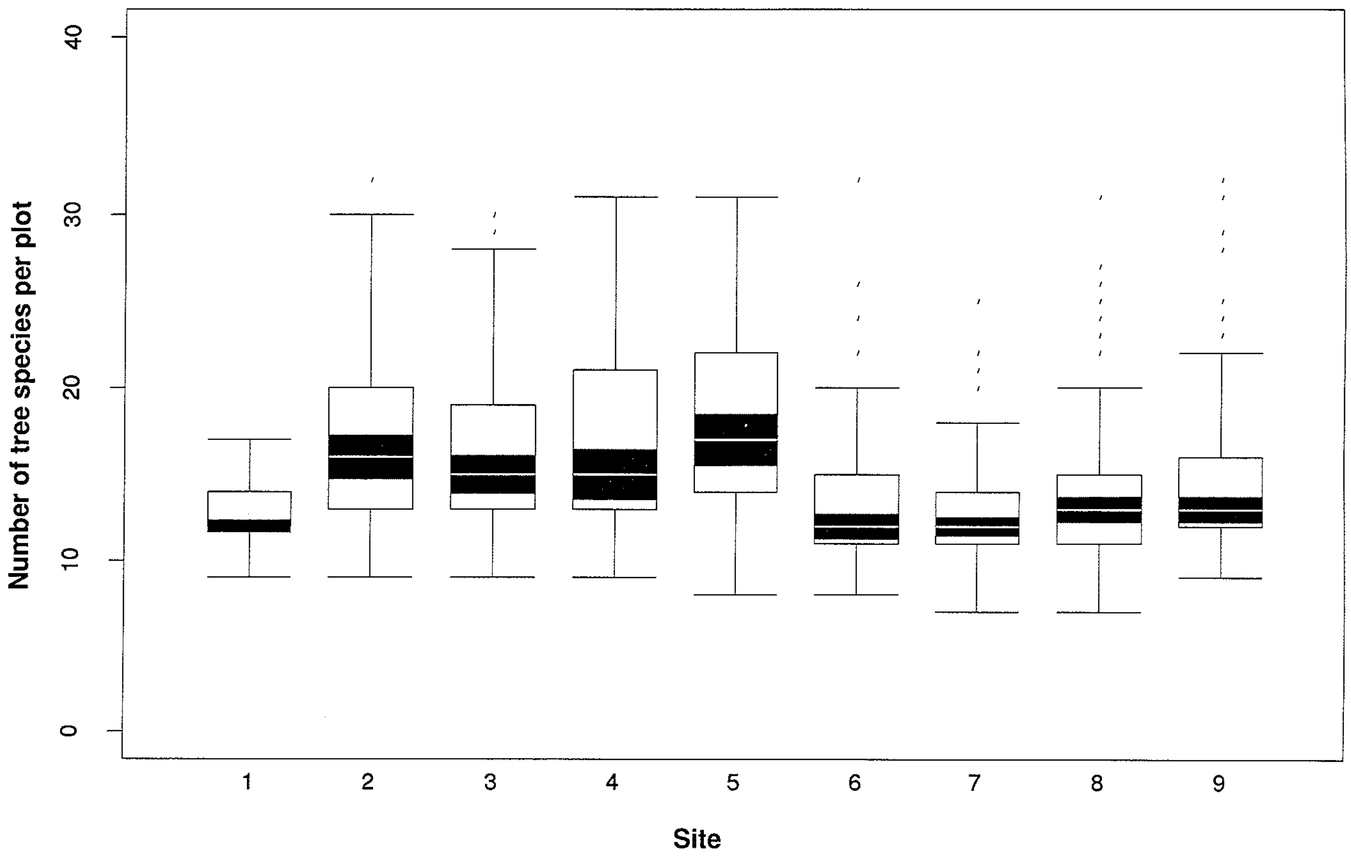

Figure 1.—*Number of tree species per plot summarized by site from plot-level data. The central (white) bar in each box plot represents the median. The black bars around the median show the 95 percent confidence interval for the median. The box indicates the range of 50 percent of the data. Brackets indicate the range of continuous data. Dots at the top or bottom indicate values beyond the range of continuous data.*

Table 3.—*Mean, standard deviation, and minimum and maximum of observations by site for selected attributes. Number of plots per site is shown in table 1.*

Characteristic		Site 1	2	3	4	5	6	7	8	9
All species										
Number of species per plot										
	Mean	13	17	17	17	18	14	13	14	15
	SD	2	5	5	6	5	5	4	5	5
	Min	9	9	9	9	8	8	7	7	9
	Max	17	32	30	36	31	32	25	31	32
No. of trees > 0 in. d.b.h.										
	Mean	1,314	1,749	1,421	1,665	1,715	1,400	1,227	1,528	1,696
	SD	411	897	817	1,082	695	6,011	667	855	682
	Min	710	841	628	573	714	577	264	531	750
	Max	3,003	6,492	5,532	6,472	5,005	3,760	3,324	5,320	4,497
No. of trees ≥ 1.5 in. d.b.h.										
	Mean	515	557	500	499	499	429	390	380	547
	SD	89	102	72	87	88	91	137	118	168
	Min	299	313	344	323	285	229	89	144	217
	Max	814	867	668	836	708	686	905	700	980
No. of trees > 4.5 in. d.b.h.										
	Mean	184	176	169	167	160	160	140	133	126
	SD	36	36	36	356	33	39	42	37	31
	Min	98	86	52	102	64	86	14	78	72
	Max	254	262	262	262	246	292	250	254	204
Qmd[1] ≥ 1.5 in. d.b.h.										
	Mean	6	6	6	6	6	7	7	7	6
	SD	1	1	1	1	1	1	1	1	1
	Min	5	3	3	4	4	5	4	4	4
	Max	7	7	8	8	8	9	11	11	10
Qmd ≥ 4.5 in. d.b.h.										
	Mean	9	9	10	10	10	10	11	11	10
	SD	1	1	1	1	1	1	2	1	2
	Min	7	7	7	7	8	8	7	7	6
	Max	12	13	12	12	13	13	14	14	14
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.										
	Mean	95	96	99	96	96	100	91	92	88
	SD	11	12	16	16	12	12	15	13	12
	Min	77	55	25	47	40	75	7	38	56
	Max	120	124	127	150	124	136	133	123	113
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.										
	Mean	82	80	85	82	82	89	81	83	73
	SD	11	14	17	18	12	12	15	14	15
	Min	61	31	13	30	29	60	5	27	36
	Max	108	110	117	139	110	124	125	116	109
White oak										
No. of trees > 0 in. d.b.h.										
	Mean	173	138	157	143	137	108	106	122	195
	SD	82	88	71	99	82	66	116	114	143
	Min	57	0	5	0	0	0	0	0	0
	Max	530	388	322	534	513	308	544	625	790
No. of trees ≥ 1.5 in. d.b.h.										
	Mean	130	102	139	113	100	83	61	76	130
	SD	54	59	63	68	53	52	60	68	114
	Min	45	0	5	0	0	0	0	0	0
	Max	288	289	307	383	220	292	283	379	615

(table 3 continued on next page)

(table 3 continued)

Characteristic		Site 1	2	3	4	5	6	7	8	9
No. of trees ≥ 4.5 in. d.b.h.										
	Mean	46	41	48	41	42	47	20	24	29
	SD	26	26	24	24	24	30	19	20	22
	Min	8	0	0	0	0	0	0	0	0
	Max	150	128	94	110	118	172	112	84	92
Qmd ≥ 1.5 in. d.b.h.										
	Mean	5	6	5	6	6	7	6	6	5
	SD	1	1	1	2	2	2	2	3	2
	Min	3	0	2	0	0	0	0	0	0
	Max	8	11	9	9	14	17	12	12	11
Qmd ≥ 4.5 in. d.b.h.										
	Mean	8	8	8	9	9	9	8	9	9
	SD	1	2	2	2	2	2	3	3	4
	Min	5	0	0	0	0	0	0	0	0
	Max	12	16	12	18	16	17	15	16	18
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.										
	Mean	19	17	23	19	22	22	10	14	18
	SD	9	9	11	11	12	13	10	12	14
	Min	5	0	0	0	0	0	0	0	0
	Max	50	45	56	56	52	60	58	53	62
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.										
	Mean	15	14	18	16	19	20	8	12	14
	SD	8	8	10	10	12	11	10	12	126
	Min	3	0	0	0	0	0	0	0	0
	Max	45	36	51	47	51	53	55	52	58
Black oak										
No. of trees > 0 in. d.b.h.										
	Mean	77	63	52	42	44	37	101	83	95
	SD	62	61	49	37	37	49	130	82	84
	Min	8	0	0	0	0	0	0	2	0
	Max	344	373	226	167	167	301	1,048	374	445
No. of trees ≥ 1.5 in. d.b.h.										
	Mean	50	50	40	34	33	21	48	38	51
	SD	27	37	33	29	23	14	35	29	39
	Min	8	0	0	0	0	0	0	0	0
	Max	145	184	143	139	90	55	236	132	211
No. of trees ≥ 4.5 in. d.b.h.										
	Mean	42	41	36	25	29	19	30	30	29
	SD	25	27	29	20	20	14	22	21	20
	Min	6	0	0	0	0	0	0	0	0
	Max	140	144	138	70	80	54	126	114	104
Qmd ≥ 1.5 in. d.b.h.										
	Mean	10	10	10	10	10	12	9	11	9
	SD	2	3	4	4	4	5	3	3	3
	Min	5	0	0	0	0	0	0	0	0
	Max	15	17	20	16	21	21	16	19	17
Qmd ≥ 4.5 in. d.b.h.										
	Mean	11	10	11	10	11	12	11	12	11
	SD	2	3	4	4	4	4	3	3	3
	Min	7	0	0	0	0	0	0	0	0
	Max	17	17	20	17	21	21	16	19	19
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.										
	Mean	26	26	25	19	20	20	22	25	24
	SD	15	15	18	15	14	15	17	18	18
	Min	2	0	0	0	0	0	0	0	0
	Max	74	63	70	58	50	64	93	85	97

(table 3 continued on next page)

(table 3 continued)

Characteristic	Site 1	2	3	4	5	6	7	8	9
Basal area (ft²/ac) ≥ 4.5 in. d.b.h.									
Mean	26	25	25	19	20	20	22	25	23
SD	15	15	17	15	14	15	17	18	18
Min	1	0	0	0	0	0	0	0	0
Max	74	61	70	58	50	64	93	85	97
Scarlet oak									
No. of trees > 0 in. d.b.h.									
Mean	82	49	54	56	35	27	85	56	93
SD	73	34	48	45	26	17	75	56	93
Min	0	0	4	2	2	0	2	0	0
Max	348	138	292	218	135	71	306	311	655
No. of trees ≥ 1.5 in. d.b.h.									
Mean	60	40	43	46	29	22	66	31	60
SD	48	25	32	29	19	14	54	24	48
Min	0	0	4	2	2	0	0	0	0
Max	198	108	194	165	96	60	237	108	230
No. of trees ≥ 4.5 in. d.b.h.									
Mean	45	31	34	32	21	20	41	24	26
SD	36	19	28	24	15	14	31	17	20
Min	0	0	2	2	2	0	0	0	0
Max	170	78	184	160	76	60	158	78	90
Qmd ≥ 1.5 in. d.b.h.									
Mean	8	9	9	9	9	12	10	12	8
SD	3	3	3	3	3	4	3	4	3
Min	0	0	4	4	4	0	0	0	0
Max	14	17	17	16	22	19	18	17	17
Qmd ≥ 4.5 in. d.b.h.									
Mean	9	10	10	11	11	12	12	13	10
SD	2	3	3	2	3	4	3	3	4
Min	0	0	6	6	6	0	0	0	0
Max	14	17	19	18	22	19	18	18	17
Basal area (ft²/ac) ≥ 1.5 in. d.b.h.									
Mean	21	18	18	20	13	18	29	22	18
SD	14	13	12	13	10	16	17	16	13
Min	0	0	2	1	1	0	0	0	0
Max	60	65	60	74	64	66	75	67	61
Basal area (ft²/ac) ≥ 4.5 in. d.b.h.									
Mean	20	18	17	19	13	18	28	22	16
SD	15	13	12	13	10	16	17	16	13
Min	0	0	1	1	0	0	0	0	0
Max	57	65	59	74	64	66	75	67	61
Shortleaf pine									
No. of trees > 0 in. d.b.h.									
Mean	26	21	15	17	16	36	20	27	34
SD	36	45	17	23	24	80	29	61	96
Min	0	0	0	0	0	0	0	0	0
Max	182	270	66	96	93	574	135	290	539
No. of trees ≥ 1.5 in. d.b.h.									
Mean	23	16	15	17	16	30	18	18	18
SD	30	33	17	23	23	51	261	35	38
Min	0	0	0	0	0	0	0	0	0
Max	122	195	66	96	93	289	110	165	239

(table 3 continued on next page)

(table 3 continued)

Characteristic		Site 1	2	3	4	5	6	7	8	9
No. of trees ≥ 4.5 in. d.b.h.										
	Mean	19	10	13	16	14	25	16	10	5
	SD	25	18	15	21	20	38	23	17	7
	Min	0	0	0	0	0	0	0	0	0
	Max	108	108	66	86	78	214	110	88	36
Qmd ≥ 1.5 in. d.b.h.										
	Mean	7	5	9	7	7	7	9	7	6
	SD	4	5	4	5	5	4	5	5	6
	Min	0	0	4	4	4	0	0	0	0
	Max	14	17	17	16	22	19	18	17	17
Qmd ≥ 4.5 in. d.b.h.										
	Mean	8	5	9	7	7	7	9	7	6
	SD	4	5	4	5	5	4	5	5	6
	Min	0	0	0	0	0	0	0	0	0
	Max	16	17	18	15	17	16	18	17	20
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.										
	Mean	9	5	8	8	8	11	11	6	4
	SD	11	9	10	10	11	16	16	10	5
	Min	0	0	0	0	0	0	0	0	0
	Max	45	52	55	45	41	87	84	47	21
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.										
	Mean	8	5	8	8	8	10	11	6	3
	SD	10	8	108	108	108	16	16	10	5
	Min	0	0	0	0	0	0	0	0	0
	Max	44	50	55	44	40	82	84	43	21

[1] Qmd = quadratic mean diameter.

analyzed separately (tables 4-8). The lowest treatment-level P-values at P=0.06 were for differences in white oak basal area, but most P-values were ≥ 0.1.

We found block-level differences in total number of trees per acre ≥ 4.5 in. (11 cm) d.b.h. (P=0.001), quadratic mean diameter of trees ≥ 4.5 in. (11 cm) d.b.h. (P=0.01), and total basal area (P=0.03). When significantly different, variables of one of the three blocks generally had substantially smaller magnitudes than the same variables of the other two blocks (table 4). Although the overall quadratic mean diameter of trees was greatest for block 3, that block contained fewer trees and less total basal area per acre than blocks 1 and 2 (table 4). Much of this difference is attributable to white oaks ≥ 4.5 in. (11 cm) d.b.h., which were least abundant and had the least basal area in block 3 (table 5). Black oak was least abundant and had the least basal area in block 2. The quadratic mean diameter for black oak was the same among blocks (table 6). No significant differences for scarlet oak and shortleaf pine were observed at either the treatment or block levels (tables 7 and 8).

Differences in Environmental Variables

We summarize important site-level differences in key soil, geology, and landform attributes in figures 3 and 4. Sites 7 and 8 have a greater proportion of broad and level summit landform positions, Roubidoux-derived parent materials, and soils with loamy surface textures (figs. 3 and 4). In contrast, sites 3, 4, and 5 have a lower proportion of summit positions, a lower proportion of Roubidoux-derived parent materials, and fewer Ultisols. They also have a greater proportion of Eminence-derived parent materials and soils with silty surfaces (figs. 3 and 4). The remaining sites (1, 2, 6, 9) are intermediate in these characteristics, although sites 2, 6, and 9 are generally similar to sites 3, 4, and 5 while site 1 is similar to sites 7 and 8 (figs. 3 and 4).

Meinert *et al.* (1997) show that MOFEP sites 7 and 8 occur in the Current-Eleven Point Hills Landtype Association (Hills LTA) while the remaining sites occur in the Current-Black River Breaks Landtype Association (Breaks LTA). The Breaks LTA has greater relief, a greater range of geological strata, a greater

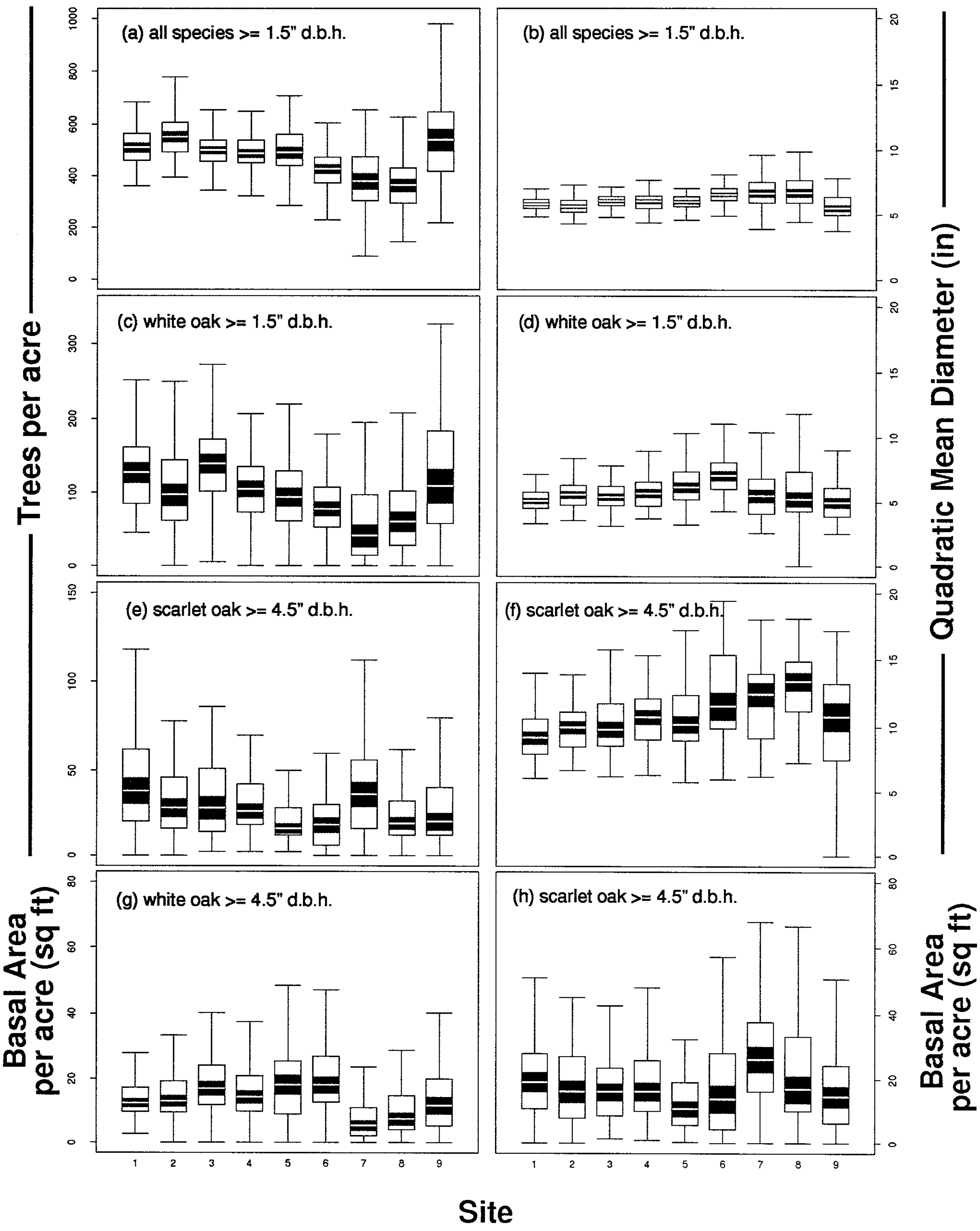

Figure 2.—*Box plots of several attributes summarized by site from plot-level data. The central (white) bar in each box plot represents the median. The black bars around the median show the 95 percent confidence interval for the median. The box indicates the range of 50 percent of the data. Brackets indicate the range of continuous data.*

Table 4.—*Site, block, and treatment means for woody species attributes. Treatment means did not differ significantly (α = 0.05) for any listed attribute, although block effects were significant for some attributes.*

Attribute[1,2] (per acre except as noted)	Site 1	2	3	4	5	6	7	8	9
Number of species per plot	13	17	17	17	18	14	13	14	15
No. of trees > 0 in. d.b.h.	1,314	1,749	4,121	1,665	1,715	1,400	1,227	1,528	1,696
No. of trees ≥ 1.5 in. d.b.h.	514	557	500	466	466	429	390	380	547
No. trees ≥ 4.5 in. d.b.h.	184	176	169	167	160	160	140	133	126
Qmd ≥ 1.5 in. d.b.h.	5.9	5.7	6.0	6.0	6.0	6.6	6.8	6.9	6.0
Qmd ≥ 4.5 in. d.b.h.	9.1	9.2	9.6	9.6	9.8	10.2	10.5	10.9	10.0
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.95	96	99	96	96	100	91	92	88	
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.82	80	85	82	82	89	81	83	73	

	Block 1 (sites 1, 2, 3)	Block 2 (sites 4, 5, 6)	Block 3 (sites 7, 8, 9)	F-value[3]	P-value[3]
Number of species per plot	15	16	14	1.3	0.36
No. of trees > 0 in. d.b.h.	1,495	1,593	1,483	0.2	0.82
No. of trees ≥ 1.5 in. d.b.h.	524	476	439	1.5	0.32
No. trees ≥ 4.5 in. d.b.h.	176	162	133	58.4	<0.01
Qmd ≥ 1.5 in. d.b.h.	5.9	6.2	6.4	1.3	0.37
Qmd ≥ 4.5 in. d.b.h.	9.3	9.9	10.6	14.5	0.01
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.	97	97	90	8.9	0.03
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.	82	85	79	1.2	0.38

	No harvest (sites 1, 6, 8)	Even-aged (sites 3, 5, 9)	Unven-aged (sites 2, 4, 7)	F-value[3]	P-value[3]
Number of species per plot	14	17	16	2.7	0.18
No. of trees > 0 in. d.b.h.	1,413	1,609	1,551	0.6	0.60
No. of trees ≥ 1.5 in. d.b.h.	442	515	483	1.1	0.41
No. trees ≥ 4.5 in. d.b.h.	159	152	161	2.9	0.16
Qmd ≥ 1.5 in. d.b.h.	6.5	5.9	6.1	1.19	0.39
Qmd ≥ 4.5 in. d.b.h.	10.1	10.0	9.8	0.9	0.48
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.	96	94	94	0.4	0.72
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.	85	80	81	0.9	0.48

[1] Qmd = quadratic mean d.b.h. (in inches) for trees in the specified size class.

[2] Reported values are per acre except as noted. Metric conversions are 1.5 in. = 4 cm, 4.5 in. = 11 cm, and generally 1 in. = 2.54 cm. Also, (2.47) (no. of trees/ac) = no. trees/ha and (0.2296) (basal area ft^2/ac) = basal area m^2/ha.

[3] For ANOVA of block effects for the indicated attribute based on model [1]. F has (2,4) degrees of freedom.

[4] For ANOVA of treatment effects for the indicated attribute based on model [1]. F has (2,4) degrees of freedom.

Table 5.—*Site, block, and treatment area means for white oak attributes. Treatment means did not differ significantly (α = 0.05) for any listed attribute, although block effects were significant for some attributes.*

Attribute[1,2] (per acre except as noted)	Site 1	2	3	4	5	6	7	8	9
No. of trees > 0 in. d.b.h.	173	138	157	143	137	108	106	122	195
No. of trees ≥ 1.5 in. d.b.h.	130	103	139	113	100	83	61	76	130
No. trees ≥ 4.5 in. d.b.h.	46	41	48	41	42	47	20	24	29
Qmd ≥ 1.5 in. d.b.h.	5.2	5.7	5.5	5.7	6.3	7.2	5.7	5.9	5.3
Qmd ≥ 4.5 in. d.b.h.	7.6	8.2	8.1	8.5	8.8	8.9	8.0	8.9	9.0
Basal area (ft²/ac) ≥ 1.5 in. d.b.h.	19	17	13	19	22	22	10	14	18
Basal area (ft²/ac) ≥ 4.5 in. d.b.h.	15	14	18	16	19	20	8	12	14

	Block 1 (sites 1, 2, 3)	Block 2 (sites 4, 5, 6)	Block 3 (sites 7, 8, 9)	F-value[3]	P-value[3]
No. of trees > 0 in. d.b.h.	156	129	141	0.6	0.61
No. of trees ≥ 1.5 in. d.b.h.	156	129	141	0.6	0.61
No. trees ≥ 4.5 in. d.b.h.	45	43	24	50.8	<0.01
Qmd ≥ 1.5 in. d.b.h.	5.5	6.4	5.6	2.7	0.18
Qmd ≥ 4.5 in. d.b.h.	8.0	8.8	8.6	3.2	0.15
Basal area (ft²/ac) ≥ 1.5 in. d.b.h.	20	21	14	12.7	0.02
Basal area (ft²/ac) ≥ 4.5 in. d.b.h.	16	18	11	14.8	0.01

	No harvest (sites 1, 6, 8)	Even-aged (sites 3, 5, 9)	Unven-aged (sites 2, 4, 7)	F-value[3]	P-value[3]
No. of trees > 0 in. d.b.h.	135	163	129	1.0	0.44
No. of trees ≥ 1.5 in. d.b.h.	97	123	93	1.5	0.32
No. trees ≥ 4.5 in. d.b.h.	39	40	34	4.1	0.11
Qmd ≥ 1.5 in. d.b.h.	6.1	5.7	5.7	0.5	0.62
Qmd ≥ 4.5 in. d.b.h.	8.5	8.7	8.2	0.8	0.52
Basal area (ft²/ac) ≥ 1.5 in. d.b.h.	18	21	13	6.4	0.06
Basal area (ft²/ac) ≥ 4.5 in. d.b.h.	16	17	16	5.3	0.07

[1] Qmd = quadratic mean d.b.h. (in inches) for trees in the specified size class.
[2] Reported values are per acre except as noted. Metric conversions are 1.5 in. = 4 cm, 4.5 in. = 11 cm, and generally 1 in. = 2.54 cm. Also, (2.47) (no. of trees/ac) = no. trees/ha and (0.2296) (basal area ft²/ac) = basal area m²/ha.
[3] For ANOVA of block effects for the indicated attribute based on model [1]. F has (2,4) degrees of freedom.
[4] For ANOVA of treatment effects for the indicated attribute based on model [1]. F has (2,4) degrees of freedom.

Table 6.—*Site, block, and treatment area means for black oak attributes. Treatment means did not differ significantly (α = 0.05) for any listed attribute, although block effects were significant for some attributes.*

Attribute[1,2] (per acre except as noted)	Site 1	2	3	4	5	6	7	8	9
No. of trees > 0 in. d.b.h.	77	63	52	42	44	37	101	83	95
No. of trees ≥ 1.5 in. d.b.h.	50	50	40	34	33	21	48	38	51
No. trees ≥ 4.5 in. d.b.h.	42	41	36	25	29	19	30	30	29
Qmd ≥ 1.5 in. d.b.h.	9.8	9.9	10.5	9.5	10.2	12.1	9.3	10.8	9.2
Qmd ≥ 4.5 in. d.b.h.	10.6	10.5	10.9	10.2	10.9	12.5	11.3	11.7	11.4
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.	126	26	25	19	20	20	22	24	24
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.	26	25	25	19	20	20	22	25	23

	Block 1 (sites 1, 2, 3)	Block 2 (sites 4, 5, 6)	Block 3 (sites 7, 8, 9)	F-value[3]	P-value[3]
No. of trees > 0 in. d.b.h.	64	41	93	16.9	0.01
No. of trees ≥ 1.5 in. d.b.h.	47	29	46	7.1	0.05
No. trees ≥ 4.5 in. d.b.h.	40	24	29	12.0	0.02
Qmd ≥ 1.5 in. d.b.h.	10.1	10.6	9.8	0.8	0.51
Qmd ≥ 4.5 in. d.b.h.	10.6	11.2	11.5	1.4	0.35
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.	26	20	24	63.6	<0.01
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.	25	19	23	50.5	<0.01

	No harvest (sites 1, 6, 8)	Even-aged (sites 3, 5, 9)	Unven-aged (sites 2, 4, 7)	F-value[3]	P-value[3]
No. of trees > 0 in. d.b.h.	66	64	68	0.2	0.85
No. of trees ≥ 1.5 in. d.b.h.	37	41	44	1.0	0.44
No. trees ≥ 4.5 in. d.b.h.	30	31	32	0.16	0.86
Qmd ≥ 1.5 in. d.b.h.	10.9	10.0	9.6	2.1	0.24
Qmd ≥ 4.5 in. d.b.h.	11.6	11.1	10.6	1.7	0.29
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.	24	23	22	3.1	0.15
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.	23	22	22	4.0	0.11

[1] Qmd = quadratic mean d.b.h. (in inches) for trees in the specified size class.
[2] Reported values are per acre except as noted. Metric conversions are 1.5 in. = 4 cm, 4.5 in. = 11 cm, and generally 1 in. = 2.54 cm. Also, (2.47) (no. of trees/ac) = no. trees/ha and (0.2296) (basal area ft^2/ac) = basal area m^2/ha.
[3] For ANOVA of block effects for the indicated attribute based on model [1]. F has (2,4) degrees of freedom.
[4] For ANOVA of treatment effects for the indicated attribute based on model [1]. F has (2,4) degrees of freedom.

Table 7.—*Site, block, and treatment area means for scarlet oak attributes. Neither treatment nor block effects were significant (a = 0.05) for any attributes examined.*

Attribute[1,2]	**Site**								
(per acre except as noted)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
No. of trees > 0 in. d.b.h.	82	49	54	57	35	27	85	56	93
No. of trees ≥ 1.5 in. d.b.h.	60	40	44	46	29	22	66	31	60
No. trees ≥ 4.5 in. d.b.h.	45	31	34	32	21	20	41	24	26
Qmd ≥ 1.5 in. d.b.h.	8.3	9.1	9.0	9.3	9.5	11.7	10.0	11.6	7.8
Qmd ≥ 4.5 in. d.b.h.	9.2	9.9	10.3	10.6	10.6	12.0	11.7	12.7	10.5
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.	20	18	17	19	13	18	28	22	16
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.	21	18	18	20	13	18	29	22	18

	Block 1 (sites 1, 2, 3)	**Block 2 (sites 4, 5, 6)**	**Block 3 (sites 7, 8, 9)**	**F-value[3]**	**P-value[3]**
No. of trees > 0 in. d.b.h.	62	40	78	2.5	0.89
No. of trees ≥ 1.5 in. d.b.h.	48	32	53	1.4	0.35
No. trees ≥ 4.5 in. d.b.h.	37	25	30	1.5	0.33
Qmd ≥ 1.5 in. d.b.h.	8.8	10.1	9.8	0.9	0.49
Qmd ≥ 4.5 in. d.b.h.	9.8	11.1	11.6	3.2	0.15
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.	18	17	22	3.1	0.16
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.	19	17	23	2.6	0.19

	No harvest (sites 1, 6, 8)	**Even-aged (sites 3, 5, 9)**	**Unven-aged (sites 2, 4, 7)**	**F-value[3]**	**P-value[3]**
No. of trees > 0 in. d.b.h.	55	61	63	0.1	0.89
No. of trees ≥ 1.5 in. d.b.h.	38	44	50	0.5	0.64
No. trees ≥ 4.5 in. d.b.h.	30	27	35	0.7	0.56
Qmd ≥ 1.5 in. d.b.h.	10.5	8.8	9.5	1.3	0.36
Qmd ≥ 4.5 in. d.b.h.	11.3	10.5	10.7	0.6	0.58
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.	20	16	21	3.3	0.14
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.	21	16	22	3.7	0.12

[1] Qmd = quadratic mean d.b.h. (in inches) for trees in the specified size class.

[2] Reported values are per acre except as noted. Metric conversions are 1.5 in. = 4 cm, 4.5 in. = 11 cm, and generally 1 in. = 2.54 cm. Also, (2.47) (no. of trees/ac) = no. trees/ha and (0.2296) (basal area ft^2/ac) = basal area m^2/ha.

[3] For ANOVA of block effects for the indicated attribute based on model [1]. F has (2,4) degrees of freedom.

[4] For ANOVA of treatment effects for the indicated attribute based on model [1]. F has (2,4) degrees of freedom.

Table 8.—*Site, block, and treatment area means for shortleaf pine attributes. Neither treatment nor block effects were significant (a = 0.05) for any attributes examined.*

Attribute[1,2] (per acre except as noted)	Sites 1	2	3	4	5	6	7	8	9
No. of trees > 0 in. d.b.h.	26	21	15	17	16	36	20	27	34
No. of trees ≥ 1.5 in. d.b.h.	23	16	15	17	16	30	18	18	180
No. trees ≥ 4.5 in. d.b.h.	19	9.6	13	16	14	25	16	10	5.3
Qmd ≥ 1.5 in. d.b.h.	7.1	4.5	8.7	6.8	7.0	6.9	8.9	7.1	5.7
Qmd ≥ 4.5 in. d.b.h.	7.6	5.0	9.0	7.0	7.2	7.0	9.0	7.5	6.4
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.	9	5	8	8	8	10	11	6	3
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.	9	5	8	8	8	11	11	6	4

	Block 1 (sites 1, 2, 3)	Block 2 (sites 4, 5, 6)	Block 3 (sites 7, 8, 9)	F-value[3]	P-value[3]
No. of trees > 0 in. d.b.h.	21	23	27	0.6	0.61
No. of trees ≥ 1.5 in. d.b.h.	18	21	18	0.7	0.57
No. trees ≥ 4.5 in. d.b.h.	14	18	10	2.1	0.23
Qmd ≥ 1.5 in. d.b.h.	6.8	6.7	7.2	<0.1	0.96
Qmd ≥ 4.5 in. d.b.h.	7.1	7.1	7.6	0.1	0.92
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.	7	9	7	0.5	0.65
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.	7	9	7	0.5	0.65

	No harvest (sites 1, 6, 8)	Even-aged (sites 3, 5, 9)	Unven-aged (sites 2, 4, 7)	F-value[3]	P-value[3]
No. of trees > 0 in. d.b.h.	30	21	19	1.6	0.31
No. of trees ≥ 1.5 in. d.b.h.	24	16	17	3.7	0.12
No. trees ≥ 4.5 in. d.b.h.	18	11	14	2.0	0.25
Qmd ≥ 1.5 in. d.b.h.	7.0	7.1	6.7	<0.1	0.96
Qmd ≥ 4.5 in. d.b.h.	7.3	7.5	7.0	0.1	0.92
Basal area (ft^2/ac) ≥ 1.5 in. d.b.h.	8	6	8	0.4	0.71
Basal area (ft^2/ac) ≥ 4.5 in. d.b.h.	9	7	8	0.3	0.73

[1] Qmd = quadratic mean d.b.h. (in inches) for trees in the specified size class.
[2] Reported values are per acre except as noted. Metric conversions are 1.5 in. = 4 cm, 4.5 in. = 11 cm, and generally 1 in. = 2.54 cm. Also, (2.47) (no. of trees/ac) = no. trees/ha and (0.2296) (basal area ft^2/ac) = basal area m^2/ha.
[3] For ANOVA of block effects for the indicated attribute based on model [1]. F has (2,4) degrees of freedom.
[4] For ANOVA of treatment effects for the indicated attribute based on model [1]. F has (2,4) degrees of freedom.

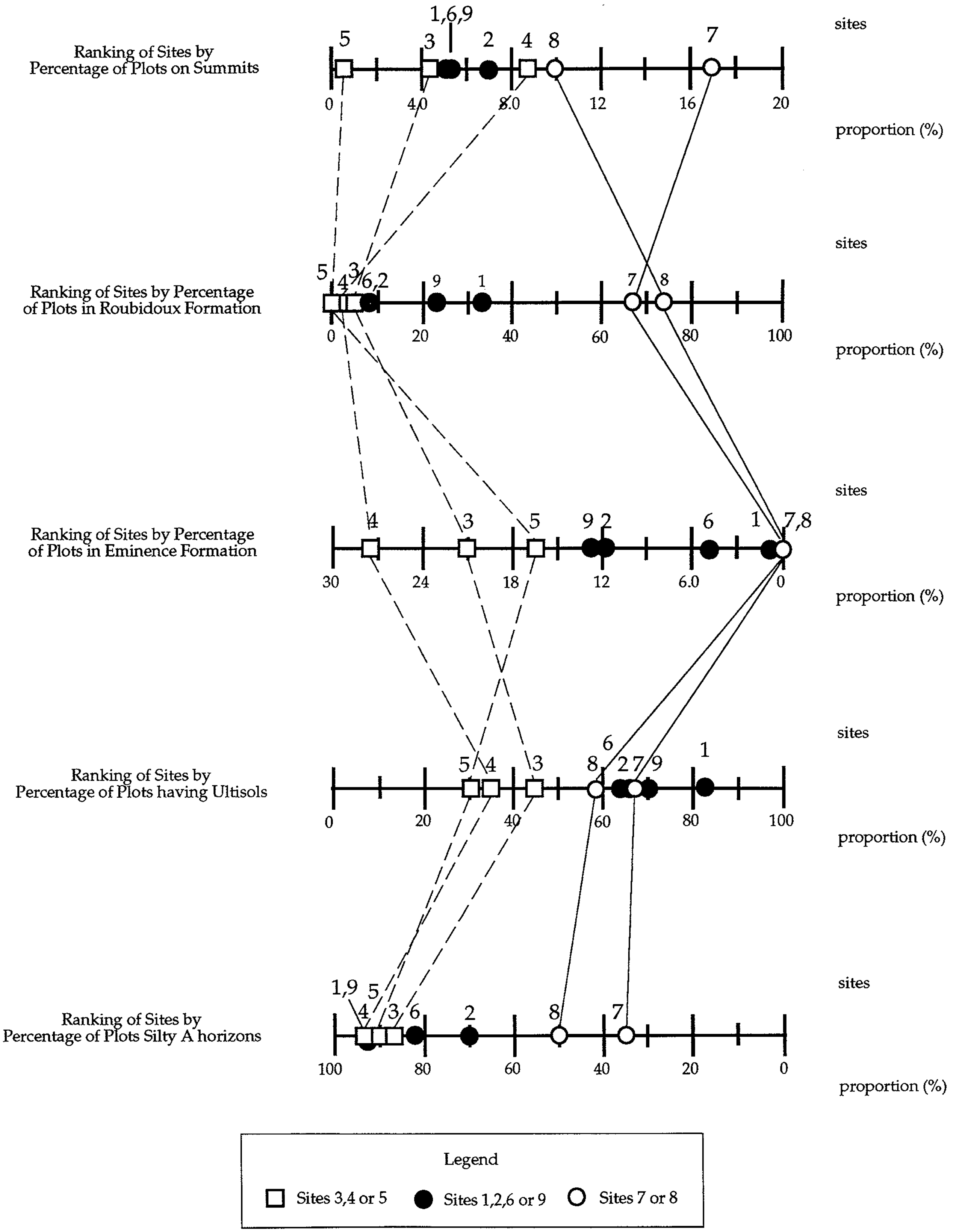

Figure 3.—*Ranking of sites for several key environmental variables. Lines connecting values for sites 3, 4, and 5 and sites 7 and 8 illustrate the similarity of those groups of sites relative to the others.*

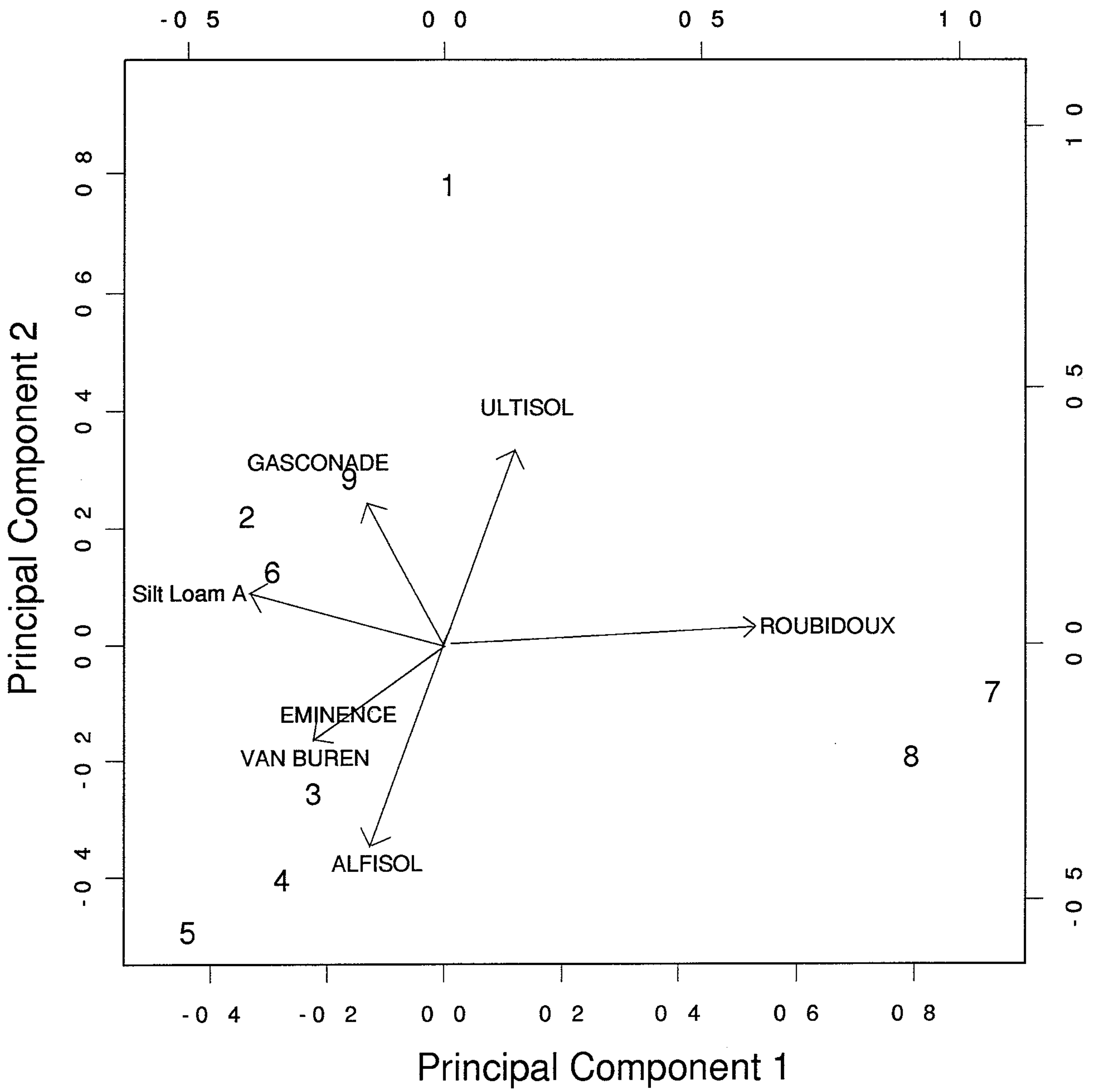

Figure 4.—*Biplot of first two Principal Component axes derived from environmental variables. Numbers correspond to sites. Arrows point toward environmental characteristics that differentiate sites. The labels "ROUBIDOUX," "GASCONADE," and "VAN BUREN" indicate geological strata; "ULTISOL" and "ALFISOL" are important soil orders (i.e., Taxonomic classes); and "Silt Loam A" = silt loam soil textures in the A-horizon.*

variety of soils, and contains more mesic vegetation and glade-savanna complexes than the Hills LTA (Meinert *et al.* 1997).

All of the EAM treatments occurred in sites having more basic soils (Alfisols) and soils with siltier surface soil horizons. No-harvest (NH) treatment areas generally occurred in more acidic soils (Ultisols) and in soils that had greater variation of surface horizon texture (primarily silt loams and loams). Block 2 (sites 4 through 6) appeared to be much more internally uniform in the environmental variables evaluated than block 1 (sites 1 through 3) or block 3 (sites 7 through 9). Block 1 contained site 1, which had somewhat errant properties relative to other sites. Block 3 contained two very similar sites (7 and 8), but one site (9) that contained igneous parent material and outcrops and proportionally less Roubidoux geology.

DISCUSSION

We attribute a portion of the site-level differences in numbers of species, abundances, quadratic mean diameters, and basal area to differences in environmental conditions among sites and to land-use history. Greater numbers of species per acre, greater abundance and basal area of white oak, and fewer scarlet oaks were associated with sites having a greater proportion of base-rich geological strata and soils classified as Alfisols, and they were also associated with greater overall landscape relief and slope steepness. Site 6 appeared to be the only anomaly. Environmental conditions of site 6 were more similar to those of sites 2 through 5, although its woody vegetation characteristics were more similar to those of sites 7 and 8.

Using environmental differences to describe among-site differences in quadratic mean diameter, trees per acre, and total basal area (rather than basal area of specific species) was problematic. Diameter and tree densities are greatly influenced by past management and may not indicate site quality (Reineke 1933). Differences in total basal area can reflect differences in site productivity, but only in fully stocked forests of similar age. Moreover, logging, grazing, and other disturbances can greatly affect total basal area. Land-use histories of all sites prior to Missouri Department of Conservation ownership are generally considered similar. However, the gentler topography of sites 7 and 8 made them more suited for grazing, more susceptible to widespread burning, and more accessible for selective logging than the other sites. These past disturbances may reduce the numbers of trees per unit area, without removing all trees, allowing growth concentrated to fewer trees. This may explain why sites 7 and 8 had fewer but larger trees than the other sites.

Potential Treatment Response Differences

Differences in environmental variables at site-, block-, and treatment-levels prompted us to develop hypotheses about potential differences in woody vegetation responses to proposed silvicultural treatments during the course of the MOFEP experiment. We hypothesize that NH and UAM treatment responses will be more variable and consequently may be more difficult to interpret because these treatments have been delegated to more contrasting sites than the EAM treatments. Moreover, we hypothesize that EAM treatment areas will support a greater abundance of mesic species and have greater growth rates because these treatments were randomly assigned to sites having siltier surface soil textures and a greater proportion of base-rich parents materials.

Effectiveness of Blocking

The goal of blocking in experiments is to create strata that are internally homogenous in conditions thought to affect the experiment so that the response differences to treatments can be identified (Samuals 1989). Blocking is generally considered effective when blocks are internally homogenous and there are significant differences among blocks. Significant pre-treatment differences in woody vegetation variables among blocks suggest that blocking is useful for the MOFEP study. However, our analysis of site-level differences in environmental data suggests that the optimal blocking arrangement has not been achieved, nor can it be, under the current study design. We consider there to be little difference in environmental variables among sites 2 through 6 and between sites 7 and 8 (fig. 3). However, site 1 differs considerably from the remaining sites, but is most similar in soil base saturation to sites 7 and 8 (fig. 3). Site 9 is also unique in that past uplifting from underlying rhyolite (igneous) bedrock has tilted the overlying sedimentary strata. This tilting has caused the overlying sedimentary strata (primarily Gasconade and Eminence) to be more often exposed in different landform positions on site 9 than in the other sites. This essentially increases the parent material heterogeneity of site 9. However, the proportions of each geological strata within site 9 were found to be similar to sites 2 through 6. Therefore, site 9 is more similar to sites 2 through 6 than to sites 7 and 8. Based upon environmental information, improved blocking efficiency may have been achieved by grouping sites 1, 7, and 8. The remaining sites could be blocked in any combination.

Within-Site Variation

The experimental design of MOFEP cutting treatments uses sites as the experimental unit. However, there is considerable variation in both vegetation and environmental characteristics within each site. Each site contains from 16 to 22 distinctly different soil-geo-landform environments, many of which are summarized by Meinert *et al.* (1997). Unpublished data show differences in woody species abundance and site indices attributable to differences in soil-geo-landforms within sites. For example, black oak is most abundant on acid soils of Roubidoux summits; white oak is more abundant in deep, base-rich soils in Lower Gasconade and Eminence backslopes; and site indices are generally higher for all species in Lower Gasconade backslopes (Kabrick *et al.*, unpublished data). In addition to compositional and productivity differences, we anticipate that soil-geo-landforms will differ in responses to cultural treatments applied during MOFEP. For example, species composition may remain similar on Roubidoux summits regardless of cultural treatment because these soil-geo-landforms favor the xeric and shade intolerant species presently growing on these soil-geo-landforms. However, UAM may favor shade tolerant mesic species on base-rich and moist sites on Lower Gasconade and Eminence backslope positions, causing species composition to change over time. Soil-geo-landform information may become critical for interpreting within-site response heterogeneity.

SUMMARY

Compared to other sites, sites 2 through 5 had greater numbers of species per unit area. Sites 7 and 8 had fewer trees ≥ 1.5 in. (4 cm) d.b.h., less white oak, and more scarlet oak. Block 3 (sites 7, 8, and 9) had fewer trees ≥ 4.5 in. (11 cm) d.b.h., less overall basal area, and less white oak. Block 2 (sites 4, 5, and 6) had less black oak. We found no treatment-level woody vegetation differences.

Greater numbers of species per acre, greater abundance of white oak, and lesser abundance of scarlet oak were associated with sites and blocks that have a greater proportion of base-rich geological strata and a greater proportion of soils classified as Alfisols. We attribute some degree of the observed site and block differences in diameter and trees per unit area to differences in past land-use. We hypothesize: (1) NH and UAM treatment responses will be more variable and more difficult to interpret than EAM treatment responses because the NH and UAM treatments were delegated to more contrasting sites and (2) EAM treatment areas will have greater growth rates because these treatments were delegated to sites having siltier surface soil textures and a greater proportion of base-rich parent materials.

For the variables we examined, the designated blocks were effective in grouping sites with similar vegetational characteristics. However, based on an examination of environmental characteristics, blocks that combined sites 1, 7, and 8; sites 3, 4, and 5; and sites 2, 6, and 9 may improve the effectiveness of blocking.

ACKNOWLEDGMENT

We thank Jenny Grabner, Dennis Meinert, and Tim Nigh for helpful discussions during data analysis and interpretation. We also thank Jenny Grabner for her helpful comments on a previous draft of this manuscript. We gratefully acknowledge the Missouri Department of Conservation for providing the funding and data for this work.

LITERATURE CITED

Brookshire, Brian L.; Hauser, Carl. 1993. The Missouri Forest Ecosystem Project. In: Gillespie, Andrew R.; Parker, George R.; Pope, Phillip E.; Rink, George; eds. Proceedings, 9th Central hardwood forest conference; 1993 March 8-10; Purdue University, West Lafayette, IN. Gen. Tech. Rep. NC-161. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 289-307.

Brookshire, Brian L.; Jensen, Randy; Dey, Daniel C. 1997. The Missouri Ozark Forest Ecosystem Project: past, present, and future. In: Brookshire, Brian L.; Shifley, Stephen R., eds. Proceedings of the Missouri Ozark Forest Ecosystem Project symposium: an experimental approach to landscape research; 1997 June 3-5; St. Louis, MO. Gen. Tech. Rep. NC-193. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 1-25.

Gauch, Hugh G., Jr. 1986. Multivariate analysis in community ecology. New York, NY: Cambridge University Press. 298 p.

Husch, Bertram; Miller, Charles I.; Beers, Thomas W. 1983. Forest mensuration. New York, NY: John Wiley and Sons. 402 p.

Kurzejeski, Eric W.; Clawson, Richard C.; Renken, Rochelle B.; Sheriff, Steven L.; Vangilder, Lawrence, D.; Hauser, C.;

Faaborg, John. 1993. Experimental evaluation of forest management: the Missouri Ozark Forest Ecosystem Project. In: Transactions of the 58th North American Wildlife and Natural Resources conference: 599-608.

Meinert, Dennis; Nigh, Tim; Kabrick, John. 1997. Landforms, geology, and soils of the MOFEP study area. In: Brookshire, Brian L.; Shifley, Stephen R., eds. Proceedings of the Missouri Ozark Forest Ecosystem Project symposium: an experimental approach to landscape research; 1997 June 3-5; St. Louis, MO. Gen. Tech. Rep. NC-193. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 56-68.

Reineke, L.H. 1933. Perfecting a stand density index for even-aged forests. Journal of Agricultural Research. 46: 627-638.

Samuals, M.L. 1989. Statistical methods for the life sciences. San Francisco, CA: Dellen Publishing Company. 597 p.

Sheriff, Steven L.; He, Zhuqiong. 1997. The experimental design of the Missouri Ozark Forest Ecosystem Project. In: Brookshire, Brian L.; Shifley, Stephen R., eds. Proceedings of the Missouri Ozark Forest Ecosystem Project symposium: an experimental approach to landscape research; 1997 June 3-5; St. Louis, MO. Gen. Tech. Rep. NC-193. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 26-40.

Webster, R.; Oliver, M.A. 1990. Statistical methods in soil and land resource survey. New York, NY: Oxford University Press. 316 p.