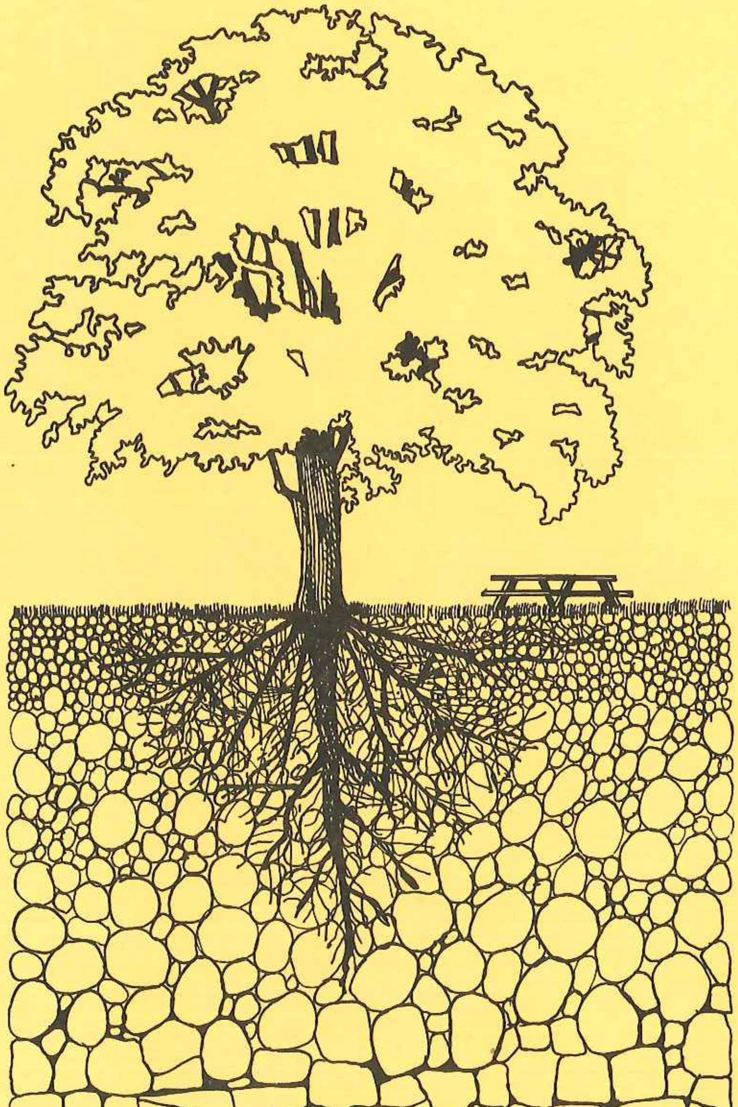
INDIANA FOREST SOILS HANDBOOK



INDIANA
DEPARTMENT OF
NATURAL RESOURCES
DIVISION OF FORESTRY

MESSAGE FROM THE DIRECTOR:

The purpose of this publication is to provide a single, although not all inclusive, source of information concerning forest soils and forest soil productivity in Indiana.

This publication was designed to be used by professional foresters but should be useful to other interested parties. It is assumed that the reader has some prior background in the area of forestry and agronomy, however extensive knowledge of either subject is not necessary.

Chapters 1 and 2 include a review of the basic principles of soil formation and basic soil properties. Chapters 3 and 4 contain a regional review of soil characteristics and a discussion on the use of published soil survey information. Chapters 5 and 6 contain a discussion of the soil characteristics that affect tree growth and a summary of techniques which can be used to assess forest site productivity.

Table 6.1 (pg. 6.55) contains the average site indexes measured on a wide range of forest soils in Indiana. This table represents the culmination of a forest soil productivity study conducted jointly by the U.S. Department of Agriculture, Soil Conservation Service and the Indiana Department of Natural Resources, Division of Forestry. Funds for the field study and this booklet were provided through a cooperative agreement between the U.S. Forest Service, State and Private, the Soil Conservation Service, and Indiana Department of Natural Resources, Division of Forestry.

It is hoped that the information contained here will further enhance the caliber of professional resource management in the state and thereby increase the contribution that forest resources make to the quality of life in this state.

James M. Ridenour

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Director
Indiana Department of Natural Resources

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SOIL FORMATION

Soil is composed of four components: 1) mineral matter, 2) organic matter, 3) air, and 4) water. The mineral fraction of the soil is composed of weathered parent material. The organic fraction is made up of plant and animal material at various stages of decomposition. In Indiana, the mineral portion of a soil can be a product of any of the following parent materials:

Residual: formed from weathered bedrock, with the soil developing in place over the underlying bedrock.

Colluvial: formed from weathered rock that has been moved by gravity to a place of lower elevation. (i.e., the soil that is formed from material deposited by a rock slide, slumps or mudslides).

Glacial drift: encompasses a wide range of material picked up, moved, and deposited by ice or water from continental glaciers. This includes glacial till (material moved directly by the ice) and outwash (material moved and sorted by meltwater from glaciers).

Alluvial: soil material moved and deposited by rivers and streams. These form some of the most productive soils in Indiana.

Lacustrine: soil material deposited from the siltation of former glacial lakes.

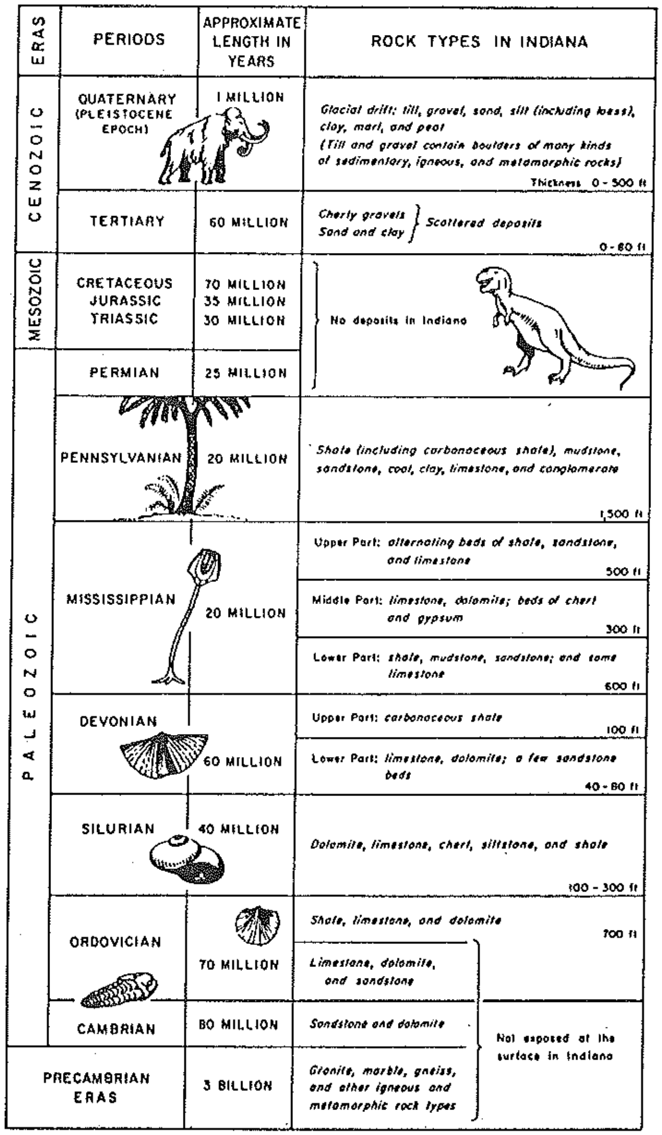
Eolian: soil material moved and deposited by wind.

GEOLOGIC HISTORY

There are three general sources of parent material in Indiana. The underlying bedrock, material deposited by continental glaciation, and materials moved about by ongoing geological processes.

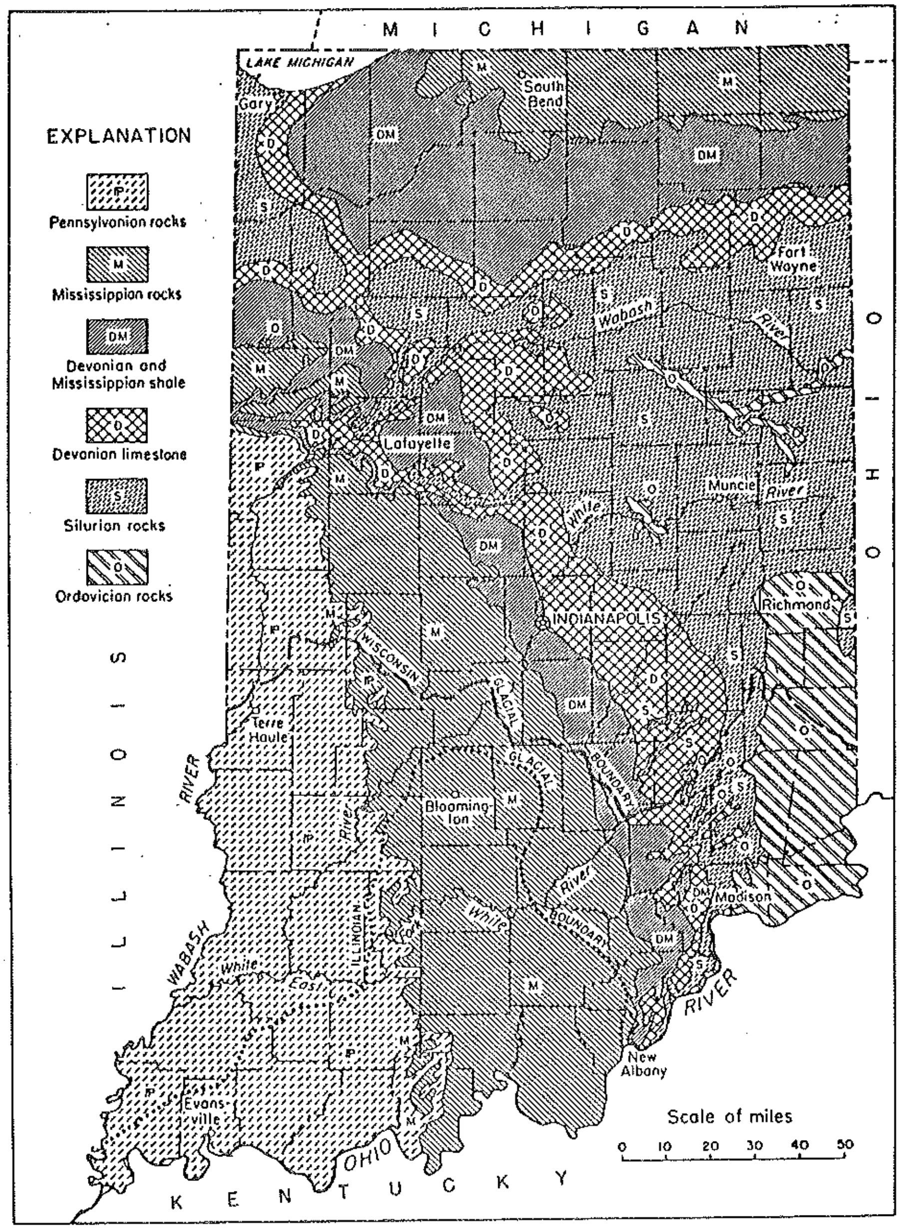
Bedrock underlying Indiana is composed entirely of sedimentary rock. This rock formed in place by the deposition and cementation of minerals, shells of organisms, or rock fragments or by precipitation of salts from solution. In general, Indiana bedrock is youngest on the west side of the state and oldest on the east side. Figures 1.1 illustrates the 'Geologic Time Scale'. Figure 1.1 provides an idea of the time frame involved when considering the ages of certain bedrock layers in relationship to the different periods of glaciation. In this table, eras and periods are listed along with their duration in years and the rock types formed during each of these periods. Figure 1.2 is a generalized bedrock geology map of Indiana, and gives the age and locations of bedrock outcropings in Indiana.

All of Indiana's bedrock layers dip gently, slanting to the west and southwest. The youngest bedrock (Pennsylvanian era) was formed over



ERAS	PERIODS	APPROXIMATE LENGTH IN YEARS	ROCK TYPES IN INDIANA
CENOZOIC	QUATERNARY (PLEISTOCENE EPOCH)	1 MILLION	*Glacial drift: till, gravel, sand, silt (including loess), clay, marl, and peat (Till and gravel contain boulders of many kinds of sedimentary, igneous, and metamorphic rocks)* Thickness 0 - 500 ft
	TERTIARY	60 MILLION	*Cherty gravels / Sand and clay* } *Scattered deposits* 0 - 60 ft
MESOZOIC	CRETACEOUS / JURASSIC / TRIASSIC	70 MILLION / 35 MILLION / 30 MILLION	No deposits in Indiana
PALEOZOIC	PERMIAN	25 MILLION	No deposits in Indiana
	PENNSYLVANIAN	20 MILLION	*Shale (including carbonaceous shale), mudstone, sandstone, coal, clay, limestone, and conglomerate* 1,500 ft
	MISSISSIPPIAN	20 MILLION	Upper Part: *alternating beds of shale, sandstone, and limestone* 500 ft
			Middle Part: *limestone, dolomite; beds of chert and gypsum* 300 ft
			Lower Part: *shale, mudstone, sandstone; and some limestone* 600 ft
	DEVONIAN	60 MILLION	Upper Part: *carbonaceous shale* 100 ft
			Lower Part: *limestone, dolomite; a few sandstone beds* 40 - 80 ft
	SILURIAN	40 MILLION	*Dolomite, limestone, chert, siltstone, and shale* 100 - 300 ft
	ORDOVICIAN	70 MILLION	*Shale, limestone, and dolomite* 700 ft
			Limestone, dolomite, and sandstone } Not exposed at the surface in Indiana
	CAMBRIAN	80 MILLION	*Sandstone and dolomite* } Not exposed at the surface in Indiana
PRECAMBRIAN ERAS		3 BILLION	*Granite, marble, gneiss, and other igneous and metamorphic rock types* } Not exposed at the surface in Indiana

FIGURE 1.1 Geologic time scale and bedrock layers formed in each geologic period (IDNR, 1980a).



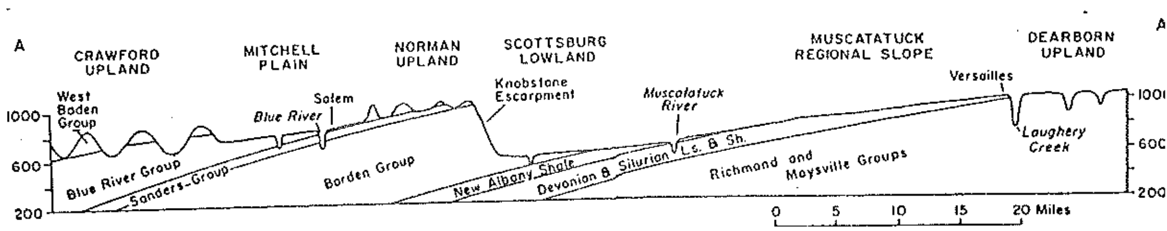


FIGURE 1.2 Bedrock in Indiana (Indiana Academy of Science, 1966)

220 million years ago (MYA) in the western part of central and southern Indiana, and is known for its coal deposits. The oldest bedrock in Indiana is Ordivician, which formed over 360 MYA, and is found in the eastern part of southern Indiana.

In the past one half million years (Quatenary period) Indiana was influenced by continental glaciers, similar to the ice sheet that covers much of Antarctica. These vast ice sheets are thought to have been as much as three kilometers thick in Indiana. Continental glaciers are different from the alpine glaciers found in mountainous areas of the U.S. today.

Continental glaciation in the United States was caused by climatic fluctuations and by the same uplifting movements in the earth's crust that formed mountains on the North American continent. These basic changes caused continental glaciers to form in Canada and spread across the northern midwest.

There are four known glacial episodes: the Nebraskan, Kansan, Illinoian and Wisconsinan. Only the latter three are thought to have altered Indiana's topography. Figure 1.3 shows the extent of the last three ice ages in Indiana. The Nebraskan glacial age occurred somewhere between 1½ to ½ MYA (Million Year Ago). The second glacial episode, the Kansan, occurred between 1 MYA to 200,000 years ago. It covered the majority of Indiana and the material it deposited is considered the oldest glacial drift found in the state. The Illinoian glacial episode followed the Kansan age between 400,000 and 125,000 years ago. The most recent glacial episode, the Wisconsinan, began about 70,000 years ago and achieved maximum coverage of Indiana 21,000 years ago.

Interglacial periods (i.e., between periods of glaciation) were characterized by warm temperatures, stream dissection and general weathering of the landscape formed by the previous ice age. The influence of continental glaciation on the soils of Indiana is highly significant and has given Indiana some of the most fertile soils in the world. The glaciers are responsible for depositing material (glacial drift) that was composed of material scraped and moved from the area of the glaciers' origin and laid down in Indiana.

This glacial drift is composed of a variety of materials:

<u>Glacial till</u>: material that is unsorted by water that is moved directly by ice.

<u>Glacial outwash</u>: sorted drift deposited by melt water from glaciers.

<u>Laustrine deposits</u>: material left from glacial melt water lakes.

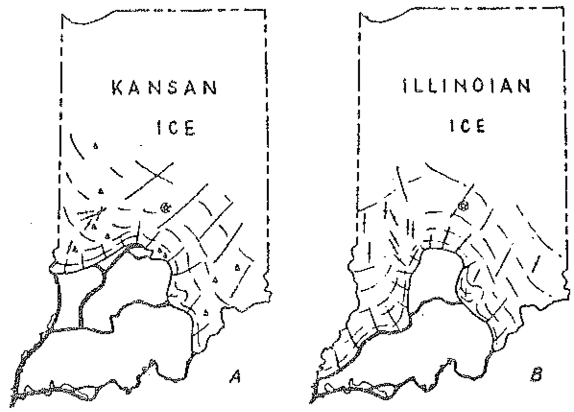


Fig. 12. Maximum extent of ice in Indiana during the Kansan and Illinoian glacial ages, showing striation directions, inferred ice flowage, drainage lines, and locations of significant exposures of Kansan till. A—Kansan ice. B—Illinoian ice.

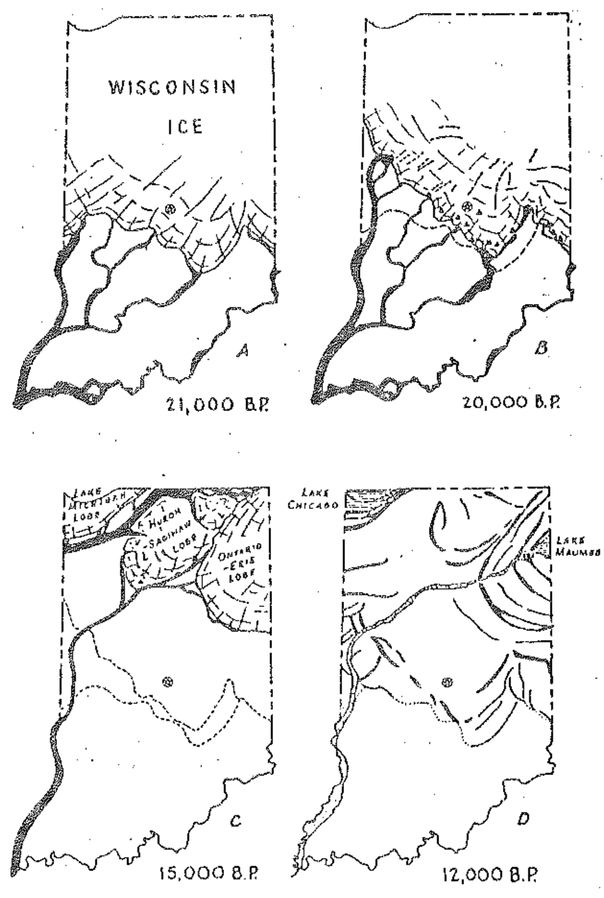


Fig. 13. Wisconsin glaciation of Indiana. A—Maximum extent of glacier (about 21,000 years ago). B—Wisconsin second maximum (about 20,000 years ago). C—Location of Wisconsin ice (about 15,000 years ago). D—Wisconsin morainal trends and extent of glacial Great Lakes (about 12,000 years ago).

FIGURE 1.3 Glacial history in Indiana (Indiana Academy of Science, 1966).

Loess deposits: Windblown deposits (aeolian sands and silts) are wind deposited material from dried glacial melt water, lakes and streams. Technically, this is not considered glacial drift.

Indiana is divided into two general areas: the glaciated areas which were covered by one or more continental glaciers, and unglaciated areas. The majority of the state has been effected by glaciation (Figure 1.3). However, a finger shaped area in the south central part of the state ('knobs area') is unglaciated. The soils in the unglaciated area are residual soils; that is, they were formed in place over the bedrock. In this region bedrock outcroppings are common and the influence of the glaciers is minimal. However, many of the soils in this area are covered by a cap of loess or wind blown glacial material.

SOIL DEVELOPMENT PROCESS

There are five main factors that are responsible for the formation of Indiana's soils: 1) parent material, 2) time, 3) relief, 4) climate and 5) organisms. The following sections will explain how these five factors have produced the soils that are present in Indiana today. It is assumed that the reader has a prior knowledge of the basic properties of soil (texture, water movement, organic matter content, etc.). A review of section II may be useful to those with a limited background in soil science.

PARENT MATERIAL

Parent material exerts a significant influence on soil development determining to a large degree the final soil texture, chemical composition and degree of stratification.

Different minerals weather at different rates. Obviously the more rapidly parent material weathers the faster soil may form. Soils formed from weathered shale and limestone will have a finer texture than those formed from weathered sandstone. Soils formed from fine textured parent material evolve more slowly than those from coarse textured materials.

Soils which develop from fine textured parent material (whether parent material is bedrock or glacial deposits) will tend to have a higher organic matter content than those formed from coarser parent material. Fine soil textures have a greater capacity to store water and nutrients and are therefore more conducive to plant growth (providing other soil characteristics do not act to limit plant growth). Fine textured soils are also less well aerated which retards the rate of organic matter decomposition. As a result organic matter is produced more rapidly on fine textured soils but is broken down more slowly.

Well drained, coarse textured soils hold less water for plant growth and produce less organic matter. These soils are more permeable. As a result, leaching and weathering occur rapidly and organic matter is broken down before it can accumulate.

Certain parent materials tend to be more acidic than others. Soils formed from weathered limestone for example, tend to be less acidic then those formed from sandstone. The degree of acidity (as measured by pH) affects the rate of weathering and leaching. Limestone soils, for example, tend to develop more slowly.

Finally, the degree to which parent material was originally stratified also influences soil development. Soils which developed in-place over bedrock, formed more slowly than those formed over glacial till.

The rate of soil development on glacial till is determined by the texture of the original parent material, which was largely determined by how the material was transported and laid down.

Water Deposited Sediments:

Rivers created by melting glaciers moved considerable quantities of parent material (alluvium). As rivers flowed over their floodplains they deposited the heaviest and largest sized particles closest to the river bank, and the smallest particles furthest from the bank. In this manner, large quantities of sand, silt and clay sized particles were distributed over vast areas. Because the character of the sediment carried by rivers varied each year, as did the extent and duration of spring flooding, alluvial deposits are usually stratified with layers of different sized particles over-lying each other. The heavier sand sized particles were deposited when the speed of water slowed, while clay and silt sized particles were carried further to settle out in slow moving water and lakes. In this way lakes, floodplains and depressions filled with silt and formed lacustrine plains.

Glacial Deposited Material:

As glaciers moved across the landscape they pushed before them, and gathered up within them, quantities of unconsolidated parent material. Movement of the ice sheets was determined by climatic conditions which varied even within periods of glaciation. Through this pattern of progression and recession, gently rolling till plains and steeper (terminal or lateral) moraines were formed. Moraines are usually made up of unsorted material ranging in size from minute clay particles to boulders. The character of this material varied considerably from place to place and both till plains and moraines were later altered by water movement and wind.

Glaciers did not advance and recede smoothly, but rather ebbed and flowed with climatic changes. Because of this pattern glaciers layed down new material over older deposits and altered that which had been layed down previously.

Wind Deposited Material:

During the dry periods which followed the retreat of the glaciers, the wind moved soil particles over great distances. During these periods, fine wind blown particles (loess) were distributed over much of the central United States. This phenomenon has probably had its greatest impact in southern Indiana, where many ridges are covered with a loess (wind blown) silt cap. Where this cap is very thick, the A and B horizon may have formed from loess, while the C layer was formed from bedrock. Where this loess cap was thinner, only the A horizon may have formed in loess, while the B and C horizons may have formed from bedrock or glacial till.

Organic Parent Material:

The retreat of the glaciers formed many depressional lakes of varying sizes. In some parts of Indiana these became swamps or bogs. In these areas, aquatic vegetation grew rapidly and decomposition of plant material was limited by excess water. These conditions led to the accumulation of peat. As the lakes filled in and dryed up, the peat began to decay producing muck soils which are extremely high in organic matter.

TIME

Soils do not develop at the same rate and are constantly evolving. Soils are said to be young, mature or old depending on the extent of soil profile development. Most of Indiana's soils are mature, although there are a few which have characteristics similar to older soils.

The terms old and young, as applied to soil development, can be misleading in that they imply that soil classification is based on their age rather than on the degree of soil profile development. Young soils are characterized by a simple profile such as a thin layer of organic material over the original parent material. As weathering (or breaking down) of the parent material progresses and as organic matter is leached from the surface layers, a soil's horizons begins to differenciate and develop different characteristics. A mature soil profile has three or more distinct horizons. As soils mature organic matter and fertile generally increase. However, as weathering and leaching progress further, organic matter and fine particles are leached from the surface layer and accumulate in lower layers. This may leave a surface layer that is acidic, infertile and low in organic matter. Many soils that have a thick, fine-textured B horizon, have characteristics similar to old soils.

Time is a significant factor in this process, but the rate of soil profile development varies greatly from location to location and is effected by other factor which will be discussed further in this section.

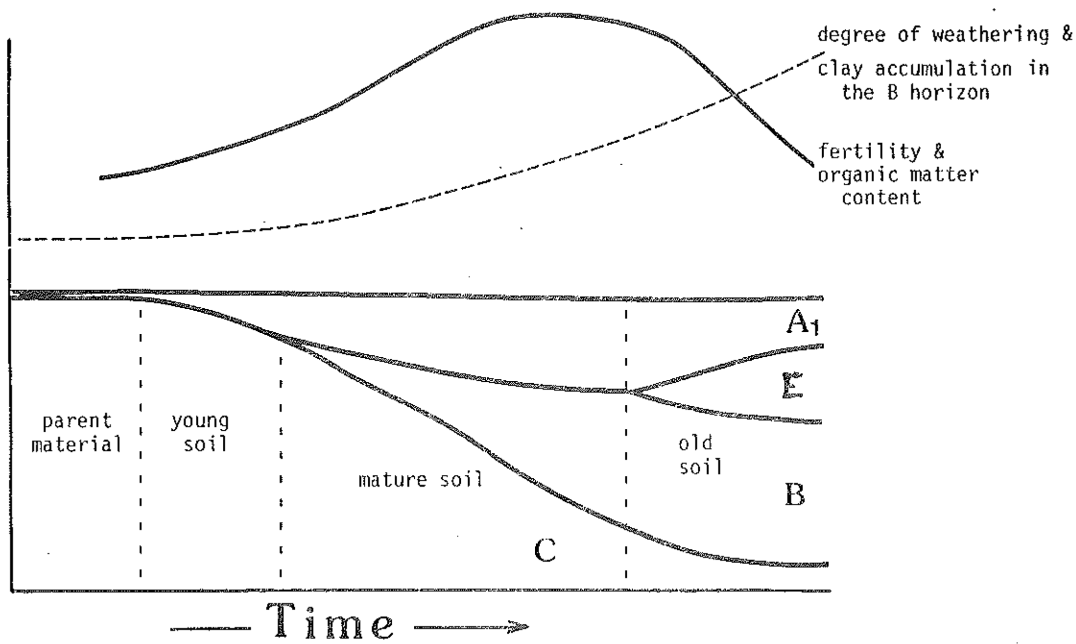


FIGURE 1.4 The development of a typical soil profile over time.

In general conditions that tend to:

increase the rate of horizon development:

1) warm, humid climate
2) forest vegetation
3) permeable, unconsolidated parent material low in lime
4) flat or depressional topography with good drainage

retard development:

1) cold or dry climate
2) grass vegetation
3) impermeable, consolidated parent material high in lime content
4) steeply sloping topography.

TOPOGRAPHY

Topography influences soil profile development primarily through the influence it exerts on water movement. On steep sites water is more inclined to run off rather than percolate down through the soil horizon. This runoff moves surface materials from one location to another affecting soil profiles at both the erosion site and the site of deposition. Water that runs off an area is not available to percolate down through the soil profile. This limits the movement of material from upper to lower layers in the soil profile. The less water that moves down through the soil profile, the less water that will be available for plant growth. Drier sites of course produce less total biomass and consequently organic matter accumulates more slowly.

Generally, steep slopes retard soil profile development causing sloping soils to have thinner surface layers, less organic matter and less conspicuous differentiation between soil layers, than soils on level ground.

CLIMATE

Climate affects soil development through its influence on plant growth, precipitation and soil microbial activity. All other things being equal, warm moist climates being more conducive to plant growth, increase the rate at which organic matter accumulates. Increased precipitation, speeds the rate of weathering of parent material and clay formation. Finally, warm moist climates are more favorable to microbial activity leading to a rapid breakdown of plant material. Because of these influences, warm moist climates increase the rate of soil development, while warm and dry, cold and dry, and cold and moist climatic conditions tend to slow the rate of soil development.

Annual precipitation in Indiana varys from 36 inches in the north to as much as 46 inches in the south. Temperatures can vary widely at any given time of the year in Indiana especially around Lake Michigan, which moderates the climate in the northwest Indiana by warming the surrounding land in winter and cooling it in summer (Figures 1.5 and 1.6). In a small area due east of Lake Michigan, snowfall amounts are significantly greater than anywhere else in the state. The lake (in combination with other factors) causes the northern half of the state to have a greater number of cloudy days during the year than what is characteristic for other parts of the state. Urbanization and industrialization of areas surrounding Lake Michigan (Gary, Hammond, East Chicago) cause local changes in climate, such as slight increases in temperature and precipitation.

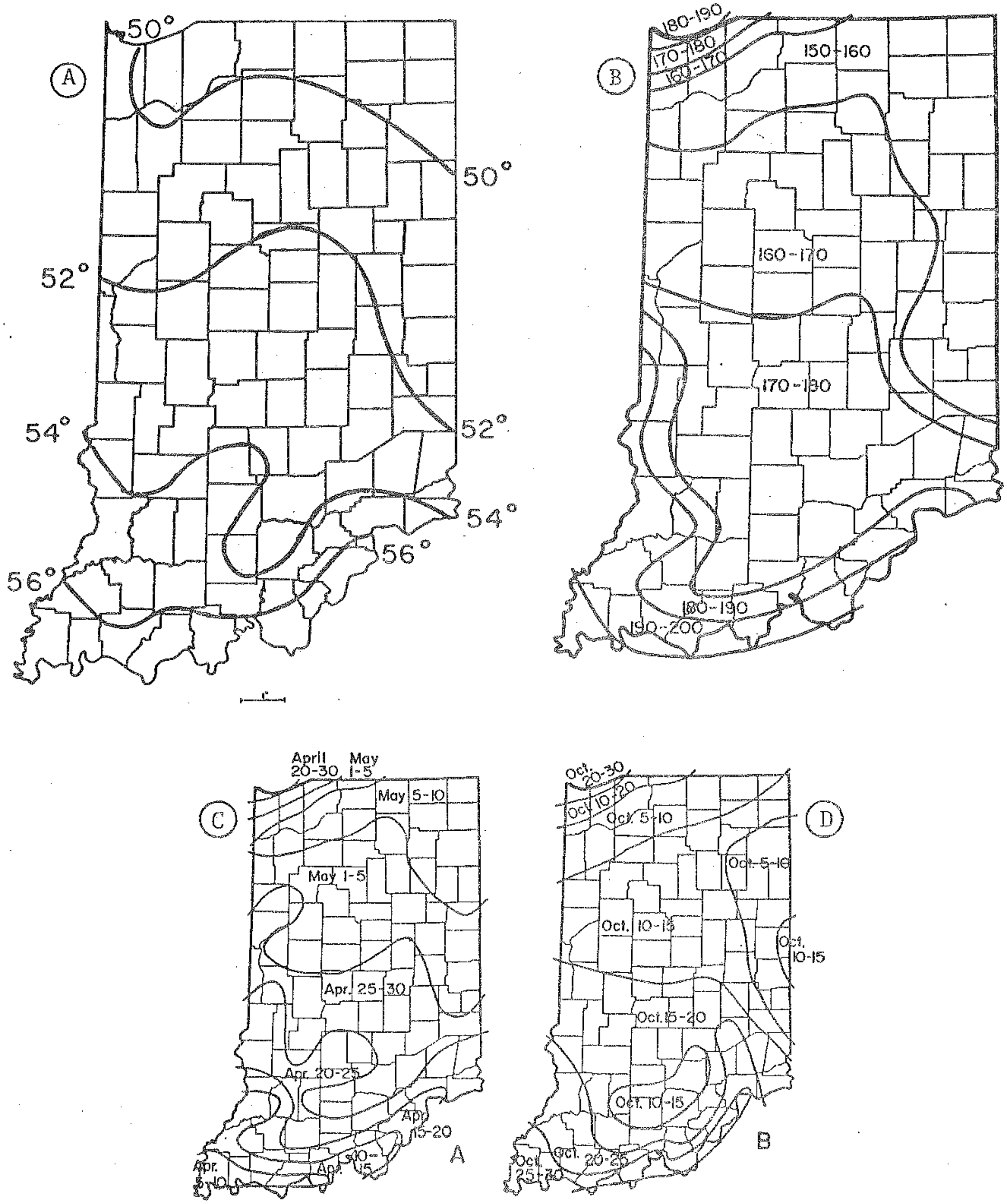
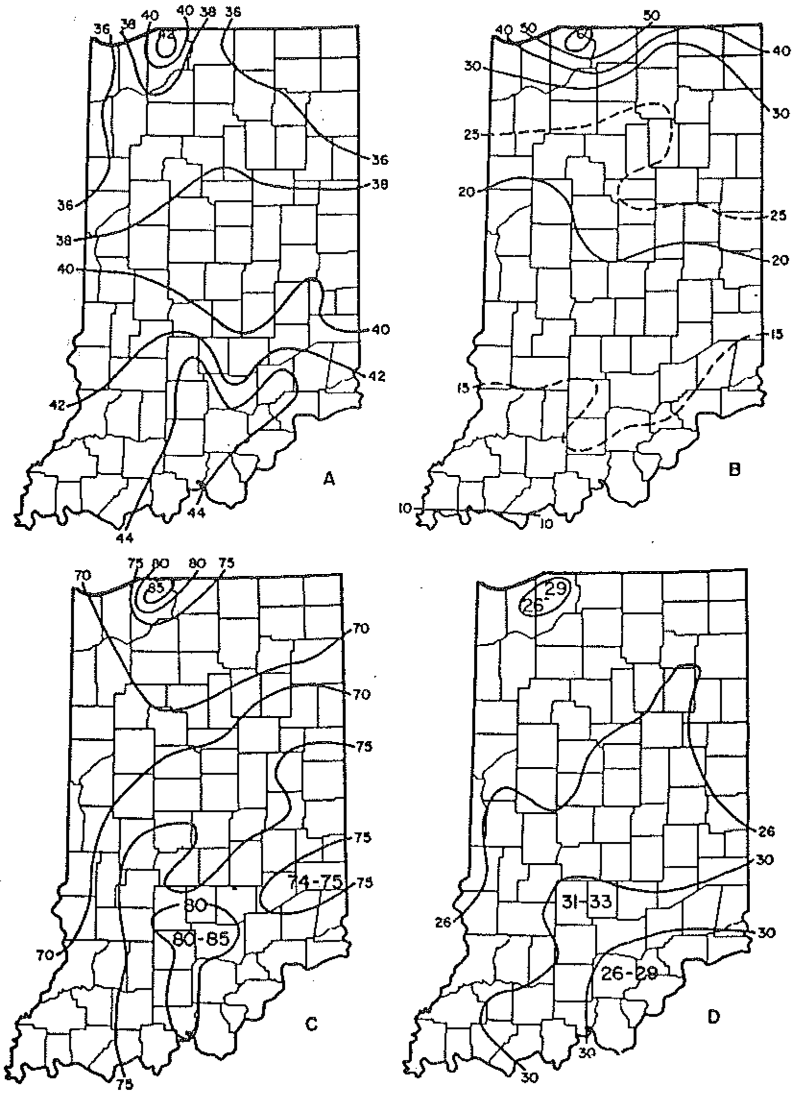


FIGURE 1.5 Temperatures in Indiana: A) average annual temperature (degrees F) (IDNR, 1980a), B) average frost free growing season (days/yr.) (Indiana Academy of science, 1966), C) Average daye of last temperature of 32° F in spring (ibid), D) average date of first temperature of 32° F in fall (ibid).



A—Normal annual precipitation (1931-1960); B—Mean annual snowfall (inches) (1931-1960); C—Mean annual number of days precipitation exceeds 0.1 inch (1951-1960); D—Mean annual number of days precipitation exceeds 0.5 inch (1951-1960).

FIGURE 1.6 Precipitation in Indiana (Indiana Academy of Science, 1966)

VEGETATION

The rate of soil development is affected by the type of vegetation present. Most of Indiana's soils formed under forested conditions. However, Indiana has some areas (e.g., prairies, sand dunes and glacial lakes) where grasses played a significant role in soil development (Figure 1.7).

In soils that formed under grassland, organic matter content is greater and is more uniformly distributed through the soil profile. Forest soils are lower in organic matter and organic matter tends to be concentrated in surface layers (Figure 1.8).

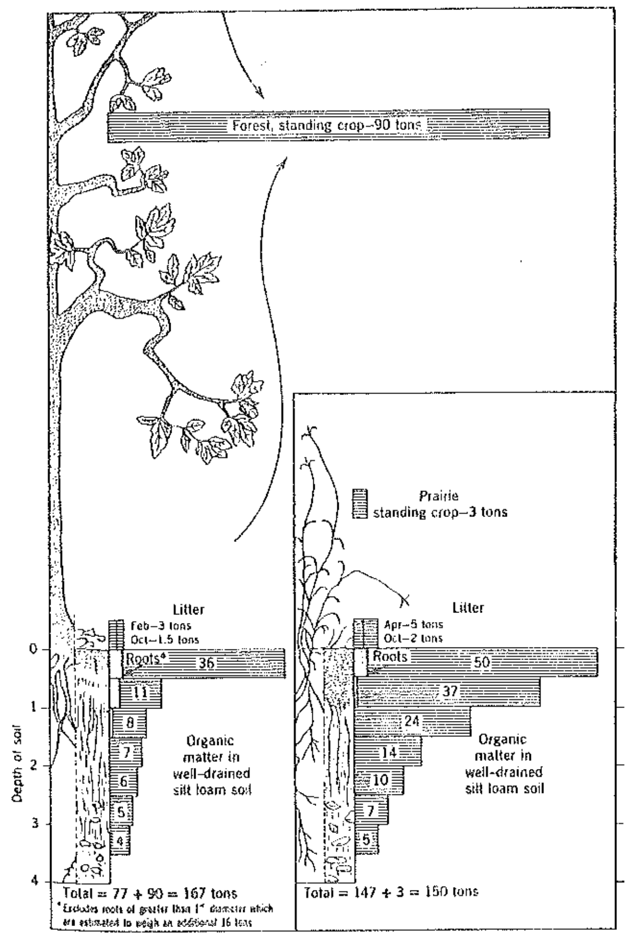


FIGURE 1.8 Distribution of organic matter in soils formed under forest and pairie vegetation.

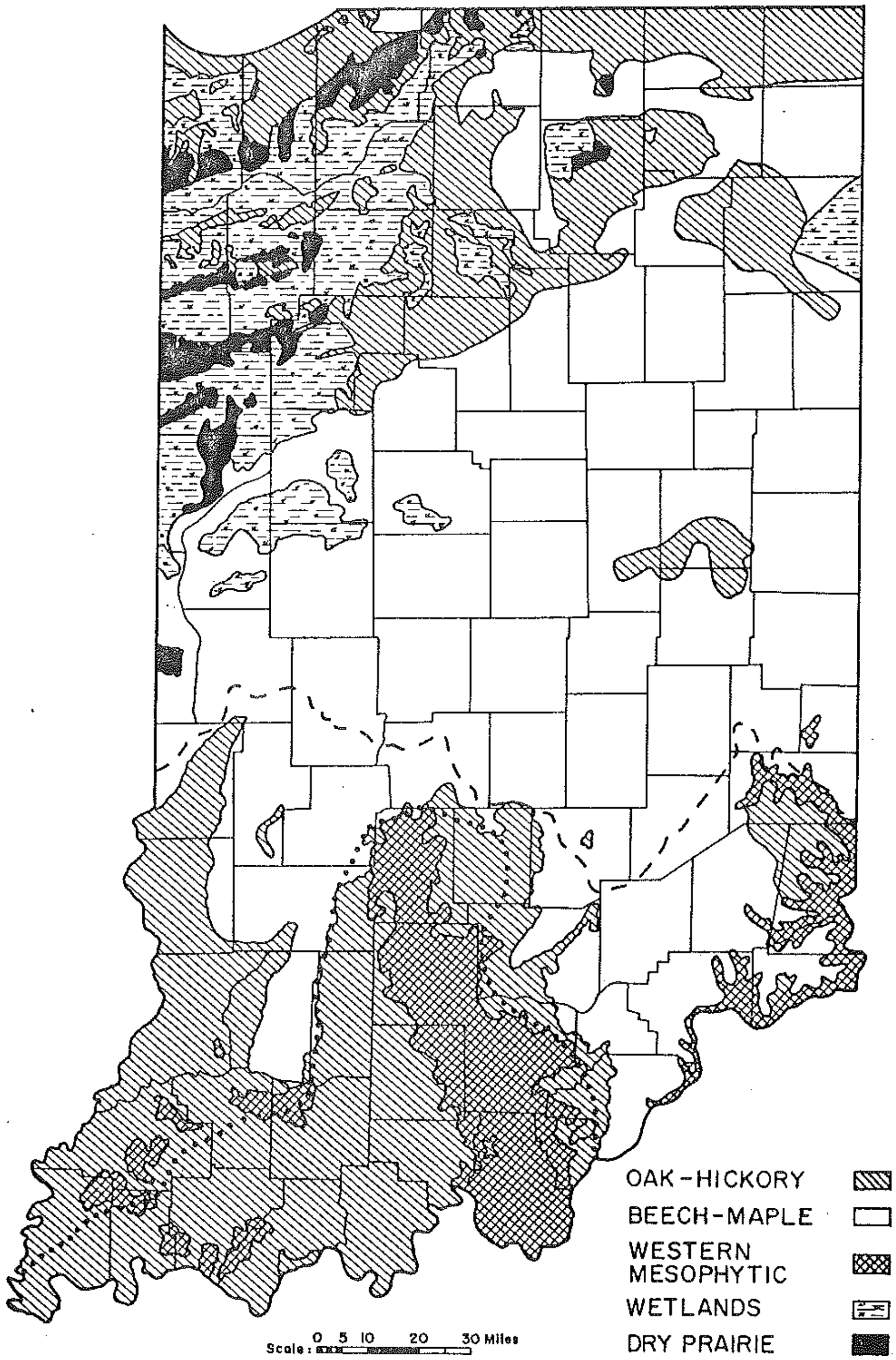


FIGURE 1.7 Presettlement vegetative distribution patterns in Indiana (based on 1816 land survey records) (Indiana Academy of Science, 1966)

Except for poorly drained soils, leaching of organic matter and clay particles occurs more rapidly in forest soils. As a result, soils forming under forests generally appear to be more weathered.

The climatic forces acting on the two soils represented above were the same and their profiles may be remarkably similar in old age, but the time required to produce an old-age-like profile is significantly longer in grasslands than in forestland.

SUMMARY

Soil development in Indiana was affected by parent material, climate, time, topography, and vegetation. Glaciers had a tremendous influence on the soils in the northern two-thirds of the state and a lesser (although significant) influence on the southern third. Material deposited by glaciers, sorted by water and blown about by the wind had a major influence on the soils we see today.

This chapter could create the impression that soil development in Indiana was a rather orderly and smooth progression from the last ice age to today. From an overall perspective, this impression is fairly realistic. However, locally, soil formation was most likely affected by random catastrophic events which produced the variation in soils we see today.

One of the most significant of these catastrophic events would include the activities of man. Fires caused (or set) by Indian's and by early settlers surely had their effect on vegetative patterns and probably caused erosion in many cases.

At one time Indiana was approximately 87% forested. Today only 17% of the state is forested. This massive conversion of forestland to cropland and grassland has resulted in accelerated erosion which in many cases altered existing soil properties.

Changes in the hydrologic cycle brought about by changing land use patterns and by drainage projects have likewise affected the moisture regimes of some depressional and bottomland soils. Because of the powerful and seldom gentle (or controlled) influence of man, Indiana's soils have been altered radically in the last 100 years.

PHYSICAL SOIL PROPERTIES

SOIL HORIZONS

Soils are characterized by their profiles. A soil's profile is a cross sectional look at the layers (or horizons) making up the soil. A profile may be simple or very complex. Soil scientists have devised a classification system to refer to these layers. Figure 2.1 provides a generalized look at how this classification system works. Variations in soil properties at different depths are used to categorize individual soils into soil types.

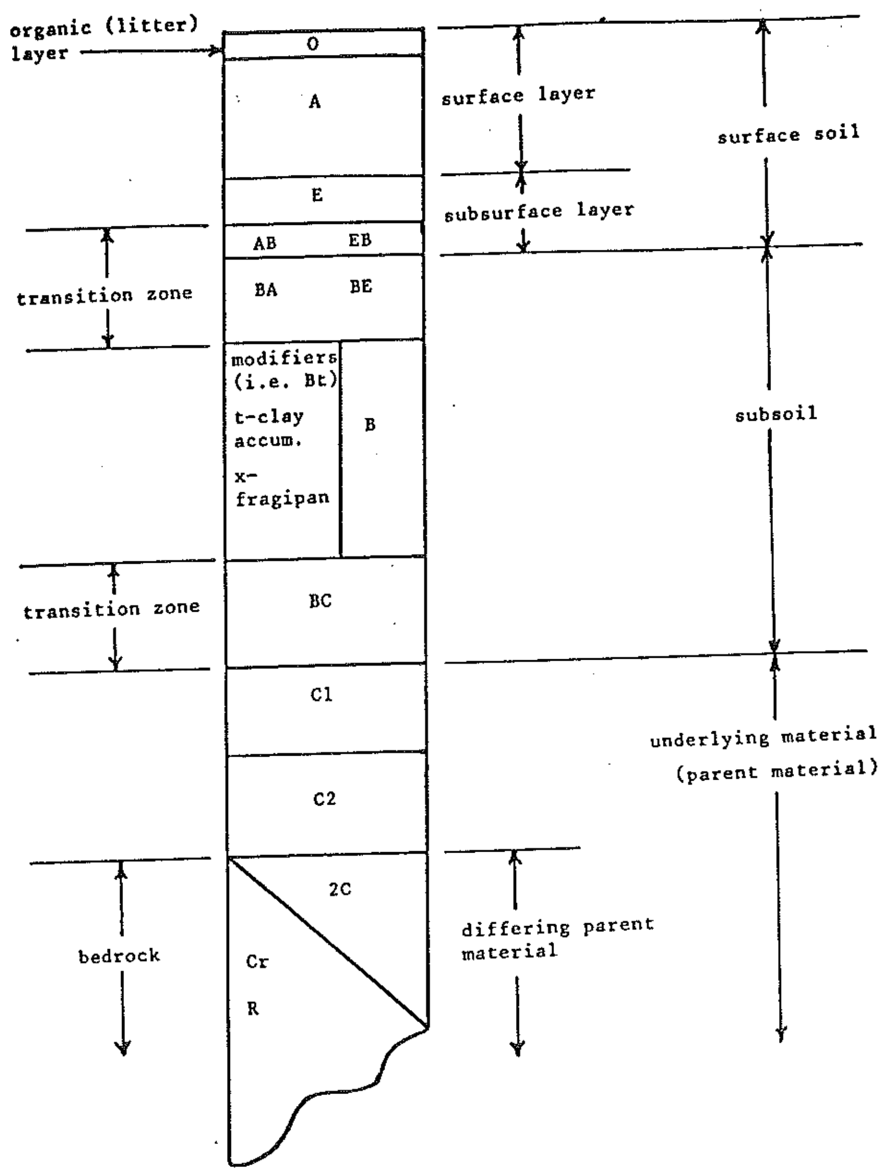


FIGURE 2.1 General soil profile.

SOIL TEXTURE

Soil texture is defined as the relative proportion of sand, silt and clay sized particles that make up soil (Table 2.1). Soil texture governs the amount of surface area per unit volume of soil available for chemical bonding. This in turn determines the rate and extent of chemical reactions, which influences a significant portion of the soils physical and chemical properties.

TABLE 2.1

	PARTICLE SIZE (dia., mm)	NO. OF PARTICLES[a] PER GRAM OF SOIL	SURFACE AREA IN 1 GRAM OF SOIL (cm^2)
Sand	2.0-.05 mm	90	11
Silt	.05-.002	5.7×10^6	454
Clay	.002	90.2×10^9	8.0×10^6

[a] assumes particles to be spheres with a diameter equal to the largest permitted within the range listed.

The proportions of these three particle sizes, mixed together, determine a soil's textural class. The textural class triangle (figure 2.2) shows the various categorize used.

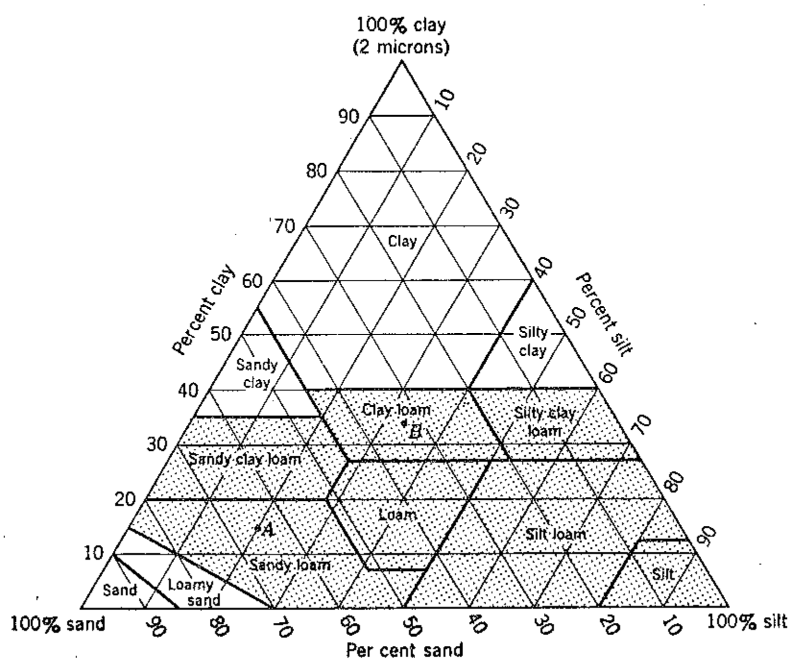


FIGURE 2.2 Soil textural triangle (Foth and Turk, 1972). Point A represents 15% clay, 65% sand and 20% silt. Point B represents a soil containing equal amounts (33.3%) of each.

The texture of a soil can be divided into two parts, the fine fraction and the coarse fraction. The coarse fraction of a soil is composed of particles larger than 0.05 mm in diameter and includes sand, gravel, and stones. The coarse fraction has a minor role in supplying nutrients to the tree but plays an important role in soil aeration and in providing physical support for the tree. The fine fraction of the soil is composed of all soil particles that are less than 0.05 mm in diameter which includes all silt and clay sized particles. Because of the small size of the individual particles, the fine fraction represents a major portion of the surface area in the soil and is the source of the soil's water and nutrient holding capacity.

Sandy (or coarse textured) soils are typically well aerated, highly permeable (well drained), but lack water holding capacity. As a result sandy soils are often droughty.

Clayey (or extremely fine textured) soils are poorly aerated, are impermeable (poorly drained) and hold substantial amounts of water. Despite their high water holding capacity, this water maybe unavailable for plant use.

Loamy soils are usually the best soils for growing trees. Woodland productivity tends to decrease as soil textures move toward the extremes; clay or sand. Exceptions can always be found in nature, but in general loamy textured soils are the most productive. In figure 2.2, the shaded area represents loamy soils.

Loamy textured soils hold more available water than both sandy and clayey textured soils. Loamy soils permit adequate drainage and soil aeration, while supplying substantial amounts of the nutrients that are important for tree growth.

Soil texture varies with soil depth. The name of a soil mapping unit may include a textural class, but this only refers to the texture of the surface layer.

Subsoil texture and structure influence tree roots a great deal. Productivity and tree growth will decrease where subsoil textures are heavy (heavy textured soils have high percentages of clay-sized particles). High clay content in the subsoil, causes poor internal drainage which in turn causes poor aeration of the subsoil and hence, poor root development. Site quality will also decrease where the subsoil is coarse textured. In this case, rooting is restricted by excessively drained conditions and a lack of nutrients.

Subsoil layers can greatly restrict root penetration. Fragipans are dense, fine textured and relatively brittle layers in the subsoil that are slowly permeable to water and air. Fragipans can totally or partially limit root growth. Similarly, compact glacial till layers, formed by the continental ice sheet (Wisconsinan aged) twenty thousand years before, can also restrict root growth. Cemented layers, like "ortsteins" are occasionally found in extreme northwest Indiana along Lake Michigan but are not very significant. They are indurated (cemented subsoil that will not soften when wet) layers of subsoil cemented by iron and organic matter restrictive to roots and slowly permeable to water.

SOIL STRUCTURE

Soil "structure refers to the aggregation of primary soil particles (sand, silt, clay) into compound particles, or clusters of primary particles" (Foth & Turk, 1972). Soil structure influences soil aeration, drainage, nutrient availability and root growth.

Seven basic soil structural classes are recognized, granular, crumb, plate angular, blocky, subangular blocky, prismatic, and columnar.

Air spaces in the soil between aggregates are larger than those that could exist between individual particles of sand or silt. The large pore spaces created by soil aggregates (macropore spaces) facilitate aeration, soil permeability, and root penetration. Soil structure (the degree and type of aggregation) usually varys between layers in a soil profile.

Aggregates do not form in every soil, and two structure-less classifications are recognized: single-grained and massive. Single-grained, as its name would imply, simply means that the individual soil particles do not aggregate into groups. This usually occurs in sandy soils. Massive soil aggregates can occur in soils that have been compacted by machinery or livestock when wet. Upon drying the soil forms large clods. This is commonly referred to as puddled.

A more comprehensive discussion of aggregate formation and behavior is beyond the scope of this booklet. An agronomy textbook would be a good source of additional information on this subject.

SOIL PORE SPACE

Plants need both water and oxygen from the soil to survive. Soil is comprised of solid particles and aggregates of particles. Between the individual particles and aggregates of particles, are pores of various sizes. Two general sizes of soil pores are recognized: macropores (large) and micropores (small). These pores are associated with aeration and water movement. Both the total volume of pore space and the ratio of large to small pores influence soil properties.

The proportion of large to small pores is a function of a soil's texture and, to a lesser extent, structure. Fine textured soils have more total pore space, but very few large pores. While on the other hand, coarse textured soils have less total pore space, most of which is in the form of large pores.

TABLE 2.2

SOIL TEXTURE	TYPICAL BULK DENSITY	PERCENT SOLID	PERCENT AIR SPACE
Fine (clayey)	1.0	37.7%	62.3%
Medium (loamy)	1.3	49.7%	50.3%
Coarse (sandy)	1.8	67.9%	32.1%

The distribution of total pore space varies with depth, as does the ratio of large to small pores. Figure 2.3 illustrates the distribution of pore spaces through a mature soil profile. Other soil properties associated with the amount and distribution of pore space will be discussed in the following sections.

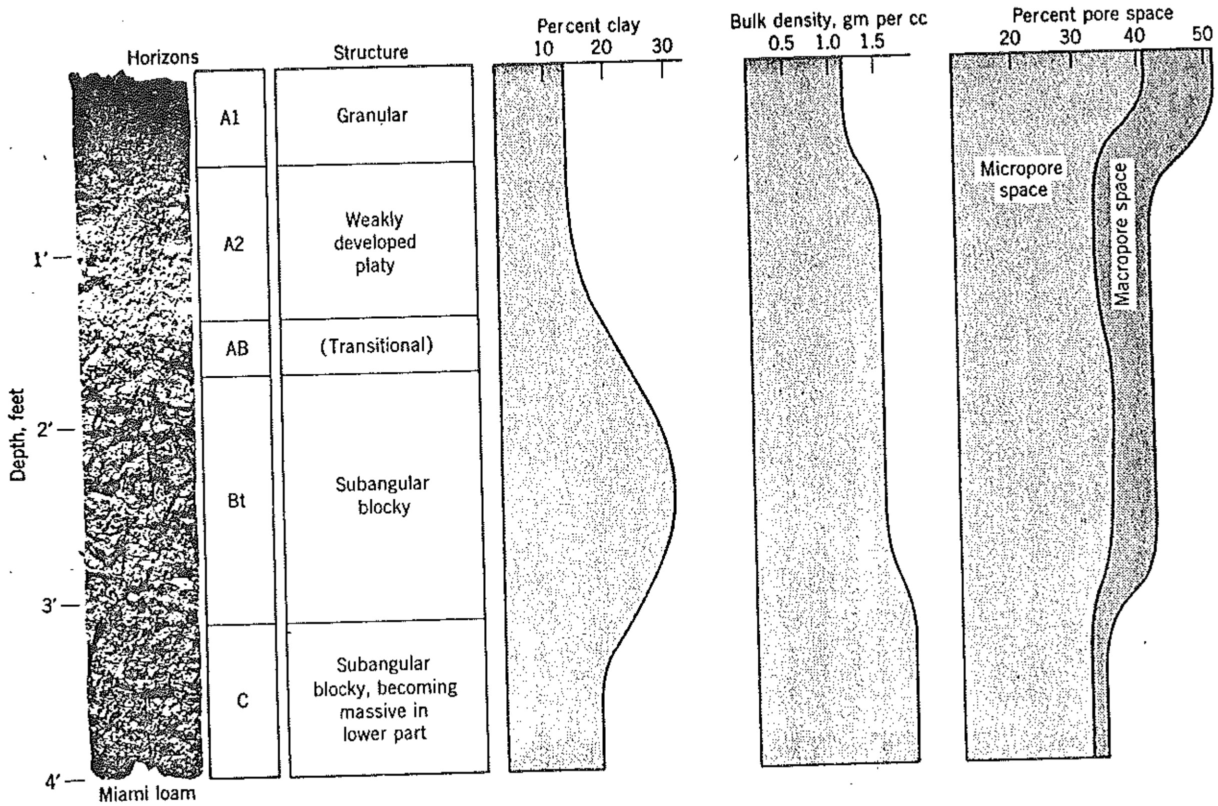


FIGURE 2.3 Percent clay content, bulk density and percent pore space at varing depths through mature soil profile.

BULK DENSITY

Bulk density is a measure of the total pore space in a soil. Bulk density (B.D.) is the weight per unit volume of oven dry soil expressed in grams per cubic centimeters (g/cm^3).

$$\text{BULK DENSITY } (g/cm^3) = \frac{\text{weight of oven dry sample of soil (grams)}}{\text{volume of sample } (cm^3)}$$

For all practical purposes individual soil particles can be assumed to have the same density (weight per volume), irregardless of particle size. Consequently, the higher the bulk density of a sample of soil, the less air space it will contain. Conversely, the lower the bulk density for a sample of soil, the higher the portion of pore space in the soil.

The bulk density of fine textured soils usually range from 1.0 to 1.3 g/cm^3 and coarse textured soils range from 1.3 to 1.8 g/cm^3. 2.65 g/cm^3 is generally accepted as the average density of soil particles. The bulk density of a soil sample, divided by this constant, yields an indication of the proportion of the sample made up of solid matter.

$$\frac{\text{B.D. } g/cm^3}{2.65\ g/cm^3} \times 100 = \underline{\quad\quad} \text{ \% solid matter}$$

Using the above formula and substituting the bulk density of a loamy soil (approximately 1.3 g/cm^3) would reveal that 50.3% of the soil is made up of solids, and 49.7% is made up of pore space.

$$\frac{1.3\ \ g/cm^3}{2.65\ \ g/cm^3} \times 100 = 50.3\%$$

SOIL WATER

Water is held by soil particles by the same molecular forces that hold all matter together. Surrounding every soil particle (and air-borne dust particles for that matter) is a thin film of water molecules. The water molecules are chemically bonded to the particle. In the soil this water is referred to as hygroscopic water and is unavailable to plants because of the amount of energy needed to break these bonds.

Beyond this layer of hygroscopic water is a thicker film of water held to the hygroscopic water by hydrogen bonds. This water is 'capillary water'. The forces which hold this water can be illustrated by observing the behavior of a bead of water on a freshly waxed car.

The same attractive forces that allow the drop of water to hold its shape on the hood of a car are the same that hold capillary water to hygroscopic water surrounding the soil particle.

The closer a water molecule is to the soil particle the more tightly it is held and the more energy a plant will have to exert to draw it away.

The energy with which water is held by soil particles is called soil moisture tension (SMT) and is measured in atmospheres (1 atmosphere = 14.7 pounds per square foot).

Water in unsaturated soil is said to be under tension. This tension increases with increasing distance above the water table. The availability of water in the soil to plants is primarily related to the SMT and not total water content. That is, a plant must be able to exert a force greater than the SMT to utilize soil water.

SOIL MOISTURE CLASSIFICATION	SOIL TENSION (atmospheres)	APPROXIMATE % PORE SPACE OCCUPIED BY WATER
SATURATION	0	100
Gravitational Water (subject to drainage)		
FIELD CAPACITY	1/3	50
Capillary Water (available to plants)		
WILT POINT	15	25
Capillary Water (unavailable to plants)		
HYGROSCOPIC COEFFICIENT	31	15
Hygroscopic Water (unavailable to plants)		
OVEN DRY	10,000	0

FIGURE 2.4 Soil water classification.

Water in soil can be classified as hygroscopic water, capillary water, or gravity water. Hygroscopic and capillary water is water held by soil particles, and was discussed above. Gravity water is water not held by soil particles and flows freely through the soil under the force of gravity. Gravity water moves through the larger macropores down through the soil profile. Gravity water is under very low pressure, is readily available to plants, and typically drains downward fairly quickly.

Soil is said to be at field capacity when all gravity water has been removed. At field capacity all micropores are filled with water and the macropores are filled with air. Water in micropores is held at very low tension. As the soil dries, the tension under which the water is held, increases until plants can no longer exert the force necessary to extract water. This is called the wilt point. Substantial quantities of water may still remain in the soil, but it is held so tightly that it is unavailable for plant use.

Water Holding Capacity:

The quantity of water a particular soil can hold is a function of the total surface area of the soil particles, which is a function of soil texture. Fine texture soils have the largest volume of pore space and surface area, and consequently the highest water holding capacity. Coarse textured soils are just the opposite (see table 2.1). Even though fine textured soils may hold more water, not all of this is available to plants. Generally, medium textured soils hold less total water than fine textured soils, but typically more water is available for plant use. Not surprisingly the best forest growth occurs on deep loamy textured soils.

Figure 2.5 illustrates the differences in moisture availability and total moisture holding capacity for 10 soil textural classes. Soil moisture available for plant growth is indicated by the vertical distance between field capacity and wilt point.

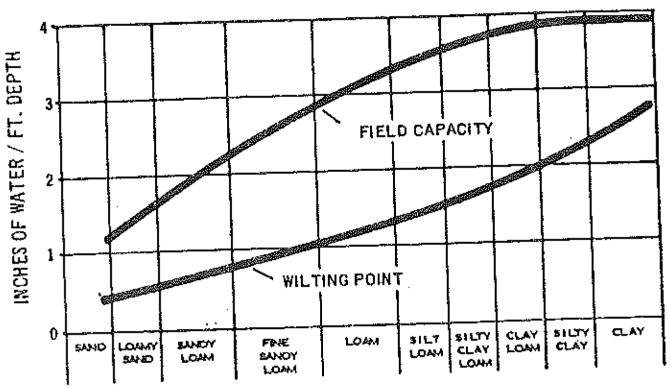


FIGURE 2.5 Field capacity and wilt point for 10 soil textural classes (Ohio Cooperative Extension Service, 1974).

Drainage:

Soil drainage is classified based on the frequency, and duration of periods when the soil is not saturated. Seven categories are recognized:

Very poorly drained soils are formed on level or depressional areas. The water table will remain at or above the surface for long periods of time. The surface colors are black or dark gray with gray colors in the subsoil. Muck (organic) soils may remain dark throughout the profile.

Poorly drained soils have a water table that remains at or near the surface for long periods of time. Gray colors dominate the profile although the surface soil may be dark.

Somewhat poorly drained soils are wet for significant periods during the year due to a seasonally high water table. Soil colors are gray, brown or yellow on the surface, with mottled colors at lower depths.

Moderately well drained soils are only wet for short periods during the year. The water table is generally below a depth of 2½ and 3 ft. Mottled colors are present in subsoil layers.

Well drained soils are considered to have "good" drainage and include most soils with a significant slope. Water is removed readily from the profile, and colors are bright and free of mottling.

Somewhat excessively drained soils are usually the sandy or more porous soils. Colors are bright brown, yellow and red, and free from any mottling. Frequently these soils are found on steep slopes.

Excessively drained soils are coarse textured soils (sandy, gravelly, stony) or shallow soils on steep slopes. Soil water is removed rapidly. Colors are brown, yellow, red or gray, and free of any mottling.

The movement of water in soil is controlled by soil texture and structure. Water moving in the soil is said to "percolate" through the soil. The rate at which water moves through the soil determines it 'permeability'.

Permeability of undisturbed soils, particularly forest soils, tends to be higher than that for soils under cultivation.

Soil drainage influences tree growth in two ways 1) when it occurs too rapidly, and 2) when it doesn't occur rapidly enough. Both conditions may act to limit growth.

Soil drainage is influenced by topography, soil texture and soil structure. In upland areas, on steep slopes, water may run off before capillary forces are able to draw the water down into the soil. This limits the amount of water entering the soil profile. Once water enters the soil its movement is controlled by the soil's texture and structure. Water moves more rapidly through coarse textured soils than fine textured soils.

In Indiana, soils on ridge tops and side slopes tend to be thinner, lower in organic matter, and coarser in texture. This limits their water holding ability and makes trees on these sites more subject to moisture stress. Lower slopes receive additional water from above and usually are finer textured and deeper than soils on ridge tops.

Some ridge tops in Indiana are covered with a layer of loess. Where this silty layer has not been disturbed, soils tend to have a higher moisture holding capacity.

Ridge top sites are usually very well drained, but it is possible to have poorly drained conditions on wide ridges. The presence of a fragipan or slowly permeable layer may hold water near the surface. This is referred to as a "perched water table".

Too much water can be just as detrimental to tree growth as not enough. Trees need to extract oxygen as well as water from the soil. Meristematic tissue at root tips have a high oxygen requirement and are the site of cell division and elongation (growth) in roots. Because oxygen is unavailable to plants in saturated soils, roots typically do not penetrate water saturated layers. Tree species are adapted to tolerate varying periods of poor soil aeration. A few species are especially adapted to tolerate prolonged periods of poor drainage.

Soil above field capacity, and poorly drained soils, will limit tree growth and may restrict rooting depth. Shallow rooted trees are less stable and subject to wind throw.

On bottomland sites tree growth is frequently limited by a high water table or poor drainage conditions. On these sites, slight changes in elevation can have a significant impact on the depth of well aerated rooting material available to trees. This may produce a major change in species composition. This change in tree species is usually easier to spot than the change in elevation itself.

CHEMICAL PROPERTIES

SOIL pH

pH is a measure of soil acidity. pH ranges from 1 to 14, with 1 being very acidic, 14 being very alkaline and 7 being neutral. Technically, pH is the logarithum of the reciprocal of the hydrogen ion concentration of in the soil.

$$pH = \text{Log} \frac{1}{H^{+} \text{ moles/liter}}$$

The pH of most Indiana soils ranges from 5.5 to 7.5, except for some residual soils in the south and some sandy soils in the northwestern portion of the state.

Soil pH has its greatest influence on nutrient availability and the activities of soil organisms. These effects will be discussed later.

ION EXCHANGE

Soil particles are electrically charged. These charges are the result of the exchange of electrons between atoms. Charged soil particles are called colloids. Negatively charged colloids are called anions, and positively charged particles are called cations.

Both positively and negatively charged particles are important, but the negatively charged anions are more important for plant growth. Through electrical attractions, colloids hold water molecules and nutrients in the soil. The number of potential sites for chemical bonding is related to the total surface area of soil particles (the more surface area, the more bonding sites). This in turn determines the water holding capacity and supply of nutrients in the soil.

Clay particles and humus are the most important soil components in this respect. Clay and humus have a high surface area to volume ratio and act as a giant warehouse of nutrients, holding oppositely charged ions (nutrients) in the soil. Without colloids, nutrients released by the weathering of parent material or the decomposition of organic matter would be leached from the soil.

Because of this feature, clay and loamy soils are more fertile than sandy soils. This is the reason herbicides and other chemicals are so easily leached from sandy soils.

SOIL NUTRIENTS

Ninteytwo chemical elements are known to exist on earth, but approximately 98 percent of the planet's crust is made up of 8 chemical elements. In fact, 75 percent of the earth's crust is made up of silicon and oxygen. Seventeen chemical elements are essential for plant growth. Most are relatively abundant, but some are quite rare. A deficiency of one element, even with abundant supplies of the other sixteen, will limit plant growth.

Plant nutrients have been divided into two groups based on the quantities needed for plant growth. They are:

Macronutrients	Micronutrients
Carbon*	Iron
Hydrogen*	Manganese
Oxygen*	Boron
Nitrogen	Molybdenum
Phosphorus	Copper
Potassium	Zink
Calcium	Chlorine
Magnesium	Cobalt
Sulfur	

* obtained mostly from air or water. These three elements together make up 94 to 99.5 percent of plant tissue.

The distribution and concentration of these elements in soils varies considerably, but they are usually sufficiently abundant in all Indiana soils to support plant growth.

The availability of nutrients in most soils in Indiana, with the exception of some sandy and severly eroded soils, is not likely to limit forest growth. The availability of water is likely to be of far greater significance in limiting forest growth than the supply of soil nutrients. Two exceptions are noteworthy: 1) iron may be deficient in nursery or in ornamental settings and 2) copper may be deficient in organic soils.

Soil pH effects the availability of nutrients to plants. Some nutrients are more soluble at higher or lower pH. For example, pin oak is sensitive to the availability of iron in the soil. In urban settings, where soils have been disturbed, this is frequently a problem. Decreasing soil pH would increase the availability of iron in the soil. Figure 2.6 shows how the availability of some elements change at different pH levels.

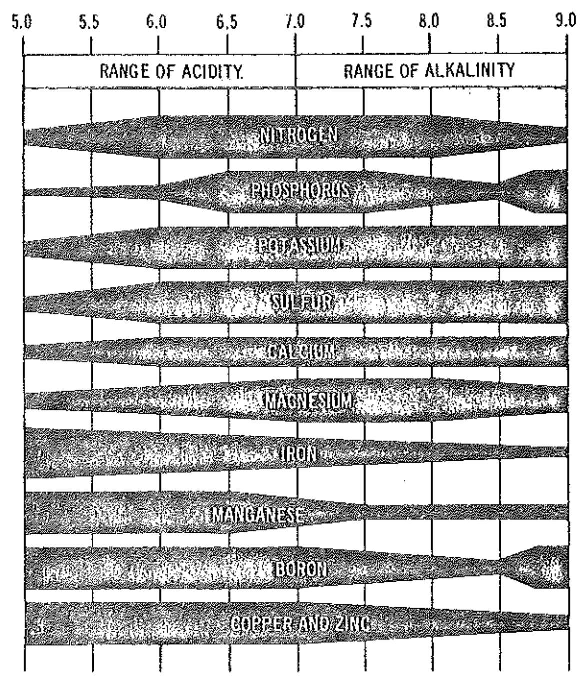


FIGURE 2.6 Relative availability of elements essential for plant growth at varying levels of soil pH for mineral soils (Ohio Cooperative Extension Service, 1974).

Gardeners and farmers found long ago that increasing the supply of macronutrients can increase crop yields. Until very recently fertilization of forest stands was thought to be uneconomical. This situation is changing in other regions and may eventually change in Indiana.

Research has shown that hardwoods will respond (increase diameter growth) to fertilization. On poor sites, additions of macronutrients (N·P·K) have increased radial growth as much as 100 percent for hardwood species. In these studies: Nitrogen has consistently been found to be the most limiting nutrient; growth response usually peaks in the second growing season after fertilization; and the growth response typically last several years, but this has been extremely variable.

A good summary of research findings in the area of hardwood fertilization prior to 1972 is presented in (Auchmoody and Filip, 1973).

ORGANIC MATTER

Organic matter is plant and animal matter that is in various stages of decomposition. Humus is organic matter that has been decomposed to the point where it is fairly resistant to further decomposition.

Organic matter is one of the single most important components of forest soil. The quantity and distribution of organic matter in soils under a forest canopy is distinctly different from the pattern seen in prairie soils (Figure 2.7).

Because of the large quantity of organic matter stored as vegetation in a forest, timber harvesting can have a significant impact on the cycling of organic matter in the forest ecosystem.

The more complete the removal of vegetation is, the more significant the impact. Fortunately, due to the long period between forest crops (rotation), forest systems have a chance to replenish lost organic matter. Intensive management practices, such as extensive mechanical site preparation and whole tree harvesting, pose potential threats to nutrient cycling in forest soils. This threat is potentially more significant on nutrient poor, steep and sandy soils.

Organic matter is broken down by microorganisms into humus. Organic matter serves as food for microorganisms. A healthy microflora in the soil is important for soil fertility and nutrient availability (particularly nitrogen).

In soil, humus has many of the same characteristics as clay. Humus has a high cation exchange capacity and acts to hold water and nutrients in the soil. In addition, humus is important in the formation of soil aggregates (see soil structure). Humus is responsible for holding 30 to 90% of the nutrients in the soil (MDNR, 1983).

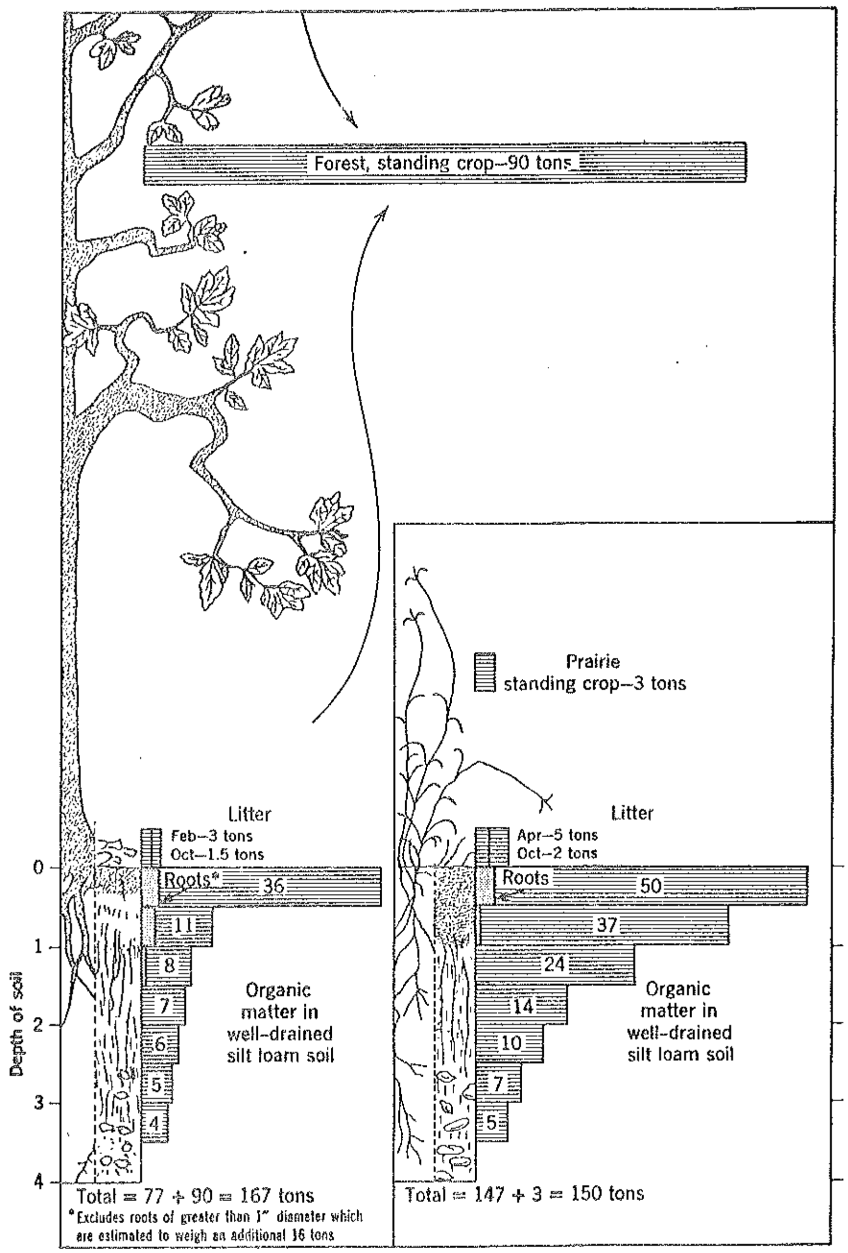


FIGURE 2.7 Distribution of organic matter in forest and prairie ecosystems (Foth and Turk, 1972).

SOIL ORGANISMS

Soils support a wide range of small plants and animals. These organisms are an intricate part of the soil ecosystem and in turn the forest community. These organisms are responsible for breaking down both organic and inorganic compounds, converting organic matter to compounds needed for plant growth, and aerating the soil. Soil organisms can crudely be classified as follows:

Microflora	Microfauna
Bacteria*	Protozoa
heterotrophic	Worms (nematodes & earth worms)
autotrophic	Mollusks (snails & slugs)
Fungi	Arthropods (centipedes, ants, spiders, etc.)
Actinomyces	Vertebrates (moles, gophers, etc.)
Algae	

* note: these may also be classified as aerobic or anaerobic. Aerobic organisms are more abundant, but anaerobic organisms may also function in non-saturated soils.

Microflora and microfauna function together to break down organic matter and recycle the nutrients tied up as plant tissue into forms available for future plant growth. The interactions are too complex to explain in this publication, except to say that they are an essential component of the forest community.

The activities of these organisms are effected by soil pH, temperature, organic matter content, moisture and aeration. Generally, medium textured soils, at field capacity, at approximately 35° C with abundant supplies of organic matter are optimal for microbial activity.

Soil microfauna is particularly active and diverse in the forest community. Worms, arthropods, and burrowing animals are important for mixing organic matter with the mineral soil. Their tunneling through the soil improves soil aeration, facilitates water percolation and infiltration, and provides channels for root growth.

To the forester, perhaps the most significant soil organisms are mycorrhizae. Mycorrhizae interact with the roots of higher plants to form a functional symbiotic association . The mycorrhizal association combines the plant root and the fungus and serves to increase the total surface area of a plant's root system enabling the plant to absorb more water and nutrients.

Approximately 95 percent of all vascular plants belong to families that form these associations. Non-mycorrhizal plants are usually the exception rather than the rule (Trappe, 1977).

Mycorrhizal associations were first recognized in 1985. Two types are generally recognized: ectomycorrhizae and endomycorrhizae. Endomycorrhizae are found on herbaceous and woody plants of the Cupressaceae, Aceraceae, Taxodiaceae, some species of Ericaceae, and others (Harvey et al, 1976). These fungi are characterized by hyphae that penetrate into the cortical cells of the unsuberized (not covered with protective corky layer) portion of the root. Virtually no change in root morphology is associated with this type.

Ectomycorrhizae are found on woody plants of the Fagaceae, Pinaceae, Tiliaceae, Salicaceae, Betulaceae, some species of Juglandaceae, Rosaceae, Leguminosae, and others (Meyer, 1973). The fungi are usually Basidiomycetes or Ascomycetes with septate (segmented) hyphae that cover the short roots with a mat of fungal tissue. The hyphae penetrate the unsuberized portion of the lateral root just behind the root tip, and are normally restricted to the space between plant cells. The proliferating hyphae may completely surround plant cells but rarely penetrate them. Inside the root, distinct changes in root morphology occur, generally in the form of swelling, discoloration, and increased branching of the lateral roots.

Many species that host ectomycorrhizal fungi grow poorly when mycorrhizae fail to develop. This is especially true for the pines, which require the association for normal development after the first two years of growth (Trappe, 1977). Increased fertility levels in soils with non-mycorrhizal trees may alleviate the problem somewhat, however, mycorrhizal trees in soils of low fertility have been shown to perform better than non-mycorrhizal trees which have been fertilized (Ashton, 1976; Harley, 1969).

The formation of the mycorrhizal association is influenced by many factors. Soil acidity, moisture content, fertility level, texture and temperature are the most important. Soil moisture is particularly important since high moisture contents inhibit mycorrhizal development due to poor aeration. On the other hand, excessively dry conditions cause rapid suberization (development of protective corky layer), reduce root growth, and inhibit mycorrhizal development.

Water and nutrient movement toward roots in the soil is very slow, consequently any extensions of a tree's root system will prove beneficial. Mycorrhizal infection enchances the branching pattern in the root systems, enabling the plant to exploit a larger volume of soil. In addition to the branching and swelling resulting from the mycorrhizal association, the fungal hyphae penetrate into the soil where they often fuse with hyphae infecting adjacent trees, thereby vastly increasing the water and nutrients available to the plant.

A mild deficiency of nutrients, in particular, the macronutrients (N, P, K, and Ca) enhance mycorrhizal formation (Hesterburg and Jergensen, 1972). However, acute deficiencies of these macronutrients leads to a low level of photosynthetic activity and interrupts the movement of carbohydrates to the roots (Ikonenko, 1959).

The primary importance of the ectomycorrhizal association is in increasing the water uptake and drought resistance of the infecterd trees. However, recent research indicates that mycorrhizae also enable plants to selectively absorb and accumulate nutrients, to render otherwise unavailable substances in the soil available to the host, and to increase the absorption surface of the roots (Marx, 1977). In return, the host plant supplies the energy source for the fungus through excretion of simple sugars.

Inoculation of hardwood seedlings while in the nursery beds and in greenhouse containers has been shown to increase root fibrosity, leaf area, and total plant dry weight (Wright, 1979; Pope et al, 1983). These increases in root surface area and total root volume help the plant avoid water deficits that frequently occur after outplanting. Research with white oak has shown that mycorrhizal seedlings were more drought resistant and recovered much more rapidly than non-mycorrhizal seedlings when wate red (Dixon et al, 1980).

Mycorrhizae management is a prime concern of nursery managers. Inoculation of nursery beds with naturally occurring strains of known mycorrhizae formers, reducing the use of fumigation that eliminates natural forms of mycorrhizae, and careful monitoring of soil fertility and moisture levels insures that colonization of the seedling roots occurs prior to outplanting. Work continues on efforts to identify the optimal natural forms of fungi to be used in inoculation of commercial forest species.

REGIONAL REVIEW OF INDIANA SOILS

Indiana has been divided into nine major physiographic units based on geologic history and similarities between the soils in the area (Figure 3.1). Similarly Indiana has been divided into 13 major soil regions (Figure 3.2). In this section the nine physiographic units are described and the major soil associations in each soil region are discussed.

Indiana's major physiographic units are:

Dearborn Upland: This is a plateau north of the Ohio River in southeastern Indiana composed of level Ordivician limestone and shales overlain by glacial drift of varying thickness (15-20 ft. at the Ohio River to 200 ft. at the northern boundary).

Muscatatuck Regional Slope: This is a gentle westerly sloping plain composed of Silurian and Devonian aged carbonate rocks. It ranges in elevation from 1100 ft. in the east, to 725 ft. in the west.

Scottsburg Lowland: This linear belt of generally low relief is a valley composed of non-resistant shales of Devonian and Mississippian age. Elevation ranges from 750 ft. in the north to 500 ft. at the Ohio River. The depth of glacial drift ranges from 150 ft. in the north to much thinner in the south.

Norman Upland: This is a very prominent escarpment (a landform of high relief and steep slopes), which rises 300 ft. above the Scottsburg lowland and is located east of the Knobstone unit. It is the most distinct physiographic boundary in the state and is composed of siltstone and shales of Mississippian age with limestone outcrops. In general, it is an area of strong relief that rises out of the Tipton Till Plain in central Indiana.

Mitchell Plain: This unit lies west of the Norman Upland and is characterized by generally low relief. It is composed of Mississippian aged limestone which, because of its thickness and soluble nature, exhibits some of the best examples of Karst topography in the world. Karst topography is a rolling sink hole landscape formed by the limestone bedrock being dissolved by ground water thus causing localized "sinking" or collapsing of the bedrock. This dissolving process occurs over many thousands of years.

Crawford Upland: This dissected west sloping plateau resembles the Norman Upland. It is composed of sandstone, shale and limestone of Mississipian age overlayed by Pennsylvanian sandstone. Its diverse topography includes the state's most famous caverns, Wyandotte and Marengo Caves.

Wabash Lowland: This is a large lowland tract with an average elevation of 500 ft. Its average elevation is three to four hundred feet below that of the adjacent Crawford Upland. Composed of non-resistant siltstones and shale of Pennsylvanian age, this unit is known for its layer of coal deposits. The partially glaciated landscape which is characterized by broad lowland valleys and rolling hills, contains some former lake beds.

Tipton Till Plain: This extensive landform is a ground moraine (a gentle landform of low relief formed by continental ice) created by the Wisconsin ice sheet. The Tipton Till Plain is characterized by flat to gently rolling featureless glacial topography. Its southern borders are composed of poorly developed end moraines (drift accumulated and left by the leading edge of a glacier often in a hummocky ridge formation).

Northern Moraine and Lake Region: This unit is composed of the following five sub-units:

The Calumet Lacustrine Plain is the former lake bottom of Glacial Lake Chicago, which occupied the Lake Michigan basin during the retreat of the Wisconsin ice sheet. It is composed of lowlands and sand ridges which were formerly beaches. Some of this country's best examples of sand dunes surround Lake Michigan in this region.

The Valparaiso Morainal Area is a moraine complex created by the Wisconsin ice sheet; it can be traced from Wisconsin through Illinois and Indiana to Michigan. Elevations rise 150 feet above the Calumet Lacustrine Plain in some places. In general, relief is greater than surrounding units and topography is complex. A few lakes are present in the northeast part of this area.

The Kankakee Outwash and Lacustrine Plain is a poorly drained lowland composed of glacial outwash (water sorted material) deposited by Wisconsin glacial meltwaters. There are also some lacustrine (lake bed) deposits. The topography was modified by westerly winds that reworked the sandy landscape when ground cover was absent. In general, it is an area of broad featureless topography with sand dunes (usually covered by woods or pasture).

The Steuben Morainal Lake Area is a complex topographic area in which local relief varies by as much as 200 ft. in some areas, while resembling the relatively flat Tipton Till Plain in other areas. There are many glacial landforms: kames (knolls of water sorted material), kettles (depressions caused by ice blocks that melted in place after being left by a receding glacier), kettle lakes (kettleholes filled with water), eskers (snake-like ridges composed of water-sorted sand and gravel deposited by sub-glacial streams), and bogs. Both outwash and till materials are mixed in a complex fashion.

The Maumee Lacustrine Plain, which closely resembles the Calumet Lacustrine Plain, averages 750 ft. elevation. It is the former lake bottom of Glacial Lake Maumee which occupied the Lake Erie basin in the late Wisconsin glacial episode. Lake Maumee was dammed along its western border by the Ft. Wayne Moraine, but spilled over the dam at Ft. Wayne and drained into what is now the Wabash River.

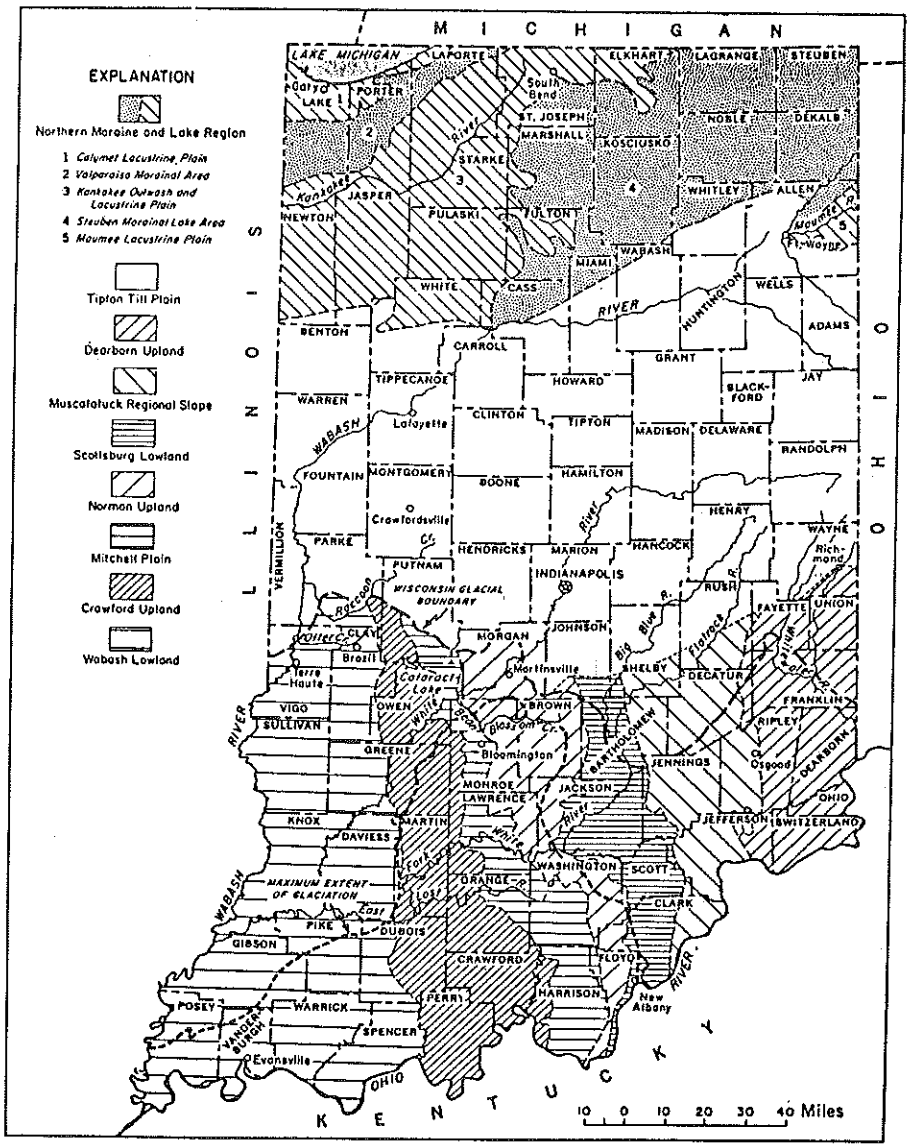


FIGURE 3.1 Indiana's major physiographic units. (Indiana Academy of Science, 1966)

U. S. DEPARTMENT OF AGRICULTURE | SOIL CONSERVATION SERVICE

SOIL REGIONS

SOIL REGIONS OF INDIANA

SOIL PARENT MATERIALS REPRESENTATIVE SOILS

1 SANDY AND LOAMY LACUSTRINE DEPOSITS AND EOLIAN SAND: Maumee, Rensselaer, Plainfield

2 SILTY AND CLAYEY LACUSTRINE DEPOSITS; McGary, Patton, Joytville, Dubois

3 ALLUVIAL AND OUTWASH DEPOSITS: Fox, Genesee, Warsaw, Wheeling

4 EOLIAN SAND DEPOSITS: Plainfield, Oshtemo, Bloomfield

5 THICK LOESS DEPOSITS: Alford, Hosmer, Iva

6 LOAMY GLACIAL TILL: Riddles, Miami, Crosier, Brookston

7 CLAYEY GLACIAL TILL: Blount, Pewamo, Morley

8 THIN LOESS OVER LOAMY GLACIAL TILL: Brookston, Crosby, Miami, Parr

9 MODERATELY THICK LOESS OVER LOAMY GLACIAL TILL: Fincastle, Russel, Miami, Brookston

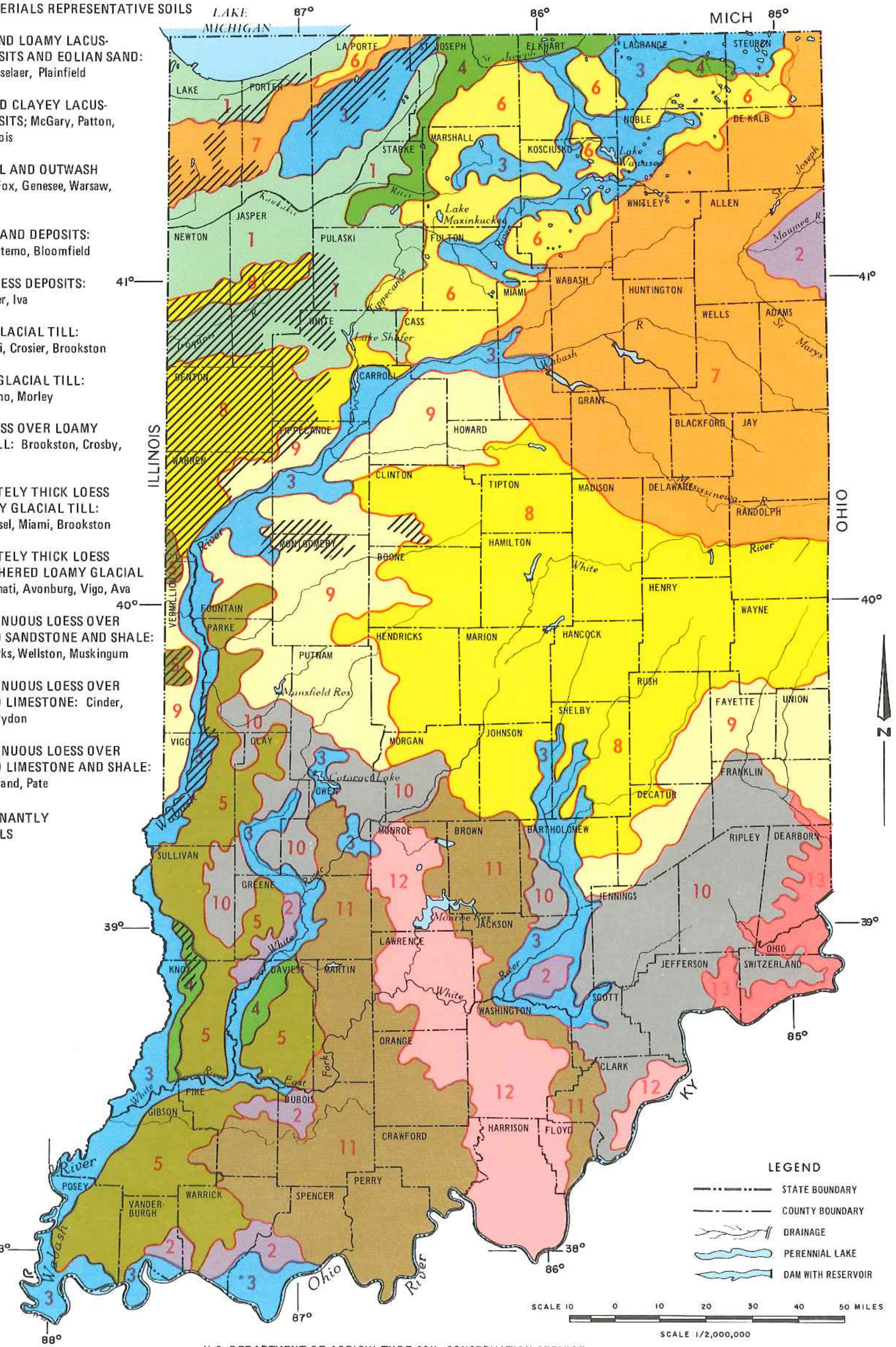
10 MODERATELY THICK LOESS OVER WEATHERED LOAMY GLACIAL TILL; Cincinnati, Avonburg, Vigo, Ava

11 DISCONTINUOUS LOESS OVER WEATHERED SANDSTONE AND SHALE: Zanesville, Berks, Wellston, Muskingum

12 DISCONTINUOUS LOESS OVER WEATHERED LIMESTONE: Cinder, Frederick, Corydon

13 DISCONTINUOUS LOESS OVER WEATHERED LIMESTONE AND SHALE: Eden, Switzerland, Pate

PREDOMINANTLY PRAIRIE SOILS



SOURCE:
1970 NATIONAL ATLAS OF THE UNITED STATES OF AMERICA AND INFORMATION FROM FIELD TECHNICIANS. ALBERS EQUAL AREA PROJECTION

U.S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE
in Cooperation with
PURDUE UNIVERSITY AGRICULTURAL EXPERIMENT STATION
and COOPERATIVE EXTENSION SERVICE

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MAJOR SOIL REGIONS IN INDIANA

Indiana has been divided into thirteen major soil regions. In the remainder of this section each soil region will be discussed individually and a brief description of the major soils within each region will be given.

SOILS REGION #1

SANDY AND LOAMY LACUSTRINE DEPOSITS AND EOLIAN SAND
IDNR Division of Forestry Districts: 1,2

The topography of this region consists of nearly level glacial outwash plains and lacustrine plains with numerous eolian sand ridges (dunes). All topographic features existing today were formed during or after the Wisconsinan glacial age.

The soils of this region are poorly drained, very poorly drained, or excessively drained. They formed in organic material (Houghton and Adrian); in sandy or loamy sediments (Maumee, Gilford, Sebewa, and Rensselaer); or in wind blown sands (Plainfield).

The <u>Houghton</u> series consists of deep, very poorly drained soils, that formed in organic materials deposited in lakes after the last continental glacier retreated. Layers of weathered organic deposits, formed from dead plant material, are generally more than 51 inches thick. Slopes are less than 2 percent.

The <u>Adrian</u> series consists of deep very poorly drained soils that formed in organic material deposited in lakes after the last continental glacier retreated. The weathered organic deposits are less than 50 inches and overlays sandy deposits. Slopes are generally less than 2 percent.

The <u>Maumee</u> series consists of deep, very poorly drained soils formed in sandy sediments on lacustrine plains and outwash plains. Slopes range from 0 to 2 percent. This soil has a fine sand or loamy fine sand surface layer and subsoil.

The <u>Gilford</u> series consists of deep, very poorly drained soils that formed in loamy and sandy sediments on lacustrine plains and outwash plains. Slopes range from 0 to 2 percent. This soil has a fine sandy loam surface layer and subsoil, over sand deposits.

The <u>Sebewa</u> series consists of poorly drained and very poorly drained soils formed in loamy and sandy deposits on outwash plains and terraces. Slopes range from 0 to 2 percent. This soil has a loam surface layer and a clay loam subsoil over gravelly sand.

The Rensselaer series consists of deep, poorly drained and very poorly drained soils that formed in loamy sediments on lacustrine plains, terraces and outwash plains. Slopes range from 0 to 2 percent. This soil has a loam surface layer and a clay loam subsoil.

The Plainfield series consists of deep, excessively drained soils that formed in wind blown sandy drift on outwash plains, stream terraces and glacial morains. Slopes range from 0 to 35 percent. This soil has a sand textured surface layer and subsoil.

SOILS REGION #2

SILTY AND CLAYEY LACUSTRINE DEPOSITS

IDNR Division of Forestry Districts: 3, 5, 8, 10, 11, 16

The topography of this region consists of nearly level to moderately sloping lacustrine plains and slack water terraces in northeastern Indiana, south central and southwest Indiana. The soils in this region are Hoytville and Nappanee in northeastern Indiana (the lake bed of a former glacial lake - Lake Maumee); and Bartle, Peoga, Dubois, Patton, Lyles, Henshaw, Zipp, Markland, and McGary in the south. These soils and their characteristics are as follows:

The Hoytville series consists of deep, very poorly drained soils that formed in glacial till modified by wave action on lake plains. Hoytville is found in swales where slopes range from 0 to 2 percent. This soil typically has a silty clay surface layer and a silty clay or clay subsoil.

The Nappanee series consists of deep, somewhat poorly drained soils that formed in clayey material on glacial till plains, lake plains, and moraines. Nappanee is found on swells where slopes range from 0 to 12 percent. This soil typically has a silt loam or silty clay loam surface layer and a silty clay or clay subsoil.

The Bartle series consists of deep, somewhat poorly drained soils that formed in lacustrine or alluvial sediments on terraces and lake plains. Bartle is found on slight rises or flats and slopes range from 0 to 3 percent. This soil has a silt loam surface layer and a silty clay loam subsoil with a fragipan.

The Peoga series consists of deep, poorly drained soils that formed in lacustrine or alluvial sediments of mixed origins on lake plains and terraces. Peoga is found on low-lying flats and slopes range from 0 to 2 percent. This soil has a silt loam surface layer and a silty clay loam subsoil.

The Dubois series consists of deep, somewhat poorly drained soils formed in loess and stratified sediments on upland areas. Slopes range from 0 to 6 percent. This soil has a silt loam surface layer and a silty clay loam subsoil with a fragipan.

The Patton series consists of deep, poorly drained soils that formed in silty sediments on lacustrine plains and terraces. Slopes range from 0 to 2 percent. This soil has a silty clay loam surface layer and subsoil.

The Henshaw series consists of deep, somewhat poorly drained soils that formed in alluvial deposits on lacustrine plains and low stream terraces. Slopes range from 0 to 6 percent. This soil has a silt loam surface layer and a silty clay loam subsoil.

The Lyles series consists of deep, very poorly drained soils that formed in stratified loamy glacial outwash on terraces or high bottomlands. Slopes range from 0 to 1 percent. This soil has a loam or sandy loam surface layer and a sandy clay loam subsoil.

The Zipp series is discussed in soils region #3.

The Markland series consists of deep, moderately well drained and well drained soils that formed in developed from loess and the underlying lacustrine sediments on upland areas. Slopes range from 2 to 12 percent. This soil has a silt loam surface layer and a silty clay subsoil.

The McGary series consists of deep, somewhat poorly drained soils that formed in lacustrine sediments on lake plains. McGary is found on swells and slopes range from 0 to 6 percent. This soil has a silt loam surface layer and a silty clay subsoil.

SOILS REGION #3

ALLUVIAL AND OUTWASH DEPOSITS

IDNR Division of Forestry Districts: 1 through 6, 8, 10, 11, 14, 16

The topography of this region consists of nearly level to steep outwash plains and nearly level to gently sloping stream terraces, flood plains and slackwater terraces.

This soil region is the most complex in Indiana and is separated into two parts: the outwash soils (deposited by melting glaciers) and the alluvial soils (recently deposited by the running water).

With the except some areas of south central and southwest Indiana, the soils formed in outwash material are mainly found in the northern one-third of the state. The outwash soils are formed from water worked glacial drift of Wisconsinan age in the north and Illinoian age in the south.

The alluvial soils developed from material more recently deposited by water. These sediments originated from the Wisconsinan and Illinoian glaciers and are found on river and stream bottoms and terraces throughout the state. These soils and their characteristics are listed below. (Note: Warsaw soils will not be considered here).

SOILS DEVELOPED IN OUTWASH MATERIAL

The Tracy series consists of deep, well drained soils that formed in shaly sediments on outwash plains. Slopes range from 0 to 12 percent. This soil usually has a sandy loam surface layer and a loam or sandy loam subsoil.

The Oshtemo series consist of deep, well drained soils that formed in loamy and sandy glacial deposits on outwash plains. Slopes range from 0 to 18 percent. Oshtemo has a loamy sand or sandy loam surface layer with a sandy loam subsoil.

The Ormas series consists of deep, well drained soils that formed in wind-reworked sandy outwash on terraces. Slopes range from 0 to 18 percent. This soil has a loamy sand or sand surface layer and a sandy loam subsoil.

The Fox series consists of deep, well drained soils that formed in loamy sediments over sand and gravel on outwash plains and terraces. Slopes range from 0 to 18 percent. This soil has a silt loam, sandy loam or loam surface layer with a clay loam or sandy clay loam subsoil.

The Ockley series consists of deep, well drained soils that formed in loess or silty material on terraces and outwash plains. Slopes range from 0 to 6 percent. This soil has a silt loam surface layer and a clay loam subsoil. The lower subsoil is gravelly clay loam or gravelly sandy clay loam.

The Parke series consists of deep, well drained soils that formed in loses over outwash sediments on upland areas. Slopes range from 2 to 18 percent. This soil has a silt loam surface layer and a silty clay loam subsoil.

The Negley series consists of deep, well drained soils that formed in outwash sediments on kames eskers and terraces in southern Indiana. Slopes range from 18 to 35 percent. This soil has a loam surface layer and a sandy clay loam subsoil.

SOILS DEVELOPED IN ALLUVIUM

The Genesee series consists of deep, well drained soils found on flood plains of streams and rivers that originate in areas of Wisconsin aged glaciation. Slopes range from 0 to 2 percent. This soil has a loam surface layer and a substratum of stratified loamy material.

The Eel consists of deep, moderately well drained soils found along narrow stream valleys and flood plains. Slopes range from 0 to 2 percent. This soil has a loam surface layer and stratified loamy material in the subsoil.

The Shoals series consists of deep, somewhat poorly drained soils found on wide flood plains. Slopes range from 0 to 2 percent. This soil has a loam surface layer with stratified loamy material in the subsoil.

The Sloan series consists of deep, poorly drained soils found on flood plains of the lower Wabash River Valley. Slopes range from 0 to 2 percent. This soil has a silty clay loam surface layer with a silty clay loam and clay loam subsoil.

The Vincennes series consists of deep, poorly drained soils found in slackwater terraces in the lower Wabash River Valley. Slopes range from 0 to 2 percent. This soil has a loam surface soil and a clay loam subsoil.

The Zipp series consists of deep, very poorly drained soils that formed in lacustrine sediments in low slackwater terraces in the lower Wabash River Valley. Slopes range from 0 to 2 percent. This soil has a silty clay or silty clay loam surface layer and subsoil.

The Stendal series consists of deep, somewhat poorly drained soils found on bottomland sites. Slopes range from 0 to 2 percent. This soil has a silt loam surface layer and a silty clay loam or silt loam subsoil.

The Wakeland series consists of deep, somewhat poorly drained soils on bottomland sites. Slopes range from 0 to 2 percent. This soil has a silt loam surface layer and subsoil.

The Haymond series consists of deep, well drained soils found on flood plains. Slopes range from 0 to 3 percent. This soil has a silt loam surface layer and a silty loam subsoil.

The Wheeling series consists of deep, well drained soils found on terraces of the Ohio River. Slopes range from 0 to 30 percent (mostly 0 to 6 percent). This soil has a silt loam surface layer and a silty clay loam subsoil.

The Huntington series consists of deep, well drained soils found on the flood plains of the Ohio River. Slopes range from 0 to 15 percent (commonly 0 to 2 percent). This soil has a silt loam surface layer and a silt loam or silty clay loam subsoil.

SOILS REGION #4

EOLIAN SAND DEPOSITS

IDNR Division of Forestry Districts: 1, 3, 5, 16

In the northern segment of this region topography is comprised of nearly level glacial outwash plains and old lake plains with numerous sand dunes rising above these lower areas. This area is composed of stabilized sand dunes and beach ridges interspersed with areas of very poorly drained organic soils.

The topography of the portion of this region located in southwestern Indiana, consists of dunes and associated swales along the Wabash River and its tributaries.

The soils of this region are composed of Wisconsinan aged eolian sands and organic soils: Plainfield, Maumee, Oshtemo, Oakville and Adrian in north central Indiana; and Princeton, Bloomfield, Lyles and Ayrshire in southwestern Indiana. These soils are listed below by their location.

North Central Indiana

The Plainfield series consists of deep, excessively drained soils that formed in wind-blown sandy drift on outwash plains, stream terraces, and glacial moraines. Slopes range from 2 to 35 percent. This soil has a sandy surface layer and subsoil.

The Maumee series consists of deep, poorly drained soils that formed in sandy sediments on lacustrine plains and outwash plains. Slopes range from 0 to 2 percent. This soil has a loamy fine sand or fine sand surface layer and subsoil.

The Oshtemo series consist of well drained soils that formed in loamy and sandy glacial deposits on outwash plains. Slopes range from 0 to 18 percent. This soil has a loamy sand or sandy loam surface layer and a sandy loam subsoil.

The Oakville series consists of deep, well drained soils that formed in sandy sediments on outwash plains and lake plains. Slopes range from 0 to 25 percent. This soil has a fine sand surface layer and subsoil.

The Adrian series consists of very poorly drained soils that formed in 16 to 50 inches of organic material over sands on swales in outwash plains. Slopes are generally less than 2 percent.

Southwestern Indiana

The Princeton series consists of deep, well drained soils that formed in eolian material on upland areas along the Wabash River and its tributaries. Slopes range from 0 to 12 percent. This soil has a fine sandy loam surface layer and a sandy clay loam subsoil.

The Bloomfield series consists of deep, well drained and somewhat excessively drained soils that formed in sandy sediments on terraces along the Wabash River and its tributaries. Slopes range from 2 to 18 percent. This soil has a fine sand or loamy fine sand surface layer and a subsoil with bands of find sandy loam mixed in fine sand.

The Ayrshire series consists of deep, somewhat poorly drained soils that formed in eolian material on upland areas. Slopes range from 0 to 6 percent. This soil has a fine sandy loam surface layer and a sandy clay loam subsoil.

The Lyles series consists of poorly drained soils that formed in loamy outwash material. Slopes range from 0 to 1 percent. This soil has a fine sandy loam surface layer and a sandy loam subsoil.

SOILS REGION #5

THICK LOESS DEPOSITS

IDNR Division of Forestry Districts: 2, 4, 5, 7, 11, 16

The topography of this region consists of nearly level to moderately sloping areas of glacial till covered by thick loess deposits of Wisconsinan age. The soils are: Alford, Hosmer, Iva, Reesville, and Ragsdale and are described below.

The Alford series consists of deep, well drained soils that formed in loess on upland areas. Slopes range from 2 to 18 percent. This soil has a silt loam surface layer and silty clay loam suboil.

The Hosmer series consists of deep, well drained and moderately well drained soils formed in loess on uplands. Slopes range from 2 to 12 percent. This soil has a silt loam surface layer, and a silty clay loam subsoil with a fragipan.

The Iva series consists of deep, somewhat poorly drained soils that formed in loess on uplands. Slopes range from 0 to 6 percent. This soil has a silt loam surface layer and a silty clay loam subsoil.

The Reesville series consists of deep, somewhat poorly drained soils formed in loess and the underlying glacial till on uplands. Slopes ranging from 0 to 6 percent. This soil has a silt loam surface layer and a silty clay loam subsoil.

The Ragsdale series consists of deep, very poorly drained soils that formed in loess on uplands. Slopes ranging from 0 to 2 percent. This soil has a silt loam or silty clay loam surface layer and a silty clay loam subsoil.

SOILS REGION #6

LOAMY GLACIAL TILL
IDNR Division of Forestry Districts: 1, 2, 3

The topography of this region is composed of sloping areas of end moraines and rolling to nearly level till plain of the Wisconsinan glacial age. The soils of this region developed from loamy glacial till of Wisconsinan age. Many soils in this region are covered with a thin thin layer of loess. The soils included in this region are: Riddles, Miami, Crosier, Brookston, Chelsea, and Tracy, and are described below.

The Riddles series consists of deep, well drained soils that formed in glacial till on uplands. Riddles is found on the slopes of end moraines. Slopes range from 2 to 18 percent. This soil has a loamy surface layer and a clay loam or sandy clay loam subsoil over loam glacial till.

The Miami series consists of deep, well drained soils that formed in glacial till on uplands. Slopes range from 2 to 12 percent. This soil has a silt loam surface layer and a clay loam subsoil.

The Crosier series consists of somewhat poorly drained soils that formed in glacial till on uplands. Crosier is found on toe slopes and swells with slopes ranging from 0 to 4 percent. This soil has a loam surface layer and a clay loam subsoil.

The Brookston series consists of deep, very poorly drained soils that formed in glacial drift and the underlying glacial till in depressions and small drainageways. Slopes range from 0 to 2 percent. This soil has a silt loam, silty clay loam, clay loam, or loam surface layer and a clay loam or silty clay loam suboil.

The Tracy series consists of deep, well drained soils that formed in shaly sediments on outwash plains. Slopes range from 2 to 18 percent. This soil has a sandy loam or loam surface layer and subsoil.

The Chelsea series consists of deep, well drained upland soils that formed in eolian sand. Slopes range from 2 to 18 percent. This soil has a fine sand surface layer, and a fine sand subsoil that contains bands of sandy loam.

Soils Region #7

Clayey Glacial Till

IDNR Division of Forestry Districts 1, 2, 3, 12

The topography of this region ranges from gently sloping areas on glacial end moraines and moderately sloping to nearly level glacial till plains of Wisconsinan age. The soils of this region are of glacial origin, composed of silty clay loam or clay loam glacial till. The major soils are Morley, Blount, and Pewamo.

The Morley series consists of well drained or moderately well drained soils that formed in glacial till. Slopes range from 2 to 12 percent. This soil has a silt loam surface layer and a silty clay or clay loam subsoil.

The Blount series consists of somewhat poorly drained soils that formed in glacial till. Slopes range from 0 to 6 percent. This soil has a silt loam surface layer and a silty clay loam subsoil.

The Pewamo series consists of deep, very poorly drained and poorly drained soils that formed in glacial till or lacustrine sediments. Pewamo is found in depressions, small drainageways, and swales in gently rolling upland areas. Slopes range from 0 to 2 percent. This soil has a silty clay loam surface layer and a silty clay or clay subsoil.

Soils Region #8 and #9

Thin Loess or Moderately Thick Loess Over Loamy Glacial Till

IDNR Division of Forestry Districts 1, 2, 4, 6, 12, 13, 14, 15, 16

The topography in this region ranges from very steep glacial end moraines to nearly level glacial till plain from the Wisconsinan period. This soil region represents a major portion of the Tipton till plain (see figure 1.3, volume 1). The soils of this region are composed of loamy glacial till covered by a loess layer that varies from 10 inches to 40 inches in thickness. Soils of this region are: Hennepin, Miami, Russell, Crosby, Fincastle, Brookston, and Ragsdale.

The Hennepin series consists of deep, well drained soils that formed in glacial till. Hennepin is found on side slopes ranging 18 to 35 percent slope. This soil has a loam surface layer and subsoil. Glacial till is found at depths of less than 20 inches.

The Russell series consists of deep, well drained soils that formed in 20 to 40 inches of loess over glacial till. Russel is found on convex slopes ranging from 2 to 12 percent. This soil has a silt loam surface layer and a silty clay loam or clay loam subsoil. Glacial till is found at a depth of 20 to 40 inches.

The Miami series consists of deep, well drained soils that formed in glacial till. Slopes range from 2 to 18 percent. In uneroded areas this soil has a silt loam surface layer and silty clay loam or clay loam subsoils over glacial till (at less than 18 inches).

The Fincastle series consists of deep, somewhat poorly drained soils that formed in 20 to 40 inches of loess over glacial till. Slopes range from 0 to 6 percent. This soil has a silt loam surface layer, and a silty clay loam, a clay loam subsoil. Compact glacial till is at a depth of 20 and 40 inches.

The Crosby series consists of deep, somewhat poorly drained soils formed in glacial till. Slopes range from 0 to 6 percent. This soil has a silt loam surface layer, and a silty clay loam or silty clay loam or clay loam subsoil. Glacial till is found at a depth of less than 18 inches.

The Ragsdale series consists of deep, very poorly drained soils that formed in loess. Ragsdale is found in swales depressions and small drainageways. Slopes range from 0 to 2 percent. This soil has a silt loam or silty clay loam surface layer, and a silty clay loam subsoil.

The Brookston series consists of deep, very poorly drained upland soils that formed in glacial drift and the underlying glacial till, in swales and small drainageways. Slopes range from 0 to 2 percent. This soil has a silt loam, silty clay loam, clay loam, or loam surface soil, and a silty clay loam or clay loam subsoil.

Soils Region #10

Moderately Thick Loess Over Weathered Loamy Glacial Till
IDNR Division of Forestry Districts: 4, 5, 6, 8, 9, 14, 15, 16

Soils region #10 will be treated as two sections: The east side (Bartholomew, Jackson, Jennings, Scott, Clark, Franklin, Ripley, Jefferson, Dearborn, Ohio, and Switzerland Counties), and the west side (Morgan, Monroe, Owen, Putnam, Parke, Greene, Clay, Sullivan, and Vigo Counties).

The topography of the eastern portion of this region consists of steep to nearly level glacial till plains of Illinoian age. The western portion of this region consists of moderately steep to nearly level glacial till plains, lacustrine plains, and terraces of Illinoian age or later.

The soils in the eastern portion of this region are formed in Illinoian aged glacial till overlain by Wisconsinan aged loess of varying thickness. The soils are: Cincinnati, Hickory, Rossmoyne, Avonburg, and Clermont.

The Cincinnati series consists of deep, well drained soils found on uplands. Slopes range from 6 to 18 percent. This soil has a silt loam surface layer, a silty clay loam subsoil and a fragipan.

The Hickory series consists of deep, well drained soils on uplands. Slopes range from 6 to 60 percent. This soil has a loam or silt loam surface layer, a clay loam subsoil and overlays a sandy loam or loam textured layer.

The Rossmoyne series consists of deep, moderately well drained soils on upland. Slopes range from 2 to 6 percent. This soil has a silt loam surface layer, a silty clay loam subsoil and a fragipan.

The Avonburg series consists of deep, somewhat poorly drained soils found on upland flats. Slopes are less than 2 percent. This soil has a silt loam surface layer, a silty clay loam subsoil and a fragipan.

The Clermont series consists of deep, poorly drained soils found on upland flats. Slopes are less than 2 percent. This soil has a silt loam surface layer, and a silty clay loam subsoil with a fragipan like horizon.

The soils in the western portion of this region are formed in Wisconsin aged loess and the underlying Illinoian glacial till. Soils on low lying areas contain some acidic silty material, which was deposited in Illinoian aged lakes or washed from acid material deposited later. The soils are: Cincinnati, Ava, and Vigo.

The Cincinnati series consists of deep, well drained soils found on uplands. Slopes range from 6 to 25 percent. This soil has a silt loam surface layer, a silty clay loam subsoil and a fragipan.

The Ava series consists of deep, moderately well drained soils found on upland. Slopes range from 2 to 6 percent. This soil has a silt loam surface layer, a silty clay loam subsoil and a fragipan.

The Vigo series consists of deep, somewhat poorly drained soil found on upland. Slopes range from 0 to 2 percent. This soil has a silt loam surface layer and a silty clay loam subsoil.

Soil Region #11

Discontinuous Loess Over Weathered Sandstone and Shale
IDNR Division of Forestry Districts: 5, 7, 8, 9, 10, 11, 14, 16

The topography of this region consists of unglaciated, sharply dissected hills, narrow ridges and valleys. The underlying bedrock is Mississippian and Plennsylvanian sandstone, shale, and siltstone. The major soils in this region are well drained and moderately well drained, that formed in residuum (formed in place on bedrock). A thin layer of loess covers some of these soils. The major soils are: Zanesville, Wellston, Gilpin, Berks, and Weikert.

The Zanesville series consists of deep, well drained and moderately well drained soils. Slopes range from 2 to 18 percent. This soil has a silt loam surface layer, a silty clay loam subsoil and a fragipan.

The Wellston series consists of deep, well drained soils. Slopes range from 12 to 25 percent. This soil has a silt loam surface layer and a silty clay loam subsoil.

The Gilpin series consists of moderately deep, well drained soils. Slopes range from 12 to 25 percent. This soil has a silt loam surface layer and a loamy subsoil. Gilpin soil contains a moderate amount of rock fragments.

The Berks series consists of moderately deep soils. Slopes ranging from 18 to 35 percent and greater. This soil has silt loam and loam texture throughout and contains abundant shale fragments. Bedrock can be found 20 to 40 inches below the surface.

The Weikert series consists of shallow (less than 20 inches to bedrock) soils. Slopes are greater than 25 percent. This soil a has silt loam and loam texture throughout and contains abundant shale fragments.

Soil Region #12

Discontinuous Loess Over Weathered Limestones
IDNR Division of Forestry Districts: 5, 7, 8, 9

The topography of this region consists of gently sloping and moderately sloping uplands that contain many sinkholes. The underlying bedrock is Mississipian aged limestone. In this region, ground and surface water have dissolved bedrock forming caverns, sink holes, underground streams, and blind drainage systems (karst topography). Karst topography is characterized by areas dominated by weathered water soluble limestone bedrock.

The major soils of this region are moderately well drained or well drained. Many soils formed in a thin layer of loess and the underlying limestone bedrock. The major soil series in this region are: Bedford, Crider, Caneyville, and Corydon. (Note: Frederick is not commonly used any more).

The Bedford series consists of deep, moderately well drained soils found on uplands flats. This soil has a silt loam surface layer, a silty clay loam subsoil and a fragipan. Slopes range from 2 to 6 percent.

The Crider series consists of deep, well drained soils. Slopes range from 2 to 18 percent. This soil has a silt loam surface layer and a silty clay loam subsoil.

The Caneyville series consists of moderately deep, well drained soils. This soil has a silt loam surface layer and a silty clay loam or silty clay subsoil. Bedrock is found at a depth of 20 to 40 inches and slopes range from 2 to 60 percent.

The Corydon series consists of shallow, well drained soils. This soil has a silt loam surface layer. and a silty clay loam subsoil that has a high stone content. Slopes range from 6 to 70 percent. Bedrock is commonly found at a depth of 10 and 20 inches.

Soil Region #13

Discontinuous Loess Over Weathered Limestone and Shale
IDNR Division of Forestry Districts 6, 8, 15

The topography of this region is composed of gently sloping to steep dissected uplands. Soils of this region are formed in place from both shale and limestone bedrock (Ordovician aged), and commonly contain large limestone fragments in subsoil layers. The major soils of this region are well drained and have a thin layer of loess (wind blown silt). The major soils in this region are: Switzerland, Pate, Carmel, and Eden.

The Switzerland series consists of deep, well drained soils found on narrow ridges and slopes. This soil has a silt loam surface layer and a silty clay loam, silty clay or clay subsoil. Slopes range from 2 to 18 percent.

The Pate series consists of deep, well drained soils found on slopes that range from 12 to 25 percent. This soil has a silt loam surface layer and silty clay loam, silty clay or clay subsoil. Rock fragments may be found in the subsoil.

The Carmel series consists of deep, well drained soils found on slopes ranging from 6 to 25 percent. This soil has a silt loam surface layer and a silty clay loam or silty clay subsoil containing rock fragments. Weathered bedrock is commonly found within 40 to 60 inches of the surface.

The Eden series consists of moderately deep, well drained soils found on slopes ranging from 15 to 50 percent. This soil has a silty clay loam surface layer and a silty clay or clay subsoil. Rock fragments are present throughout the soil's horizon. Bedrock and layers of clay and shale are found at a depth of 20 to 40 inches.

INCREASING THE UTILITY OF THE SOIL SURVEY

For the forester, the soil survey contains a wealth of vital information concerning the physical and chemical properties of forest soils. This information can be extremely useful for management purposes.

This section is designed to increase the utility of published soil surveys for the forester and includes brief descriptions of some of the terms most frequently used in soil surveys. A better understanding of the terminology and how soils information is categorized will enhance the utility of the soil survey.

The type, amount and format of information contained in the modern soil survey varies from county to county. As a result, it is difficult to make broad generalization about the location of specific types of data in any soil survey. However, there are essentially six sections within the more recent soil surveys, that contain the majority of information of interest to a forester.

1) soil series description
2) table of physical or engineering properties
3) woodland suitability table
4) wildlife habitat suitability table
5) recreation suitability table
6) windbreak and environmental planting table

Only the most recently published surveys contain all of the above tables, but most of the earlier surveys contain the same basic information, only in a different format. In addition, the soil survey contains information potentially useful to the forester (besides that listed above) such as climatic data, general land use description and statistics. However, only those general categories listed above will be discussed here.

SOIL SERIES DESCRIPTION

SERIES DESCRIPTION

The soil series description consists of a short paragraph which describes the range of drainage classes within the series, the kind of parent material that the soil formed in and the range of slopes found within the series. The distinctive soil profile characteristics are listed along with other pertinent data such as the landforms the soil is commonly found on, annual precipitation, common management practices, etc.

SOIL SERIES NAME

A soil series is the lowest unit in a soil classification system, which is structured as follows:

- soil orders (10),
  - suborders (47),
    - great groups (185),
      - subgroups (670),
        - families (4500)
          - soil series (10,500)

A soil series, is made up of groups of soils that have similar soil profile. The series name is chosen from the name of a nearby community or feature where the soil was first observed.

Soil mapping units are phases of a soil series that are (usually) distinguished by slope-class and erosion characteristics. The slope classes and erosion classes are listed below. Slope Classes (normally used in Indiana)

A	0-2%	slopes
B	2-6%	"
C	6-12%	"
D	12-18%	"
E	18-25%	"
F	25-35%	"
G	35% and higher	

Erosion Classes

1	None to slight (not listed in unit but understood as 1)
2	Moderate (25-50% of area has subsoil exposed)
3	Severe (50% and more of area has subsoil exposed)

The soil mapping unit contains a two letter abbreviation of the soil series name, a capital letter from A to G indicating slope class and either a 2 for moderate erosion, or a 3 for severe erosion (a blank indicates erosion is slight or non-existent). For example:

Mn B 2

Miami Silt Loam — Mn

2-6% slope — B

Moderate erosion — 2

A soil variant is a unique soil that differs from a recognized soil series in one or more properties and does not occupy a large enough area to warrant the establishment of a new soil series. A soil complex is a soil mapping unit that consists of two or more dissimilar soil series or miscellaneous areas occurring in a regularly repeating fashion on the landscape.

Although they are common in the field and on soil maps, soil variants and complexes are not considered in this section.

DRAINAGE CLASSES

Excessively drained soils are very porous and rapidly permeable; they have low available water holding capacity (available water is soil moisture that is available for use by trees and plants).

Somewhat excessively drained soils are very permeable and free from mottling throughout the profile. This includes shallow bedrock soils. Available water capacity is low.

Well drained soils are those that are nearly free from mottling.

Moderately well drained soils commonly have a slowly permeable layer in the subsoil. Mottling can usually be found in the lower subsurface layers.

Somewhat poorly drained soils are wet for significant periods during the year, but not continuously. These soils commonly have mottling at a depth of 12 to 16 inches.

Poorly drained soils are wet for long periods, are light gray in color and are generally mottled from the surface downward. Mottling, however, may be absent or nearly so in some of these soils.

Very poorly drained soils are nearly always wet. They have a dark gray or black surface and a gray or light gray subsurface with or without mottling in the deeper parts of the profile.

TABLE OF PHYSICAL OR ENGINEERING PROPERTIES

The following soil properties are generally found in either the table of physical properties or the table of engineering properties depending of the format of the individual soil survey.

DEPTH (IN.)

The major soil layers or horizons of a particular soil series are listed by their depth (in inches). The upper and lower boundaries of each layer is indicated as distance (in inches) from the surface.

USDA TEXTURE

Texture is defined as the percentage of sand, silt and clay particles in a particular soil. USDA texture classes are listed for the major soil layers in a section at the upper left of the table. It is common for more than one texture to be listed for a particular layer because many series have different textures present in the profile. The following textural classes are listed with the corresponding abbreviations frequently used.

S	sand	LS	loamy sand
SL	sandy loam	L	loam
SI	silt	SIL	silt loam
SCL	sandy clay loam	CL	clay loam
SICL	silty clay loam	SC	sandy clay
SIC	silty clay	C	clay

possible MODIFIERS:

CB	cobbly	CN	channery
CR	cherty	FL	flaggy
GR	gravely	MK	mucky
SH	shaly	ST	stony
SY	slaty		

possible SUFFIXES:

V	very	X	extremely
C	coarse	F	fine

For Example: GRX SL = extremely gravely sandy loam.

FRACT > 3 IN (PCT)

This is a measure of the amount of rock or stone fragments at various depths in the soil. This value is expressed as a percentage of the total soil (on a dry weight basis) greater than 3 inches in diameter.

Increases in the percentage of stone or rock fragments in the soil will limit the volume of soil suitable for rooting. As the volume of stone or rock fragments in the soil increase, the amount of nutrients available to the plant will decrease because these fragments are basically inert material. Also, increased stone or rock fragment content decreases the water holding capacity of the soil because it displaces the soil material that would hold water.

PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO.; 4, 10, 40, 200

The percent of soil material (less than three inches in diameter) that passes through a set of calibrated sieves can be used as in indicator of soil texture. The higher the sieve number, the smaller the holes in the sieve. These sieves are numbered 4, 10, 40 and 200 with opening sizes of 0.187 in. (4.76mm), 0.079 in. (2.00mm), 0.0165 in. (0.420mm) and 0.0029 in. (0.074 mm) respectively. The material left on the #10 sieve is considered coarse fragments. The soil that passes through the #10 sieve, but is left on the #40 sieve is mainly coarse and very coarse sand. That portion passing through the #40 sieve, but remaining on the #200 sieve is medium to very fine sand. The soil material that passes through all these sieves are silt and clay particles. This gives the percentages of fine and medium sized soil particles and how they are distributed in the profile.

CLAY (PCT)

This expresses the average percent of clay-sized particles ($<$.002mm) in a layer of soil. The range of percent values is expressed on an oven dry weight basis for each layer of the soil.

The amount of clay in the soil greatly effects soil fertility and structure, the moisture holding capacity of the soil, permeability and shrink-swell potential.

MOIST BULK DENSITY (G/CM^3)

Moist bulk density is defined as the weight per unit volume, of an oven-dry sample of soil. Moist bulk density ranges for each major soil horizon is listed in grams per cubic centimeter (G/CM^3).

Soils that are loose and porous have low values and those soils that are compacted have high values. Sandy soils will have higher values than silty and clayey soils. Undisturbed forest soils will have lower bulk densities in the surface than the same soil in a cultivated field. Bulk densities of forest soils range from 0.2 G/CM^3 in some organic soils to 1.9 in coarse, sandy soils, with 1.0 to 1.3 G/CM^3 being a good average figure. The bulk density of rock is considered to be 2.65 G/CM^3.

Soils with high bulk densities can limit rooting and plant growth. Compacted soil layers or those that are naturally hard (fragipans, firm till layers, etc.). Bulk densities of 1.75 G/CM^3 for sands and 1.55 G/CM^3 for clays can restrict root penetration and water storage. By observing the bulk densities of the major layers, potential limiting layers can be detected.

Moist bulk density is influenced by texture, content of organic matter, soil structure and type of clays. There are some types of clays that will expand when exposed to water, others will not. Bulk density is an indicator of porosity, the degree of aeration and infiltration rate for the soil.

PERMEABILITY (IN/HR)

Permeability is defined as the amount of water in a column that will move into the soil in one hour. The ranges in the table indicate the downward movement of water when the soil is saturated. Permeability can be used to identify soil layers that could restrict root growth of water movement.

Permeability is rated as follows:

CLASS	POSSIBLE RATES (IN/HR.)
VERY SLOW	0.06
SLOW	0.06 - 0.2
MODERATELY SLOW	0.2 - 0.6
MODERATE	0.6 - 2.0
MODERATELY RAPID	2.0 - 6.0
RAPID	6.0 - 20.0
VERY RAPID	20.0

Permeability is a function of bulk density and porosity (amount of open spaces in a soil). Impermeable or slowly permeable layers can be caused by compaction. Grazing, overwash on eroded clayey soils, raindrop impact on bare soil, and the use of heavy machinery can compact soil.

Both air and water are needed for plant respiration and photosynthesis. Lack of air and water movement in the soil can be very detrimental to tree growth.

AVAILABLE WATER CAPACITY (IN/IN)

Available water capacity is defined as the amount of water that can be stored by the soil for plant use. Available water is the moisture content of the soil between wilting point and field capacity.

Wilting point is reached when all soil moisture held by soil particles is held so tightly that it cannot be taken up by plants.

At wilt point, most plants will wilt steadily and never recover.

Field capacity is the point at which the soil is so saturated that water will begin to move by force of gravity. This excess water is of minor importance to plants.

Available water capacity for each major soil layer is expressed in inches of water stored per inch of soil and should be multiplied by the depth of a soil layer to obtain a value for the moisture holding ability of that layer.

Example (Berks soil series, silt loam texture):

DEPTH (in.)	AVAILABLE WATER CAPACITY (in./in.)	TOTAL WATER AVAILABLE BY SOIL LAYER (in.)
0-10	.08 - .12	.8 - 1.2
10-26	.04 - .10	.6 - 1.6
26-33	.04 - .10	.28 - 0.7
		1.68 - 3.5

INCHES OF WATER FOR 60" PROFILE	AVAILABLE WATER CAPACITY
0 - 3	Very low
3 - 6	Low
6 - 9	Moderate
9 - 12	High
12+	Very high

Water holding capacity has a great influence on forest growth. The amount of available water present in the soil can determine the vigor and the composition of a stand of timber.

SOIL REACTION (pH)

Soil reaction, or pH, is a measure of soil acidity.

$$pH = \log \frac{1}{H^{+} \text{ ion concentration}}$$

The values express the pH of the soil solution and not the pH of the actual soil medium. The soil has the ability to neutralize the initial effects of certain amounts of introduced acids and bases because of "buffering" agents like clays and organic matter. The pH estimates in the table do not account for this buffering capacity of the soil.

Soil pH influences nutrient availability, and soil organisms. Direct injury to plants occurs at the extremes in pH; below 3.0 and above 9.0. Few Indiana soils have such extreme pH levels.

Soil pH between 5.0 and 7.0 seldom influences the selection of planting stock. On sites where pH is below 5.0 and above 7.0 site alteration such as spreading lime or sulfur, or planting species tolerant of high (low) pH may be required. Planting on soils with a pH above 6.0 increases the incidences of fungal diseases, this however, is usually only a consideration for nursery operators.

In southern Indiana, soils with a pH below 5.0 are usually the result of extensive weathering. Some of these soils have a dense subsoil layer or fragipan. Some sandy soils in northern Indiana may also have a pH below 5.0.

Soil pH is seldom uniform throughout the soil profile. Tree roots will not grow where soil pH is extreme and consequently pH can limit rooting and tree growth.

Soil reaction categories are as follows:

Class	pH Range
Extremely acid	4.5 and below
Very strongly acid	4.6 - 5.0
Strongly acid	5.1 - 5.5
Medium acid	5.6 - 6.0
Slightly acid	6.1 - 6.5
Neutral	6.6 - 7.3
Mildly alkaline	7.4 - 7.8
Moderately alkaline	7.9 - 8.4
Strongly alkaline	8.5 - 9.0
Very strongly alkaline	9.0 and above

SHRINK-SWELL POTENTIAL

The shrink-swell potential is defined as the potential for a volume of soil to change volume with a gain or loss of moisture. Shrink-swell potential is classed as low, medium, high and very high.

The amount and kinds of clays (some clays expand more than others) and the magnitude of soil moisture change, dictates the amount of shrinking and swelling that occurs on a particular site.

The use of heavy logging equipment may be hampered, and seedling mortality may be a problem, on soils with high shrink-swell potentials.

EROSION FACTORS (K & T)

The K factor is a component of the universal soil loss equation. It is one of the six factors used to calculate the amount of soil lost (in tons per acre) due to erosion. "K" indicates the susceptibility of a soil to sheet and rill erosion by the forces of water. "K" values range from 0.05 to 0.69; the higher the value the more susceptible a soil is to sheet and rill erosion. "K" values are a function of the percentages of silt, sand and organic matter, soil structure and permeability.

WIND ERODABILITY GROUP

The wind erodability groups indicate the relative susceptibility of the bare surface soil to wind erosion. Soils are grouped for wind erodability by texture. Ratings range from 1 (most susceptible) to 8 (least susceptible). These ratings are defined as follows:

1. Sands, coarse sands, fine and very fine sands and mucks are classed as extremely erodable. Estimated soil loss expected on bare organic or mineral soil is 310 tons per acre per year (T/A/yr).

2. Loamy sands, loamy fine sands and loamy very fine sands are classed as very highly erodable. Estimated soil loss expected on bare mineral soil is 134 T/A/yr.

3. Sandy loams, coarse sandy loams, fine sandy loams, very fine sandy loams are classed as erodable. Estimated soil loss expected on mineral soil is 86 T/A/yr.

4. Clays, silty clays (these have granulated structure on the surface) are classed as erodable. Estimated soil loss expected on exposed soil is 86 T/A/yr.

5. Loams, sandy clay loams and sandy clays are classed as moderately erodable. Estimated soil loss expected on these mineral soils is 56 T/A/yr.

6. Silt loams and clay loams are classed as moderately erodable. Estimated soil loss expected on these mineral soils is 47 T/A/yr.

7. Silty clay loams are considered to be slightly to moderately erodable. Estimated soil loss expected on these mineral soils is 38 T/A/yr.

8. Soils in this class are wet or stony and are not considered to be subject to wind erosion.

ORGANIC MATTER (PCT)

Organic matter is plant and animal residues in various stages of decomposition. Percent organic matter content is expressed on a dry weight basis. The percent of organic matter content is listed for the surface layer only. Organic matter content normally ranges from 1 to 6 percent for nearly all of Indiana's mineral soils. Organic soils will have much higher values.

Organic matter is a general indicator of site productivity. Organic matter increases the water holding capacity and nutrient content of the soil. Humus and organic matter promote good soil structure, and increase pore space, porosity, and soil aeration.

FLOODING

The frequency of flooding is classified as none, rare, occasional or frequent based on the observed frequency of standing water on the site. Standing water for short periods after snow melt or rain, and swamp or marsh conditions, are not considered flooding.

Frequency of flooding is classified as follows:

None:	Flooding is not probable.
Rare:	Flooding is unlikely but possible under unusual weather conditions.
Occasional:	Flooding is expected to occur on average less frequently than once in two years (5 to 50 time in 100 years).
Frequent:	Flooding is expected to occur on average more frequently than once in two years (more than 50 times in 100 years).

Duration is expressed as:

Very brief:	The soil is flooded less than two days.
Brief:	The soil is flooded from 2 to 7 days.
Long:	The soil is flooded from 7 days to 1 month.
Very Long:	The soil is flooded longer than 1 month.

Probable times are expressed as a range of months when flooding may occur.

HIGH WATER TABLE

High water table is defined as a saturated soil layer that exists seasonally most years, within six feet of the surface.

Estimates of the depth of the water table are based on evidence of a saturated zone in the soil profile such as gray or mottled colors. The information in the table indicates the depth to the water table, the kind of water table and the months of the year the water table is commonly high. To be considered a high water table a saturated zone must exist within six feet of the surface for longer than one month during an average year.

Water tables are classified as follows:

1. A perched water table is a saturated zone usually close to the surface that is separated from other saturated layers by a relatively dry, impermeable or slowly permeable layer.

2. An artesian water table is one that is under a hydrostatic head generally beneath a slowly permeable layer of soil. When this layer is broken, water will rise through the break.

3. An apparent water table is a thick zone of free water in the soil. A bore hole will gradually fill with water to the level of the water table.

The depth (ft.) to the high water table is indicated by a range of numbers. The numbers indicate the depths between which the water table will fluctuate during the year. If ponding exists on a particular soil, the first number will be proceeded by a "+" sign. This indicates how high the water level will typically rise above the soil surface. The period during the year when the water table is high is indicated by a range of months.

CEMENTED PANS

Cemented pans are subsurface layers that are compacted, cemented, or hardened in some way and are slowly permeable to water and air. The pans are listed at the depth they usually occur and are classified as thick or thin:

"Thin" refers to a pan that is cemented uniformly and less than 3 inches thick, or discontinuously cemented or fractured and less than 18 inches thick.

"Thick" refers to a pan that is uniformly cemented and more than 3 inches in depth, or discontinuously cemented or fractured and more than 18 inches thick.

The depth of soil to the pan itself is the volume of soil most favorable for root growth. The degree to which the pan will restrict root growth depends upon its thickness and how uniformly it is cemented or hardened. Roots may pass through cracks, or thin areas of the pan. A thin or easily fractured pan will inhibit rooting while a thick or cemented pan may restrict rooting completely.

DEPTH TO BEDROCK

The depth to bedrock is expressed in inches. The presence of bedrock is considered to a depth of 60 inches. The values for depth are based on many field observations made during sampling and mapping. The "HARDNESS" of bedrock is classed as follows:

"Soft" bedrock is so soft or fractured that excavations can be made (usually) with trenching machines, backhoes or small rippers.

"Hard" bedrock is so hard and massive that blasting and special equipment is needed to excavate.

The depth to bedrock generally indicates the depth of soil material favorable for root growth. Even though this layer will tend to inhibit root growth, roots may penetrate soft or fractured bedrock. If bedrock is hard or massive, rooting will be restricted almost completely.

HYD GRP (HYDROLOGIC GROUP)

Hydrologic groups indicate the potential for bare topsoil to absorb precipitation.

The infiltration rate and the transmission rate (the rate water moves in the profile of the soil) are considered in these hydrologic groups. The potential for soil runoff is divided into four categories listed from the lowest potential to the highest.

1. "A" (low runoff potential) - Soils having a high infiltration rate even when thoroughly wetted, consisting of deep, well drained to excessively drained sands or gravels. These soils have a high rate of water infiltration and transmission.

2. "B" - Soils having moderate infiltration rates when thoroughly wetted, consisting chiefly of moderately deep to deep, moderately well drained to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

3. "C" - Soils having slow infiltration rates when thoroughly wetted, consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures. These soils have a slow rate of water transmission.

4. "D" (high runoff potential) - Soils having very slow infiltration rates when thoroughly wetted, consisting chiefly of clayey soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Dúal hydrologic groups are given for certain soils that can be drained (e.g., A/D, B/D & C/D). The first letter indicates the drained condition and the second represents the undrained condition.

These classes pertain to exposed soil. The presence of forest litter is not considered in these groups. Any type of litter layer will increase infiltration rates (except in group "A") and protect the exposed mineral soil from being detached and moved by water.

Mineral soil may be exposed or disturbed during logging. These hydrologic groups can be used to determine when erosion control measures are needed.

POTENTIAL FROST ACTION

Potential frost action is defined as the potential of upward or lateral movement of the soil caused by the formation of segregated ice lattices (frost heaving) and the subsequent loss of soil strength upon thawing. Potential frost action is rated as high, moderate or low.

Potential frost action is influenced by soil texture, density, permeability, organic matter content, depth to the water table, and soil temperature. Normally, silty and clayey soils with high water tables are most susceptible in late fall, winter and early spring. Well drained gravelly or sandy soils are least susceptible. An undisturbed litter layer will act as a buffer to reduce the amount of frost action occurring on a particular site.

Some forestry practices need to be modified when frost action potentials are high. When seedlings are planted on soils that have high frost action potentials the danger of frost heaving of seedlings will be great in the late fall, winter and early spring. Soils with high ratings for frost action are unstable, and may restrict access for logging. Little can be done to overcome this problem except to avoid periods of the year when frost action is a likely occurrence.

WOODLAND SUITABILITY TABLE

This table is designed to give woodland productivity and management information for a particular soil series. Each soil series is classified into five possible classes according to the following factors: mean average annual temperature (MAAT), slope class in percent, textural class, aspect and erosion class. These are listed under the heading, "Class Determining Phase".

Ordination symbols for woodland suitability accompany each mapping unit under the heading ORD SYM. Soils with the same ordination symbol require the same general management and have about the same potential productivity.

The ordination symbol is a number/letter combination. The number indicates productivity (1 being the highest and 5 being the lowest), and the letter indicates the major limitations associated with the soil that effect tree growth. These limitations are:

x - stoniness or rockiness;
w - excessive water in or on the soil;
t - toxic substances in the soil;
d - restricted root growth;
c - clay in the horizons of the soil;
s - sandy texture;
f - high content of coarse fragments in the soil;
r - steep slopes
a - no significant limitations

For soils with more than one limitation, limitations are listed in the following order: x, w, t, d, c, s, f, r and a.

Management problems are listed next in the Woodland Suitability Table and include the headings: Erosion Hazard, Equipment Limitations (EQUIP. LIMIT), Seedling Mortality (SEEDLING MORT'Y), Windthrow Hazard (WINDTH HAZARD), and Plant Competition (PLANT COMPETITION). Each problem is rated slight, moderate or severe and indicates the general degree that these problems effect management.

<u>EROSION HAZARD</u>: The risk is rated slight if the expected soil loss is small, moderate if practices to control erosion are needed for logging roads and skid trails, and severe if special equipment or erosion control measures are needed to prevent great losses of soil.

<u>EQUIP. LIMIT</u>: A slight limitation indicates that there is no limitation to the use of equipment at anytime of the year.
A moderate limitation indicates the need for a modification in

equipment, management practice, or a reduction in use during a short period. A severe limitation indicates special equipment or management is needed.

SEEDLING MORT'Y: This indicates how much the mortality rate for seedlings is effected by the soil (this does not include plant competition). These ratings consider seedlings from good stock, properly planted during a time when adequate moisture is present. Seedling mortality is rated slight if expected mortality is 25% or less; moderate if 25-50% and severe if mortality is greater than 50%.

WINDTH HAZARD: A slight hazard indicates that few trees will be blown down, moderate that some trees will blow down during periods of high winds and excessive wetness. A severe rating indicates that many trees will blow down during periods of excessive wetness and high winds.

PLANT COMPET: This indicates the amount of plant competition that will occur following a disturbance. A severe rating indicates that the establishment of a desirable stand is expected to be prevented by competition from undesirable plants unless the site is managed to control the invading species.

The POTENTIAL PRODUCTIVITY section of the Woodland Suitability Table lists site index estimates for some common trees found on a particular site. The site index values are taken from data that has accumulated by the USDA Soil Conservation Service. These values are averages of estimates taken from plots throughout the state where the soil was first identified (not necessarily Indiana). More accurate estimates can be found in section VI, of this publication.

WILDLIFE HABITAT SUITABILITY TABLE

The Wildlife Habitat Suitability Table lists the potential of different soils to provide habitat for wildlife. The ratings used in this table are as follows:

Good: The element of habitat is easily established, improved and maintained with few limitations effecting management. Good results are expected.

Fair: The particular element of habitat can be established, improved and maintained in most places but moderately intensive management is required for satisfactory results.

<u>Poor</u>: Limitations are severe for the designated element of habitat. Habitat can be created, improved or maintained in most places but management is difficult and must be intensive.

<u>Very Poor</u>: The limitations for the element of habitat are severe and results would be very unsatisfactory.

Under the subheading, POTENTIAL FOR HABITAT ELEMENTS, the following categories exist.

GRAIN & SEED: These are domestic grains and seed producing herbaceous plants. The soil factors that effect this element are depth of the root zone, texture of the surface layer, available water capacity, wetness, slope, surface stoniness, flood hazard, soil moisture and soil temperature.

GRASSES & LEGUMES: These are domestic and perennial grasses and legumes. Depth of the root zone, surface soil texture, available water capacity, wetness, surface stoniness, flood hazard, slope, soil temperature and moisture are properties that effect this element of wildlife habitat.

HERBACEOUS PLANTS: This element consists of naturally established forbes, grasses and weeds. The following soil properties effect their establishment and growth: depth of the root zone, surface soil texture, available water capacity, surface stoniness, wetness, flood hazard, soil temperature and moisture.

HARDWOOD TREES: This habitat element is effected by the depth of the A horizon, effective rooting depth, soil texture and drainage.

CONIFEROUS PLANTS: This element, like hardwood trees, is effected by the depth of the A horizon, effective rooting depth, soil texture and drainage.

SHRUBS: These consist of woody plants. This element is effected by the surface texture, wetness, pH, slope, and surface stoniness.

WETLAND PLANTS: These are annual or perennial wild herbaceous plants that grow on moist or wet sites (excluding submerged or floating aquatic plants). Soil factors effecting this element are: surface texture, wetness, reaction, salinity, slope and surface stoniness.

SHALLOW WATER AREAS: These are areas that have less than five feet of water. This element of habitat is effected by the depth to bedrock, wetness, surface stoniness, slope and permeability.

The elements of the section POTENTIAL AS HABITAT FOR are listed as follows:

OPEN LAND WILDLIFE: This element consists of pastures, meadows and areas overgrown with grasses, herbs, shrubs and vines which produce grain, seed, grasses and legumes for wildlife.

WOODLAND WILDLIFE: This element is composed of deciduous and coniferous plants, associated grasses, legumes and herbaceous plants.

WETLAND WILDLIFE: This element consists of open marshes, swamps and shallow water areas.

RANGELAND WILDLIFE: This element consists of shrubs and wild herbaceous plants.

RECREATIONAL DEVELOPMENT TABLE

This table gives the general ratings for camp areas, picnic areas, playgrounds and trails according to the following characteristics: wetness, percent slope and surface soil texture. The ratings for the suitability of these recreational developments on a particular site are slight, moderate and severe.

Slight - The soil properties are generally favorable. Any limitations are minor and easily overcome.

Moderate - Any limitations for these soils can be overcome or alleviated by planning, special maintenance, or design.

Severe - Soil properties are unfavorable and limitations can be offset only by costly soil reclamation, special design, intensive maintenance, limited use, or a combination of these measures.

Other aspects that should be considered when evaluating a site are the scenic quality of an area, its size, shape, accessibility, availability of water and the ability of the soil to support vegetation. Also, soils that will flood are limited in their recreation use by frequency and duration of flooding during the period of the year when flooding could be a problem.

WINDBREAK & ENVIRONMENTAL PLANTINGS TABLE

Listed in this table are the species most suitable to plant for windbreaks on a particular soil and the height these plants will achieve in 20 years. The estimates are based on healthy plantings given adequate care.

A NOTE OF CAUTION:

Although modern soil maps are available (or soon will be) for most Indiana counties, users should be aware of the level of detail with which these maps are made. In wooded areas soils are not mapped as intensively as in non-forested areas. As a result small inclusions of different soils may be present within a map unit. An inclusion is a different soil unit too small to be mapped out within the boundaries of a normal mapping unit. Inclusions are more likely to be present where map units are large.

Frequently two or three different soils are lumped together to form one map unit called a "soil complex". These are designated by the soils included in the complex name (e.g., Gilpin-Berk complex). In this situation, soil characteristics will vary depending on which series is actually present on the site. It is important to distinguish the differences between what is mapped and what actually exists in the field. At the very least, it is important to be aware that this situation exists.

Many soil characteristics important to tree growth can be determined in the field with a soil probe. This field check can identify localized variations in soil characteristics and confirm information listed in the soil survey.

ASSESSING THE PRODUCTIVITY OF FOREST SOILS

FACTORS INFLUENCING TREE GROWTH

There are several factors which influence tree growth and most have been discussed in proceeding sections. However, four factors stand out as being particularly significant:

1) effective rooting depth
2) depth of surface soil
3) drainage
4) soil texture

Many of these are interrelated and are influenced by topography. In fact, aspect, position on slope, percent slope and shape of slope could just as easily be listed as additionally significant factors influencing growth.

EFFECTIVE ROOTING DEPTH

Soil depth determines the amount of soil available for root growth. As discussed earlier, tree roots will not grow in a hostile medium. Layers that restrict root development will limit tree growth by limiting access to water and soil nutrients. High water tables, fragipans, and plow layers will restrict root growth. In the field rooting depth can be determined with a soil probe.

Bedrock can restrict root growth completely. However, where bedrock is soft or fractured, roots may be able to penetrate rock layers. To determine the characteristics of underlying bedrock it may be necessary to dig a soil pit or to check with local authorities concerning the nature of the bedrock in a particular area.

Finally rooting depth may be limited by soil layers with extreme textures. Clay or gravelly layers may limit rooting depth somewhat by being either too wet or too dry for root growth.

DEPTH OF SURFACE SOIL

Although a trees roots may extend for several feet, the majority of a tree's roots are in the top layer of soil. This is the area of highest water and nutrient uptake during the spring. The condition of this surface layer has a major influence on the availability of water, nutrients and oxygen.

Auten (1945) reported that on shallow soils, productivity increased rapidly with increasing depth of the surface layer. However, on soils with a greater total depth (greater than 36 inches) productivity was less strongly tied to the depth of the surface layer alone. On deep soils, texture and organic matter content in this upper layer becomes more important in determining tree growth. Tree growth will suffer where surface layers are thin, textures are extremely fine (clay) or coarse (sandy), and where organic matter is low.

The depth of the A horizon may vary with stand age. This may be particularly significant in stands that have developed on badly eroded sites.

SOIL DRAINAGE

Soil drainage is a function of soil texture, depth to an impervious layer and topography. Obviously extremely well drained or poorly drained conditions will limit growth by limiting the availability of oxygen or water.

Upland areas generally have better soil drainage than bottomland areas. In fact, excessive drainage is more frequently a problem on upland sites. However, relying on topography alone to assess soil drainage can be misleading for two reasons.

First, it is possible to have poorly drained conditions on ridgetop sites. A dense clay layer may act to hold moisture near the surface. This is especially a problem on some broad ridge tops where there is not enough relief to permit surface runoff of excess moisture. Under these conditions root growth may be restricted.

Secondly, some ridges are covered with a loess (wind blown) silt cap. Where this layer has not been disturbed, soil moisture holding capacity will be high, drainage adequate and tree growth excellent.

A soil probe should be used to assess soil drainage in the field. A grayish or mottled color is usually an indication of poor drainage. In addition, rubbing a small sample of soil between the thumb and fore finger will (with a little practice) provide a reliable indication of soil texture. Samples of clay can usually be pressed into a fine ribbon, while silty and sandy layers will feel gritty.

Published soil survey information can be used to determine soil texture, but it is always best to take several field sample to confirm survey information. The mapping of soils in forested areas tend to be more extensive than intensive, and great variations in soil texture may exist over very short distances.

SOIL TEXTURE

Soil texture influences a soil's water and nutrient holding capacity, drainage, and degree of aeration. All of these in turn effect root growth and ultimately tree growth. In general, medium-textured soils are best, and extremely fine or coarse-textured soils are less favorable.

Soil texture will vary within a soil profile. Under certain circumstances the texture of subsoil layers may be more important in determining the character of the site than the texture of the surface layer alone. For the reason stated above (see SOIL DRAINAGE), it is advisable to determine soil texture by taking several field sample rather than relying on published soil survey data alone.

SUMMARY

Being aware of how these soil characteristics and topographic features interact will aid the field forester in developing a sixth sense for assessing soil productivity. Because of past management the quality of the existing growing stock may not accurately reflect the productivity of the soil. Forester need to be aware of a soil's characteristics in order to develop silvicultural prescription that are appropriate for a particular site.

ASSESSING SOIL PRODUCTIVITY

Assessing the productivity of forest soils is more complicated than it might initially appear. Traditionally, foresters have used site index (the height attained by dominant and codominant trees at 50 years of age) as an indicator of site productivity. This is the most widely accepted, although not the only, indicator of site productivity.

This section includes a general discussion of the use of site index, and a discussion of some of the ways site index can be estimated. The advantages and disadvantages of each of four methods of assessing site productivity are discussed.

The methods are:

1) direct measurement of site index from trees currently growing on the site.

2) indirect measurement of site index based on soil characteristics and topographic features.

3) internodal method -- a relatively new technique that can be used with white and red pine in Indiana.

4) qualitative site assessment -- a forester's qualitative assessment of site productivity based on experience and a fundamental understanding of the site characteristics that influence tree growth.

PRODUCTIVITY

"Productivity", whether of an acre of soil or of a factory worker, is a measure of output, per unit of input. Output is usually measured in dollars or physical units. Input is usually expressed as time, but may also be expressed in terms of dollars or other units.

The output of a forest is a function of many inputs (water, management, nutrients, time, etc.). Foresters frequently lump many separate inputs together and label them "site". Another group of inputs are commonly referred to as "management". In the common useage of these terms, the output of a forest is a function of site, management and time.

To assess "site productivity", the contribution of the group of inputs known as site, must be isolated from the contribution of the other inputs. Because it would be impossible to directly measure the contributions of the individual inputs that comprise site, foresters must rely on measurements of features of the forest that provide a reliable expression of the contribution of these inputs. With site index, tree height is used to estimate the output that can be attributed to the inputs (site).

A tree's volume is a function of its diameter and height. Forest growth (output), therefore, is a function of the change in diameters and heights over time. Both diameter and height growth is affected by stocking and management. Height growth, however, seems to be less sensitive to the level of stocking than diameter growth. Because height growth is strongly correlated to volume growth, height growth is useful for predicting future volume growth.

SITE INDEX: Limitation and use

The traditional approach to assessing site productivity has been through the use of site index. With site index it is possible to use tree height (while holding other factors such as tree age, management, stocking and species, etc. constant) as an expression of the contribution of inputs known as site.

Foresters need to quantify site productivity for basically two purposes: (1) predict current volume and future volume growth, (i.e., through the use of stand tables and growth and yield models) and (2) to classify or rank different forest stands on the basis of productivity. These are distinctly different applications, the implications of which will be apparent later.

A site index curve would more accurately be described as a "height growth curve". A site index curve is a graph of how the height of a tree, on a particular type of site, will change over time. With a set of site index curves, a tree's past and future height can be estimated if, site index and age are known. Further, given site index, age and appropriate volume tables, current and future stand volume can be predicted. Height growth curves (site index curves) are appropriate for this application (application number 1 cited above).

Height growth curves (site index curves) are frequently applied to an entirely different task -- assessing the productivity of a particular site (application number 2 above). In this situation there are a few facts that foresters should be aware of.

Most site index curves are defined by a regression equation of the following form:

$$HT = f\ (AGE, SI) \qquad (1)$$

That is, height is a function of age and site index. In other words, site index and age are used to predict height. Height is called the "dependent variable". That is, the value for height is 'dependent' on the values of the "independent variables", age and site index. The appropriate use of an equation of this form then is to estimate height, when age and site index are known (McQuilkin, 1974; Curtis et al, 1974).

Most frequently, however, height and age are known and site index is the variable which needs to be estimated. The traditional application of site index is to find the site index for a tree or group of trees (stand) of known age and height. To accomplish this an equation of the following form is needed.

$$SI = f\ (HT, AGE) \qquad (2)$$

In this equation, height and age are used to predict site index. Technically it is incorrect to take equation (1), substitute the known variables (HT and AGE), and solve for SI. This at first seems counter-intuitive, because simple algebra tells us: if $A = B + C$, then $A - B = C$. If the regression curve HT = f (AGE, SI) was a precise mathematical expression of reality, then the equation could be manipulated algebraically. However, a regression equation is only an estimate of reality. A regression equation defines a line that minimizes the sum of the squared differences from observed values and predicted values for a given set of points.

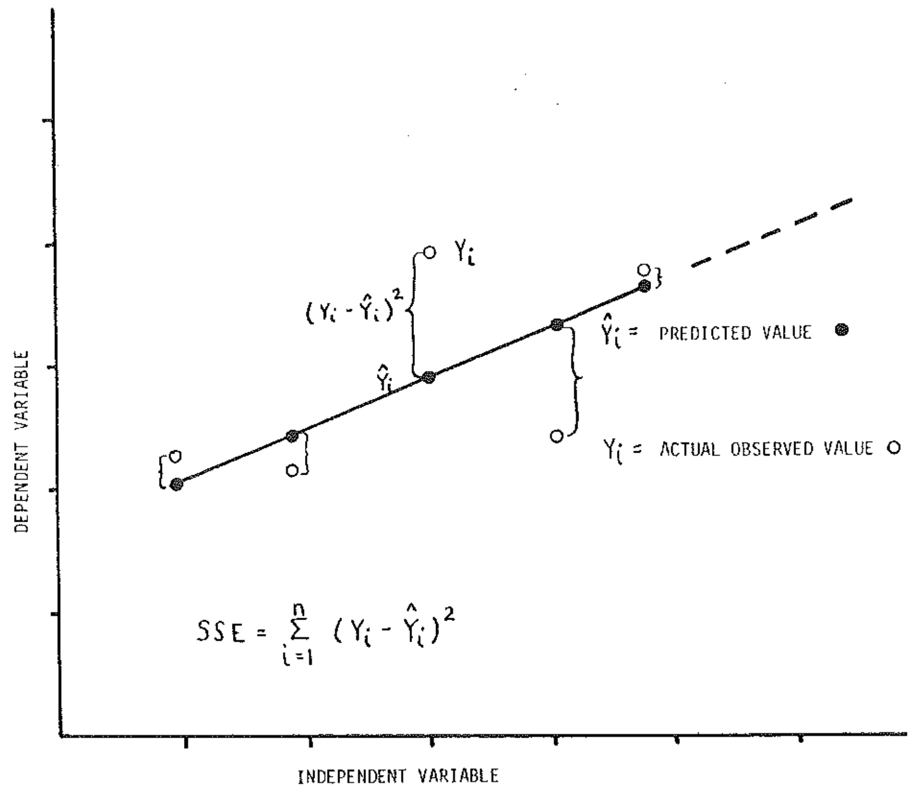


FIGURE 5.1 Sample least squares regression line. The equation that defines this line is the mathematical equation that minimizes the sum of the squared differences between all observed values "o" and all predicted values "●".

Regressing SI on HT and AGE (equation 2, as opposed to a regression of HT on AGE and SI, equation 1) minimizes the sums of squares for a different set of observed and predicted values and generates a different equation.

Fortunately, in most cases this does not create a large source of error! But scientific data is of little value if it is not applied properly and foresters using site index to assess site productivity should be aware of this situation. In addition, some site index equations are available of the form of equation (2) (Beck, 1962; Losch & Schlesinger, 1975; McQuilkin, 1974); but most site index curves applicable in Indiana are of the form of equation (1).

A second limitation of traditional site index curves evolves from the way they are constructed. In the traditional site index study a large number of trees are felled and age is determined at even intervals up the bole (stem analysis). Some older site index curves have been developed using other methods (Schnur, 1937), but stem analysis is universally recognized as the most accurate method (Beck & Trousdell, 1973; Hagglund, 1981). From the stem analysis data height is plotted against age for each tree (Figure 5.2).

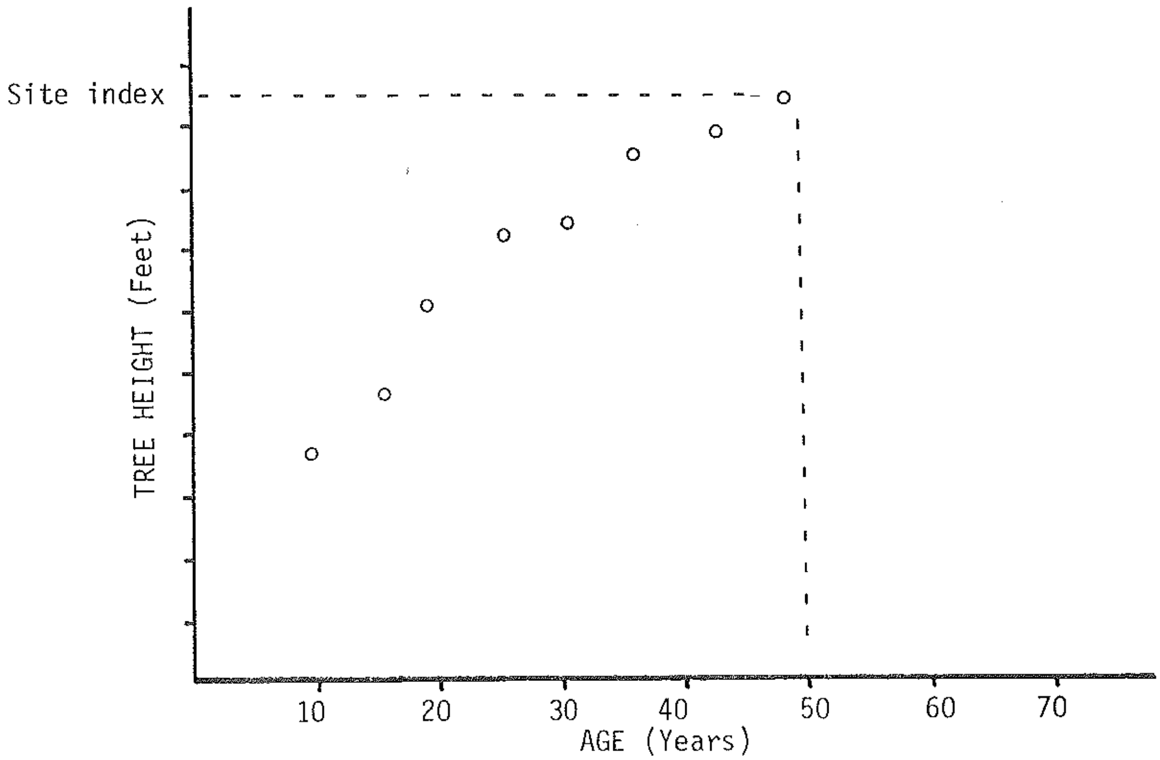


FIGURE 5.2 Hypothetical plot of an individual tree's height over age.

The height of a particular tree at the base (50 yrs.) determines the site index for that tree. Plotting the height growth pattern for several trees produces a scatter diagram (Figure 5.3).

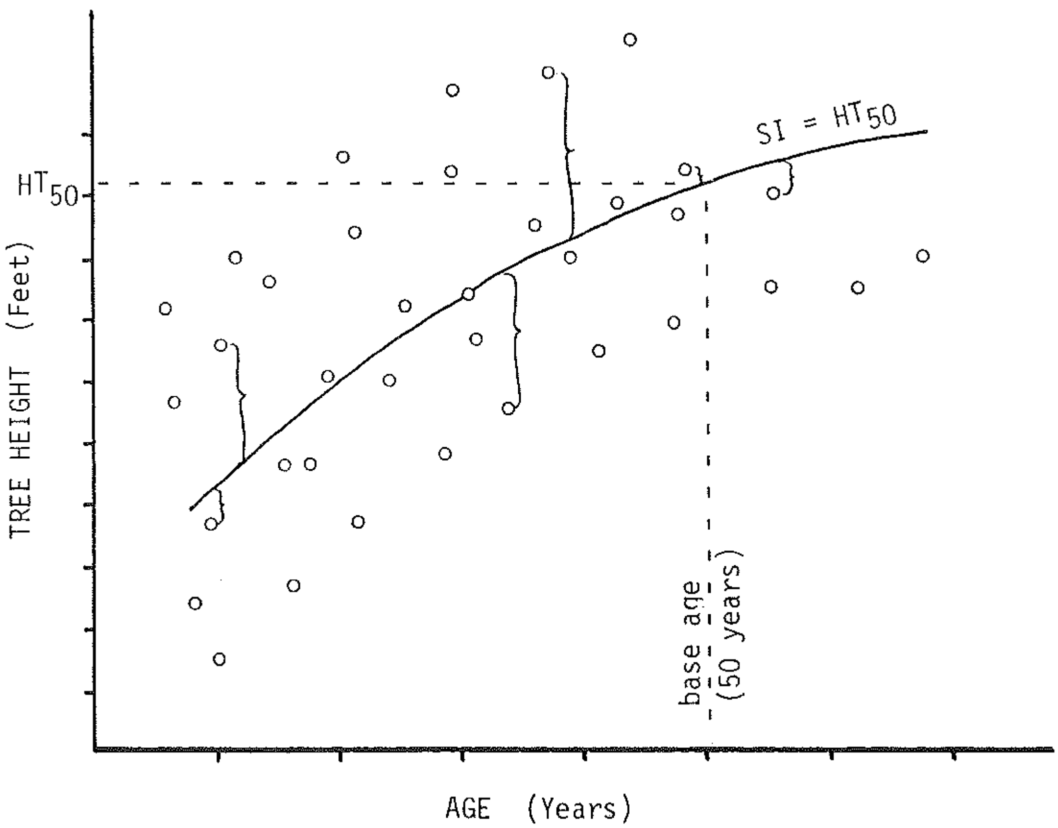


FIGURE 5.3 Hypothetical scatter diagram of the height growth patterns of five trees on a variety of sites. The regression line fitted to these points represents the height growth pattern for all trees on all sites represented in this sample.

There are two aspects about this diagram that are important: (1) the range of ages sampled and (2) the range of site qualities sampled. The importance of these aspects will be discussed later.

To construct site index curves from this scatter diagram, a regression line is fitted to all observations. This is a prediction equation of height growth over age if only one curve for all sites was to be generated. This would be the site index curve for the average site in the study (see figure 5.3). The shape of this curve is then used to define the shape of the other site index curves. The heights of the other site index curves of course are defined by the site index and base age (i.e., the 80 ft. site index line by definition passes through the point AGE = 50, HT = 80). These types of site index curves are said to be "harmonized".

Harmonized growth curves are quite common and can be identified by the neat, nested sets of curved lines they produce. The underlying assumption behind harmonized curves is that the rate of height growth is proportional on all sites at any age. Recent research has cast some doubt on the validity of this assumption (Carmean, 1971b; Carmean, 1970).

Research has shown that trees on good site tend to grow rapidly (in height) when young and slow down somewhat with increasing age. Trees on poor sites, however, grow slower in the early years but increase their rate of growth (relative to trees on good sites) with increasing age. This is consistent with intuition. On good sites competition is intense in young stands. Trees are forced to grow tall rapidly to compete with fast growing pioneer species. Later, as the more short lived species drop out of the stand, the pressure to grow tall is not as intense. On a poor site however, early competition is not as intense and height growth is slower in the early years. In some cases it may take several years for a tree's root system to expand to the extent, or depth, needed to support maximum growth. As the trees begin to more completely utilize the site, competition for sunlight increases and provides an incentive for trees to grow tall. As a result, growth on poor sites starts to increase relative to the rate of height growth on good sites (Beck and Trousdell, 1973; Carmean, 1971a). This pattern of height growth is called "polymorphic". Most modern site index curves reflect this polymorphic growth pattern.

The amount of error introduced from the use of harmonized curves will vary with the quality and quantity of data used to develop the curves, the growth characteristics of the species involved and the range of sites over which the data was collected. Generally this effect will be smaller the closer stand age is to the base age, and the closer site index is to the average quality site upon which data was originally collected to construct the curves. In older stands, and on very good or very poor sites, this influence has been shown to be significant (Carmean, 1979a; Carmean, 1971a)

Not only will height growth patterns vary on different sites, but they will also vary with species. White oak, and to a lesser extent Chestnut oak, tend to grow more slowly when young but maintains a rapid rate of height growth longer than Black and Scarlet oak. This feature is significant when using site index curves developed for groups of species and for species with distinctly polymorphic growth characteristics. In general, it is probably advisable to use polymorphic site index curves when they are available and especially when stand age exceeds 75 to 80 years.

A third potential danger in the use of site index curves comes from the range of ages over which the data was collected. A study, for example, that sampled tree of ages 20 to 80 will not provide a reliable basis from which to estimate site index for trees 120 years old. There is no way to get around this other than to be aware of the range of observed ages used to construct the curves. Typically, individual site index curves will be made up of a solid line segment and a broken or dashed segment. The solid line indicates the range of ages over which observations were actually made in the original study. The broken segment indicates a projection beyond the range of ages actually sampled. Similarly, the highest or lowest site index line will usually have major dashed segments, indicating that few samples were taken on very high or very low productivity site. Projections of this nature, beyond the range of actual observations, are usually reliable but should be viewed with some suspicion.

A fourth limitation to the use of site index curves involves the geographical range over which data was collected. Generally, the narrower the geographical range over which data was collected in the original study, the less that variations in regional climatic conditions and regional genetic variation within species will effect height growth patterns. Site index curves from other regions frequently must be used because of a lack of home grown data. Curves developed in regions close to your location, should provide reasonably good estimates of site index. However, site index curves developed where growing conditions are significantly different should be used only with caution.

In spite of what must seem like over-whelmingly negative information about site index, site index remains a very effective management tool, provided it is applied properly.

METHODS OF MEASURING SITE INDEX

DIRECT MEASUREMENT

The most familiar way of estimating site index is to sample several trees directly by measuring age and height in the field. A series of problems arise when site index is measured directly in the field.

To insure that tree height measurements accurately express the productive potential of the land, care must be taken to hold constant, or account for, all factors (inputs) which influence height growth other than the inherent productivity of the land ("site"). By accounting for these factors (species, age, etc.) the variations in tree heights measured will reflect real differences in site productivity rather than differences in the levels of other inputs. To accomplish this, sample trees should be selected based on the following criterion:

1) sample trees should be representative of the stand and their ages should be within 8 years of each other.

2) trees should be free growing and show no evidence of past suppression.

3) trees should be in a fully stocked stand which has not been disturbed by fire, grazing, or timber harvesting.

Because of past management trends, only a few sites meet this rigid list of requirements in the central hardwood region. Typically, stand conditions vary considerably over relatively short distances. To insure that all sample trees have grown under comparable conditions, sample trees should be located close to one another.

Silviculturally an even aged stand is one where "the difference in age between the oldest and youngest tree does not exceed 20 percent of the length of rotation" (Smith, 1962). For site index purposes however, the less variation in the ages of sample trees the better. Ideally, ages should not range more than 8-10 years. A variation in tree age of 3 years has been shown to change site index by 1 ft. (McQuilkin, 1975). A variation of just a few years could be enough to put a single observation into an adjacent 10 ft. site index interval.

When measuring tree height and age, foresters should remember that they are making a statistical estimate. The accuracy of this estimate is determined by the character and size of the sample used. At least three trees should be sampled to provide a reliable estimate of site index.

It is very difficult to measure the confidence surrounding a site index estimate. However, the following generalizations apply:

The further age is from the base age, the less confident one can be in a site index estimate. Or stated differently, the further age is from the base age, the greater the sample size must be to achieve the same desired level of confidence. Figure 5.4 illustrates how the width of a confidence interval surrounding a site index estimate will vary with age and sample size. Figure 5.4 is based on Black/Scarlet oak site index curves developed by McQuilkin and Rogers (1978). Although the exact shape and height of these lines are unique for this set of site index curves, the same general pattern will hold for all site index curves.

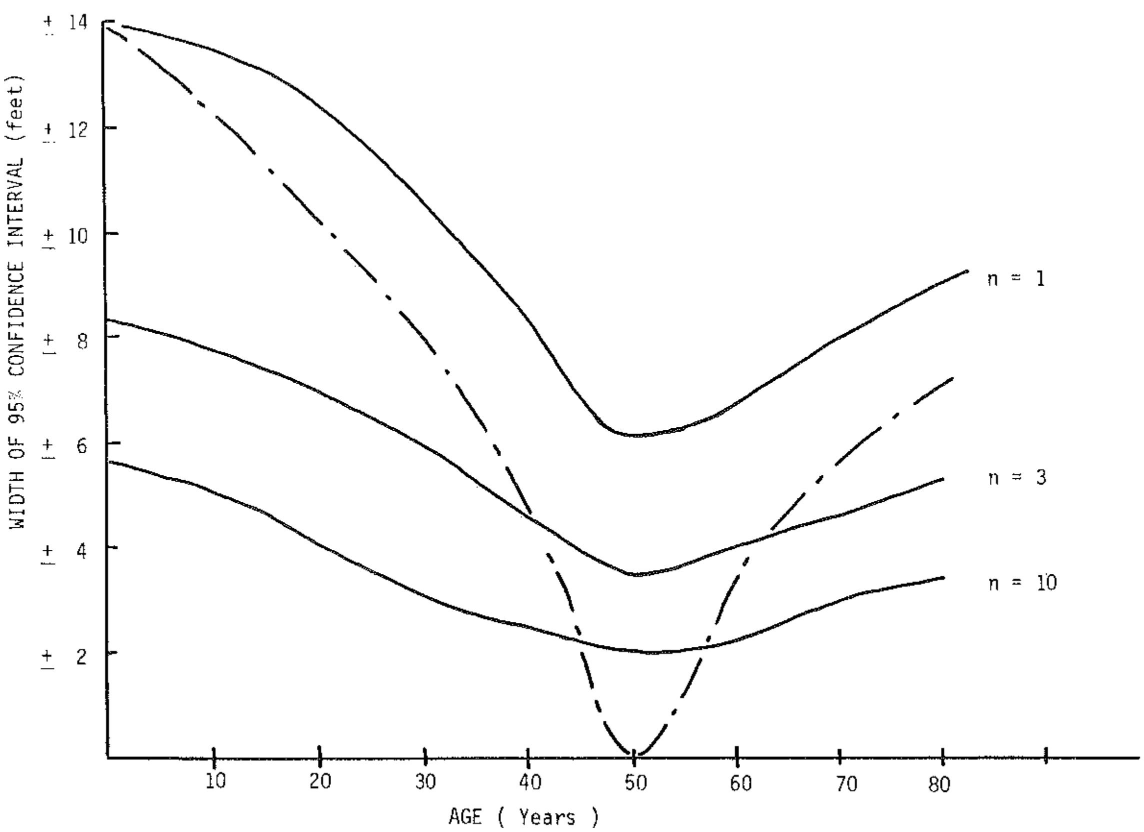


FIGURE 5.4 Width of site index confidence interval (in feet) at different ages and sample sizes for a stand (solid lines) and for an individual tree (dashed line) (McQuilkin and Rogers, 1978).

Similarly, with harmonized site index curves, the further site index is from the average quality site used to construct the table, the less confident one can be in the estimates made. Figure 5.5 illustrates how the width of a confidence interval surrounding a site index estimate for an individual tree increases as age deviate from the base age and as site index deviates from the average site index (SI). Once again the magnitude and shape of these lines are unique to the set of curves for which they were constructed (Heger, 1971).

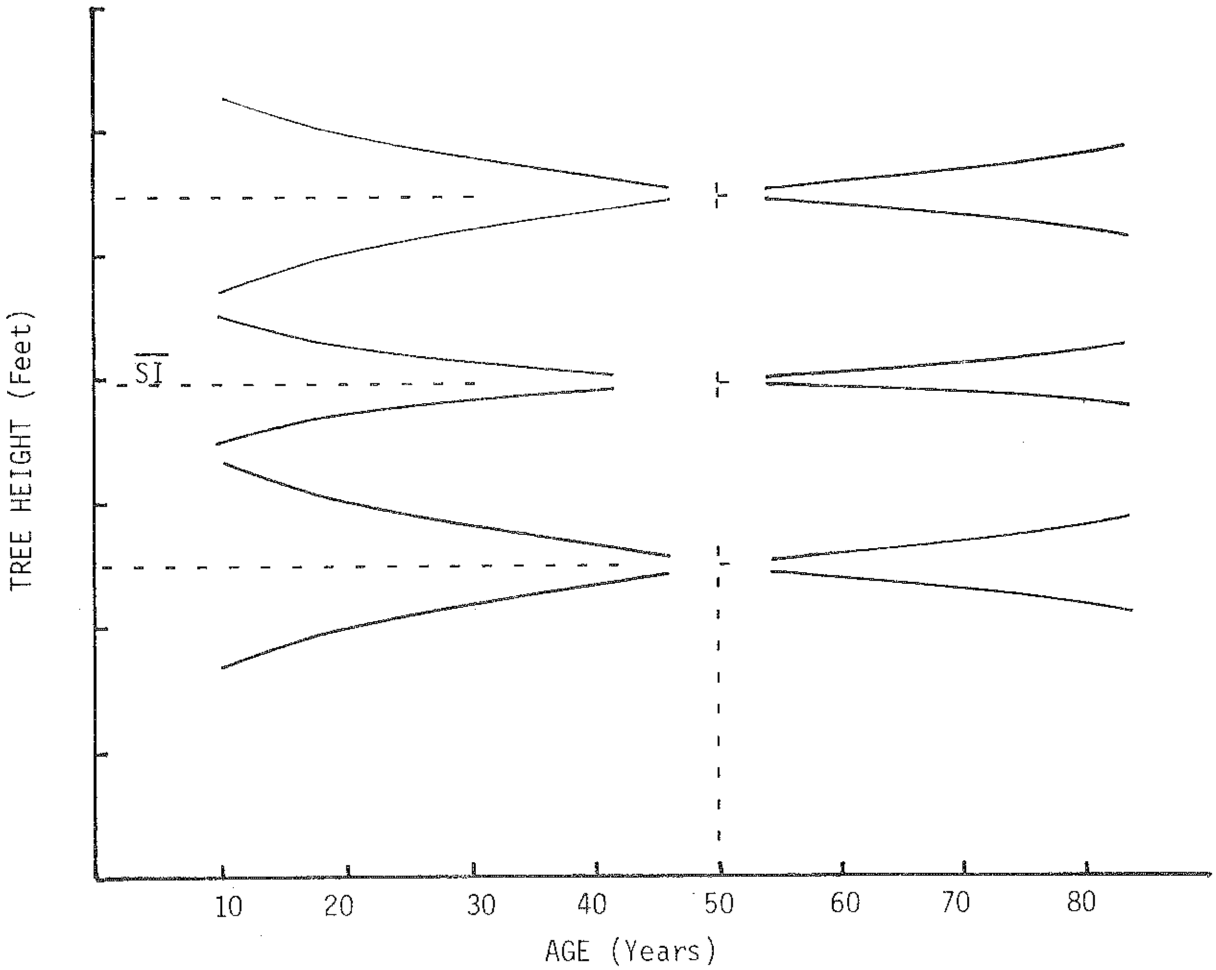


FIGURE 5.5 Confidence interval width for estimate of an individual tree's site index at different ages and site indexes.

Direct measurement of site index in very young stands (eg. less than 30 yrs.) is subject to very large sources of error. In these stands small errors in height measurements will produce large errors in site index estimates. In addition, the effects of early plant competition have a more pronounced impact on site index estimates in young stand than in older stands. There are however, two sets of site index curves for black walnut and white pine that partially alleviate this problem in young stands (Lundgren, 1975; Brown, 1981). Also, other methods of determining site index, which are discussed later, minimize this problem.

Directly measuring site index is the most reliable way to estimate site index. Direct measurement is time consuming, but provides additional (potentially useful) data such as stand age and current annual increment. However, direct measurement is limited to sites where stands meeting a very restrictive list of criterion currently exist. The remainder of this section is devoted to other methods of measuring site index, some of which alleviate these problems.

INDIRECT METHOD

Another approach to estimating site index involves measuring physical and environmental site characteristics that influence height growth rather than measuring the heights and ages of individual trees. Several attempts have been made to correlate site index to soil characteristics and/or topographic features (e.g., aspect, soil depth, position on slope, soil texture, nutrient content, etc.). These studies involve measuring site index, soil characteristic and topographic features on a range of sites within a narrow geographical area. Regression techniques are then used to develop equations to predict site index based on measurable site characteristics.

Attempts to correlate site index to soil series alone have generally failed to provide more than just general estimates of site quality because of the wide range of conditions that may exist within a particular soil series (Carmean, 1970; Carmean, 1967; Robles et al., 1976). Studies that have included soil and topographic variable however, have generally been more successful.

The indirect approach to estimating site index has a number of advantages and disadvantages. On the plus side, this method can be used on sites regardless of the age, species composition, or condition of the existing stand. Large areas can be mapped without the need for costly on the ground surveys, and site index can be determined for undisturbed bare land.

The indirect method of determining site index has some limitations however. For example, it may require some training or experience to apply. Regression equations are applicable only to a very narrow geographic area or group of soils, and are only applicable on undisturbed sites. Finally, the regression equations may involve considerable calculations.

Although several researchers have used this method, only one study of this type has been conducted in Indiana and it is only applicable to the knobs region (Hannah, 1968a). This line of research is promising because it holds out the hope that some day foresters will be able to quantify the site characteristic which influence tree growth and more precisely model the interactions of the factors which control tree growth.

From these studies several variables are consistently found to be highly correlated to site index, these include:

1) Thickness of surface soil layers -- this is typically measured as depth of the "A" horizon or depth to the "B" horizon.

2) Total rooting depth -- this has most frequently been measured as depth to bedrock or depth to an impervious layer.

3) Aspect -- this is measures in degrees azimuth.

4) Position on slope -- this is most frequently expressed as a percentage (or ratio) of the distance from the plot to the ridge top, to the total length of the slope.

5) Percent slope -- this turns up less frequently, but seems to be significant when slope is greater than 30%.

6) Shape of slope -- that is concaved, linear or convex.

Several other factors have been found to be significant less frequently: (e.g., percent organic matter, percent clay or large stone content in subsurface layers and nutrient availability). Many of these are of little use to the field forester because of the difficulty of making the measurements necessary to apply formulas containing these variables.

Many of the factors cited above are interrelated. For example, the rate of soil formation is affected by topography. Consequently soil depth, and organic matter content will be greater on north slopes and lower slopes. As rooting depth and organic matter content increase, water holding capacity and soil nutrients also increase.

Currently there is only one study of this kind that could be used in Indiana (Hannah, 1968a). This study used an extremely long list of variables to predict site index for Black oak. Fortunately the original equation was presented in a simplified form in (Hannah, 1968a). The simplified tables are presented in chapter 6 (page 6.38).

INTERNODAL METHOD

The internodal method is a relatively new technique, but one that holds some promise for tree species that produce a single whorl of branches each year. The method involves measuring the distance between 3 or 5 branches whorls (3 to 5 year height growth increment) above breast height. A study conducted recently in Ohio (Brown and Stires, 1981) may be applicable in Indiana. In this study, the distance between the second whorl above BH and the seventh whorl above BH was used to predict site index.

A major advantage of this technique is that it minimizes the influence that a stand's early history may have had on height growth. For example, the lack of weed control or heavy deer browse in a young pine stand would adversely effect height growth and result in an under estimation of site index.

Unlike other direct measurement techniques the internodal method could be used on fairly young stands.

This method of determining site index is quick, relatively easy, requires no special tools or training; but can only be applied to white and red pine in Indiana.

QUALITATIVE EVALUATION OF SITE PRODUCTIVITY

A means of site evaluation not discussed in the literature, but which in the absence of other techniques is valuable to the field forester involves a qualitative evaluation of site attributes. This method might be called "field foresters intuition", or could also accurately be described as a seat-of-the-pants judgement.

Although the reliability of this technique is low, because of the economy of time involved in its use, it remains a legitimate technique if only crude or comparative estimates of site productivity are required.

By being aware of topographic features (aspect, slope, shape of slope, position on slope) and observing the condition of existing growing stock, an experienced field forester may be able to use his/her judgement and experience to appraise relative site productivity. This may be useful for management over very small areas.

By boring many trees, and observing bark patterns and general physical condition (e.g., limbiness, size and shape of crown) a forester over time can become experienced enough to fairly accurately estimate radial growth of a particular tree (without boring it) just by examining its external characteristics. A forester equally willing to use a soil probe may find this to be of similar educational value. Noting the rooting depth, depth of the A horizon and textural characteristic, then comparing this with the condition of the growing stock or site index, a forester may eventually reach the point where he/she is comfortable with their ability to use soils information to assess site potential. This would add yet another tool to the forester's bag of skills.

This technique is not held in high repute in some circles, but because of the time involved, should not be overlooked entirely.

METHODS OF ESTIMATING SITE INDEX

This section contains graphs, equations and tables that can be used to estimate site index. This section is organized by method of estimation, and species. Every attempt has been made to select data from the literature that is most applicable in Indiana. In some cases the best data available, was determined to be the "best available" because it was the only information available for a particular species. In these cases, notes of caution are included.

In all cases the source of the graph, table, or equation is cited along with information concerning the character of the sample (geographical range, number of observations, range of ages and site indexes) used to develop the information.

In several cases 2 or more sets of site index curves were available for a particular species. When one set of curves did not seem overwhelmingly suited to Indiana, both sets of curves were included. In this case the user will need to decide which is more applicable to their particular area.

The final part of this section includes a table which will allow the user to convert site index from one species to site index for another.

SUMMARY OF SITE INDEX INFORMATION
PRESENTED IN THIS SECTION:

Method of Estimation/ Species	Citation	Geographical Source of Data	Comments	Pg.
DIRECT MEASUREMENT				
black oak white oak scarlet oak chestnut oak	(Carmean, 1972) NC-62	Kentucky Ohio Indiana Illinois Missouri	Polymorphic height growth curves developed from stem analysis data	6.6
sugar maple red maple american basswood white ash northern red oak	(Carmean, 1978) NC-160	Wisconsin Upper Michigan	Polymorphic height growth curves developed from stem analysis data	6.13

black walnut	(Losche and Schlesinger, 1975) NC-187	Southern Illinois	Linear site index curves for young walnut stands. Two sets of curves are presented.	6.20
black walnut	(Kellogg, 1937)	Southern Illinois	Harmonized height growth curves.	6.23
yellow poplar	(Beck, 1962) SE-180	North & South Carolina, and Virginia	Harmonized height growth curves based on total height and age observations.	6.25
cherrybark oak	(Broadfoot, 1961) S-190	Arkansas Mississippi Louisiana	Harmonized height growth curves based on stem analysis.	6.27
eastern cottonwood	(Neebe & Boyce, 1959)	Illinois Indiana Missouri Kentucky	Linear site index curves.	6.28
sweetgum	(Broadfoot and Krinard, 1959)	Southern Mississippi River Valley	Harmonized height growth curves.	6.30
eastern white pine	(Gevorkiantz, 1957)	Wisconsin	Harmonized height growth curves.	6.32
eastern white pine	(Frothingham, 1914)	New England	Harmonized height growth curves.	6.34
upland oaks	(Schnur, 1937)	Central States	Harmonized height growth curves developed from observations of total height and total age.	6.36
<u>INDIRECT METHOD</u>				
black oak	(Carmean, 1967)	S.E. Ohio	Site index estimated based on shape of slope, aspect, and position on the slope.	6.38

black oak & white oak	(Hannah, 1968a)	Indiana (Knobs area)	Site index estimated based on percent slope, position on the slope, aspect, depth to the B horizon, subsoil texture, and percent stone content.	6.40
cherrybark oak	(Broadfoot, 1961) S-190	Lower Mississippi River Valley	Site index estimated based on soil depth and soil texture.	6.43
INTERNODAL METHOD				
eastern white pine	(Brown and Stires, 1981b)	S.E. Ohio	Site index estimated based on length of 3,5, or 10 year growth intercept and position on the slope.	6.45
OTHER METHODS				
black, white, scarlet, chestnut, & northern red oak and yellow poplar	(Carmean & Hannah, 1983)	Central states region	Equations for converting site index for one species to site index for an other species.	6.49
misc. hardwood species	(unpublished)	Indiana	Site index estimates for some major soil series in Indiana.	6.52

DIRECT MEASUREMENT OF SITE INDEX

Estimating site index from actual field measurements is the most accurate method of determining site index. This method is limited in many circumstances, is time consuming, and is subject to some unique sources of error. Because of the time and cost involved, care must be exercised so that the best estimates possible can be obtained. It doesn't make sense to spend the time required to collect field data if it is not going to be done right!

Collecting tree height and age data in the field provides the opportunity to simultaneously collect other potentially useful data (e.g., total stand age, 10 year growth increment). The location of sample trees and the original field data should be filed in an appropriate location so that it will be available for future reference. A minimum of data collected for each tree should include: Tree species, diameter at breast height (DBH), age at breast height (BH), total height, and approximate location described with enough detail that the plot could be relocated. Additional data that could be collected includes: 10 year radial growth increment, a brief description of the site (including aspect, shape of slope, position on slope), a brief description of the stand (including species composition, average diameter of overstory, basal area), and a map showing the location of the sample trees. These additional data may be useful in the future and require only a minimum of additional effort.

When estimating site index all efforts should be thoroughly documented. Adjustments made to age at BH to determine total age should be identified. The set of site index curves used to calculate site index should likewise be documented.

Site index is specific to a particular species or group of species and a base age. The following expression is for all practical purposes meaningless: "site index = 75". For comparison, the following expression contains more useful information: "Black oak site index SI_{BLO} = 75 feet (on a 50 year basis), sample size = 3, ages ranged from 44-49, heights ranged from 70-76, SI curves for black oak from (Carmean, 1971 NC-160) were used". Although the latter expression may seem more cumbersome, but it adds meaning to measurements made. The former expression tells us only that the tree(s) measured should be 75 feet tall when they are (or were) 50 years old.

When selecting site index trees, a minimum of three dominant and codominant trees should be measured. Trees sampled should contain a range of diameters representative of the stand in which they are located. Trees sampled should be fairly close to one another to minimize variations in soil and site characteristics; and to insure that all trees sampled have had a similar history, grown under similar conditions, and originated at approximately the same time.

Trees should be approximately even aged. Variations in the ages of sample trees of more than 10 years are probably the result of past management. Sample trees should be free from evidence of past suppression or release. Similarly, trees should be straight and undamaged.

Finally, the reliability of a site index estimate is greater the closer age is to the base age and the closer site index is to average site quality. The reliability of site index estimates decreases rapidly as age drops below 30 years or increases above 100 years.

There are exceptions to the above rule concerning age and these exceptions are noted in the following section. Site index curves for black walnut and eastern cottonwood presented in this section are designed to be used on younger stands.

Trees selected to estimate site index ("site index trees") should meet the following characteristics:

1) Sample trees should be even aged. Tree ages should be within 10 years of each other.
2) Stands sampled should be fully stocked and unaffected by past management, fire, and other damaging agents.
3) Stands should be at least 20 years old and preferably 30 years or older.
4) Site index trees should be straight, undamaged and show no indication of past suppression.

Site index for BLACK, WHITE, SCARLET, and CHESTNUT OAK (Carmean, 1971; Carmean, 1972)

SAMPLE: Location: S.E. Ohio, S. Indiana, S. Illinois, E. Kentucky, and S. Missouri

Sample included data from 559 trees on 204 plots. Table 1, shows the number of plots and trees samples by tree species and location. Regression analysis techniques were applied to the data and a set of four polymorphic height growth curves were produced. The final regression equations were of the form illustrated in Figure 2. Presented for reference purposes, the coefficients for these regression equations are presented in table 3.

The distribution of ages and site qualities sampled for each species is presented in table 1.

APPLICATION: Select 3 to 5 site index trees over a small area. Tree ages should not vary by more than 10 years. Age differences of more than 10 years are probably the result of past management.

Age refers to total age (i.e., age at BH, plus 4 years)

Reliability of estimates made with these curves is enhanced when age and site index of trees sampled fall within the following brackets:

SPECIES	AGE	SITE INDEX
Black Oak	30 - 110	40 - 90
White Oak	30 - 100	40 - 75
Scarlet Oak	30 - 100	50 - 80
Chestnut Oak	30 - 105	40 - 80

These curves can be used for stands where age or site index falls outside these ranges, but users should be aware that the greater the deviation from these ranges, the less reliable estimates will be. In such cases additional observations can improve reliability slightly.

To estimate site index for northern red oak, site index curves for black oak may be used.

Table 1.—Number of plots and trees used in constructing site index curves from stem analyses of four species of upland oaks in the Central States[1]

Species	State					Totals
	Ohio	Kentucky	Indiana	Illinois	Missouri	
	Total number of plots[2/]					
Black oak	9(27)	7(30)	16(36)	3(10)	85(197)	120(300)
White oak	8(26)	5(25)	17(37)	4(12)	7(12)	41(112)
Scarlet oak	5(20)	8(34)	--	1(2)	11(32)	25(88)
Chestnut oak	13(43)	4(15)	1(1)	--	--	18(59)
Totals	35(116)	24(104)	34(74)	8(24)	103(24)	204(559)

1/ Trees in Kentucky, Indiana, Illinois, and many of the Missouri trees were sectioned as a part of a hardwood decay study conducted by the Northeastern Forest Experiment Station. Data for the remainder of the Missouri trees were furnished by Robert A. McQuilkin, North Central Forest Experiment Station. A portion of the statistical computations was accomplished using cooperative funds from the Kentucky Conservation Department.

2/ Numbers in parentheses are the number of trees sectioned.

TABLE 2. Regression equation to predict tree height.

$$H = b_1(1-e^{-b_2 age})^{b_3}$$

where H = tree height at any age

b_1 = coefficient expressing asymptotic tree height, (i.e., estimated ultimate tree height)

b_2 = coefficient determining rate of tree height growth

b_3 = coefficient determining initial pattern of height growth

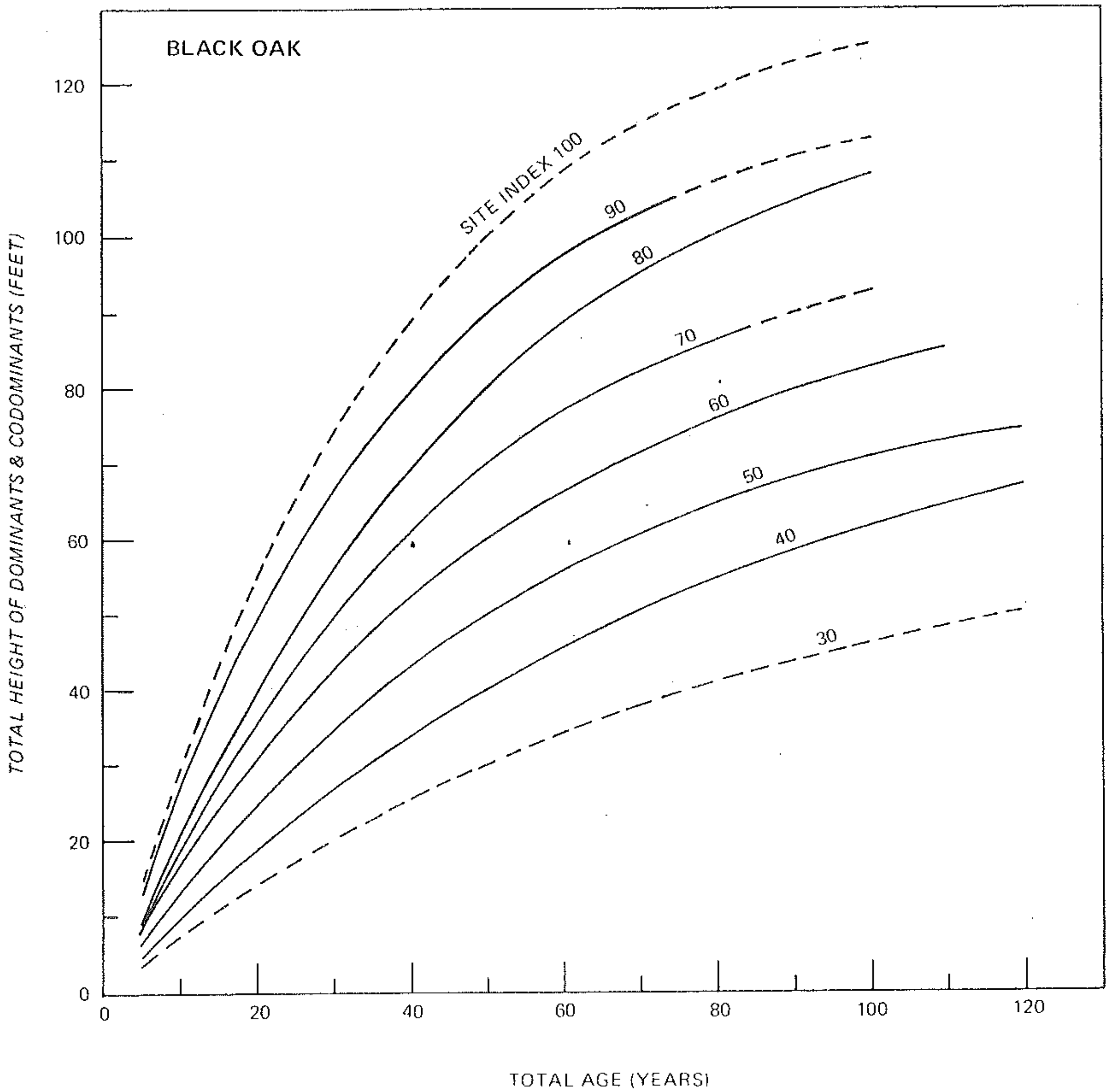
e = base of natural logarithm ≅ 2.718.

TABLE 2. Coefficients for nonlinear height growth equations $[H = b_1(1 - e^{-b_2 age})^{b_3}]$ *listed by individual site index classes.*

Site index class	No. of plots	Asymptotic height[1] (b_1)	Height growth: Rate[1] (b_2)	Height growth: Initial pattern[1] (b_3)	[2] R^2	Predicted tree height at 50 yr (ft)
			BLACK OAK			
86–106	5	119.75 ± 5.92	−0.0296 ± 0.0048	1.118 ± 0.113	0.97	89.7
76–85	12	119.92 ± 1.85	−0.0246 ± 0.0013	1.183 ± 0.044	0.99	79.7
66–75	26	102.57 ± 1.56	−0.0260 ± 0.0013	1.169 ± 0.036	0.98	70.7
56–65	41	95.63 ± 1.56	−0.0196 ± 0.0011	1.015 ± 0.033	0.96	59.4
46–55	29	85.05 ± 1.12	−0.0199 ± 0.0009	1.104 ± 0.033	0.97	51.1
34–45	7	85.40 ± 6.48	−0.0134 ± 0.0027	1.047 ± 0.097	0.94	40.4
			WHITE OAK			
66–75	10	134.76 ± 6.38	−0.0157 ± 0.0017	1.082 ± 0.046	0.99	69.8
56–65	13	151.67 ± 8.53	−0.0100 ± 0.0012	0.993 ± 0.034	0.99	60.3
46–55	7	111.40 ± 4.42	−0.0139 ± 0.0015	1.106 ± 0.059	0.98	51.8
34–45	9	100.45 ± 5.39	−0.0097 ± 0.0013	0.935 ± 0.043	0.98	41.0
			SCARLET OAK			
76–85	6	118.08 ± 4.26	−0.0247 ± 0.0023	1.186 ± 0.057	0.99	78.6
56–75	15	106.86 ± 2.26	−0.0199 ± 0.0014	1.059 ± 0.045	0.97	65.6
43–55	4	83.81 ± 6.82	−0.0199 ± 0.0053	1.041 ± 0.160	0.92	51.9
			CHESTNUT OAK			
66–85	7	123.39 ± 10.51	−0.0206 ± 0.0046	1.028 ± 0.102	0.96	78.4
56–65	4	121.94 ± 11.14	−0.0131 ± 0.0029	0.916 ± 0.066	0.98	62.2
34–55	7	92.64 ± 17.31	−0.0102 ± 0.0047	0.830 ± 0.112	0.89	43.3

[1] Numerically estimated standard errors of the regression coefficients are also shown.
[2] Coefficient of multiple determination.

SITE INDEX FOR BLACK OAK (CARMEAN, 1971)

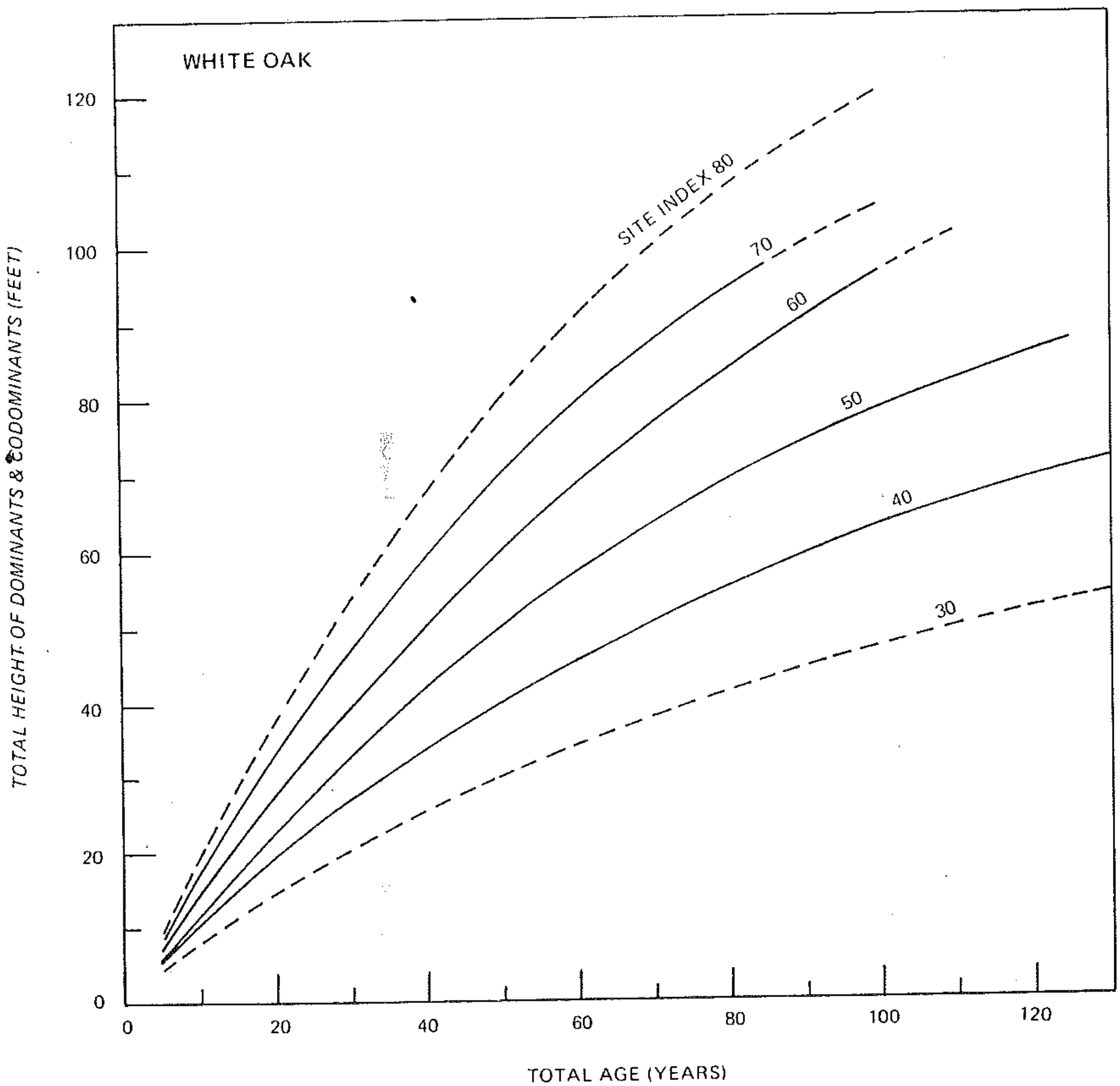


.—Site index curves for black oak in the Central States. These curves are based on stem analyses of 300 dominant and codominant black oaks growing on 120 plots located in the unglaciated portions of southeastern Ohio, eastern Kentucky, southern Indiana, southern Illinois, and southern Missouri.

base age = 50 yrs. total age = age at BH + 4 yrs.

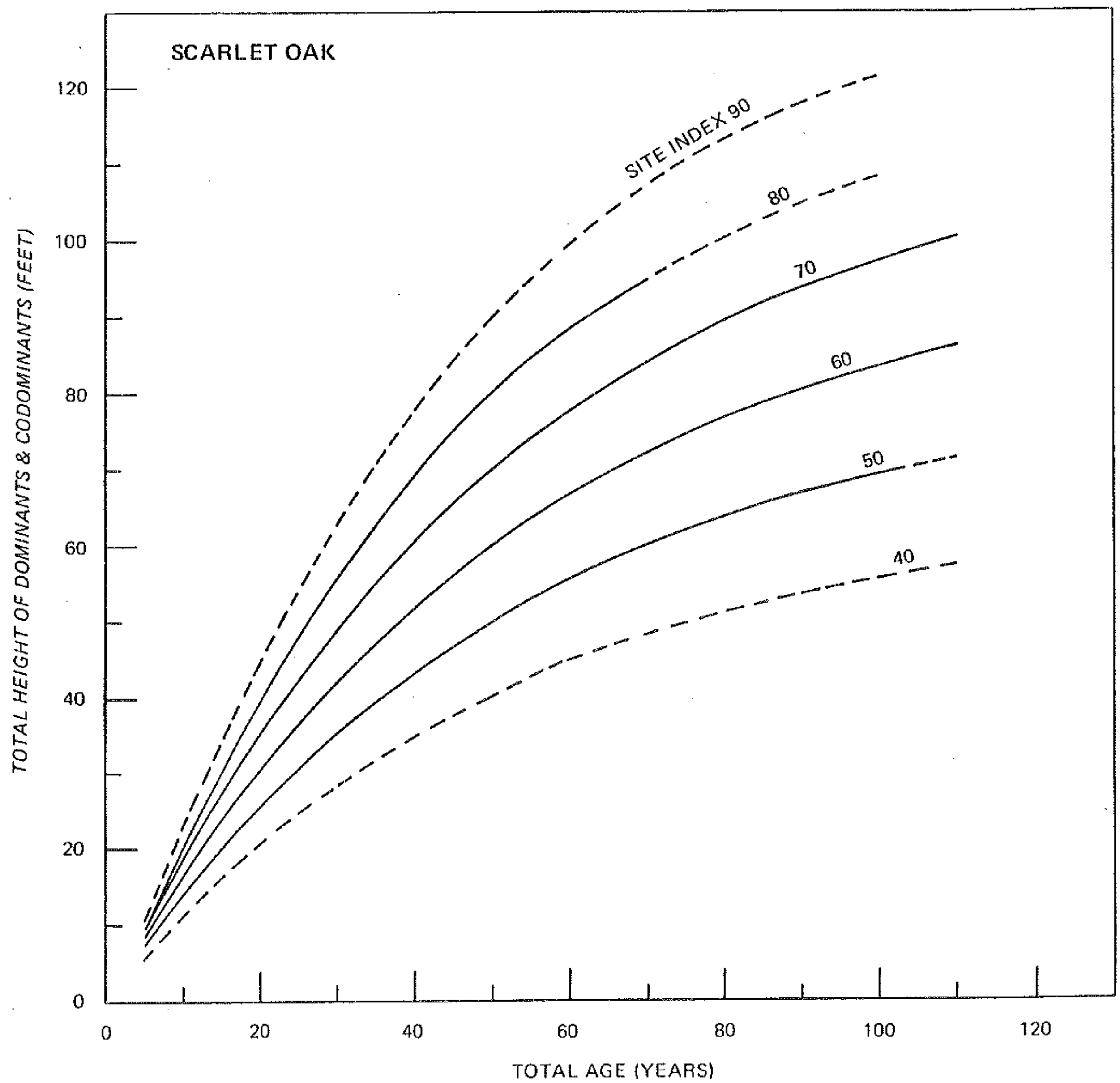
From Carmean (1971), NC-62 .

SITE INDEX FOR WHITE OAK (CARMEAN, 1971)



-Site index curves for white oak in the Central States. These curves are based on stem analyses of 112 dominant and codominant white oaks growing on 41 plots located in the unglaciated portions of southeastern Ohio, eastern Kentucky, southern Indiana, southern Illinois, and southern Missouri.
base age = 50 yrs, total age = age at BH + 4 yrs.
From Carmean (1971), NC-62.

SITE INDEX FOR SCARLET OAK (CARMEAN, 1971).

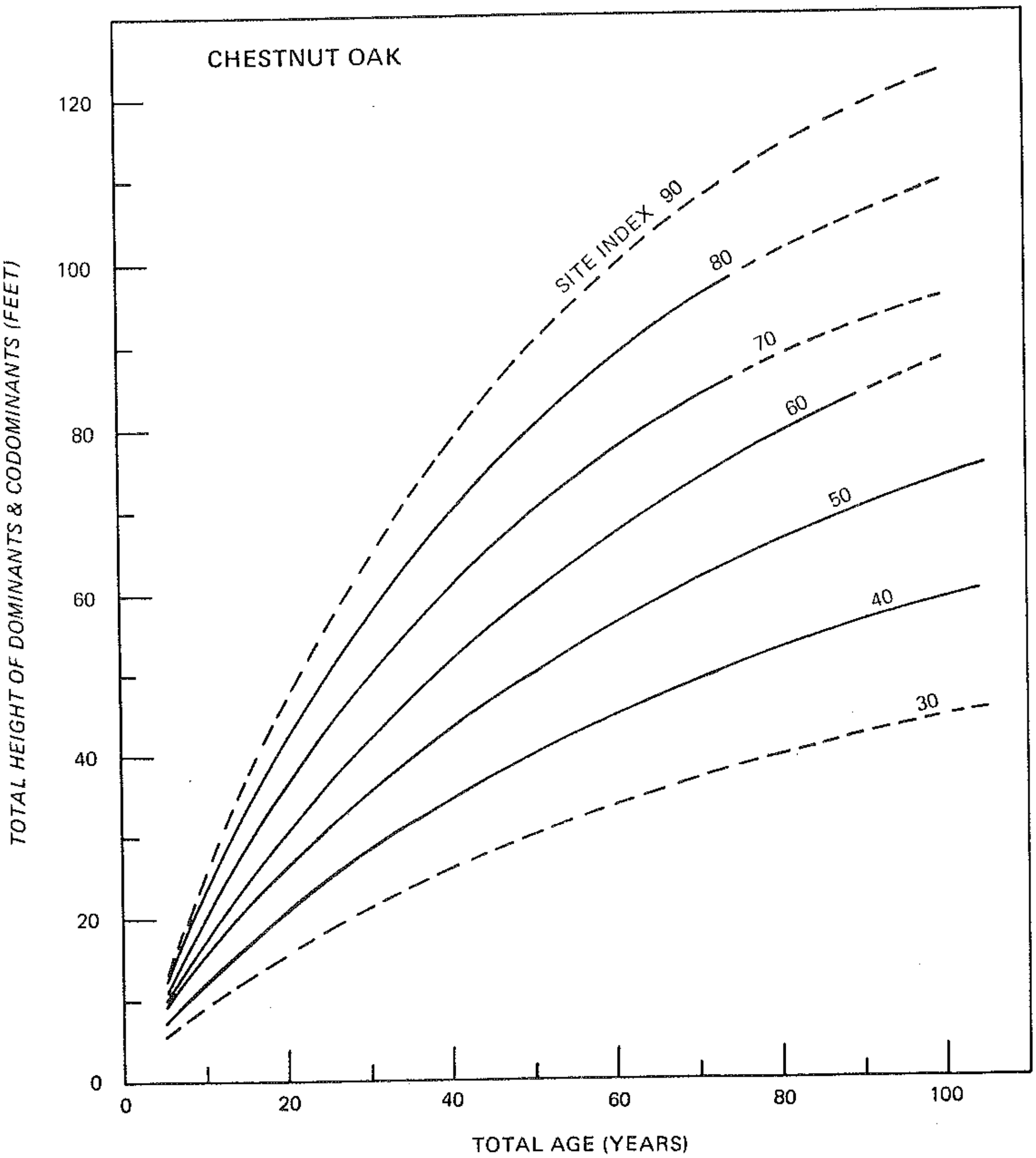


-Site index curves for scarlet oak in the Central States. These curves are based on stem analyses of 88 dominant and codominant scarlet oaks growing on 25 plots located in the unglaciated portions of southeastern Ohio, eastern Kentucky, southern Illinois, and southern Missouri.

base age = 50 yrs, total age = age at BH + 4 yrs.

From Carmean (1971), NC-62

SITE INDEX FOR CHESTNUT OAK (CARMEAN, 1971)



—Site index curves for chestnut oak in the Central States. These curves are based on stem analyses of 59 dominant and codominant chestnut oaks growing on 18 plots located in the unglaciated portions of southeastern Ohio, eastern Kentucky, and southern Indiana. base age = 50 yrs, total age = age at BH + 4 yrs. From Carmean (1971), NC-62.

Site index estimates for SUGAR MAPLE, RED MAPLE, BASSWOOD, WHITE ASH, and NORTHERN RED OAK (Carmean, 1978b).

SAMPLE: Location: Northern Wisconsin and the Upper Peninsula of Michigan.

Sample characteristics are as follows:

TABLE 1. Number of plots and (trees) sampled by species and site index.

Species	Site index class									Total
	<43	43-47	48-52	53-57	58-62	63-67	68-72	73-77	>77	
	Total number of plots[1]									
Sugar maple	2(9)	8(27)	25(105)	35(139)	54(220)	33(140)	18(76)	2(5)		177(721)
Red maple	1(4)	5(18)	19(77)	22(77)	36(145)	21(77)	9(37)	1(3)		114(438)
Yellow birch	3(9)	3(10)	11(37)	30(116)	38(157)	22(82)	10(42)	2(6)		119(459)
American beech		2(6)	6(23)	7(27)	4(14)					19(70)
American basswood		3(9)	5(17)	14(48)	23(87)	37(154)	31(131)	6(22)	3(15)	122(483)
American elm		3(11)	7(26)	14(52)	24(87)	22(80)	26(107)	12(48)	1(5)	109(416)
White ash		2(7)	2(10)	5(15)	10(35)	18(57)	19(86)	12(50)	5(15)	73(275)
Black ash			4(13)	6(24)	11(39)	6(20)	8(33)	3(13)	1(1)	39(143)
Black cherry	1(3)	2(9)	3(10)	7(19)	5(14)	14(48)	5(12)	4(8)	1(3)	42(126)
Northern red oak			2(3)	3(15)	11(42)	15(49)	5(23)	1(4)		37(136)
Paper birch		1(2)		8(22)	6(18)	7(20)	8(31)			30(93)
Aspens[2]				2(7)	4(13)	2(5)	1(2)	2(5)	2(10)	13(42)
Total	7(25)	29(99)	84(321)	153(561)	226(871)	197(732)	140(580)	45(164)	13(49)	894(3,402)

[1]Numbers in parentheses are the number of trees sectioned.
[2]Data combined for bigtooth and quaking aspens.

Regression analysis techniques were applied to the data and polymorphic height growth curves were developed for each species. The coefficients for the resulting regression equations (for predicting tree height) are presented in table 2. Coefficients for a regression equation of a slightly different form (for predicting site index) are presented in table 3.

TABLE 2. REGRESSION COEFFICIENTS FOR HEIGHT GROWTH EQUATIONS[a] (Hahn & Carmean, 1982).

	Regression Coefficients					
SPECIES	b_1	b_2	b_3	b_4	b_5	r^2
Sugar Maple	6.1308	0.6904	-0.0195	10.1563	-0.5330	.99
Red Maple	2.9435	0.9132	-0.0141	1.6580	-1.1095	.99
Basswood	4.7633	0.7576	-0.0194	6.5110	-0.4156	.99
White Ash	4.1492	0.7531	-0.0269	14.5384	-0.5811	.99
Northern Red Oak	6.1785	0.6619	-0.0241	25.0185	-0.7400	.99

a/ $\text{Height} = b_1 \; S^{b2} \; (1 - e^{b3\,A})^{b4\,S^{b5}}$

where: S = site index, A = age (total age), e = 2.7183 b_i = above regression coefficients.

TABLE 3. REGRESSION COEFFICIENTS FOR SITE INDEX EQUATIONS[b] (Hahn & Carmean, 1982).

SPECIES	Regression Coefficients b_1	b_2	b_3	b_4	b_5	r^2
Sugar Maple	0.1984	1.2089	-0.0110	-2.4917	-0.2542	.98
Red Maple	0.3263	1.2186	-0.0110	-2.0184	-0.3180	.99
Basswood	0.1921	1.2010	-0.0100	-2.3009	-0.2331	.99
White Ash	0.1728	1.2560	-0.0110	-3.3605	-0.3452	.99
Northern Red Oak	0.1692	1.2648	-0.0110	-3.4334	-0.3557	.97

b/ site index = $b_1 H^{b2} (1 - e^{b3 A})^{b4 H^{b5}}$

Where: S = site index, A = age (total age), e = 2.7183 b_i = above regression coefficients.

APPLICATION: Select 3 to 5 site index trees over a small area. Tree ages should not vary by more than 10 years. Age differences of more than 10 years are probably the result of past management.

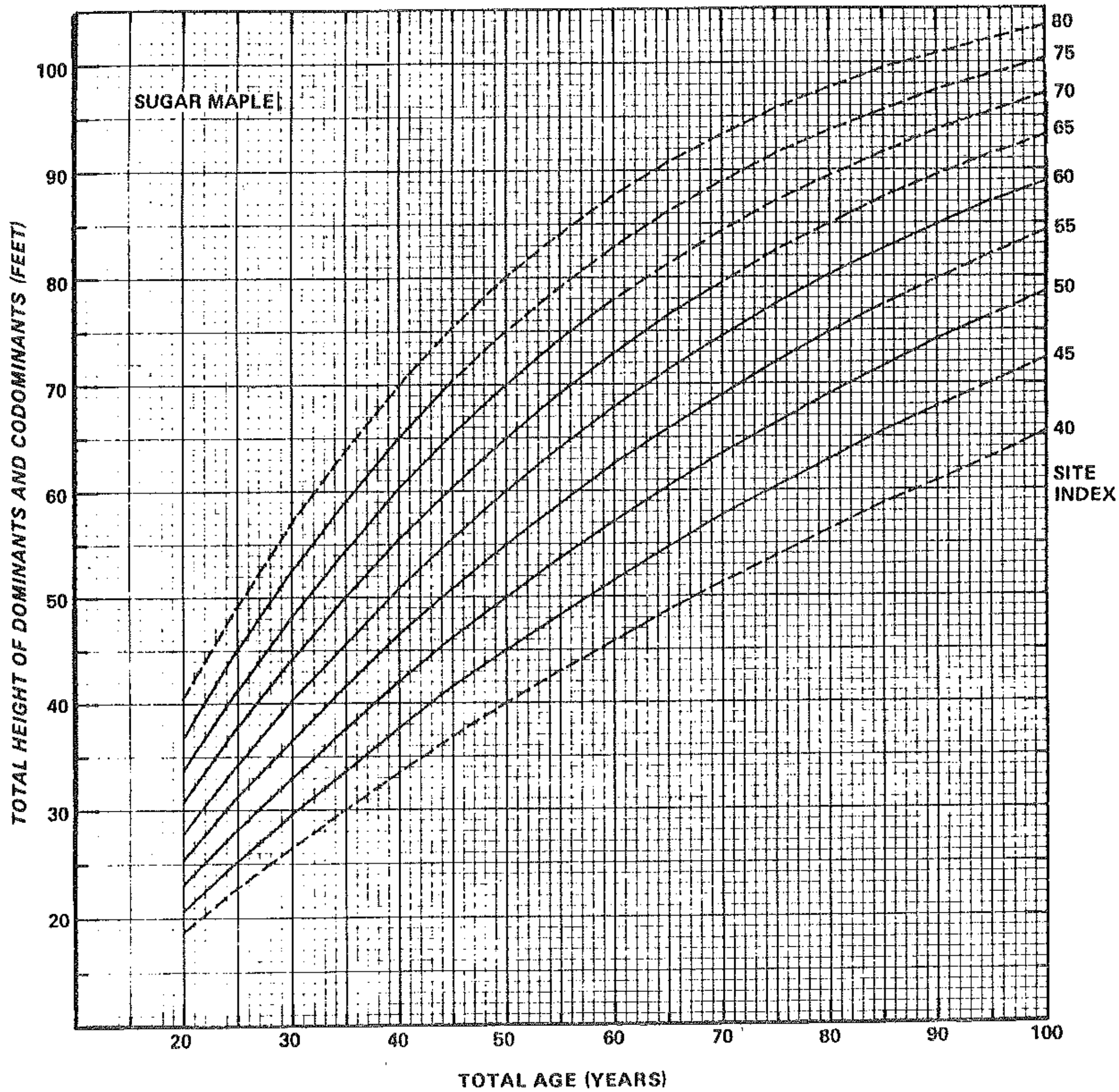
Age refers to total age (age at BH, plus 4 years).

Reliability of estimates made with these curves is enhanced when age and site index of trees sampled fall in the following ranges:

SPECIES	AGE	SITE INDEX
Sugar Maple	30 - 85	40 - 70
Red Maple	30 - 80	45 - 70
Basswood	30 - 80	45 - 80
White Ash	30 - 75	45 - 80
Northern Red Oak	30 - 80	50 - 75

These curves can be used for stands where age or site index falls outside these ranges, but users should be aware that the greater the deviation from these ranges, the less reliable estimates will be. In such cases, additional age/height measurements will increase the reliability of the estimates made.

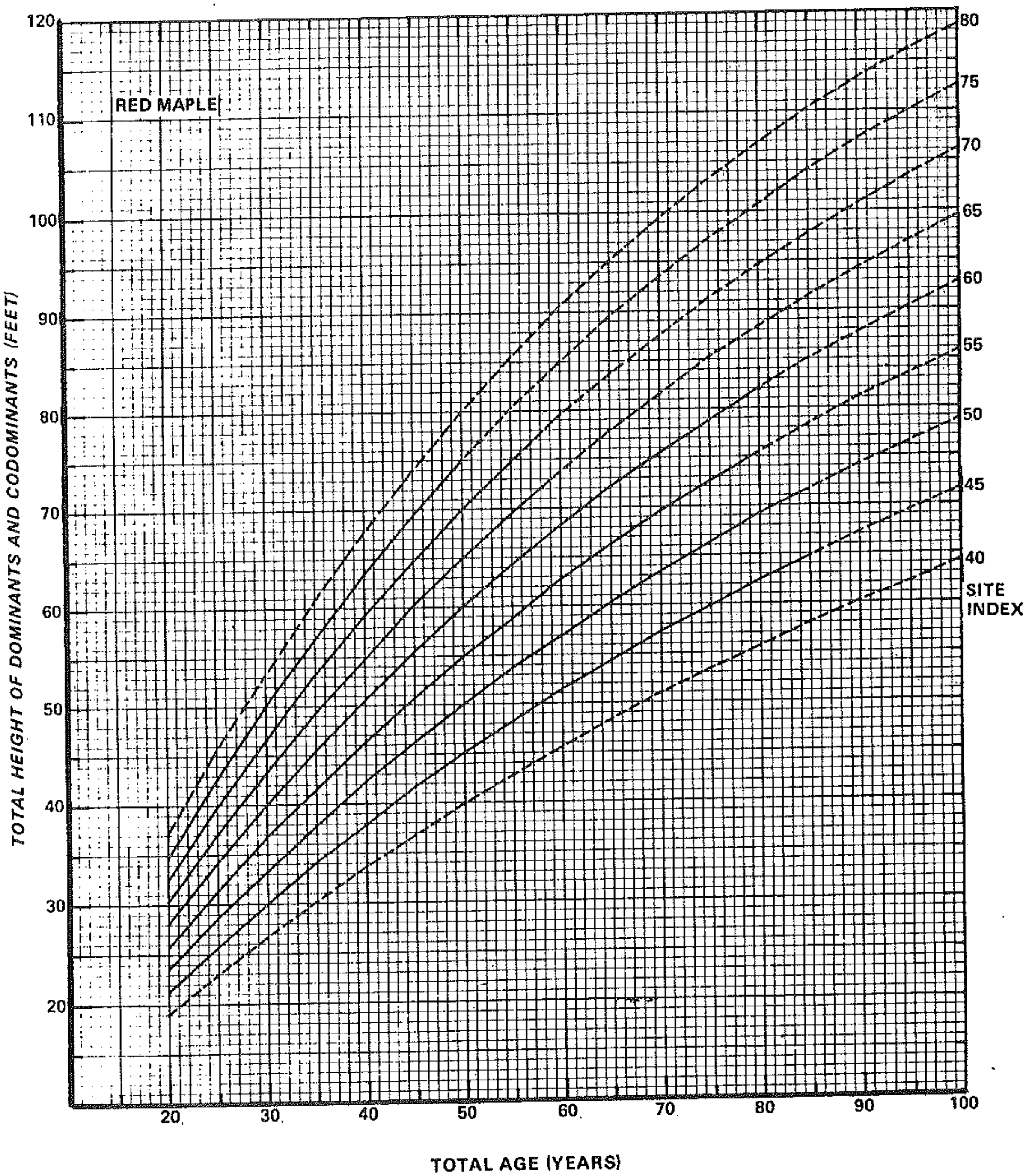
SITE INDEX FOR SUGAR MAPLE (CARMEAN, 1978b)



— Site index curves for sugar maple in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 721 dominant and codominant trees growing in 177 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.

base age = 50 . From Carmean (1978b), NC-160.

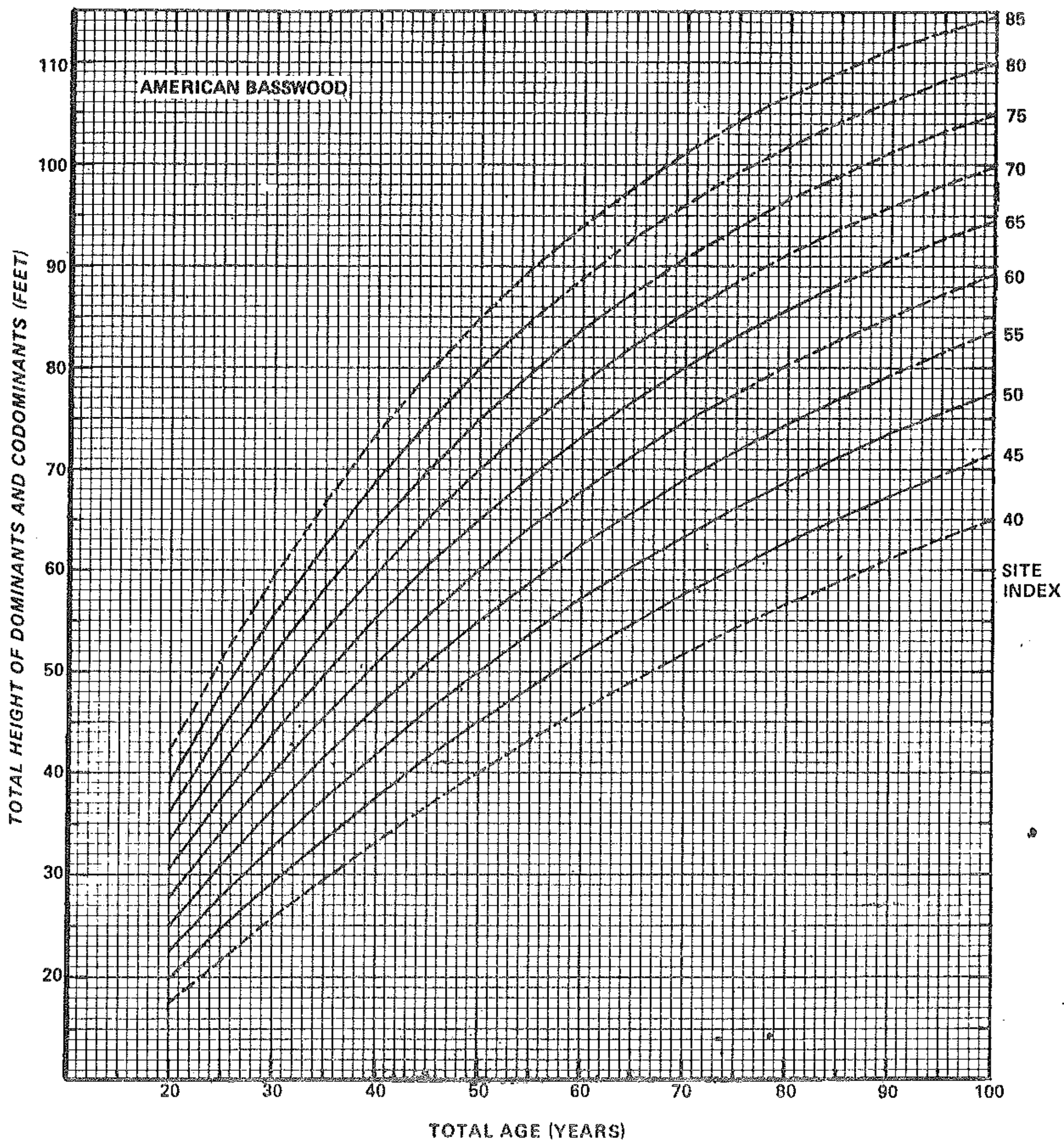
SITE INDEX FOR RED MAPLE (CARMEAN, 1978b)



— Site index curves for red maple in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 438 dominant and codominant trees growing in 114 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.

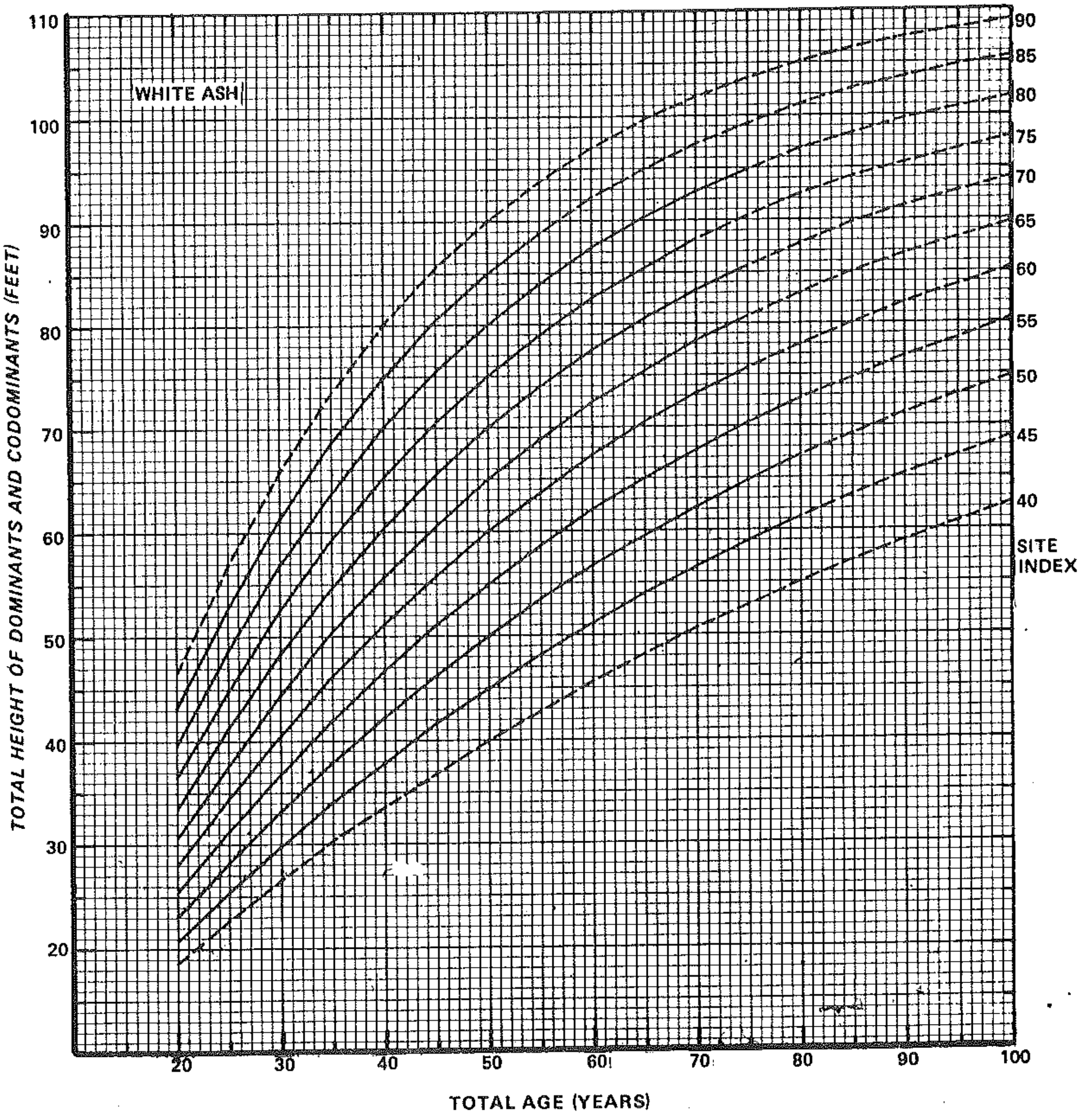
base age = 50. From Carmean (1978b), NC-160.

SITE INDEX FOR BASSWOOD (CARMEAN, 1978b)



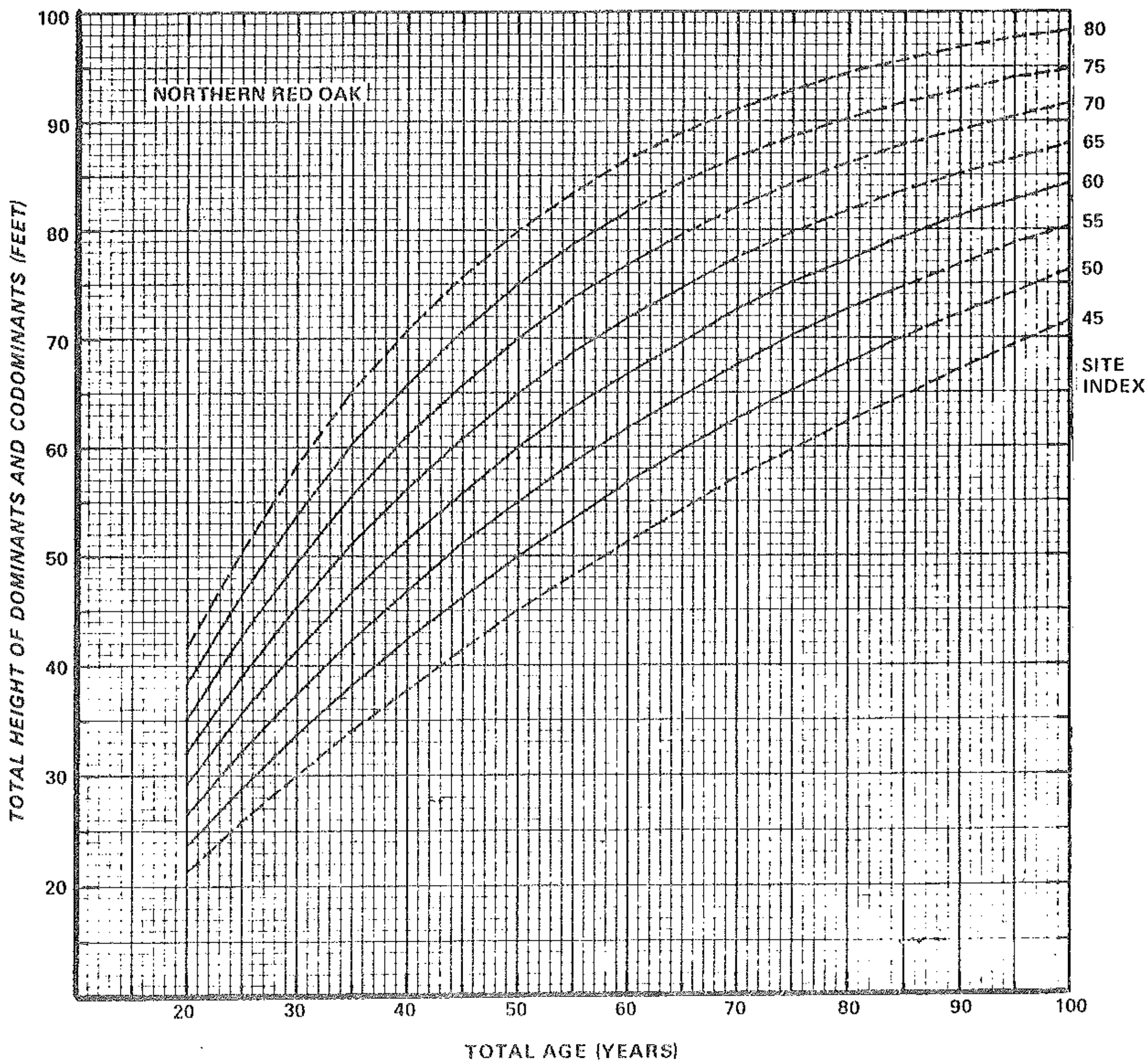
—Site index curves for American basswood in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 483 dominant and codominant trees growing in 122 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.
base age = 50yrs. From Carmean (1978b) NC-160.

SITE INDEX FOR <u>WHITE ASH</u> (CARMEAN, 1978b)



Site index curves for white ash in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 275 dominant and codominant trees growing in 73 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.
base age = 50 yrs. From Carmean (1978b), NC-160.

SITE INDEX FOR NORTHERN RED OAK (CARMEAN, 1978b)



—Site index curves for northern red oak in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 136 dominant and codominant trees growing in 37 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.
base age = 50 yrs. From Carmean (1978b), NC-160.

Site index for BLACK WALNUT (Losche and Schlesinger, 1975).

SAMPLE: Location: Southern Illinois

Sample included 255 trees on 60 plots. 45 plots were classified as flood plain stands and 15 plots were classified as upland stands. The data was collected for unmanaged plantations ranging in age from 25 to 30 years. Plantations were originally established on a 4 X 4 or 6 X 6 spacing and included both plantations of seed and seedling origin.

Data was stratified into 2 groups: shallow flood plain soils (having a distinct gravel layer with 40 inches of the surface) (19 plots, 85 trees) and deep flood plain and upland soils (sites having no gravel layer with 40 inches of the surface) (41 plots, 170 trees). Table 1 shows the distribution of heights and sites included in this study.

Site index curves are designed to predict site index when age and height are known. In other words, these are based on site index prediction equations rather than height growth equations (see Section 4 for more complete explanation).

APPLICATION: Select 3 to 5 site index trees over a range of diameters (sampling only dominants and codominants).

Select the site index graph that is appropriate for your area (i.e., shallow flood plain soils, or deep flood plain and upland soils).

Reliability of estimates made is enhanced when stand age is between 13 and 25 years and when site index SI_{BLW} (on a 25 year basis) is between 25 and 45 feet. These curves can be used (with caution) on stands as young as 5 years.

At age 5, height estimates should be with 6.6 feet 2 out of 3 times. At age 13, error should be less than 5 feet 2 out of 3 times.

Site index estimates made in upland stands, managed plantations and natural stands using these curves should be interpreted with caution.

For plantations more than 25 years old, the curves developed by Kellogg should be used.

Table 1. Number of plots and trees sectioned from each soil group within each height class.

Height class (height at 25 yr): (ft)	Floodplain Shallow (<40" to gravel)		Floodplain Deep (40"+ to gravel)		Upland[1]		All	
	Plots	Trees	Plots	Trees	Plots	Trees	Plots	Trees
15 to 25	3	14					3	14
25 to 35	9	40	2	8	3	14	14	62
35 to 45	5	22	4	17	5	20	14	59
45 to 55	2	9	9	39	5	20	16	68
55 to 65			11	44	2	8	13	52
Total	19	85	26	108	15	62	60	255

[1] Miscellaneous group of plots located on a variety of upland slope positions and aspects with too few in any one topographic situation to group separately.

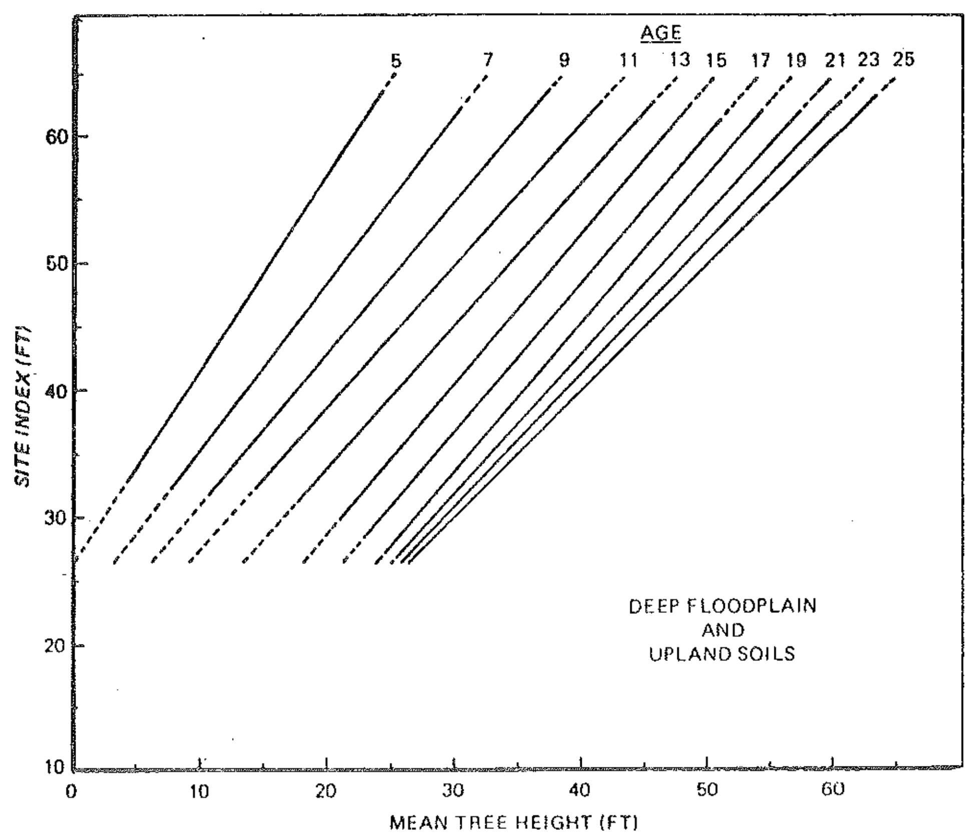
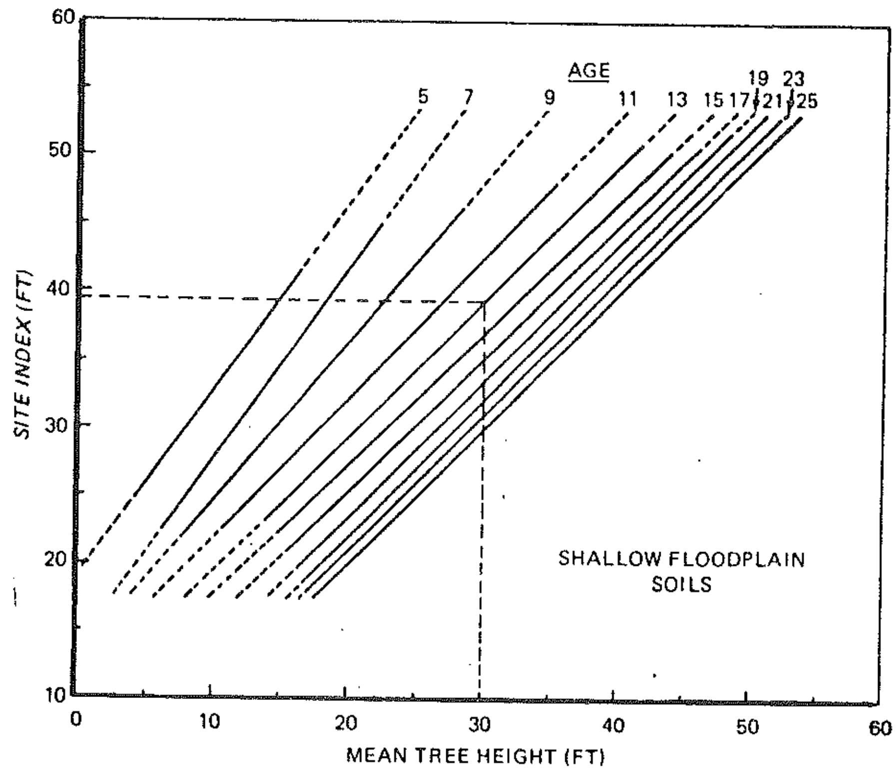


Figure 2. Relation of measured height and age to site index (height, in feet, at 25 years) for deep floodplain and upland soils. Solid portion of lines show extent of data.



Relation of measured height and age to site index (height, in feet, at 25 years) for shallow floodplain soils. Solid portion of lines show extent of data.

Site index for BLACK WALNUT (Kellogg, 1939)

SAMPLE: Location: Iowa, Illinois, and Indiana

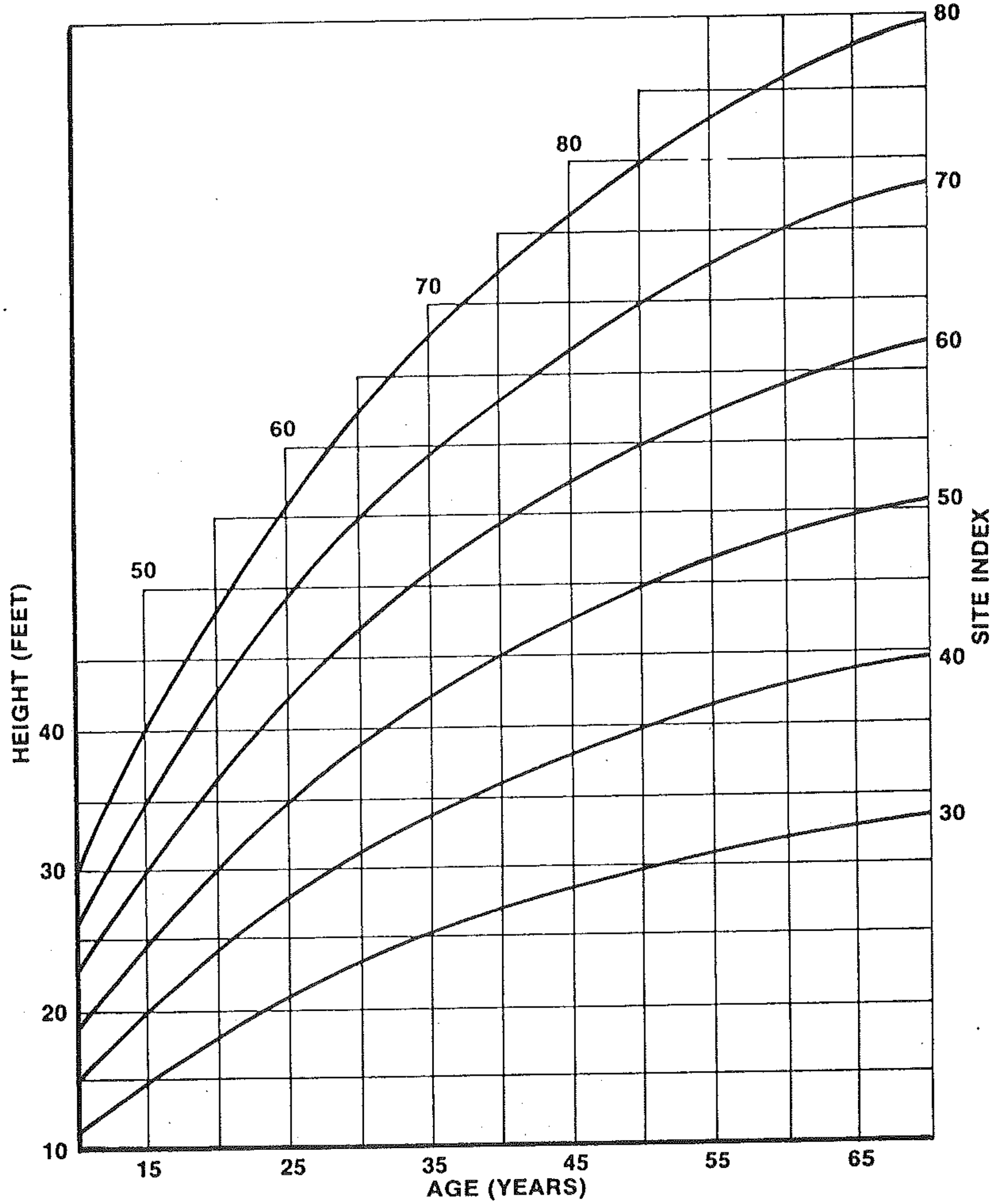
Sample induced data from 200 walnut plantations ranging in age from 10 to 75 years. Initial spacing of the plantations varied from 3 X 3 to 10 X 10. Site index ranged from 40 to 80 feet (on a 50 year basis) (Ferrel and Lundgren, 1975). Specifics concerning the methods used in the study were unavailable, but the harmonized height growth curves are probably the result of total age and total height measurements (rather than more reliable stem analysis techniques).

APPLICATION: Select at least 3 site index trees. Age may be determined from plantations records or by boring inferior trees (these should be the same age as the rest of the plantation).

Reliability of estimates obtained using these curves are enhanced when site index is between 40 and 80 feet, and when age is between 25 and 70 years.

Age refers to total age (i.e., age at BH, plus 4 years).

SITE INDEX FOR BLACK WALNUT (KELLOGG, 1939)



– Black walnut site index curves.

NOTE: base age = 50, total age = age at BH + 4
From Kellogg (1939), Sta. Note No. 36.

Site index for YELLOW POPLAR (Beck, 1962)

SAMPLE: Location: Southern Appalachian Mountains in Western North Carolina, and Northern Georgia.

Sample included data from 267 plots, with 4 to 6 trees per plot. Curves base on total height and total age observations.

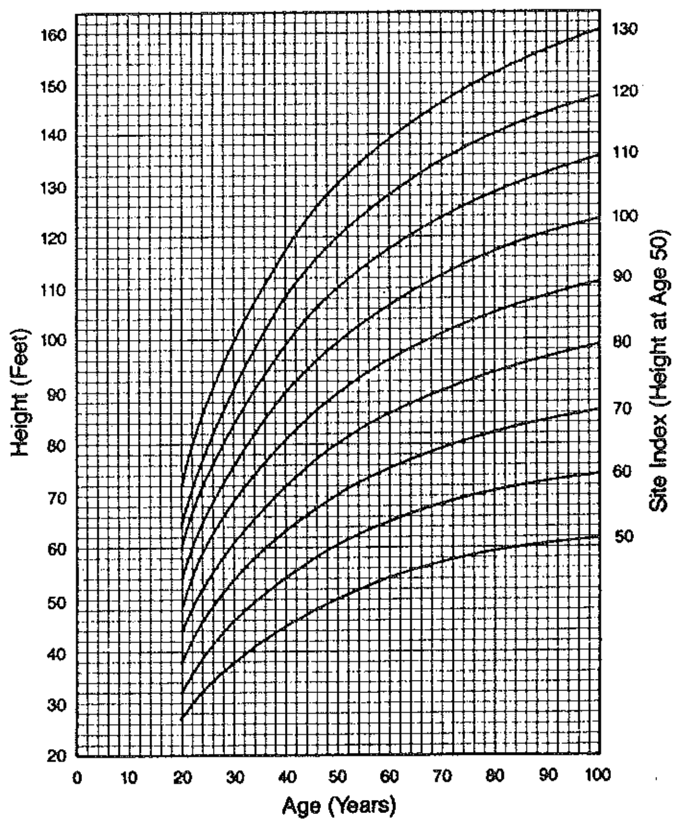
Observed ages ranged from 20 to 82 years and heights ranged from 36 to 134 feet. Site index on the 267 plots ranged from 58 to 123 feet and averaged 87 feet. Curves are harmonized and based on total tree height and total age observations (rather than the more reliable stem analysis technique).

APPLICATION: Select at least 3 site index trees.

Reliability of estimates made with these curves is enhanced when stand age is between 25 and 75 years and site index, SI_{YEP} is between 65 and 115 feet. It may be worth noting that in Indiana's recently completed soil site index study (see Pg. XX.x), site index for yellow poplar ranged from 89 to 105 feet on 25 plots statewide. The lack of a wider range of observed site index measurements may be caused by the manner in which the sample was collected, but it may also indicate that the majority of yellow poplar sites in Indiana fall somewhere in the 90 to 100 foot site index interval.

Age refers to total age (age at BH, plus 3 years).

SITE INDEX FOR YELLOW POPLAR (Beck, 1962).



Site index for YELLOW POPLAR in the Southern Appalachian Mountains. Base age = 50yrs, age = age at BH + 3yrs. From Beck (1962).

Site index for CHERRYBARK or SOUTHERN RED OAK (Broadfoot, 1961)

SAMPLE: Location: Southern Mississippi River Valley

Sample included data from 285 plots. Although not explicitly stated, curves are based (at least partially) on stem analysis data. Curves have been harmonized and do not reflect any polymorphic growth patterns that may exist.

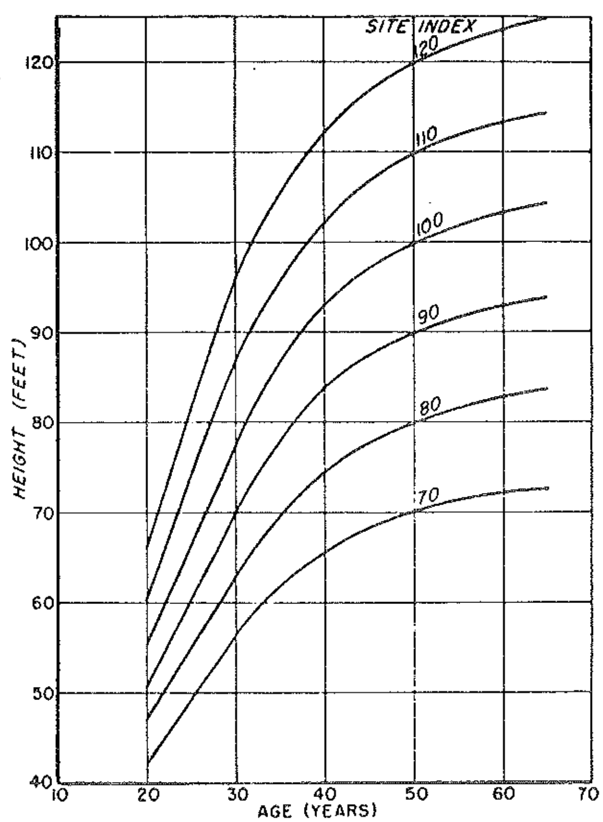
APPLICATION: Select a minimum of 3 site index trees from a range of diameters (sampling only dominants and codominants).

Reliability of estimates made using these curves is enhanced when stand age is between 30 and 60 years and site index SI_{CBO} is between 75 and 115 feet.

Because of the difference in the length of the growing season between northern and southern sites, these curves probably overstate site index slightly.

Although not explicitly stated, age probably refers to total age (age at BH, plus 3 years).

For evaluating prospective sites for planting cherrybark oak, see section on Indirect Methods of Site Assessment (pg. XX.X).



base age = 50 yrs.
age = age at BH + 3yrs
From: Boardfoot (1961), S-190.

Site index for EASTERN COTTONWOOD (Neebe and Boyce, 1959).

SAMPLE: Location: Illinois, Indiana, Missouri, and Kentucky

Sample included 172 trees on 65 sites. 59 sites were classified as bottomland, 3 were classified as upland sites and 3 plots were on strip-mined sites.

Observed ages ranged from 11 to 53 years, and the majority of the trees sampled were between 11 and 32 years old.

Heights observed ranged from 38 to 131 feet.

Average site index was 98 feet on bottomland sites, and 78 feet for upland and strip mined sites.

APPLICATION: Select a minimum of 3 site index trees from a range of diameter classes (sampling only dominants and codominants).

Find tree height on the X - axis, move vertically to the line which corresponds with total age, move horizontally and read site index from the Y - axis.

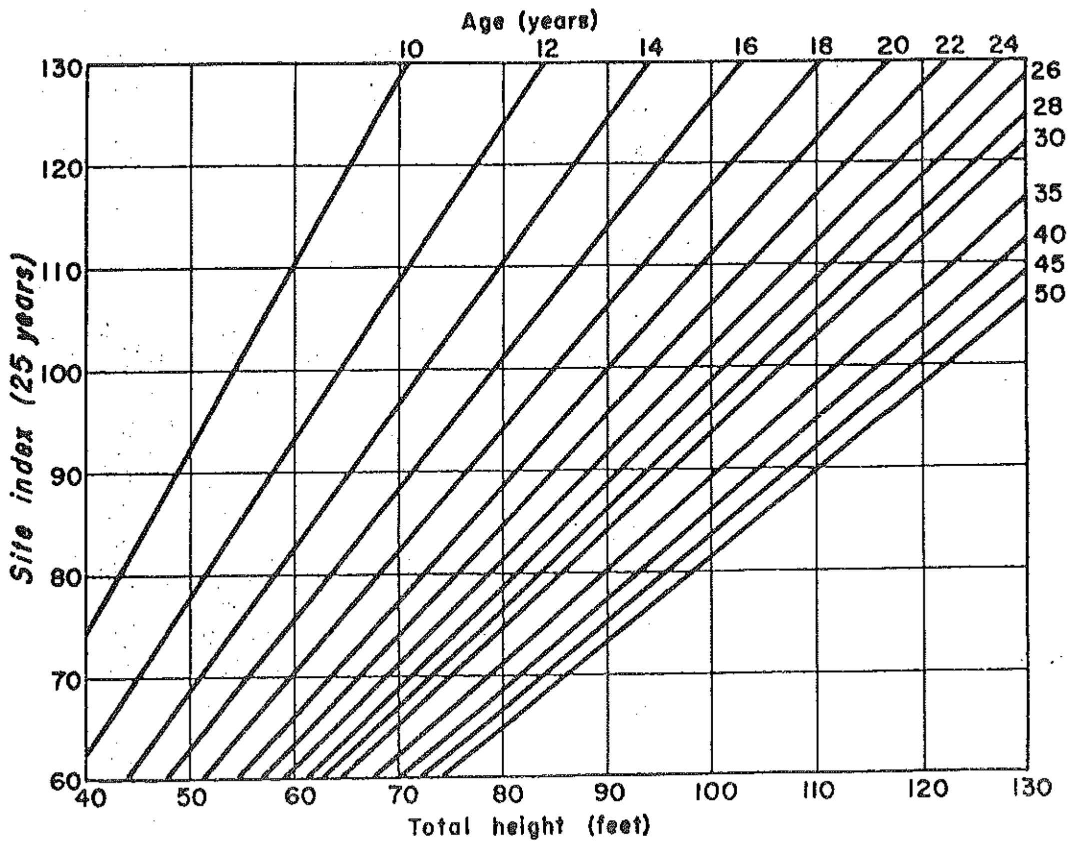
Age refers to total age (i.e., age at BH, plus 2 years).

Site index is on a 25 year basis.

Reliability is enhanced when estimates are made on trees between 10 and 40 years, and on sites SI_{COT} between 70 and 125 feet.

Site index estimates made using these curves on upland sites should be used with caution.

SITE INDEX CURVES FOR EASTERN COTTONWOOD



site index of eastern cottonwood in the midwest from Neebe and Boyce (1959). Base age = 25 yrs., total age = age at BH + 2 yrs. Sta. Note No.126.

Site index for SWEETGUM (Broadfoot and Krinard, 1959)

SAMPLE: Location: Southern Mississippi River Valley

Data concerning sample size and methodology was unavailable, however based on similar studies conducted by this author, the curves are probably based on stem analysis data from bottomland (flood plain) sites. Curves have been harmonized, and do not reflect any polymorphic growth patterns that might exist for this species.

APPLICATION: Select a minimum of three site index trees from a range of diameters.

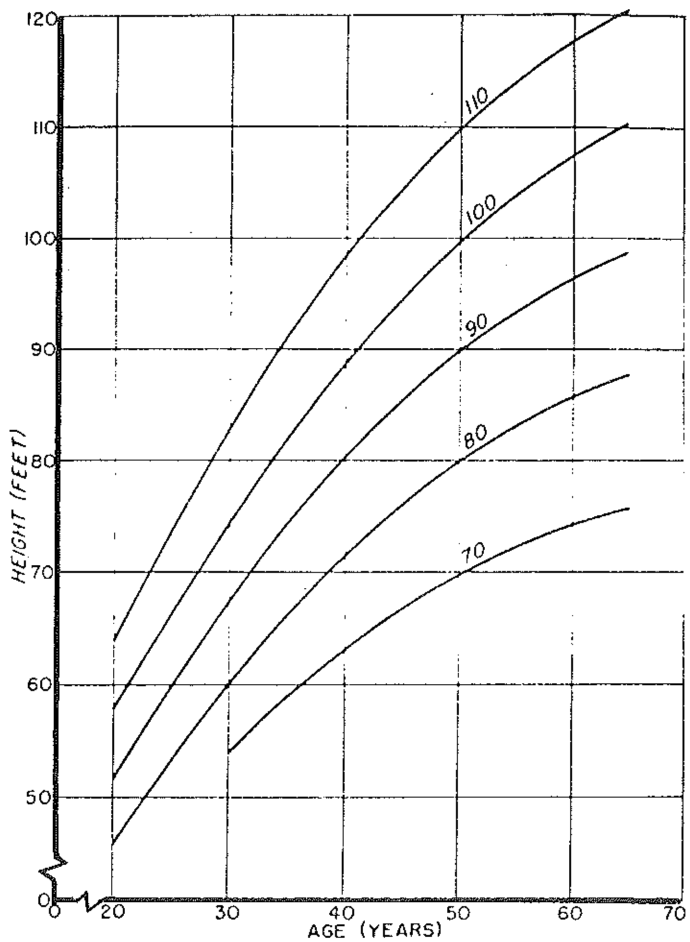
Reliability of estimates is enhanced when used on stands between 35 and 75 years old, and on sites with SI_{SWG} between 75 and 110 feet.

Due to climatic differences between Indiana and the Southern Mississippi River Valley, these curves should not be applied to trees on upland sites.

Although not explicitly stated, age probably refers to total age (i.e., age at BH, plus 3 years).

Comparisons between site index curves constructed from northern data to those constructed from southern data for the same species indicate that southern curves tend

SITE INDEX FOR SWEETGUM (Broadfoot & Krinard, 1959)



base age = 50 yrs., age = age at BH + 3 yrs.
From: Broadfoot & Krinard (1959)

Site index estimates for EASTERN WHITE PINE (Gevorkiantz, 1957).

SAMPLE: Location: Wisconsin

Data concerning sample size and methodology were not available. Curves are harmonized and do not reflect any polymorphic growth patterns that may exist.

APPLICATION: Select 3 to 5 site index trees from the full range of diameter classes (sampling only dominant and co-dominants).

Site index is on a 50 year basis and age used to estimate site index is total age (age at BH plus 5 years).

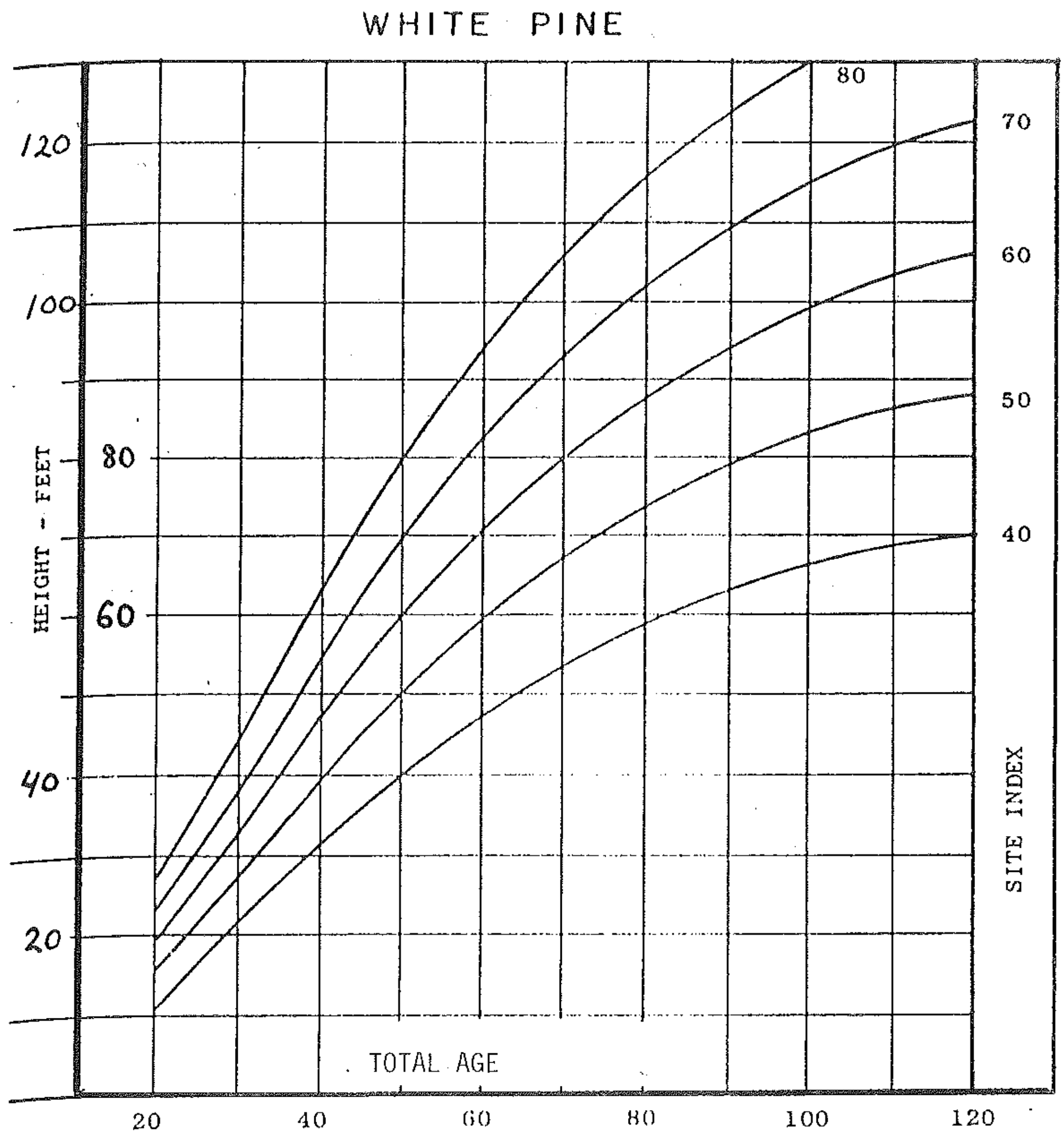
Reliability of estimates is enhanced when curves are applied to data from stands 40 to 80 years old, on sites with SI_{WHP} 45 to 75 feet and on sites with minimal of past site disturbance.

For young stands (less than 45 years old) and those on old field sites, use internodal method.

Although these curves were developed for a region closer to Indiana, the use of total age rather than age at BH increases the potential bias introduced by differences in early stand development.

White pine grows well on a wide range of sites with the exception of heavy clay soils. Because of the problem of hardwood competition on good sites Lancaster and Leak (1978) recommend not planting white pine on sites with SI_{WHP} greater than 65 feet.

SITE INDEX FOR WHITE PINE (Gevorkiantz, 1957)



Expected heights of White Pine in Wisconsin on various sites.
base age = 50 yrs., total age = age at BH + 5 yrs.
From Gevorkiantz (1957), Sta. Tech. Note No. 483.

Site index for EASTERN WHITE PINE (Frothingham, 1914), from Lancaster and Leak (1978).

SAMPLE: Location: New England

Data concerning the character of the sample used in this study were unavailable, however, Leak et al (1970) reported that the curves seemed consistent with more recent stem analysis data collected in New England. Curves are harmonized and probably the product of total age and total height observations.

APPLICATION: Select 3 to 5 site index trees.

Site index is on a 50 year basis.

Use age at BH (not total age) to find site index.

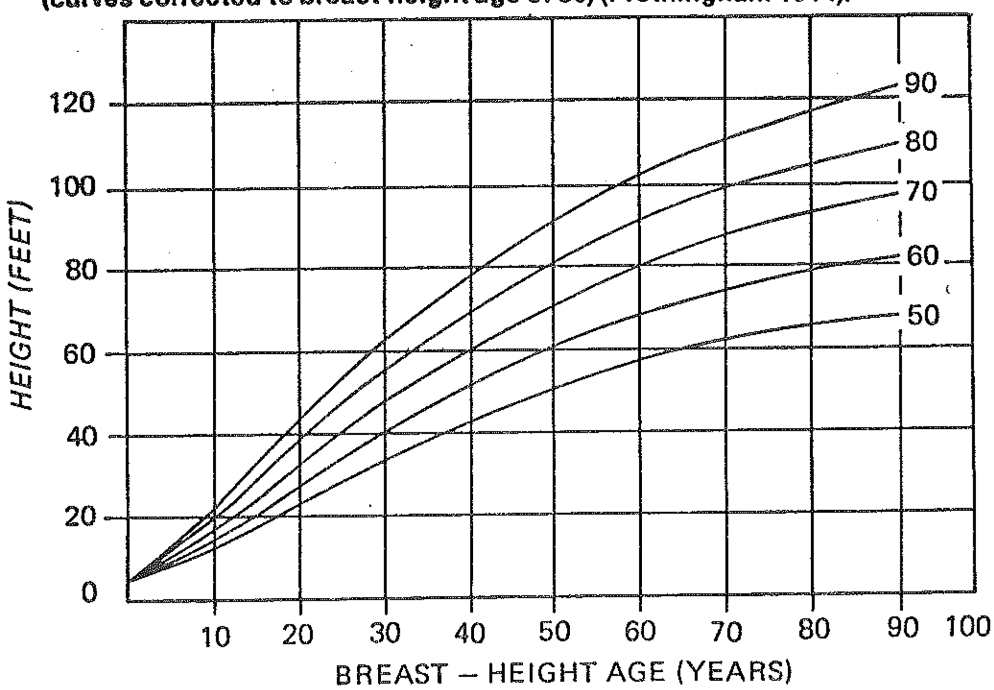
Reliability is enhanced when samples are from stands 30 to 100 years old, on sites between SI_{WHP} 55 - 85 feet and when past site disturbance has been minimal (i.e., this probably should not be used on badly eroded, old field sites).

For young stands (less than 45 years old) and stands on old field sites, use an internodal method.

White pine grows well on a wide range of sites with the exception of heavy clay soils. Because of the problem of hardwood competition Lancaster and Leak (1978) recommend not planting white pine on sites SI_{WHP} greater than 65 feet.

SITE INDEX FOR WHITE PINE

Site-index curves for eastern white pine in New England (curves corrected to breast-height age of 50) (Frothingham 1914).



From Leak etal (1970), NE-176.

Site index for UPLAND OAK (Schnur, 1937).

SAMPLE: Location: Entire Central States Region: Minnesota, Wisconsin, Michigan, Ohio, Indiana, Illinois, Missouri, Tennessee, and Kentucky.

Sample included data from 409 temporary plots located in stands which were fully stocked, even aged, lacking a dense understory, and containing trees which are uniformly spaced. Observations of total age and tree height were plotted and height growth curves were fitted by hand. A single set of harmonized height growth curves were produced.

Observed ages by site index classes included in the sample are as follows:

TABLE 1. Distribution of Plots by Age and Site Index Class

Age (years)	Plot distribution by site index							
	<40	40-49	50-59	60-69	70-79	80-89	90+	Total
10-19			10	15	5			30
20-29		5	18	29	12			64
30-39		1	25	35	13	1	1	76
40-49	1	2	33	36	10	2		84
50-59		2	17	28	19	2		68
60-69	1	2	17	23	9	2		54
70-79			8	15	2			25
80+				2	1			3
TOTAL	2	12	128	183	71	7	1	404

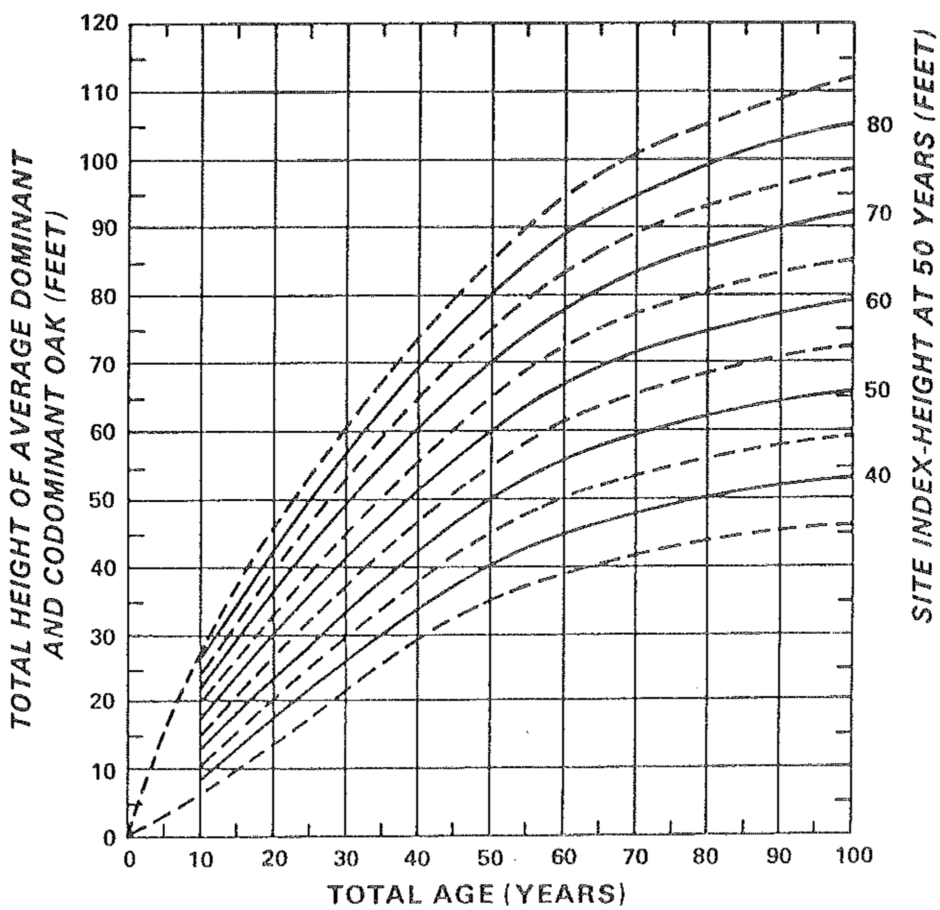
APPLICATION: Select at least 3 site index trees over a range of diameters representative of the stand in general.

Reliability of estimates made using these curves is enhanced when sample trees are between 30 and 80 years old and when site index is between 50 and 60 feet.

Note: These curves were produced from a much larger study conducted in 1937. The methods used have been improved upon over the years and a number of shortcomings have been found in these curves. These curves are for all practical purposes obsolete. They have been included in this document, however, because they were used in many previous studies and surprisingly are still being used by some organizations.

Considering the age of this study, the results obtained using these curves are surprisingly similar to those obtained using curves for individual oak species (Carmean, 1971). However the curves for individual oak species contained in this section are more reliable and should be used in all but the most unusual circumstances.

Age refers to total age (i.e., age at BH, plus 4 years).



UPLAND OAK

Schnur, 1937

age = BH + 4

INDIRECT METHOD

1) Estimating site index for <u>BLACK OAK</u> (Carmean, 1967).

<u>SAMPLE</u>: Location: 21 county area of the unglaciated portion of Southeastern Ohio.

163 plots, with at least 4 dominant or codominant trees per plots. Plots were stratified on the basis of soil texture (fine-textured soils having restricted internal drainage; and medium-textured soils having medium to rapid internal drainage).

Additional data concerning the character of the sample was unavailable. For this reason this method should be used with caution or should be verified with field observations.

<u>APPLICATION</u>: Applicable to unglaciated soils (southern third of state). Use on soil types other than those listed would introduce a substantial source of error.

On ridge-top sites, where soil is medium textured and internal drainage good (i.e., sites with loess cap), this method will underestimate site index. The presence or absence of a silt cap can be determined with a soil probe.

Select the table which is appropriate for the soil type involved.

Table 1 is used to estimate site index for black oak on medium-textured soils with good internal drainage when position on slope, length of slope, aspect, percent slope and shape of slope is known or can be estimated.

Table 2 is used to estimate site index for black oak on fine-textured soils with restricted internal drainage when position on slope, aspect and shape of slope is known or can be estimated.

Table 1—Predicted site index for black oak growing on medium-textured, well-drained upland soils in southeastern Ohio (Muskingum Berks, Wellston, Gilpin, Litz, Dekalb, Hartsells, Neotoma, Jefferson, and Chillicothe soil series)

Distance to ridge, %	Slope length*	Slope aspect+	Plot shape: Convex, Gentle‡	Convex, Steep‡	Linear, Gentle	Linear, Steep	Concave, Gentle	Concave, Steep
0 to 25 (upper slopes and ridges)	short	NE	66	68	70	71	73	74
		SW	64	60	67	63	70	65
	long	NE	62	64	65	66	68	69
		SW	60	56	63	59	66	61
26 to 50 (upper mid-slopes)	short	NE	71	73	75	76	78	79
		SW	69	64	72	67	75	70
	long	NE	67	68	70	71	73	74
		SW	64	60	67	63	70	66
51 to 75 (lower mid-slopes)	short	NE	76	78	80	81	84	85
		SW	74	69	77	72	80	75
	long	NE	72	73	75	76	78	80
		SW	69	65	72	67	76	71
76 to 100 (lower slopes to bottoms)	short	NE	82	83	86	87	90	91
		SW	70	74	83	77	86	81
	long	NE	77	78	80	82	84	86
		SW	74	69	77	72	81	76

*Short slopes are less than 5 chains and long slopes more than 5 chains in length.
+Northeast aspects are from 355 to 95° azimuth and southwest aspects are from 96 to 354° azimuth.
‡Gentle slopes are less than 35% and steep sloeps more than 35% steepness.

Table 2—Predicted site index for black oak growing on fine-textured upland soils having restricted internal drainage (Rarden, Coolville, Keene, Upshur, and Lathem soil series)

Distance to ridge, %	Aspect*	Plot shape: Convex	Linear	Concave
Upper slopes and ridges (0 to 25%)	NE	68	73	79
	SE and NW	65	70	75
	SW	62	66	71
Upper mid-slopes (26 to 50%)	NE	70	76	81
	SE and NW	67	72	77
	SW	64	69	74
Lower mid-slopes (51 to 75%)	NE	73	78	84
	SE and NW	69	74	80
	SW	66	71	77
Lower slopes and bottoms (76 to 100%)	NE	75	81	87
	SE and NW	72	77	83
	SW	68	74	79

* Northeast aspects are from 337 to 113°, southeast from 114 to 155, southwest from 156 to 295, and northwest from 296 to 336° azimuth.

From Carmean (1967)

2) Estimating site index for BLACK AND WHITE OAK (Hannah, 1968a & 1968b).

SAMPLE:

Location: Norman and Crawford uplands, Knobs region, South Central Indiana.

154, 1/5 acre plots, with 5 or more dominant or co-dominant trees per plot. White Oak was measured on 126 plots, Black Oak on 86 plots.

Observed ages ranged from 28 to 106 years.

Plots included Zanesville, Tilsit, Muskingum and Wellston soil types.

APPLICATION:

Applicable only in Knobs region of South Central Indiana.

Reliability of estimates is enhanced when data is applied to sites with the soil types listed above. Application of this data to other soil types, or outside the Knobs region, should be done with extreme caution and only with actual field checks. Presence of an unusually thick loess cap, or prior disturbance will introduce a potentially significant source of error.

When using these tables, depth of the A horizon should be measured at several locations in the field, but % clay content and stone content can be determined from soil survey information. Note: This formula looks more complicated to apply than it really is.

Table 1 is used to estimate white oak site index when position on slope, percent clay content from the B horizon, thickness of the A horizon and aspect is known.

Table 2 is used to estimate black oak site index when position on slope, and depth of the A horizon is known. Adjustments can further be made for sites with stony subsoils (less than 30% stone content in the B horizon) and for soils with a high clay content in the subsoil (less than 40% clay content in B horizon).

Figure 1 illustrates a simplified method of estimating black oak site index based on these data.

Table 1.—Site-Index Prediction Table for White Oak in Southern Indiana

Position	Clay content of the lower subsoil horizon (B_2) (in percent)	A_1- and A_2-horizon thickness—inches: 2.0-4.0		4.1-6.0		6.1-8.0		8.1-10.0	
Ridges	Less than 40	51		57		64		73	
	40-60	44		50		56		63	
	More than 60	38		43		48		55	
		North	South	North	South	North	South	North	South
Upper slopes 2-50 percent of distance from ridge	Less than 40	61	55	66	61	72	67	78	75
	40-60	55	48	60	53	65	59	71	65
	More than 60	50	42	54	47	59	52	65	58
Lower slopes 51-99 percent of distance from ridge	Less than 40	66	60	71	65	75	70	80	76
	40-60	60	53	64	57	68	62	73	66
	More than 60	55	46	58	50	62	54	66	59
Bottoms	Less than 40	73		77		80		84	
	40-60	68		71		74		77	
	More than 60	63		66		69		72	

Aspect: North slopes include azimuths from 315 to 135 degrees and south slopes include azimuths from 136 to 314 degrees.
Slope shape: All site-index values are for linear-shaped slopes. For concave-shaped slopes add 2 feet; for convex-shaped slopes subtract 2 feet.
Stone content: All site-index values are for relatively stone-free soils (0 to 30 percent stone in the B_2 horizon); for stony soils (31 to 60 percent stone in B_2) subtract 2 feet; for very stony soils (more than 60 percent stone in B_2) subtract 3 feet.
Texture of the B_3 horizon: Site-index values in the table are for conditions where all subsoil horizons have the same general texture. Four feet should be subtracted from the values for subsoil with less than 40 percent clay if the B_2 of this soil is underlain with a B_3, B_xm or C horizon having 40 to 60 percent clay. Four feet should be subtracted from the values for subsoils with 40 to 60 percent clay if the B_2 of this soil is underlain by a B_3, B_x, or C horizon with more than 60 percent clay.
Silt content: All site-index values are for soils with more than 25 percent silt in the B_1 horizon. For soils with less than 25 percent silt subtract 4 feet from the indicated site-index values.

Table 2.—Site-Index Prediction Table for Black Oak in Southern Indiana

Position	Depth of surface soil (A_1 + A_2 horizons—inches): Less than 4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0	8.1-9.0	More than 9.0
Ridges	48	54	60	66	72	79	87
Upper slopes 1-25 percent of distance from ridge	51	56	62	68	74	80	87
Upper midslopes 26-50 percent of distance from ridge	56	62	66	72	77	82	88
Lower midslopes 51-75 percent of distance from ridge	62	67	72	76	80	84	89
Lower slopes 76-99 percent of distance from ridge	69	74	78	80	84	87	90
Bottoms	73	77	80	83	86	88	91

Stone content: All site-index values are for relatively stone-free soils (0 to 30 percent stone in B_2 horizon); for stony soils (31 to 60 percent stone in B_2), and very stony soils (more than 60 percent stone in B_2), the following subtractions should be made:

Site index	Stony soil	Site index	Very stony soils
<60	−2	<60	−4
61–90	−3	61–75	−5
>90	−4	76–87	−6
		>87	−7

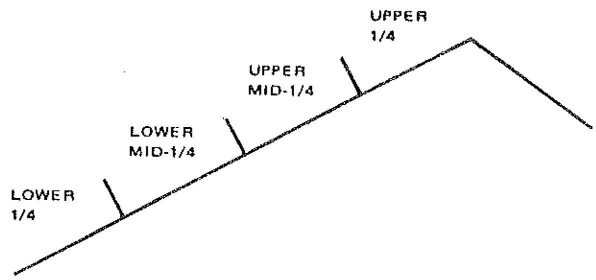
Subsoil texture: All site-index values are for soils having less than 40 percent clay in the subsoil (loams, clay loams, silty or sandy clay loams, and silt loams). For soils with heavier subsoil textures (more then 40 percent clay), the following substractions are needed:

Site index	Upper subsoil (B_2 horizon) has less than 40 percent clay; lower subsoil (B_3, B_x, or C horizon) has more than 40 percent clay (Reduction)	Site index	All subsoil horizons have more than 40 percent clay (Reduction)
<52	−2	<57	−4
53–73	−3	58–69	−5
>74	−4	70–80	−6
		>80	−7

Texture of the B_3 horizon: Site-index values are for conditions where the B_2 horizon and those underlying it have the same general texture. Subtract 4 feet if a B_2 horizon with less than 40 percent clay is underlain by a B_3, B_x, or C horizon with 40 to 60 percent clay. Subtract 4 feet if a B_2 horizon with 40 to 60 percent clay is underlain by a B_3, B_x, or C horizon with more than 60 percent clay.

Figure 1

SITE INDEX FOR BLACK OAK



NORTHEAST ASPECT[1]

Slope shape (and steepness)	Coves & lower quarter	Lower mid-quarter	Upper mid-quarter	Ridges & upper quarter
Convex	80	75	70	64
Concave	88	82	76	70

ALL OTHER ASPECTS[2]

Slope shape (and steepness)	Coves & lower quarter	Lower mid-quarter	Upper mid-quarter	Ridges & upper quarter
Convex:				
Gentle (less than 35%)	76	71	66	62
Steep (more than 35%)	72	67	62	58
Concave:				
Gentle (less than 35%)	84	78	73	68
Steep (more than 35%)	78	73	68	63

[1] *Northeast facing slopes include aspects from 355° to 95° azimuth.*

[2] *All other slopes are included in azimuths from 96° to 354°.*

From: Carmean & Ashley (1972).

3) Estimating site index for CHERRYBARK AND SOUTHERN RED OAK (Broadfoot, 1961).

SAMPLE: Location: Southern Mississippi River Valley

Sample included data from 285 plots. Although not explicitly stated, curves are based (at least partially) on stem analysis data. Curves have been harmonized and do not reflect any polymorphic growth patterns that may exist.

APPLICATION: Tables 1 and 2 are perhaps most useful for evaluating prospective site for planting cherrybark oak.

Table 1 predicts site index based on depth of the A horizon and depth to an impervious layer (i.e., depth to clay pan or mottling). Both variables should be determined in the field by taking several core samples.

Table 2 uses depth of A horizon, texture of the first 2 feet of soil, and internal drainage characteristics to predict site index.

These tables probably overstate site index in Indiana and should not be used if other methods can be used. However, these tables should be useful for evaluating planting sites.

Table 1.—*Site index of cherrybark oak as determined from depth to mottling and depth of topsoil*

If there is a pan within 30 inches of the surface, subtract 11 from the values.

Depth to mottling (inches)	Depth of topsoil in inches					
	1	2	3	4	5	6 or more
	Feet					
0 to 5.9	62	68	75	81	87	93
6.0 to 11.9	65	71	77	83	89	96
12.0 to 17.9	67	74	80	86	92	98
18.0 to 23.9	70	76	83	89	95	101
24+	73	79	85	91	97	104

Table 2.—*Key to cherrybark oak site index for soils of the Midsouth*

Soil-site description	Not eroded (more than 6 in. of topsoil)	Eroded (less than 6 in. of topsoil)
	Site index	
I. Fine texture		
A. Good internal drainage	95-104	80-89
B. Poor internal drainage		
1. Without pan		
a. Moist	80-89	65-74
b. Dry	90-99	75-84
2. With pan	75-84	60-69
II. Medium texture		
A. Good internal drainage		
1. Without pan		
a. Moist	110-119	95-104
b. Dry	100-109	85-94
2. With pan	85-94	70-79
B. Poor internal drainage		
1. Without pan		
a. Moist	90-99	75-84
b. Dry	95-104	80-89
2. With pan	80-89	65-74
III. Coarse texture		
A. Good internal drainage		
1. Without pan		
a. Moist	105-114	90-99
b. Dry	95-104	80-89
2. With pan	80-89	65-74
B. Poor internal drainage		
1. Without pan		
a. Moist	95-104	80-89
b. Dry	90-99	75-84
2. With pan	75-84	60-69

From Broadfoot (1961), S-190.

INTERNODAL METHOD

Site index for EASTERN WHITE PINE (Brown & Stires; 1981b).

SAMPLE: East Central Ohio

148 plots (3 to 5 dominant or codominant trees per plot).

Plantations on old field sites.

Total ages observed ranged from 29 to 50 years, and averaged 33 years; ages at breast height ranged from 25 to 43 years.

Site index measured ranged from 57 to 89 feet on 35 year basis.

APPLICATION: Select 5 to 10 site index trees.

Best when used on plantations on old field sites.

Reliability is enhanced with larger sample size, use of longer growth increment, and the inclusion of additional variables (i.e., position on slope, or position on slope and soil depth).

Table 1 contains the regression equations used in tables 2, 3, 4, & 5.

Table 2 is used to estimate SI_{WHP}, when length of a 3, 5, or 10 year growth intercept is known.

Table 3 is used to estimate SI_{WHP}, when the length of a 3, 5, or 10 year growth intercept and position on the slope is known.

Table 4 is used to estimate SI_{WHP}, when growth intercept and total soil depth is known.

Table 5 is used to estimate SI_{WHP}, when growth intercept total soil depth and position on the slope is known.

Site index for White Pine (Brown & Stires, 1981)

TABLE 1.—Multiple Regression Equations Developed for Predicting Height of White Pine (Based on Age at BH and Height from the Base of the BH Increment to the Growing Tip) Using Growth Intercept Singly and in Combination with Slope Position and/or Total Soil Depth.

Equation 1: $\log_e \text{Ht} = 4.48 - 21.82\ (1/\text{Age}) + 0.055\ (\text{3-Yr Growth Int})$
$r^2 = 0.62,\ \text{se} = 0.079$

Equation 2: $\log_e \text{Ht} = 4.28 - 21.74\ (1/\text{Age}) + 0.048\ (\text{5-Yr Growth Int})$
$r^2 = 0.73,\ \text{se} = 0.067$

Equation 3: $\log_e \text{Ht} = 4.16 - 22.67\ (1/\text{Age}) + 0.030\ (\text{10-Yr Growth Int})$
$r^2 = 0.79,\ \text{se} = 0.059$

Equation 4: $\log_e \text{Ht} = 4.44 - 20.78\ (1/\text{Age}) + 0.051\ (\text{3-Yr Growth Int})$
$+ 0.00095\ (\%\ \text{Dist from Ridge})$
$r^2 = 0.69,\ \text{se} = 0.071$

Equation 5: $\log_e \text{Ht} = 4.26 - 20.88\ (1/\text{Age}) + 0.045\ (\text{5-Yr Growth Int})$
$+ 0.00078\ (\%\ \text{Dist from Ridge})$
$r^2 = 0.79,\ \text{se} = 0.060$

Equation 6: $\log_e \text{Ht} = 4.15 - 21.88\ (1/\text{Age}) + 0.028\ (\text{10-Yr Growth Int})$
$+ 0.00068\ (\%\ \text{Dist from Ridge})$
$r^2 = 0.83,\ \text{se} = 0.055$

Equation 7: $\log_e \text{Ht} = 4.47 - 21.85\ (1/\text{Age}) + 0.046\ (\text{3-Yr Growth Int})$
$+ 0.0033\ (\text{Tot Soil Depth})$
$r^2 = 0.68,\ \text{se} = 0.075$

Equation 8: $\log_e \text{Ht} = 4.29 - 21.76\ (1/\text{Age}) + 0.044\ (\text{5-Yr Growth Int})$
$+ 0.0018\ (\text{Tot Soil Depth})$
$r^2 = 0.76,\ \text{se} = 0.063$

Equation 9: $\log_e \text{Ht} = 4.17 - 22.63\ (1/\text{Age}) + 0.029\ (\text{10-Yr Growth Int})$
$+ 0.0010\ (\text{Tot Soil Depth})$
$r^2 = 0.80,\ \text{se} = 0.059$

Equation 10: $\log_e \text{Ht} = 4.42 - 20.69\ (1/\text{Age}) + 0.040\ (\text{3-Yr Growth Int})$
$+ 0.0011\ (\%\ \text{Dist from Ridge})$
$+ 0.0037\ (\text{Tot Soil Depth})$
$r^2 = 0.75,\ \text{se} = 0.065$

Equation 11: $\log_e \text{Ht} = 4.27 - 20.81\ (1/\text{Age}) + 0.039\ (\text{5-Yr Growth Int})$
$+ 0.00088\ (\%\ \text{Dist from Ridge})$
$+ 0.0023\ (\text{Tot Soil Depth})$
$r^2 = 0.82,\ \text{se} = 0.056$

Equation 12: $\log_e \text{Ht} = 4.16 - 21.75\ (1/\text{Age}) + 0.026\ (\text{10-Yr Growth Int})$
$+ 0.00074\ (\%\ \text{Dist from Ridge})$
$+ 0.0016\ (\text{Tot Soil Depth})$
$r^2 = 0.84,\ \text{se} = 0.054$

TABLE 2.—Estimated 35-Year Site Index (Based on Age at BH and Height from the Base of the BH Increment to the Growing Tip) for White Pine Using the Length of 3-, 5-, and 10-Year Growth Intercept Beginning 2 Years Above BH.

3-Yr Growth Intercept*		5-Yr Growth Intercept†		10-Yr Growth Intercept‡	
Length	Site Index	Length	Site Index	Length	Site Index
ft	ft	ft	ft	ft	ft
4	59	8	57	19	59
5	62	9	60	21	63
6	66	10	63	23	67
7	70	11	66	25	71
8	73	12	69	27	76
9	78	13	72	29	80
10	82	14	76	31	85
11	87	15	80	33	89
		16	84		
		17	88		

*Based on Equation 1, Table 1.
†Based on Equation 2, Table 1.
‡Based on Equation 3, Table 1.

TABLE 3.—Estimated 35-Year Site Index (Based on Age at BH and Height from the Base of the BH Increment to the Growing Tip) for White Pine Using the Length of 3-, 5-, and 10-Year Growth Intercept Beginning 2 Years Above BH in Combination with Slope Position.

Intercept Length	Slope Position (Percent Distance from Ridge) Ridge 0%	Upper 25%	Mid 50%	Lower 75%	Bottom 100%
ft	site index, ft				
3-Year Growth Intercept*					
4	57	59	60	62	63
5	61	62	63	65	66
6	64	65	67	68	70
7	67	69	70	72	74
8	71	72	74	76	77
9	74	76	78	80	81
10	78	80	82	84	86
11	82	84	86	88	90
5-Year Growth Intercept†					
8	56	57	58	59	60
9	58	60	61	62	63
10	61	62	64	65	66
11	64	65	66	68	69
12	67	68	70	71	72
13	70	71	73	74	76
14	73	75	76	78	79
15	77	78	80	81	83
16	80	82	83	85	87
17	84	85	87	89	91
10-Year Growth Intercept‡					
19	58	59	60	61	62
21	61	62	63	64	65
23	65	66	67	68	69
25	68	70	71	72	73
27	72	74	75	76	77
29	76	78	79	80	81
31	81	82	84	85	86
33	86	87	88	90	91

*Based on Equation 4, Table 1.
†Based on Equation 5, Table 1.
‡Based on Equation 6, Table 1.

TABLE 4.—Estimated 35-Year Site Index (Based on Age at BH and Height from the Base of the BH Increment to the Growing Tip) Using the Length of 3-, 5-, and 10-Year Growth Intercept Beginning 2 Years Above BH in Combination with Total Soil Depth.

Intercept Length	Total Soil Depth, Inches				
	12	18	24	30	36
ft	site index, ft				
3-Year Growth Intercept*					
4	59	60	61	62	63
5	61	62	64	65	66
6	64	65	67	68	69
7	67	69	70	71	73
8	70	72	73	75	76
9	74	75	77	78	80
10	77	79	80	82	83
11	81	82	84	86	87
5-Year Growth Intercept†					
8	57	58	58	59	59
9	59	60	61	61	62
10	62	63	64	64	65
11	65	66	66	67	68
12	68	69	69	70	71
13	71	72	72	73	74
14	74	75	75	77	77
15	77	78	79	80	81
16	81	82	82	84	85
17	85	86	86	87	88
10-Year Growth Intercept‡					
19	60	60	60	61	61
21	63	63	64	64	65
23	67	67	68	68	68
25	71	71	72	72	73
27	75	76	76	76	77
29	80	80	81	81	81
31	84	85	86	86	86
33	89	90	91	91	91

*Based on Equation 7, Table 1.
†Based on Equation 8, Table 1.
‡Based on Equation 9, Table 1.

TABLE 5.—Estimated 35-Year Site Index (Based on Age at BH and Height from the Base of the BH Increment to the Growing Tip) Using the Length of 3-, 5-, and 10-Year Growth Intercept Beginning 2 Years Above BH in Combination with Slope Position and Total Soil Depth.

3-Year Growth Intercept*

Intercept Length	Slope Position	Total Soil Depth 12	24	36
ft		SI, ft		
4	Upper	58	61	63
	Mid	59	62	65
	Lower	61	64	67
5	Upper	60	63	66
	Mid	62	65	68
	Lower	64	67	70
6	Upper	63	66	69
	Mid	65	68	71
	Lower	66	69	73
7	Upper	65	68	71
	Mid	67	70	73
	Lower	68	72	76
8	Upper	68	71	74
	Mid	70	73	76
	Lower	72	75	79
9	Upper	71	74	77
	Mid	73	76	80
	Lower	75	78	82
10	Upper	73	77	81
	Mid	75	79	83
	Lower	77	81	85
11	Upper	77	80	84
	Mid	79	82	86
	Lower	81	85	89

5-Year Growth Intercept†

Intercept Length	Slope Position	Total Soil Depth 12	24	36
ft		SI, ft		
9	Upper	59	61	62
	Mid	60	62	64
	Lower	62	63	65
10	Upper	61	63	65
	Mid	63	64	66
	Lower	64	66	68
11	Upper	64	65	67
	Mid	65	67	69
	Lower	67	68	70
12	Upper	66	68	70
	Mid	68	70	72
	Lower	69	71	73
13	Upper	69	71	73
	Mid	70	72	74
	Lower	72	74	76
14	Upper	72	74	76
	Mid	73	75	77
	Lower	75	77	79
15	Upper	74	77	79
	Mid	76	78	80
	Lower	78	80	82
16	Upper	77	80	82
	Mid	79	81	84
	Lower	81	83	85

10-Year Growth Intercept‡

Intercept Length	Slope Position	Total Soil Depth 12	24	36
ft		SI, ft		
19	Upper	59	60	61
	Mid	60	61	62
	Lower	61	62	63
21	Upper	63	63	64
	Mid	63	64	65
	Lower	64	65	67
23	Upper	65	66	68
	Mid	66	67	69
	Lower	67	69	70
25	Upper	68	70	71
	Mid	70	71	72
	Lower	71	72	74
27	Upper	72	74	75
	Mid	73	75	76
	Lower	75	76	78
29	Upper	76	77	79
	Mid	77	79	80
	Lower	79	80	82
31	Upper	80	82	83
	Mid	82	83	85
	Lower	83	85	86
33	Upper	84	86	88
	Mid	86	88	89
	Lower	87	89	91

*Based on Equation 10, Table 1. †Based on Equation 11, Table 1. ‡Based on Equation 12, Table 1.

Conversion of a site index for a KNOWN species to an UNKNOWN species (Carmean and Hannah, 1983).

SAMPLE: Location: Ohio, Indiana, Kentucky, and West Virginia.

Sample included 540 plots, table 1 shows the distribution and number of paired observations.

Table 1. Site index comparison for upland oaks and yellow-poplar were based on 540 plots in the Central States.

Species	White oak	Scarlet oak	Chestnut oak	Northern red oak	Yellow-poplar
	Number of plots having paired observations				
Black oak	278	175	112	105	27
White oak		168	100	114	24
Scarlet oak			91	37	[a]
Chestnut oak				36	[a]
Northern red oak					29
Yellow-poplar					

[a] *Paired species combinations having too few plots for regression analyses.*

Site indexes used for white, black, chestnut and scarlet oak were determined using site index curves developed by Carmean (1971). Site index for red oak was determined using the curves for black oak (Carmean, 1971). Site index for yellow poplar site index was determined based on curves developed for the piedmont region by Beck (1962).

Stand ages observed were greater than 30 years.

Table 2 contains data concerning the character of the sample used to calculate the conversion factors for each of the 13 paired combinations, including: the range of site index observed in the dependent variable, sample size (N) and a measure of the reliability of the conversion factors (r^2).

APPLICATION: Given a site index for one species, it is possible to estimate site index for other species on that same site.

To use table 2, find the species for which site index is known along the top of the table. Follow the appropriate column down to the row that corresponds with the species for which site index is desired. Substitute the values given for b_0 and b_1 into the following equation:

SI unknown species = $b_0 + b_1$ known species.

It is important to follow this procedure exactly -- simply finding a row column combination corresponding to the two species may produce an erroneous answer.

Reliability of estimates generated by this method can be assessed by comparing the character of the sample used to arrive at b_0 and b_1. Site index should fall well within the range of site indexes listed. The closer site index is to the limits of this range, the less reliable the estimates generated will be. Similarly, the smaller the sample size (N) the less reliable the estimates generated will be. Finally, the r^2 value reported provides an indication of how strong the correlation between the site index of the known and unknown species is. The closer r^2 is to 1, the stronger the relationship. Species combination marked with an "*" (r^2 less than .7) should be used with caution. Estimates generated from species combinations where r^2 is less than .5 should be used only with extreme caution!

SITE INDEX CONVERSION EQUATIONS:
(Carmean & Hahn, 1983)

UNKNOWN VARIABLES ↓ / KNOWN VARIABLES →	WHITE OAK	BLACK OAK	RED OAK	SCARLET OAK	CHESTNUT OAK	YELLOW POPLAR
WHITE OAK	b_0 = Y-intercept b_1 = slope range = range of obs. n = sample size r^2 =	b_0 = 8.585 b_1 = 0.815 (38 - 88) n = 278 r^2 = .82	b_0 = 10.959 b_1 = 0.790 (40 - 101) n = 114 r^2 = .73	b_0 = 5.986 b_1 = 0.839 (38 - 85) n = 168 r^2 = .80	b_0 = 1.232 b_1 = 0.973 (40 - 85) n = 100 r^2 = .88	* b_0 = 30.282 b_1 = 0.531 (48 - 88) n = 24 r^2 = .40
BLACK OAK	b_0 = 4.033 b_1 = 1.002 (36 - 96 ft) n = 278 r^2 = .82		b_0 = 6.120 b_1 = 0.931 (39 - 96) n = 105 r^2 = .84	b_0 = 5.452 b_1 = 0.903 (42 - 93) n = 175 r^2 = .83	b_0 = 3.223 b_1 = 0.981 (36 - 86) n = 112 r^2 = .85	* b_0 = 28.823 b_1 = 0.627 (68 - 100) n = 27 r^2 = .52
RED OAK	b_0 = 9.064 b_1 = 0.930 (44 - 101) n = 114 r^2 = .73	b_0 = 6.169 b_1 = 0.901 (41 - 92) n = 105 r^2 = .84		b_0 = 3.724 b_1 = 0.923 (41 - 85) n = 37 r^2 = .81	b_0 = 4.750 b_1 = 0.976 (44 - 87) n = 36 r^2 = .89	* b_0 = 17.122 b_1 = 0.775 (60 - 116) n = 29 r^2 = .65
SCARLET OAK	b_0 = 8.173 b_1 = 0.953 (40 - 88 ft) n = 168 r^2 = .80	b_0 = 6.675 b_1 = 0.922 (40 - 93) n = 175 r^2 = .83	b_0 = 3.724 b_1 = 0.923 (41 - 85) n = 37 r^2 = .81		b_0 = 6.914 b_1 = 0.941 (42 - 87) n = 91 r^2 = .82	
CHESTNUT OAK	b_0 = 6.332 b_1 = 0.906 (40 - 86 ft) n = 100 r^2 = .88	b_0 = 6.889 b_1 = 0.865 (40 - 86) n = 112 r^2 = .85	b_0 = 2.582 b_1 = 0.918 (41 - 88) n = 36 r^2 = .89	b_0 = 5.082 b_1 = 0.875 (40 - 86) n = 91 r^2 = .82		
YELLOW POPLAR	* b_0 = 22.952 b_1 = 0.795 (67 - 106) n = 24 r^2 = .40	* b_0 = 16.731 b_1 = 0.852 (69 - 106) n = 27 r^2 = .52	* b_0 = 15.183 b_1 = 0.853 (67 - 110) n = 29 r^2 = .65			

INSTRUCTIONS FOR USE: / 1) find species for which site index (SI) is known along the top of the table. 2) follow the appropriate column down to the row that corresponds with the species for which SI is desired. 3) multiply the known SI by b_1, and add the product to b_0. (i.e., $SI_{\text{unknown species}} = b_0 + b_1 \, SI_{\text{known species}}$) EXAMPLE: Given $SI_{who} = 70$, then $SI_{reo} = 9.064 + 0.93\ (70) = 74.164$

SITE INDEX ESTIMATES FOR SOME FOREST SOILS IN INDIANA

Table 1 contains the results of a 20 year effort on the part of the USDA Soil Conservation Service to measure the productivity of forest soils in Indiana. In this study, site index measurements and soil site characteristics were recorded on 978 sites, representing 131 different soil series around the state. The majority of the field work was completed between 1979 and 1982.

METHODS AND PROCEDURES

Plots were selected on the basis of the soil series and species present. No attempt was made to disperse the species/soil series combinations geographically. Plots were located wherever a willing landowner and suitable site could be located. In this sense the sample is (statistically) neither randomly distributed geographically, nor is the sample randomly distributed across the range of site qualities found within an individual soil series.

On each plot at least three trees were measured and a wide variety of site characteristics were recorded. Observed ages and heights were averaged and a site index for each plot was recorded. Site index curves used are as follows:

White Oak Black Oak Scarlet Oak Chestnut Oak Northern Red Oak Chinkapin Oak	Schnur, 1937
Pin Oak	Broadfoot, 1963
Black Walnut	Kellogg, 1939
Yellow Poplar	Beck, 1962
White Ash	Curtis & Post, 1962
Silver Maple	Brendemuehl, 1961
Black Cherry	Defler, 1937
Aspen	Gevorkiantz, 1956
Virginia Pine	Nelson et al, 1961
Eastern White Pine	Doolittle, 1960

From the 978 plots, 467 species/soil series combinations were obtained. These species/soil series combinations were sorted by soil series and then by species. On each soil series with at least three observations (3 plots for a particular species), an average site index was obtained for that species, on that soil series. When 4 or more observations were available for a particular species on a soil series, average site index, standard deviation and a 90% confidence interval was calculated for that species on that soil series. The results of these calculations are presented in table XX.

APPLICATION

The information in table 1 should be interpreted with caution. Soil series are the product of a general soil classification system. Wide variations in site conditions may exist within a given soil series. Forest soils are mapped fairly extensively and inclusions of different soil series within an area delineated on a soil map are common. In addition, unique micro-site conditions, and past localized soil disturbances can have a significant impact on site productivity and site index.

The average (mean) site indexes in table 1 are the average of (N) number of observations. The sample used to calculate the average is not necessarily randomly distributed over the range of site conditions that might exist within a given soil series. It is highly likely that some samples are skewed towards one extreme of the range of site indexes that exist within a given soil series.

For each species/soil series combination, with 4 or more observations, a 90% confidence interval was calculated. This confidence interval is only meaningful (statistically) if the sample collected is representative of the population in general.

The above cautions notwithstanding, table 1 can be used as a guide to approximate site index for stands on a given soil series. The larger the sample size and narrower the confidence interval for a particular species/soil series combination listed in table 1, the more reliable the average site index reported should be.

Information reported for species/soil series combinations with a relatively large sample size, but wide confidence intervals can be used with caution. Knowledge of the soil conditions that affect site productivity, and how a particular site compares with other sites on (this soil series), may permit an educated guess concerning the productivity of a particular site. If, for example, a particular site seems to be significantly more or less productive than most sites on that particular soil series, then one may be able to narrow the range within which site index is likely to fall.

Species/soil series combinations with only three observations should be considered highly suspect.

Finally, the width of the confidence intervals reported in table 1 can safely be used as an indication of the amount of variation in site index to be expected within a given soil series.

TABLE _._ MEAN SITE INDEX, 90% CONFIDENCE INTERVAL, RANGE, NUMBER OF OBSERVATIONS AND STANDARD DEVIATION OF OBSERVATION FOR 47 SOIL TYPES IN INDIANA.

SOIL TYPE/ Species	Mean Site Index	90% Confidence Interval	Range of Observations	Number of Observations	Standard Deviation	Comment
ALFORD						
yellow poplar	105	± 3.7	101 - 112	6	4.472	
red oak	86		83, 88, 88	3		
AVONBURG						
yellow poplar	102	± 5.50	96 - 110	5	5.766	
BEDFORD						
yellow poplar	88		78, 81, 104	3		
BERK						
yellow poplar	94	± 2.2	90 - 96	5	2.345	
chestnut oak	62		53, 57, 77	3		
black oak	69		54, 73, 80	3		
BLOOMFIELD						
yellow poplar	102	± 9.6	84 - 108	5	10.124	
red oak	87		84, 87, 90	3		
black oak	84		83, 84, 86	3		
BLOUND						
ash	81	± 13.1	72 - 97	4	11.121	
red oak	81	± 6.88	76 - 86	4	5.0	
BONNIE						
pin oak	96	± 3.0	91 - 105	9	4.873	
BREMS						
black oak	72	± 1.8	68 - 78	9	2.915	

SOIL TYPE/ Species	Mean Site Index	90% Confidence Interval	Range of Observations	Number of Observations	Standard Deviation	Comment
BURNSIDE						
yellow poplar	95		90, 95, 101	3		
CAMDEN						
yellow poplar	102		100, 102, 105	3		
CANRYVILLE						
ash	79		70, 83, 83	3		
CELINA						
yellow poplar	89		81, 92, 95	3		
CHAGRIN						
ash	90		88, 90, 92	3		
CHELSEA						
black oak	69	± 6.1	63 - 74	4	5.196	
CHETWYND						
yellow poplar	98		97, 98, 100	3		
red oak	98		96, 97, 100	3		
CINCINNATI						
yellow poplar	97	± 3.9	86 - 104	7	5.354	
red oak	87	± 5.4	81 - 95	5	5.612	
black oak	89	± 3.2	87 - 95	5	3.391	
CLERMONT						
yellow poplar	97	± 7.9	88 - 108	5	8.322	
pin oak	96	± 3.5	88 - 105	9	5.69	

SOIL TYPE/ Species	Mean Site Index	90% Confidence Interval	Range of Observations	Number of Observations	Standard Deviation	Comment
CLERMONT						
red oak	96		96, 96, 97	3		
CORYDON						
chinkapin oak	66	± 7.3	59 - 74	4	6.245	
red oak	73		63, 75, 81	3		
CRIDER						
ash	87	± 6.3	81 - 93	4	5.323	
yellow poplar	98	± 2.9	95 - 108	8	4.309	
white oak	72	± 4.6	67 - 76	4	3.873	
black oak	82	± 6.7	75 - 93	5	7.018	
CROSBY						
yellow poplar	94	± 6.9	83 - 101	5	7.246	
red oak	86	± 5.3	74 - 93	6	6.481	
black oak	88		81, 90, 92	3		
DEPUTY						
black oak	84		82, 83, 86	3		
EDEN						
red oak	68	± 4.1	62 - 76	6	5.0	
ash	61		59, 60, 64	3		
ELKINSVILLE						
yellow poplar	113		102, 118, 119	3		
GILPIN						
yellow poplar	89	± 10.0	77 - 97	4	8.524	

SOIL TYPE/ Species	Mean Site Index	90% Confidence Interval	Range of Observations	Number of Observations	Standard Deviation	Comment
GILPIN						
white oak	72	± 10.4	60 - 89	5	10.851	
red oak	73	± 13.6	62 - 88	4	11.605	
black oak	83	± 6.6	75 - 88	4	5.598	
scarlet oak	77		73, 76, 83	3		
chestnut oak	73		69, 73, 78	3		
GLYNWOOD						
ash	80	± 3.8	69 - 88	9	6.195	
red oak	82	± 4.9	71 - 89	7	6.671	
GRAYFORD						
red oak	84		79, 85, 87	3		
HENNEPIN						
red oak	84	± 4.0	79 - 88	5	4.183	
yellow poplar	101		90, 99, 115	3		
HICKORY						
yellow poplar	99	± 3.7	91 - 106	8	5.529	
white oak	82	± 6.1	73 - 89	6	7.403	
red oak	89	± 3.5	85 - 92	4	3.00	
black oak	86	± 3.0	83 - 89	4	2.517	
HOSMER						
yellow poplar	93	± 7.3	81 - 110	7	9.88	
black oak	87	± 17.9	65 - 99	4	15.232	
white oak	67		63, 69, 69	3		
pin oak	87		83, 87, 91	3		
red oak	72		64, 72, 80	3		

SOIL TYPE/ Species	Mean Site Index	90% Confidence Interval	Range of Observations	Number of Observations	Standard Deviation	Comment
HOUGHTON						
silver maple	82	± 8.88	67 - 92	6	10.798	
black cherry	80	± 10.3	72 - 90	4	8.737	
IONA						
yellow poplar	104		97, 101, 113	3		
IVA						
yellow poplar	96	± 3.5	93 - 100	4	3.0	
JOHNSBURG						
yellow poplar	94	± 6.3	81 - 101	6	7.694	
KOSCIUSKO						
red oak	79		74, 80, 82	3		
LENAWEE						
ash	84	± 6.9	78 - 90	4	5.888	
pin oak	85		83, 85, 86	3		
MARTINSVILLE						
red oak	83	± 7.1	76 - 95	5	7.45	
yellow poplar	102		99, 100, 107	3		
MAUMEE						
bigtooth aspen	71		66, 72, 76	3		
pin oak	85		72, 90, 92	3		
MIAMI						
yellow poplar	93	± 5.2	87 - 99	5	5.500	
white oak	74	± 6.4	66 - 78	4	5.447	

SOIL TYPE/ Species	Mean Site Index	90% Confidence Interval	Range of Observations	Number of Observations	Standard Deviation	Comment
MIAMI						
red oak	82	± 4.4	76 - 84	4	3.786	
black oak	79	± 5.9	72 - 88	5	6.164	
MORLEY						
yellow poplar	105		98, 109, 109	3		
black oak	89		79, 93, 95	3		
MOROCCO						
pin oak	74	± 4.3	69 - 84	6	5.254	
NEWTON						
pin oak	73	± 5.1	66 - 82	6	6.178	
OCKLEY						
black oak	81	± 7.7	73 - 89	4	6.532	
yellow poplar	100		99, 99, 102	3		
ORMAS						
white oak	70	± 7.3	66 - 79	4	6.191	
red oak	78	± 14.8	67 - 96	4	12.57	
black oak	74	± 15.0	62 - 91	4	12.728	
OTWELL						
yellow poplar	99		94, 96, 108	3		
PARKE						
yellow poplar	92		90, 92, 94	3		
PEKIN						
yellow poplar	103	± 10.5	86 - 113	5	11.045	

SOIL TYPE/ Species	Mean Site Index	90% Confidence Interval	Range of Observations	Number of Observations	Standard Deviation	Comment
PEOGA						
black cherry	100	± 3.8	91 - 106	8	5.619	
PEWAMO						
ash	83	± 7.0	71 - 94	6	8.567	
pin oak	90	± 5.0	81 - 98	7	6.856	
PLAINFIELD						
black oak	66	± 2.0	61 - 72	11	3.701	
PRINCETON						
yellow poplar	101	± 5.1	92 - 109	6	6.229	
black oak	99		98, 98, 100	3		
RARDEN						
black oak	77	± 12.7	67 - 88	4	10.786	
virginia pine	60		53, 54, 72	3		
REESVILLE						
yellow poplar	96		89, 97, 101	3		
RIDDLES						
yellow poplar	94	± 3.4	87 - 99	7	4.619	
ROSSMOYNE						
yellow poplar	101	± 4.6	89 - 109	8	6.824	
black oak	87	± 6.7	80 - 93	4	5.715	
RUSSELL						
yellow poplar	105	± 7.9	95 - 109	4	6.733	
red oak	86		84, 85, 88	3		

SOIL TYPE/ Species	Mean Site Index	90% Confidence Interval	Range of Observations	Number of Observations	Standard Deviation	Comment
RYKER						
black oak	81	± 7.3	73 - 88	4	6.191	
STEFF						
yellow poplar	107	± 4.8	100 - 113	6	5.865	
STENDAL						
yellow poplar	104	± 9.2	90 - 115	5	9.631	
pin oak	95	± 3.3	87 - 100	8	4.899	
TILSIT						
yellow poplar	93	± 6.2	80 - 101	6	7.589	
TRACY						
yellow poplar	104	± 1.2	103 - 105	4	1.0	
TREATY						
ash	90	± 6.4	83 - 96	4	5.447	
VINCENNES						
pin oak	108		103, 110, 110	3		
WAKELAND						
ash	88		88, 88, 89	3		
WEIKERT						
pin oak	47	± 11.6	41 - 62	4	9.883	
scarlet oak	59		42, 59, 75	3		
WELLSTON						
yellow poplar	96	± 2.0	93 - 100	6	2.449	

SOIL TYPE/ Species	Mean Site Index	90% Confidence Interval	Range of Observations	Number of Observations	Standard Deviation	Comment
WELLSTON						
white oak	74	± 9.2	68 - 85	4	7.789	
black oak	83	± 4.6	73 - 90	7	6.232	
XENIA						
yellow poplar	99	± 4.0	95 - 103	4	3.367	
ZANESVILLE						
yellow poplar	90	± 7.6	77 - 104	6	9.252	
white oak	76	± 10.6	60 - 87	5	11.113	
black oak	81	± 3.0	73 - 89	8	4.504	
white pine	85		79, 86, 90	3		
ZIPP						
ash	94		85, 94, 102	3		
pin oak	85		79, 86, 90	3		

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GLOSSARY

Aeration:	The process by which air in the soil is replaced by air from the atmosphere. The rate of aeration depends largely on the volume and continuity of the air-filled pores within the soil.
Fine texture	Consisting of or containing large quantities of fine fractions, particularly of silt and clay. (This includes all loams and clays, i.e., clay loam, sandy clay loam, silty clay loam, sandy clay, silty clay, and clay textural classes). See Figure 2.2.
Heavy soil	A soil with a high content of the fine seperates, (particles) particularly clay.
Humus	That more or less stable fraction of the soil organic matter remaining after the major portion of added plant and animal residues have decomposed. Ususally it is dark colored.
Infiltration	The downward entry of water into the soil.
Litter layer	The surface layer of the forest flood consisting of freshly fallen leaves, needles, twigs, stems, bark, and fruits.
Mottling	Spots or blotches of different color or shades of color interspersed with the dominant color. (This is usually caused by poorly drained conditions in the soil.)
Organic matter	Any formerly living material (plant or animal) in various stages of decomposition deposited on or mixed in the soil.
Ortstein	An indurated or hardened layer in the B horizon of some soils caused by cementing of particles by iron and organic matter moving downward in the soil profile from the upper layers.
Pan	Horizons or layers in soils that are strongly compacted, indurated (hardened), or very high in clay content.
Parent material	The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of soils is developed by pedogenic (soil forming) processes.
Percolation	The downward movement of water through soil. Especially, the downward flow of water in saturated or nearly saturated soil at hydraulic gradients of the order of 1.0 or less.

Permeability — The ease with which gasses, liquids, or plant roots penetrate or pass through a bulk mass of soil or a large layer of soil. Also, the property of a porous medium itself that relates to the ease with which gasses, liquids, or other substances can pass through it.

Porosity — The volume percentage of the total bulk not occupied by solid particles.

Soil complex — This consists of two or more dissimilar soil taxonomic components or miscellaneous areas occurring in a regularly repeating fashion with landscape. The major components of a complex cannot be mapped separately at a scale of about 1:24,000.

Soil Variant — A unique soil that differs from a recognized soil series in one or more properties and does not occupy a large enough total area to warrant the establishment of a new soil series.

Structure — The combination and arrangement of primary soil particles into secondary particles, units or peds. These secondary units are characterized and classified on the basis of size, shape, and degree of distinctness into classes, types, and grades respectively.

Subsoil — The soil layer below the surface soil and above the unconsolidated parent material. See Figure 2.1.

Surface soil — The uppermost layer of the soil consisting of the surface layer and subsurface layer. See Figure 2.1

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