SOIL MANAGEMENT FOR HARDWOOD PRODUCTION

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Soil management is the key to successful hardwood management because soil properties are probably the most important determinants of forest productivity. Because of the lack of soil uniformity, however, many foresters have become frustrated with attempts to relate soil to satisfactory growth. Since soil scientists have been unable to predict site quality for trees in terms of straightforward, measurable soil properties, some forest managers are wondering whether it is worthwhile to consider soil in discriminating between sites (8).

Soil scientists, of course, must renew their efforts to render such doubts inappropriate. In the meantime, stopgap systems are needed for hardwood soil management in the South. Such systems are described in this paper.

DIAGNOSIS AND CHARACTERIZATION OF SOILS

The ultimate objective of our forest soils research is to develop systems for determining exactly what must be done to make any site produce individual hardwood species satisfactorily. We must learn what the soil requirements are for maximum growth, and what factors are likely to limit growth in given instances.

Broadly speaking, we know that four soil variables regulate forest productivity: (1) morphology and physical condition, (2) available water during the growing season, (3) aeration, and (4) nutrient availability. Soil and site factors that influence these variables are: history, past use, present cover, compaction, presence of natural or artificial pans, soil structure and texture, physiographic position, local topography, water table, growing-season wetness, flooding, mottling, soil color, presence of topsoil and organic matter, geologic source of soil, pH, and soil chemical composition.

Many of the above factors cannot be measured. Neither can they be ignored, so their effects must be estimated. Particularly difficult to estimate are the combinations of factors that determine soil moisture availability to trees in the growing season. Assessment of soil moisture is usually made in the field.

Many years of research have given us techniques for quantitatively assessing the chemical and physical properties of soils. Standard methods are available for measuring pH, organic matter content, nutrient concentrations, cation exchange capacities, and such soil physical properties as texture, bulk density, and aeration. Even though these properties are quantifiable, our ability to relate them to hardwood productivity is still largely subjective.

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Soil pH is an example of an easily determined property that is valuable to the soil manager. Most accept the indirect relationship between individual species and soil pH as it has to do with availability of certain nutrients (1, 19, 21, 22, 27). Also, it is generally recognized that plants differ in their ability to extract necessary nutrients throughout the normal pH range of soils. The range of soil pH supporting southern hardwoods is from about 4 to 8, but surface soil pH is strikingly similar under stands of certain species, whereas under others it varies widely.

Southern hardwoods are grouped in figure 1 into four classes according to pH of soils on which they are usually found in natural stands. The first group contains species found mostly on acid to medium acid soils, occasionally on neutral soils, but rarely if ever on alkaline soils. The second group is usually on soils with medium acid to neutral surface layers, and occasionally on soils that are either acid or alkaline. Apparently, these species are tolerant of the widest range in soil reaction. The third group of species also may be found on a wide range of soil pH values, but commonly they are on soils with medium acid to alkaline surface layers. Species in the fourth and smallest group are found most often on neutral to alkaline soils, occasionally on medium acid soils, and rarely if ever on acid soils.

Soil pH is both a result and a cause of the species that are present. Although alkaline soils that are leachable generally become more acid as they age, the rate and degree of change is influenced by the species that have been on them (3). Decomposing tree litter releases more basic than acid-forming elements to the soil (10).

The ranges in pH over which species normally occur are helpful guides for planning reforestation. It should be remembered, however, that other soil and site factors may exert more influence on plant distribution than does pH either directly or indirectly.

ESTIMATING GROWTH POTENTIAL FROM SOIL SERIES

Sufficiently accurate estimates of productivity for trees can often be obtained simply from the soil series present. Soil series is a taxonomic unit and it should be recognized that soils within a series vary within the limits of the official description. Nevertheless, site quality, as reflected by site index, can often be estimated from soil series with reasonable accuracy if due consideration is given to past use and decline from the virgin soil condition.

In this approach, the best that can be hoped for is a probable range in site index for a particular species on a particular soil series. The range, which may be quite wide in some cases, is caused by within-series variations in site conditions, differences in forest stand characteristics, and to some extent by genetic differences within plant species. The approximate site

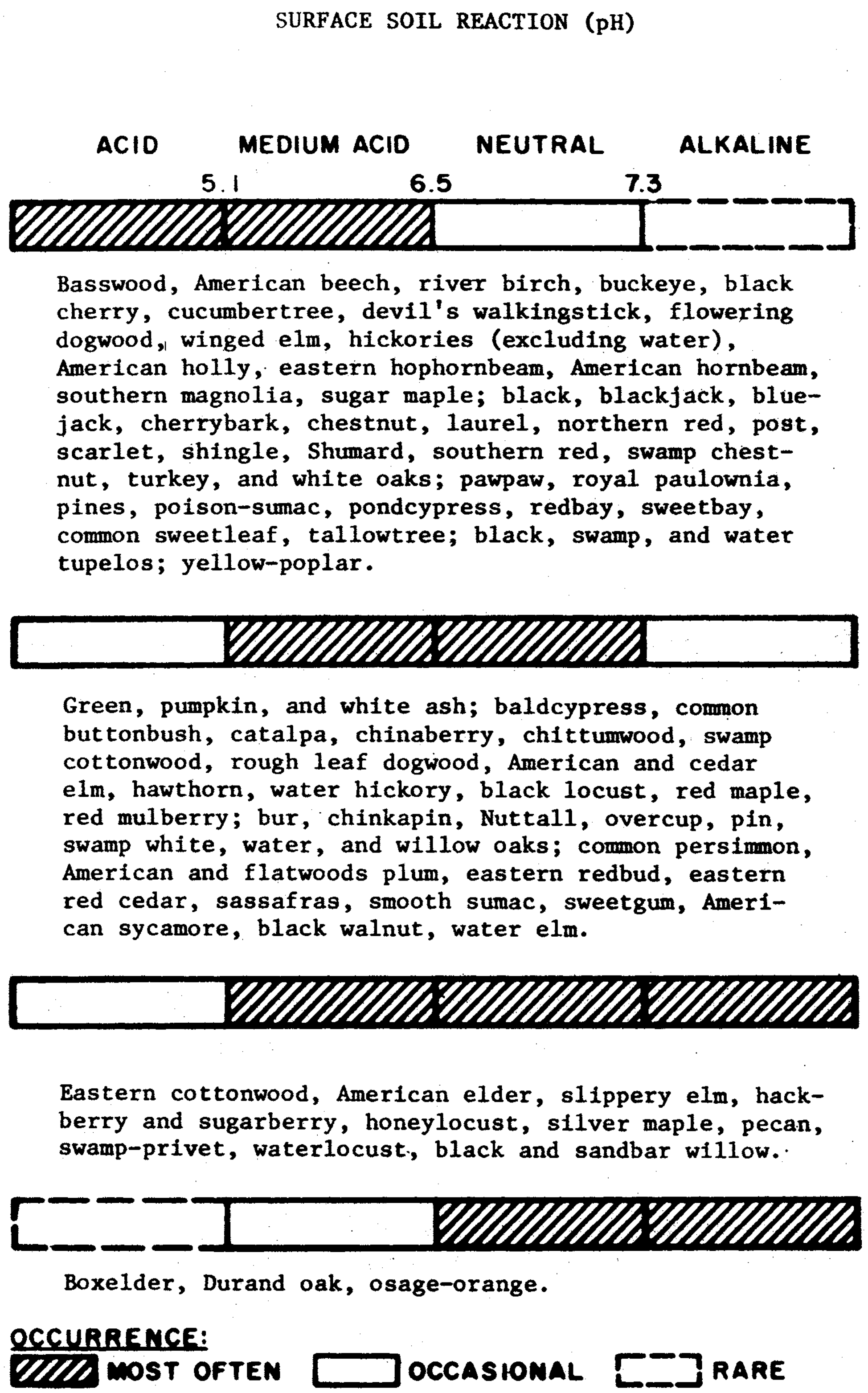

Figure 1.--Southern tree species occurrence in relation to surface soil pH.

index value within the observed range must be assigned arbitrarily from research and observation of variation within and between soils and from knowledge of the influences of physiography and past use on growth of individual species.

In applying the system it is particularly important to know what conditions are indicative of the lowest values in the site index range. For example, one should know that soils such as Adler, Commerce, Kaufman, Mhoon, Newellton, Sharkey, and Tunica are not well suited for most oaks when the pH of the surface layer is higher than 7.5. The surface layers of these soils sometimes are neutral to slightly acid, and in these situations are suitable for oak species. Other soils, especially those on upland and terrace positions, where the surface layers are eroded, are not suited for hardwood culture.

A convenient way of indicating productivity is to list soils by site class for each species. Soils may be grouped for a species into three productivity classes: highest, moderate, and lowest. These groupings are based on inherent soil-species suitability, assuming near-virgin or freshly cleared land. As an example, soils best and least suited for cottonwood are listed below:

Best	Least
Adler	Atwood
Catalpa	Calloway
Collins	Dulac
Commerce	Henry
Coushatta	Kalmia
Falaya	Lax
Kaufman	Leaf
Latanier	Mashulaville
Marietta	Stough
Morganfield	Tippo

Limiting factors are low moisture, low nutrients, and poor aeration.

SOIL FACTOR GUIDE

No methods have yet been developed for precisely relating soil factors to site quality, but a method is available for making practical approximations for southern hardwoods (table 1).

This approach is subjective, but it requires a minimum of experience and laboratory testing, and only cursory field scrutiny. This system is fast, easy, and fairly accurate in evaluating site quality for most hardwood species, and does not require soil identification.

The technique requires estimation of the four major soil factors that govern forest productivity, i.e., physical condition of the soil, moisture availability, nutrient availability, and aeration. In applying this procedure, however, one must have a reasonable understanding of growth response of each species to the various factors. One must know, for example, that green ash is tolerant of poorly aerated soils, and that sweetgum grows satisfactorily over a wide range in soil pH.

SOIL MANAGEMENT APPLICATIONS

Establishment and maintenance of good physical condition is highly important in soil management. Physical condition as determined (or controlled) by soil structure is the key to soil excellence for the production of hardwoods. Soil managers have learned from observations and research data that various species do not respond to fertilizer applied to certain soils, even though the soils are inherently low in productivity. For example, cottonwood growing on some alluvial soils in the Coastal Plain has not responded to lime and fertilizer. On other soils it has responded to such treatment, but the resulting growth did not compare favorably with that on inherently productive soils (2). Also, cottonwood has grown rapidly on Sharkey clay in greenhouse pots with or without fertilizer, whereas growth in the field on fertilized and unfertilized Sharkey clay has generally been poor. In each case, fertility obviously was not the limiting factor. Inadequate soil air and moisture, which are dependent on structure, were probably limiting growth. The potted Sharkey clay was in the "buckshot" or aggregate condition. Once these small aggregates are dried, they are very stable and do not break down easily. In the field, however, good structure does not extend deep enough to provide a favorable environment for root development and tree growth.

Soil physical conditions may be altered by land use, type of soil management, tillage, drainage, irrigation, and chemical treatments.

Land use that keeps the soil fully covered with some type of vegetation at all times is best. However, in plantations and other stands under even-aged management, the soil is uncovered and subject to rainfall impact and considerable compaction and disturbance during the first 2 years after establishment. In systems where animal grazing must be permitted, one must expect the trampling to compact the surface soil layer. Compaction greatly restricts root and shoot growth of juvenile cottonwood (9), but is more likely to be a problem on medium-textured than clayey sites.

Table 1.--Guide to hardwood site evaluation

Major soil factor	Determining influence	Best site quality	Medium site quality	Poorest site quality
Physical condition of soil	Past use or history, and cover	Undisturbed, near-virgin, forest cover	Cleared, cultivated < 50 years, open, grass	Cultivated and/or grazed more than 50 years, open, bare
	Morphology of surface 4'	Deep (without pans)	Weak pan, or > 2' depth	Strong pan < 2' depth
	Compaction, artificial pans	Loose, porous	Moderately tight	Tight, strongly compacted
	Soil structure	Good structure	Medium granular or blocky	Structureless
	Soil texture	Loams and silt loams	Sandy soils	Clays
Moisture availability in growing season	Land use, and present physical condition of soil	Cleared 0-5 years, good structure, loose, loams and silt loams	Moderate cultivation since cleared of forest within 5-10 years	Old field > 10 years, poor structure, tight, compact, puddled clays or sandy soils
	Physiographic position	Bottom	Terraces, lower slopes	Upland
	Local topography, microsite	Pocket, slough, concave, dip, swag	Level, flat	Sloping, convex, ridge, bump
	Depth to water table	4-6'	7-10'	> 10'
	Flooding frequency and duration	Short periods in winter and spring	Short periods in winter only	None
	Growing season wetness	Wet in spring and early summer	Only in spring	None
	Inherent soil moisture condition	With normal rainfall, soil is moist throughout growing season	With normal rainfall, soil is moist about 3 months of growing season	With normal rainfall, soil is dry much of growing season

Table 1.--(Continued)

Major soil factor	Determining influence	Best site quality	Medium site quality	Poorest site quality
Aeration	Soil color	Bright (black, brown, red)	Yellow, brownish gray	Gray
	Mottling	Unmottled to 18" depth	Unmottled to 8"	Mottled to surface
	Swampiness	Wet in winter only	Wet, January through July	Waterlogged entire year
	Soil structure	Good structure: porous, aggregated, permeable for water and air	Medium structure	Structureless, massive, small pores, impervious to water and air
Nutrient availability	Past use or history	Undisturbed, near-virgin	Cropped < 50 years	Heavily cropped more than 50 years
	Mineralogy	Mixed	Montmorillonitic	Siliceous
	Organic matter	> 2% in surface 12"	1-2% in surface 12"	< 1% in surface 12"
	Topsoil (A-horizon)	> 6"	3-6"	< 3"
	Geologic source of soil	Mississippi River Floodplain, loess, Blackland	Mixed, Coastal Plain, and other	Coastal Plain
	pH	5.5-7.5	7.6-8.5, 4.5-5.5	> 8.5, < 4.5
	Age of soil	Young, stratified	Moderate profile development	Old, leached

In short pulpwood rotations major soil disturbance occurs more frequently than in longer timber rotations where much of the natural structure will return to a soil with buildup in organic debris. The size of harvesting machinery influences the degree of structure damage, especially if the soil is wet. Present harvesting techniques leave an abundance of leaves and twigs that return to the soil much of the nutrients that have been removed. Procedures are envisioned in which 100 percent of the stems will be utilized, and in that case, organic matter and nutrients will not be returned and site quality may eventually be reduced.

Tillage often can damage soil physical structure. Thorough loosening of the soil is not always desirable, as some plants require rather dense soil for best root-soil contact and growth. In addition to weed control, the purpose of tillage should be to bring about a soil structure that is beneficial for tree growth. In some instances it can improve infiltration and aeration, and prevent excessive loss of moisture by evaporation. The moldboard plow is probably the best implement to loosen and break up massive soil. The plow twists and turns the soil in a way that breaks it along natural cleavage planes, leaving more stable aggregates. A disk cuts through clods and the loosened structure does not last long after rainfall. Disking also tends to pack soil. Cultivators open up soil without damage to underlying structure. Subsoilers are sometimes used to open up tight, impervious soils with compaction pans. The benefit is brief, however, because the subsoil runs back together after thorough wetting. Filling the subsoiler slits with partially decomposed sawdust mulch and fertilizer may prove beneficial in some situations.

Drainage has become common in agriculture and can be useful at times in forestry. Soils are drained mainly to increase rate of air renewal in the root zone, but sometimes they are drained to remove excessive soluble salts. Effective drainage for both purposes is accomplished by open ditches or tile, and by bedding. Pore-size distribution can be helpful in deciding whether to drain. For example, Waverly soil (fig. 2) is very poorly drained and stays wet most of the growing season. The big pore volume is 10-20 percent to 4-foot depths, which indicates it will drain nicely to that depth if treated. Alligator soil (fig. 3), however, has a big pore volume of less than 10 percent and only in

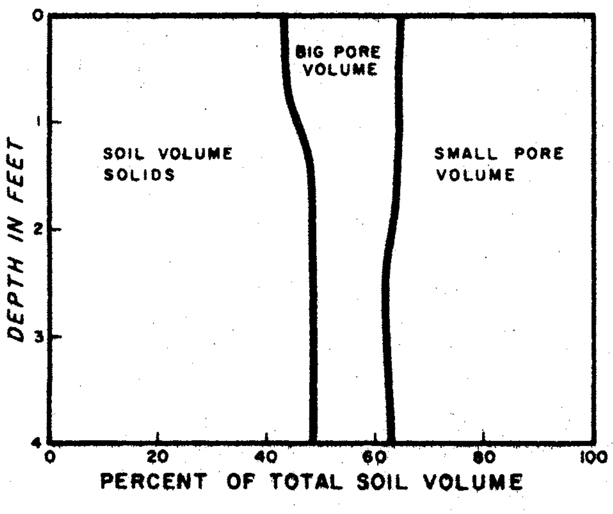

Figure 2.--Average pore-volume distribution in Waverly silt loam.

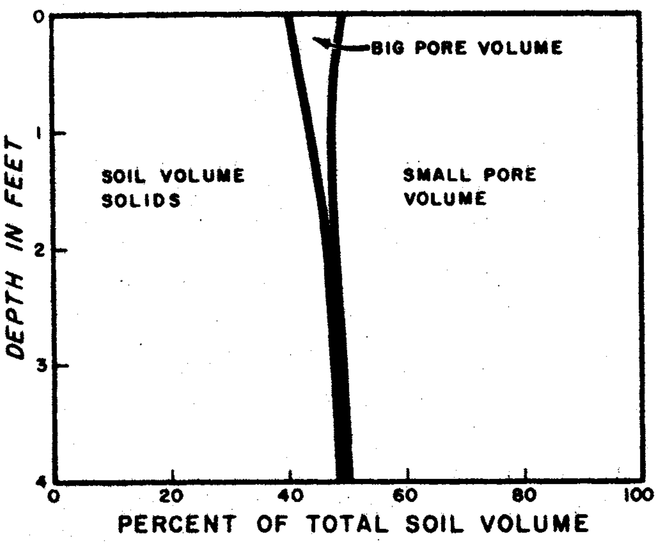

Figure 3.--Average pore-volume distribution in Alligator clay.

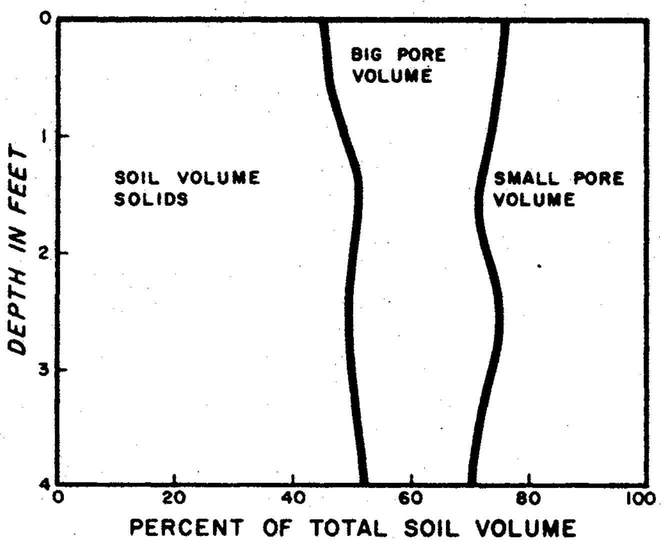

Figure 4.--Average pore-volume distribution in Bruno sandy loam.

the surface foot depth. There would be no point in attempting internal drainage of this soil. On the other hand, drainage should be done with care on soils such as Bruno (fig. 4) in order to prevent creating a droughty soil environment.

Knowledge of the structural condition of specific soils is also helpful in making other management decisions. For example, the pore-size distribution of Myatt loam (fig. 5) shows no large (or drainage) pores in the surface 2 feet. Without treatment this soil has poor aeration and, if not covered, would lose most of its available water by evaporation. Also, it would not be receptive to rainfall and, if sloping, it would have heavy runoff in periods of wet weather. Beneficial treatment would consist of increasing big-pore volume by incorporating organic matter in the surface layers, or deep plowing. Structural improvement from deep plowing would be temporary due to aggregate instability, and frequent cultivation would be necessary in the first season of soil management.

Pore-size distribution of Houlka clay (fig. 6) is strikingly different from that of Myatt loam. There is sufficient big-pore volume in the surface 3 feet for good aeration in the tree root zone and rapid absorption of rainfall. Furthermore, the lack of large pores below 3 feet means that percolation below the root zone will be slow. Water will be caught readily and held until used by plants. Even though Houlka is a clay soil, it has an inherently good structure. Fresh Houlka clay (not old-field condition) should require a minimum of physical amelioration and probably fertilization. An excellent response to irrigation can be expected on this soil.

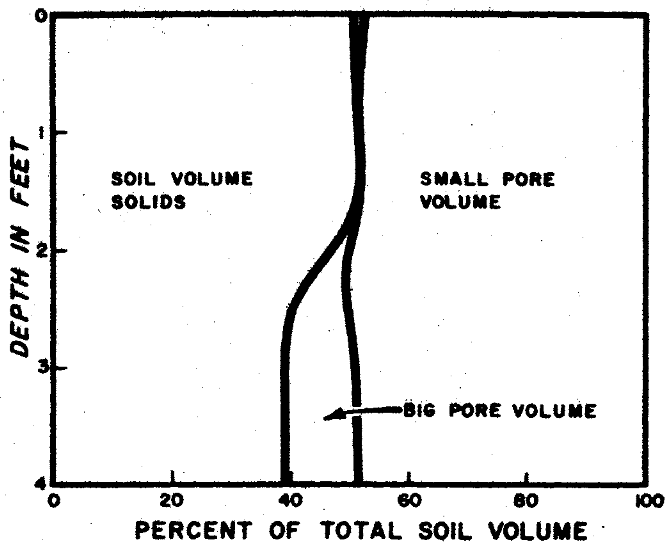

Figure 5.--Average pore-volume distribution in Myatt loam.

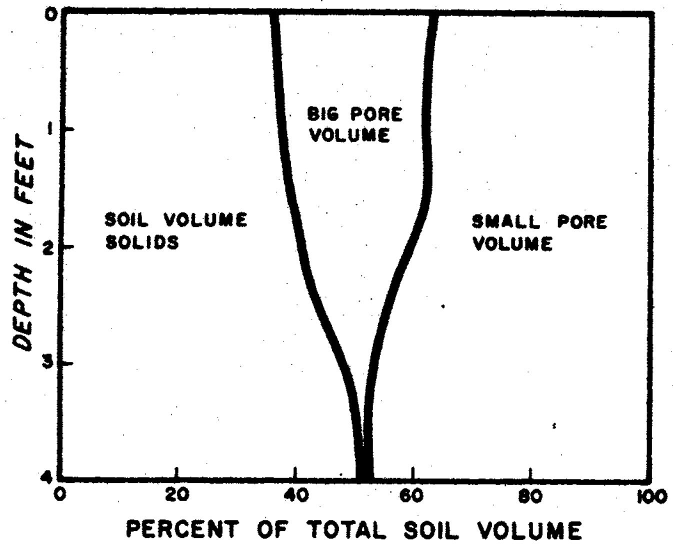

Figure 6.--Average pore-volume distribution in Houlka clay loam.

Availability of soil water in the growing season is one of the most important determinants of tree growth. Most trees need a constant supply of water at low tension for best growth, provided the soil air supply is sufficient. The requirements for these two components, however, vary widely from species to species due to differences in growth habit and root behavior. Some species require much water and get along on restricted air supply, whereas others can withstand dry periods without damage but suffer quickly when the soil air is exhausted. No species, however, can produce well on soils that are dry during much of the growing season.

About 15 years ago, drought caused heavy dieback and mortality in hardwood stands throughout the South (5, 11). At the same time, forest owners questioned the effects of shallow-water impoundments on tree growth in green-timber reservoirs built by hunting clubs to attract waterfowl (4, 7). An 8-year field study at the Southern Hardwoods Laboratory showed that soil moisture during the growing season and radial tree growth were significantly increased by impounding winter and spring rainfall until July 1 on hardwood stands. In early July, the average moisture per foot of soil amounted to 7.5 inches for the area that had been impounded and 5 inches for the control. Even late in the growing season, soil in the flooded area contained about 0.5 inch more moisture than the control. Impoundment increased timber growth by about 50 percent. Oxygen in the water was depleted after 15 days of dry weather, but was quickly replenished by rain.

Beneficial effects of irrigation on hardwood growth are well known (6, 16, 20, 25), as are the detrimental effects of excessive flooding (5, 12, 13, 14, 15, 18, 23, 24, 26, 28, 29).

The soil water table strongly influences the available moisture supply (17). Controlled water-table studies have shown the following reactions by juvenile cottonwood.[27]

(1) Planted cottonwood grows satisfactorily over shallow water tables. In years of less than normal rainfall, growth over 2- and 1-foot-deep water tables exceeds that on similar soils but without a water table.

(2) When water tables are raised into cottonwood root zones, increased growth results if the table is no nearer the surface than 2 feet.

(3) Water table raised into root zone to 1 foot below surface did not increase growth, but the cottonwood was not killed by such treatment for one growing season.

(4) Roots of juvenile planted cottonwood do not penetrate soil below constant water table level.

(5) Cottonwood planted on saturated sites, or with water table at the ground surface, will live but grow poorly during the first season. Where water was raised to the surface up through the established roots, causing waterlogged conditions, growth was stunted and most plants died near the end of the treatment year.

This information should be valuable where flood control and navigation dams are installed along watercourses in the South. With proper planning, such structures that flood the land and cause partial saturation of the root zone need not damage the forest stand. Instead, application of specific bits of information already learned can meet the needs of multiple segments of the population.

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[27] Unpublished data, Southern Hardwoods Laboratory, Stoneville, Mississippi.

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