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SOIL-SITE FACTORS AFFECTING SOUTHERN UPLAND OAK MANAGEMENT AND GROWTH

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Abstract.--Soil supplies trees with physical support, moisture, oxygen, and nutrients. Amount of moisture most limits tree growth; and soil and topographic factors such as texture and aspect, which influence available soil moisture, are most useful in predicting growth. Equations that include soil and topographic variables can be used to predict site index. Foresters can also identify good, medium, or poor sites by using simple tables that describe basic topographic and soil features.

Additional keywords: Site index, *Quercus* spp., topography.

Soil supplies trees with physical support, moisture, oxygen, and nutrients. Also, soil is an important factor influencing site quality.

PHYSICAL SUPPORT

Healthy trees seldom windthrow unless rooting depth is restricted by soil pans, high water tables, and bedrock or hard parent material. But in upland hardwood areas, windthrow is not severe, because the shallowness of bedrock limits height growth and causes trees to root in rock fissures. Trees growing over unfractured sandstone, which impounds extra moisture, sometimes windthrow.

High water table causes shallow rooting near streams and seeps. Roots forced by lack of oxygen to grow above waterlogged horizons may not support the tree against high winds. Fragipans and clay pans may also promote windthrow by restricting root penetration.

MOISTURE AND OXYGEN

In Midsouth uplands, lack of moisture is the main restraint on tree growth. In dry climates, trees are shorter than in moist climates, and species are more drought-hardy.

South and west slopes, which are more exposed to the sun, are drier than north and east slopes. Occasional droughts occur in areas where the soil volume is not large enough to store adequate moisture. Such is the case with shallow bedrock. Like many other foresters, I have believed that fragipans create a similar problem; however, Watt and Newhouse (1973) found no difference in growth of oaks on fragipan and nonfragipan soils in the Ozarks. Droughty spots are also found in deep soils whose sandiness or stoniness prevents them from storing enough water.

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Tree roots need oxygen for growth and survival. Upland oaks cannot endure long-term flooding and cannot grow into permanently waterlogged soil horizons. Drought sometimes affects plants growing in heavy clays that are wet in winter and dry in summer. In subsoils, aeration is so poor that roots can occupy only the area between soil peds. Then, during dry periods, available moisture may be only an inch or two from the root, but diffusion is so slow in fine clay that moisture arriving at the root is not enough for the plant's needs.

NUTRIENTS

Nitrogen is deficient in most forest sites, so a dominant tree will usually respond to added nitrogen. In the Midsouth, Graney and Pope (1978) noted growth increases in red and white oak poles fertilized with nitrogen. Nitrogen is added by rainfall and fixed by bacteria in the soil and in plant nodules. Excess nitrogen does not accumulate, because what is not tied up in organic matter is soon changed by bacteria to nitrate (NO_3^-), and unused nitrate can be leached from the soil by rainwater or used by denitrifying bacteria as a source of oxygen. So, nitrogen available to plants is always scarce.

Phosphorus is often deficient in forested sites, especially on highly leached soils, wet soils, and very sandy soils. Trees respond better to fertilizer phosphorus when it is applied with nitrogen. Potassium is occasionally deficient in forest sites, especially on highly leached, sandy soils.

Lack of other nutrients is rarely limiting to natural stands. But planting a species or even a provenance of a species in new soil situations may produce nutrient deficiencies. For example, severe iron deficiency will develop in many species when they are planted on soils with high pH or free lime.

Over long periods, weathering and leaching of soils replace basic cations (such as potassium and calcium) with hydrogen and aluminum. Replacement has been greatest in old soils, particularly the Ultasols. Upland oaks tolerate a wide range of acidity; however, pH's below 5 may begin to affect negatively the growth of several species (Williston and LaFayette 1978). Free aluminum, which is known to damage many field crops and a few forest trees, may adversely affect upland oaks.

SOIL TEXTURE AND STRUCTURE

Physical properties of the soil--texture and structure--determine how well the soil absorbs and holds water, how well air diffuses into soil, and how easily roots can push through it. Texture, mineral composition, and organic matter content determine a soil's nutrient-holding capacity. Physical properties influence root growth and vitality, which affect growth of trees aboveground.

Soil texture, the relative proportion of sand, silt, and clay in a soil, is not much affected by man or natural agents in less than a few hundred years. Soil structure, aggregations of soil particles, can be easily destroyed and is almost impossible to improve cheaply. Many of man's activities, such as running over the soil with a vehicle, damage soil structure and the root environment, especially if the soil is wet when disturbed. Insect activities, root growth, freezing and thawing, and wetting and drying will rebuild soil structure, but this renewal can take as long as 12 years (Dickerson 1976).

Erosion decreases site productivity by reducing soil depth and removing much of the site's nutrients, which are concentrated near the surface. Erosion from forest sites--even those that have been cut--is slight unless mineral soil is exposed. Most man-caused erosion in the forest is associated with roads, trails, and site preparation. To avoid erosion, minimize activities that bare mineral soil. Locate disturbance on the contour as much as possible, with barriers of covered soil below. Encourage revegetation.

SITE INDEX

A forester's main interest in soils is in how they affect tree growth. The most widely used indicator of a soil's ability to grow trees is site index--how tall a tree species can grow on a given site in a given time, usually 50 years. Site index curves have been developed for most species. So, knowing current height and age, we can project how tall the tree would be or was at 50 years old.

Trees used to determine site index should be dominants or codominants. They should not have been damaged, diseased, or suppressed at any time during their life. Accurately characterizing the site is important because management decisions are based on these estimates. Errors in choosing good site-index trees have weakened many studies and caused many sites to be misclassified.

Where suitable site-index trees are not available, factors of the environment--soil, topography, and climate--may be used to predict site index. We usually try to reduce or eliminate the influence of climate by sampling within a limited geographic area.

Topography affects soils in several different ways, such as angle of exposure to the sun and ease of drainage. The soil profile has many horizons, each with different textures and structures. And the 13 essential plant nutrients add to the mix of variables. Some soil horizons are less important than others, and many soil and topographic features are interrelated. For example, A-horizons are usually thicker on north slopes than on south slopes; thicker A-horizons have more organic matter; and total nitrogen is usually higher with increased organic matter.

The interrelationships among soil and topographic factors are so extensive and varied that it is impossible to determine how much growth is produced by each factor. So we use multiple regression procedures in choosing a few soil and topographic features to represent all of them. Soil-site index can be represented mathematically:

$$\text{Site index} = b_1X_1 + b_2X_2 + \text{------} \; b_nX_n$$

where b_{1-n} are coefficients and

X_{1-n} are representative soil and topographic features.

Influential but infrequently occurring soil factors, such as high water table, nutrient deficiency, or shallow bedrock, usually cannot be included in regression equations. Such exclusions can cause serious error for individual sites. We can compensate by estimating how excluded factors will affect trees growing on the site and by changing the site index to reflect this estimate.

Because soil composition often changes greatly every few feet, trees respond with a hodgepodge of site indexes. The task, then, is to obtain an average for the whole area. We can do this by systematically sampling the whole area or by identifying each unit of homogeneous site index or soil, obtaining its site index, and calculating an average weighted by the area of each unit.

Using soil-site prediction equations requires calculations, most with logarithms and trigonometric functions, but they can be done in the field with good handheld calculators. Site indexes from soil-site equations are based on measurements--usually percent slope; percent distance from the ridge; azimuth; depth of A1 or A1 + A2 horizons; depth to least permeable horizon; or depth to bedrock. An experienced soil scientist is often needed to identify soil horizons. Some systems require that foresters know percent sand, silt, or clay in a horizon, and even percent organic matter. These features can be estimated but are more reliably measured in the laboratory. A state agricultural testing laboratory will do this for a few dollars per sample in 2 or 3 weeks.

Foresters should test two or three soil-site systems developed for their region. The best one, tempered with experience, should give reliable predictions in most situations.

At least 15 papers give site index prediction systems for upland oaks (table 1).

Some foresters never use a "system" but, relying on backwoods "savvy," predict site index after simply looking at the trees. A more cautious approach is to combine experience with an easy-to-use plan such as Carmean's (1967), Merz's (1953), or the one below.

Certain soil and topographic factors that are easily recognized in the field occur consistently. Based on the published experience of many authors and my own observations, I have produced general descriptions of good, medium, and poor sites (table 2). Recent observation of sites in Arkansas, middle Tennessee, and north Mississippi has helped me to refine descriptions of good and poor sites and to set site index limits for each (table 3).

Table 1.--Soil-site studies on upland oaks in or near the Midsouth

Author	Oak species	Area
Arend and Odell (1948)	Mixed species	Ozarks, Arkansas
Auchmoody and Smith (1979)	Northern red, white, scarlet, chestnut, black	W. Virginia
Carmean (1965)	Black	S. Ohio
Della-Bianca and Olson (1961)	Scarlet, black, white	Piedmont
Doolittle (1957)	Scarlet, black	S. Appalachians
Gaiser (1951)	White	S. Ohio
Graney (1977)	Northern red, black, white	Boston Mts., Arkansas
Hannah (1968)	Black, white	S. Indiana
Hartung and Lloyd (1969)	Mixed species	Missouri
Hibb (1962)	Southern red, white	W. Tennessee
McClurkin (1963)	White	N. Mississippi and W. Tennessee
Smalley (1967)	Red, white	N. Alabama
Trimble (1964)	Mixed species	W. Virginia and Maryland
Trimble and Weitzman (1956)	Northern red, white, scarlet, chestnut, black	W. Virginia and Maryland
Yawney (1964)	Mixed species	W. Virginia

Good sites are generally found in bottoms, on benches, on mid- and lower slopes facing northeast, and on lower slopes facing northwest and southeast. Occasionally, other aspects and slopes are good sites, especially if they have soils recently developed from loess. Good sites almost always have deep, medium-textured, well-drained soils with less than 65 percent rock in them. Occasionally, good sites will occur in patches on broad ridges and on south or west slopes. These spots of good site are often the product of deep fertile soil or subsurface moving water. Sometimes areas that seem to be good sites support poor trees, possibly because of an imbalance in soil fertility or because of past suppression or disease.

Ridges, especially narrow ones, are usually poor sites, as are upper and midslopes facing southwest. Drought, the most common cause of poor growth, may be produced by shallow bedrock or excessive rock fragments in the soil. Shale parent material can occasionally result in poor growth.

Climate greatly influences site index. I found good sites west of the Mississippi River were 70+ for red oaks and 65+ for white oaks. Poor sites were less than 55 for red oaks and less than 50 for white oaks. East of the Mississippi, where the climate is moister, I found no difference between red and white oaks. Good sites were 80+, and poor sites were less than 65.

If properly used, these descriptions will classify a site correctly about 75 percent of the time. So the method sacrifices some precision for ease of use. Foresters should consider the advantages and disadvantages of each method for determining site index. Years of experience can outweigh

Table 2.--Description for good, medium, and poor upland oak sites in the Midsouth

Good Sites

Bottoms (with alluvial soil)
Benches
Mid- and lower slopes facing NE
Lower slopes facing NW and SE and occasionally other aspects and slopes, especially those with loess parent material

Should be:

Deep (> 3')
Medium-textured
Well-drained
Less than 65 percent rock

Poor Sites

Ridges
Upper and midslopes facing SW and occasionally other aspects

Especially with soils that have:
Shallow bedrock (< 24" deep)
Much rock or gravel

But not:

Broad ridges with deep friable soil
Loess soils

Medium Sites

Soils and aspects that fall between descriptions for good and poor sites

Table 3.--Site index limits for upland red oaks and white oaks in the Midsouth

West of Mississippi River

	Red oak	White oak
Good sites	- SI $\geq$ 70	SI $\geq$ 65
Medium sites	- SI 55-70	SI 50-65
Poor sites	- SI < 55	SI < 50

East of Mississippi River

	Red and white oaks
Good sites	- SI $\geq$ 80
Medium sites	- SI 65-80
Poor sites	- SI < 65

complex calculations and sophisticated laboratory analysis. But mathematics and chemistry can also compensate for lack of experience.

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