U. S. FOREST SERVICE RESEARCH PAPER NE-30
1964

NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
RALPH W. MARQUIS, DIRECTOR

OAK SITE INDEX

on Belmont Limestone Soils in the Allegheny Mountains of West Virginia

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The Need to Predict Productive Capacity

THE productive capacity of forest land in the Allegheny Mountains of West Virginia often varies greatly by soil and topography from one area to another over relatively short distances. Gross differences in site quality are readily recognized on opposite slopes, and indeed differences can be seen to occur on the same slope. As forest land values continue to increase and management practices become more intensive, foresters and forest land managers are becoming more and more aware of the need to predict the productive capacity of the land.

Research scientists at the Northeastern Station, cognizant of the need, even 10 years ago, made a study in which the site index of several oak species was related by a regression equation to several topographic and soil factors for medium-textured, well-drained, upland soils in northeastern West Virginia (Trimble and Weitzman 1956). Their study was conducted on sandstone and shale soils—mainly Dekalb, Gilpin, and Calvin soil series; the obviously inferior shaly Ashby series and the superior limestone Belmont series were not included. These two soils were deliberately excluded from that study to minimize variations in soils that might affect tree growth and confound or obscure other variables important for predicting site productivity. Since publication of the Trimble and Weitzman study, additional site work has been done on the Belmont soil series.

The limestone soils in the Allegheny Mountain Region of West Virginia, though they occupy only about 5 percent of the forest land, are probably the most productive soils of the region. So a study was made to provide guidelines as a forest-management tool where these soils exist, and to gain a better understanding of the effect of limestone parent material on site productivity with respect to other parent materials in the same region.

Results of this follow-up investigation are presented in this paper, to relate the site index of red oak by regression equation to soil and topography. Also, oak site indexes on the Belmont soil series predicted by the equation given in this paper are compared with values predicted for the same plots by the equation developed by Trimble and Weitzman for the sandstone and shale soils.

Review of the Literature

Lutz and Chandler (1946) stated that, "In relatively small regions of uniform climate, the nature of the parent material is probably more important than any other single factor in determining the character and productivity of soils." In Sweden, Tamm and Wadman (1945) have suggested that, for areas of equal soil moisture, forest conditions can be correlated with type of bedrock.

In many site-evaluation studies made in the United States, it has been found that differences in productivity attributable to parent materials are not significant. Other soil factors such as texture, drainage, and depth of soil, along with topography, were usually more important. However, it is recognized that differences in parent material are often partly responsible for these observed soil and topographic differences. Some investigations have shown that parent material contributed to site-quality differences beyond those attributed to physical factors of the soil and topography. This situation seems to occur most frequently with calcareous soils.

Lutz and Chandler (1946) reported that, in the Southwest, soils derived from Permian limestones produced the heaviest and best stands of Ponderosa pine, provided precipitation was also favorable. In contrast to limestones, the Coconino sandstones produced both poorer soils and poorer timber. In the Lake States, Kittredge (1928) reported that the best growth of jack pine was found on soil types where a limestone formation was present or where limestone had been brought in by glacial action. Stoeckeler's study (1948) of aspen in the Lake States indicated that significantly better volume growth occurred on soils with a limy subsoil than on soils with an acid subsoil — although site indexes were practically identical and the physical properties were similar on both groups of soils.

In a recent comprehensive study of the physical and chemical properties of the soil, Stoeckeler (1960) found that the site-index advantage of aspen on soils with a lime-rich substratum was about 5 feet. Diebold (1935) considered the lime content of the entire profile to be of great importance in determining forest site quality. Soils developed from calcareous material of glacial origin were reported by Cox *et al.* (1960) to be among the best sites for growth of Ponderosa pine in western Montana; this was true where depth to the zone of calcium carbonate accumulation was greater than 4 feet. Where accumulation occurred at less than 4 feet, site indexes decreased as depth to lime decreased because of the high pH of the calcareous layers, which ranged from 8.0 to 8.5.

In the Black Hills, Myers and Van Duesen (1960) reported that, although the range of site index was the same, the average site index of Ponderosa pine was higher on limestone soils than on soils derived from other parent material. They explained this difference on the basis of more favorable growing conditions that existed on the limestone soils, such as less-steep slopes and deeper soils.

In Iowa, Einspahr and McComb (1951) found that a limestone soil (of the Sogn series) had the lowest oak site indexes of any of the soils investigated. However, these soils were located on exposed ridges and were extremely shallow; their reported average total depth was 8 inches. Eschner, working with the same soil series, reported similar results.[1]

Arend and Julander (1948), reporting on a study in the Arkansas Ozarks, concluded that "in general, the best growth of oak stands was measured on sites where the soils were derived from calcareous materials and the poorest on soils derived from sandstone and shale." They noted variations in site quality on all three soils and exceptions to the higher productivity of limestone soils, as follows: "Limestone soils also vary from unproductive, shallow, rocky soils low in water-holding ability to productive, deep, silty clay soils."

Lutz and Chandler (1946) stated:

> In general, limestone weathers rapidly, particularly the porous and impure varieties. The nature of the soil which develops from limestone depends to a considerable extent on the amount and kind of impurities contained, since the principal constituent, calcium carbonate, is dissolved and removed. In view of the great differences among limestones in kinds and amounts of impurities, it is not surprising that the derived soils are also extremely variable in quality. Soils derived from limestone are probably more variable than those derived from any other kind of rock (Ramann, 1905:100; Domes, 1938:473).

The Study Area

The study was made in Tucker and Randolph Counties in the Allegheny Mountains of West Virginia. Here the topography is rough, dominated by deep narrow valleys and sharp rising ridges.

Soils in these two counties are derived mostly from residual sandstones, shales, and — to a lesser extent — limestone. Most of the soils are medium-textured and well-drained, and total depth averages between 2½ and 3 feet.

Annual precipitation averages about 50 inches and is well distributed throughout the year, with snow contributing about 6

[1]Eschner, A. R. GROWTH AND COMPOSITION OF OAK STANDS ON THE BRAYTON FOREST IN RELATION TO SOIL AND TOPGRAPHY. Unpublished master's thesis, Iowa State College. 1952.

inches. Mean annual temperature is about 50°F., and length of the average frost-free growing season is approximately 140 days.

The dry sites, which are generally the upper half of the south and west slopes and the narrow ridges, are dominated by chestnut oak (*Quercus prinus* L.), with these major associates: scarlet oak (*Q. coccinea* Muenchh.), white oak (*Q. alba* L.), black gum (*Nyssa sylvatica* Marsh.), sourwood (*Oxydendrum arboreum* [L.] DC.), and sassafras (*Sassafras albidum* [Nutt.] Nees). The lower half of the north and east slopes, and the coves, contain a rich mixture of yellow-poplar (*Liriodendron tulipifera* L.), sugar maple (*Acer saccharum* Marsh.), red oak (*Quercus rubra* L.), beech (*Fagus grandifolia* Ehrh.), white ash (*Fraxinus americana* L.), basswood (*Tilia americana* L.), black cherry (*Prunus serotina* Ehrh.), cucumber magnolia (*Magnolia acuminata* L.), and several other species of lesser importance. Between the extremes of the coves and the dry ridges a great variation in species composition occurs.

The Belmont Soil Series

The Belmont soil series, which dominates the limestone soils in the Allegheny Mountains, belongs to the Gray-Brown Podzolic group. The series occurs as upland soils developed from several beds of impure marine stone, which are separated by thin strata of alkaline red and gray shale, and sandstone. The Greenbrier stratum, the source of the parent material, ranges in thickness from about 150 feet to about 450 feet in Tucker and Randolph Counties. These strata are generally horizontal. They are bedded between the Mauch Chunk series above, which in turn are capped by the Pottsville series, and the Pocono series below.

The Belmont soils occur principally in bands along moderately steep to very steep hillsides. They are frequently influenced by colluvium from Mauch Chunk and Pottsville material. Due to the nature of the parent material and variable amounts of colluvium, Belmont soils vary considerably in depth, texture, color, content of coarse fragments, and reaction.

A representative profile description of the Belmont series is given as follows:

Horizon	*Depth (inches)*	*Description*
Aoo	3-0	--
Ao	--	Incorporated in A_1.
A_1	0-4	Dark Brown (7.5 YR 3/2) silt loam; moderate; medium granular structure; moist loose, pH 5.6; clear smooth boundary.
A_2	4-9	Dark brown (7.5 YR 4/2) silt loam, weak fine subangular blocky structure; moist friable; pH 5.6; gradual smooth boundary.
B_{21}	9-18	Dark brown (10 YR 4/3) silty clay loam; moderate medium subangular blocky structure; moist firm, slightly sticky and plastic when wet; pH 5.6; gradual boundary that tends to be irregular.
B_{22}	18-44	Dark brown (7.5 YR 4/4) silty clay loam; moderate to strong fine and medium subangular blocky structure; sticky and plastic when wet; pH 6.6 gradual smooth boundary.
C_1	44-51 +	Dark brown (7.5 YR 4/4) clay loam to sandy clay loam; moist very friable; pH 6.8. Few coarse limestone boulders throughout profile.

Study Methods

The general plan of this study was, first, to test estimates of site index made according to the Trimble-Weitzman equation for sandstone-shale soils against site-index values determined from trees on the limestone Belmont soils; and then, depending on the outcome of this test, to develop a separate regression equation for oak site on the Belmont soils.

Field procedures were similar to those followed in the Trimble and Weitzman study (1956). On selected plots, sample trees were measured to determine height-over-age site index; and observations and measurements were recorded on factors of the soil and topography.

Data for the study were collected on 22 plots located in well-stocked, even-aged oak stands on medium-textured, well-drained Belmont soils. No definite plot size was used because plot stand-volume determinations were not a consideration. However, all sample trees were limited to areas of not more than 1/5 acre to insure fairly uniform soil and topographic conditions.

Tree heights and ages were determined for 5 to 10 dominant and co-dominant red oak trees on each plot. (Red oak was the sole species sampled except for one plot where white oak comprised 4 of the 8 trees sampled.) Total age was determined by adding 3 years to cores obtained at d.b.h. Tree site indexes were read from the site-index curves described by Schnur (1937). Average ages of the trees on the study plots ranged from 43 to 96 years, and the majority averaged about 50 years. Variation in sample-tree age on any plot was limited to 10 years, and plots with greater age spread were discarded.

Topographic variables included in the study were aspect, slope position, and slope percent. The methods of measuring these variables were as follows:

Aspect.—Orientation was measured with a hand compass, facing down the slope and across the plot.

Slope position.—Plot distance from the ridge was expressed as a percent of the total length of the slope.

Slope percent.—Steepness of the slope was measured in percent with an Abney level across the plot for a distance of approximately 2 chains.

Soil profile descriptions were written for 19 of the 22 plots from pits dug at the center of each plot.[2] Soils on the remaining 3 plots were carefully examined and verified by auger samples. In each of these three cases, limestone outcroppings were in evi-

[2]Grateful acknowledgment is made for the cooperation of the Soil Conservation Service, U. S. Dept. of Agriculture. The help given by Woodrow Beverage, soil scientist of the Elkins, W. Va., office, who identified and described the Belmont soils in the field, is particularly appreciated. In addition, Mr. Beverage gave valuable assistance in interpreting the meaning of the soils data for this report.

dence close by. The profile descriptions written followed the standard procedures used by the Soil Conservation Service. Soil samples were not collected for laboratory analysis. Soil texture was determined by feel at the pit. The LaMatte field kit was used for pH measurements. On each plot, average soil depth was determined with a soil depth probe (Yawney 1959) from measurements taken at five locations — at the plot center and at spacings of about 30 feet to either side and above and below the plot center. Maximum depth to which soil was measured was 3.5 feet.

When this study was begun, the plan was to investigate site-index relationships on more than 22 plots, but the difficulty of finding suitable stands containing oak on this soil limited the size of the study.

Results and Discussion

The results of this study indicate that the Belmont soils are highly productive, and that oak site indexes have a narrow range on these soils. Measured site indexes were comparatively high for each plot regardless of the combination of site factors involved (table 1).

An intensive search was made to cover the range of oak sites existing on these soils, but no plots were found with oak site indexes lower than 65 and none higher than 83. Better sites are known to exist, but it was not possible to find an adequate sample of oak trees on them. It appears that, as site conditions become more favorable, the oaks become a minor stand component or are completely absent from the species association.

On the basis of this study, oak sites on the Belmont soils could be classed by 10-foot site-index classes as either 70 or 80. In contrast to this narrow range, measured oak site indexes on the sandstone and shale soils within the same physiographic region ranged from a low of 35 or less to a high of 95.

Early in the study, it became apparent that estimates from the sandstone and shale equation (Trimble and Weitzman 1956) were not compatible with site indexes determined from trees on

Table 1.—Distribution of plots by dependent and independent variables for an oak site-index study on Belmont soils in West Virginia

Site index	Aspect			Slope position, in percent of distance from ridge to bottom of slope			
	NE	SE & NW	SW	0-20	21-50	51-80	81-100
70 (65-74)	—	3	4	1	2	3	2
80 (75-84)	4	7	4	3	—	10	1

Site index	Steepness of slope, in percent			Soil depth, in feet		
	0-20	21-50	51+	1.5-2.4	2.5-3.4	3.5+
70 (65-74)	—	3	5	—	3	5
80 (75-84)	1	8	5	1	8	5

the Belmont limestone soils. Preliminary analysis of the 22 plots, utilizing the "t" test with paired data, revealed that differences were significant beyond the 1-percent level. Site-index values from tree measurements were generally higher than the predicted values, though not uniformly so throughout the range. The comparison revealed disagreement to be greatest on the poorer sites, where differences ranged between 15 to 20 feet of site index. On the better sites, the Trimble-Weitzman equation provided estimates closely approximating measured site index.

Regression Equation for Belmont Soils

Because the sandstone-shale equation obviously did not apply to the Belmont soils, a separate regression equation was developed for oak site index on the Belmont soils.

In the previous site study by Trimble and Weitzman, oak site index was found to be highly correlated with certain readily measured soil and topographic factors; namely, aspect, slope position, slope percent, and soil depth. The effects of these same factors or independent variables on site index were determined for the Belmont soils. Nonlinear relationships of the independent variables were made linear with respect to site index by expressing:

1. Logarithm of site index to the base 10:

$$Y = \log \text{site index}$$

2. Aspect as the sine of the azimuth taken clockwise from southeast[3] and adding 1:

$$X_1 = \text{Sine (azimuth from SE)} + 1$$

3. Slope position as the percent of distance from the ridge to the bottom of the slope:

$$X_2 = \text{Percent of distance from ridge line}$$

4. Grade or steepness of slope as the slope percent:

$$X_3 = \text{Slope percent of the plot}$$

5. Total soil depth to bedrock as the reciprocal of soil depth in feet:

$$X_4 = \frac{1}{\text{Soil depth in feet}}$$

The resulting equation is:

$$Y = 1.9792 - 0.0146\,X_1 + 0.0002\,X_2 - 0.0007\,X_3 - 0.1691\,X_4$$

The effects of several additional independent variables on site index were also investigated. These were pH of the A_1 and A_2 horizons; thickness of the A_1, A_2, and the total A horizons; and stand age. This was done by plotting residuals of site index over values of these independent variables. No relationships were evident.

R^2 for the regression is 0.503, and the regression is significant at the 5-percent level. The standard error is approximately 5-percent or about 4 feet for the average site index of 76 feet. And

[3]Starting at the southeast puts the southwest aspect (which has the lowest site index) and northeast aspect (which has the highest site index) into their proper positions. Adding the plus 1 eliminates negative values.

while only half of the variation for this regression is accounted for, the narrow range of sites on these soils permits good predictability with a small standard error.

The partial regression coefficients and the total correlation coefficients are compared in table 2 with values for the corresponding variables from Trimble and Weitzman (1956). None of the individual partial regression coefficients were significant at the 5-percent level (table 2), even though the multiple regression equation was significant. Of the total correlation coefficients (table 2) only two were significant: aspect and soil depth.

Based on the equation, site-index values were computed for ranges of the independent variables. These values are listed in table 3 for convenient reference.

Because the equation derived for the Belmont limestone soil has the same four variables as the Trimble-Weitzman equation for sandstone and shale soils, it was possible to determine quantitative differences in the potential productive capacities for oak between the two soil groups. Both equations were used to predict site-index values from the same topographic and soil-depth data measured on the 22 plots taken on the Belmont soil series. By superimposing the Trimble-Weitzman equation onto the Belmont

Table 2.—Regression and correlation coefficients for the variables on Belmont soils compared with values for corresponding variables on sandstone and shale soils

Variables	Limestone soils		Sandstone and shale soils[1]	
	Partial regression coefficients	Total correlation coefficients with Y	Partial regression coefficients	Total correlation coefficients with Y
Aspect	—0.0146	0.5068*	—0.0618**	0.5083**
Slope position	+ .0002	.0349	+ .0012**	.5299**
Slope percent	— .0007	.2264	— .0020**	.4038**
Soil depth	— .1691	.5661**	— .1509*	.4915**

*Significant at the 5-percent level.
**Significant at the 1-percent level.
[1]After G. R. Trimble, Jr., and Sidney Weitzman, 1956, Site Index Studies of Upland Oaks in the Northern Appalachians. Forest Sci. 2:162-173.

Table 3.—Site index of oak on Belmont soils as related to aspect, slope, and total soil depth in the Allegheny Mountains of West Virginia

Aspect	Soil depth (feet)	Slope percent 10	30	50	70	10	30	50	70
		TOP OF SLOPE (*1 percent distance from ridge*)				UPPER SLOPE (*33 percent distance from ridge*)			
SW (225°)	1.5	68	66	63	61	69	67	64	62
	2.5	75	73	70	68	76	74	71	69
	3.5	79	76	74	71	80	77	75	72
NW (315°) and SE (135°)	1.5	70	68	66	64	71	69	67	64
	2.5	78	75	73	71	79	76	74	72
	3.5	81	79	76	74	82	80	77	75
NE (45°)	1.5	72	70	68	66	73	71	69	67
	2.5	80	78	75	73	82	79	76	74
	3.5	84	81	79	76	85	83	80	77
		LOWER SLOPE (*66 percent distance from ridge*)				BOTTOM OF SLOPE (*99 percent distance from ridge*)			
SW (225°)	1.5	70	68	65	63	71	69	66	64
	2.5	77	75	73	70	79	76	74	71
	3.5	81	78	76	73	82	80	77	75
NW (315°) and SE (135°)	1.5	72	70	68	65	73	71	69	66
	2.5	80	77	75	73	81	79	76	74
	3.5	84	81	78	76	85	82	80	77
NE (45°)	1.5	75	72	70	68	76	73	71	69
	2.5	83	80	78	75	84	81	79	76
	3.5	87	84	81	79	88	85	82	80

soil plots, the site-index values thus calculated provided estimates applicable to other soils derived from sandstone and shale having the same topographic and soil-depth situations. Therefore, differences between the two estimates of site indexes reflect the inherent differences in the productive potential of the two soil groups.

Superiority of the limestone soil series over the sandstone and shale soils is illustrated by the regression line in figure 1. The points shown are the predicted site-index values calculated by both equations. A correlation coefficient of 0.883 resulted. Estimated mean site indexes for the 22 plots were 76 for the limestone soils and 64 for the sandstone and shale soils. The difference between the means was significant beyond the 1-percent level.

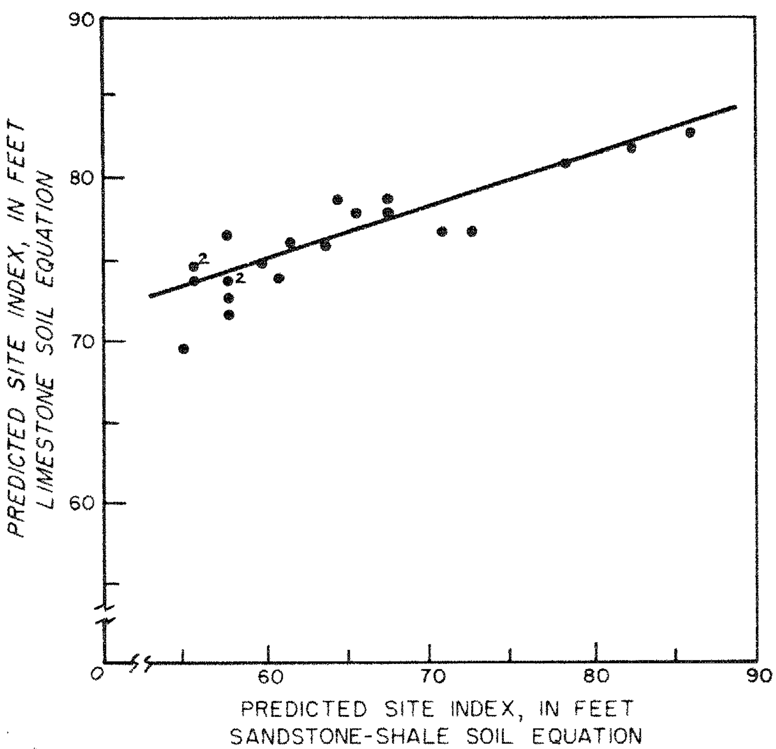

Figure 1.—Predicted oak site indexes on 22 plots of the Belmont limestone soil series compared with site indexes for sandstone and shale soils in the Allegheny Mountains of West Virginia.

The nature of the quantitative differences in the productive capacities of both soil groups for oak, as indicated by the two equations, is shown by examining the extremes in the ranges of predicted site indexes. For example, where the Belmont limestone soil equation estimates an oak site index of 73, the sandstone and shale equation indicates a site index of 55. Both equations predict approximately the same values around site index 83. Beyond this point, the trend shown by the comparison in figure 1 suggests superiority of the sandstone and shale soils. However, relationships beyond the data shown are unknown because of the absence of oak sample trees on the more productive Belmont soils.

Additional Information from Soil Surveys

Though soil samples were not collected for testing in this study, nor in the previous study by Trimble and Weitzman, recent intensive soil surveys in this mountain section by soil scientists of the U.S. Soil Conservation Service (1959) provide additional information on the soils in question.

The survey shows that Belmont silt loams have a higher clay content, particularly in the lower horizons, than the loams and silt loams of the Dekalb, Gilpin, and Calvin series, which were the predominant soils studied by Trimble and Weitzman (1956). The higher clay content indicated a greater water-holding capacity in the Belmont loams and perhaps more available moisture for tree growth. The textural difference may be the reason why Belmont soils have a higher site index in dry, topographic locations —such as upper slopes and southwest aspects—but have comparable site indexes in moist situations such as lower northeast slope.

The Belmont soils have a higher reaction. Though the range is wide within this series, the B_2 horizon averages about pH 6.5. In the sandstone and shale group the B_2 horizon averages about pH 4.6.

Soil structure is generally more favorable for plant growth in the Belmont soils. The Belmont soils have moderate to strong, fine, subangular, blocky structure in the B horizon. The Calvin and

Gilpin soils have weak to moderately strong, fine, subangular, blocky structure. And the Dekalb soil has weak, fine, subangular, blocky structure.

Percent base saturation for the Belmont soil is about 10 times greater than for soils from sandstone and shale. Of the total bases, calcium accounts primarily for these differences. As early as 1892, Hilgard (1892) observed that soils having a relatively high capacity to supply calcium are generally better forest sites than those having little available calcium.

Summary

An oak site-index study was made of the limestone-derived Belmont soil series in the Allegheny Mountains of northern West Virginia to determine and define the effect of easily measured topographic and soil factors on oak site index.

Field procedures on the 22 study plots used consisted of: (1) measuring site index by the standard height-age relationships; (2) making topographic measurements of aspect, steepness of the slope, and position on the slope; and (3) observing profile depths and horizon characteristics in soil pits. Standard Soil Conservation Service profile descriptions were made. Soil samples were not collected for laboratory analysis.

The results of the study indicate that the Belmont soils are highly productive for all of the natural combinations of topographic features and soil depth observed. However, to some extent observations were limited because oak sample trees were absent on the best Belmont sites. Oak was found to occupy an extremely narrow site range: site indexes measured on the 22 study plots fell between 63 and 83.

A prediction equation was developed for site index. The equation was based on the independent variables of aspect, slope position, slope percent, and soil depth. R^2 for the regression was 0.503, with significance at the 5-percent level. The standard error of estimate was approximately 5 percent, or about 4 feet at the average site index of 76 feet.

Differences were determined between oak site indexes on the

Belmont soils and on the shale and sandstone soils in the area for similar combinations of soil depth and topographic conditions. In the more adverse topographic locations, the Belmont soils had consistently higher site indexes. In the favorable topographic locations where the sandstone and shale soils had high site indexes, site differences between the Belmont and the sandstone-shale soils were negligible.

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