G3277

WISCONSIN WOODLANDS:

How Forest Trees Grow

Theodore T Kozlowski

Knowing how forest trees grow can help woodland owners predict yields. It can help them understand how different trees might be affected by environmental stresses, and how thinning and pruning affect wood production. Understanding the growing cycles of different trees will help the owner decide when and how to plant, thin and prune trees to increase wood production.

Forest trees grow in both height and diameter. Trees grow taller—and branches longer—because of the division of cells at the tips of branches. Roots also grow at their tips. By contrast, the diameter of trees' woody parts increases as a result of cell division in a layer located between the bark and wood. This layer is called the cambium (see Fig. 1).

Trees vary widely in their growth patterns. They vary in crown form; ultimate size; longevity and branching habits; and in the growth rates of roots, stems and leaves. Growth patterns differ between temperate-zone trees and tropical trees, evergreen and deciduous trees, and in different parts of the same tree. In many temperate-zone trees, roots begin to grow earlier in the year before shoots elongate, and diameter growth begins even later (Fig. 2).

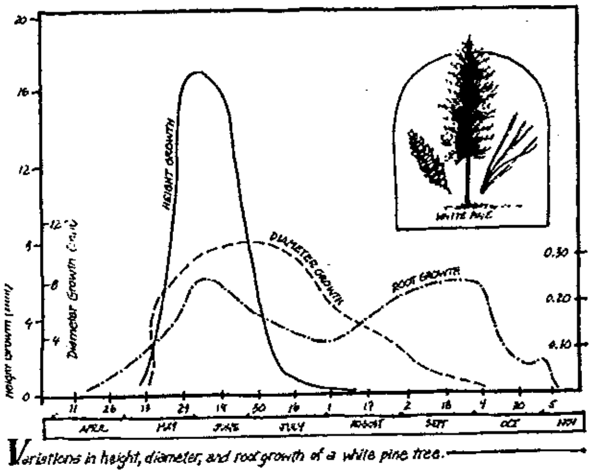
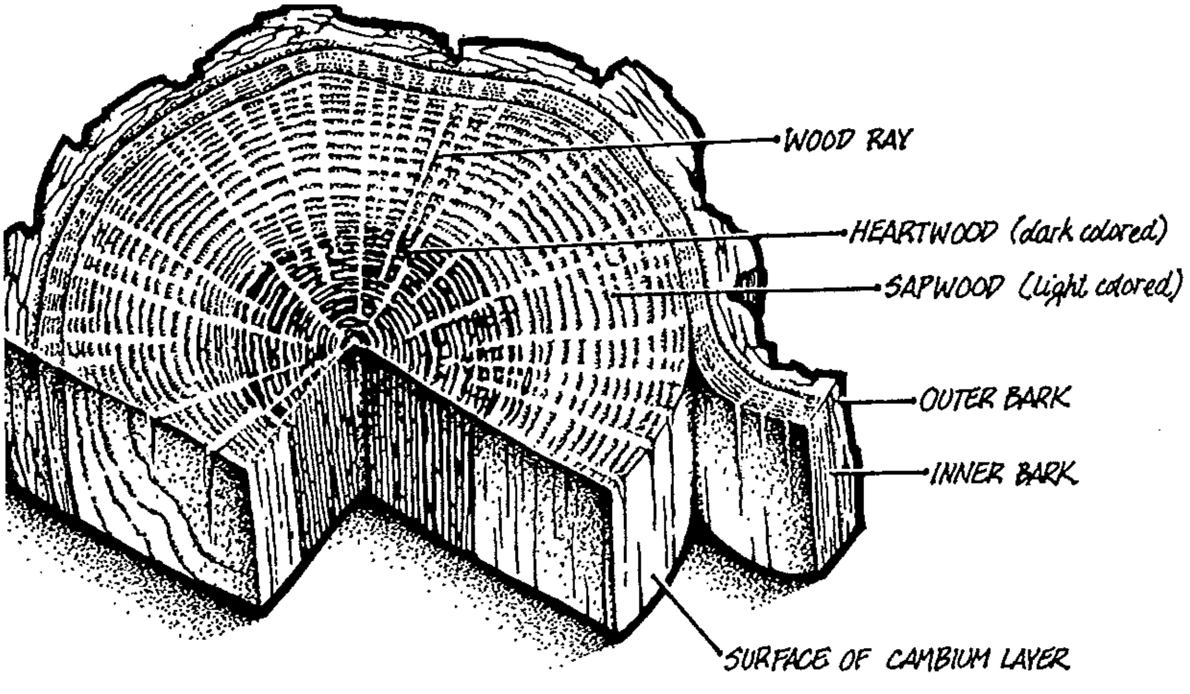


Figure 2. Seasonal differences in height growth, diameter growth and root elongation of an eastern white pine tree.

Figure 1. Annual layers of wood in a tree's stem and branches.



HEIGHT GROWTH AND ELONGATION OF BRANCHES

Species vary in the duration of their seasonal height growth. Some complete their growth in height within 2-6 weeks during the early part of the growing season. Others may increase in height for several months. Duration of height growth and branch elongation are controlled genetically.

Species with Fixed Growth

In some species, such as red pine, white pine and beech, the winter bud contains an unexpanded shoot (a branch tip with its leaves and appendages). The shoots form late in the growing season of one year and then expand during the following year. Height growth and branch elongation occur relatively rapidly in species with fixed growth. Wisconsin red pines, for example, complete their height growth by the end of June, although the needles continue to elongate until much later in the summer. Thus, a drought in August will not affect their height that year, but may affect growth in the following year.

Species with Free Growth

In other species, such as poplars and birches, some of the winter buds contain some shoots that are only partially formed (others are fully formed). In such species, leaves preformed in the bud one year expand the next year, but new leaves also form and expand as a stem or branch elongates. Height growth and elongation of branches usually take much longer in species with free growth than in species with fixed growth. Species with free growth will respond to stresses such as drought differently than species with fixed growth. A drought in August would be likely to decrease that year's growth.

Species with Recurrently Flushing Growth

In still other species, annual height and branch growth involve elongation of more than one terminal bud per shoot. This is the case for some temperate zone pines (such as loblolly and slash pines of the southern states), most tropical pines and many broad-leaved tropical trees. There are no trees with recurrently flushing growth which grow in Wisconsin. Pines with this kind of growth, for example, increase in height by extending a succession of buds formed at the tip of the stem. After a period of bud extension, height growth stops briefly while a new terminal bud cluster forms. Shortly thereafter this recently formed bud expands to "increase the height of the tree further. At the same time, a whorl of lateral branches grows from lateral buds at the base of the main bud. Typically, there are two to four such periods of elongation growth every year. The annual increase in height represents the cumulative growth of several growth flushes. Trees with recurrently flushing growth can be very productive because they continue to grow over many months. They are more affected by late season environmental stresses than are fixed growth species.

Abnormal Late-Summer Shoots

Some species with fixed growth have a tendency to produce abnormal late-summer shoots from buds that normally do not open until the following year. Hickory from some seed sources, pines, spruce, and oak are especially well-known for such shoots. Abnormal late-summer shoots are subject to winter injury because they may not harden adequately.

Tree Form

Shoots on a tree do not all grow to the same length. Differences in the elongation of shoots in different parts of a tree help determine the tree's shape. In many trees, upper shoots interfere with the elongation of lower shoots. In most conifers, for example, the terminal leader (main stem) elongates more each year than the branches below it. Furthermore, whorls of lateral branches elongate more at the top of the tree than at the bottom, and branches growing from the main stem elongate more than branches growing from other branches. This orderly pattern of growth produces a tree with a conical shape.

Many Christmas tree growers routinely "shear" trees to shape them. Removing the tips of lateral shoots stimulates expansion of subordinate shoots and the formation and expansion of new buds into additional shoots. The result is a well-shaped, bushy Christmas tree.

Shoot growth does not vary in such an orderly manner in many broad-leaved trees. Rather, many shoots elongate at about the same rate, and the trees branch and rebranch until sometimes the main stem becomes difficult to identify. Such trees often have characteristic crown shapes. Beech and oak, for example, tend to have oval or elongated crowns, whereas American elm has a vase- or umbrella-shaped crown.

Height Growth and Tree Age

A tree's annual increase in height varies with its age. Height growth of a young seedling increases a little each year, usually until the tree reaches the pole stage. The annual growth in height then remains relatively constant for a number of years and then declines fairly rapidly. Of course, the amount of height growth differs appreciably from year to year as environmental conditions, particularly water supply, vary.

Maximum Height

Trees also vary greatly in the ultimate heights they reach. A tree's maximum height is more related to its longevity than to its annual growth rate when young or to the type of shoots it produces. Trembling aspen grows fast when young, but never becomes very tall because it ages rapidly and is relatively short-lived. By contrast, the long-lived white oak, a slow grower when young, often becomes a tall tree. Tables 2 and 3 show variations in size, growth rate and longevity. Note: Both tables list species in addition to those which grow in Wisconsin.

GROWTH IN DIAMETER

The diameter of a tree determines how it can be used, and its value. In general, and particularly with hardwood species, the larger the diameter the greater the value (and age) of the tree. Trees grow in diameter because each year new layers of wood and inner bark are inserted between the previous year's layer of wood and bark. The new layers are produced by the division of cells in the cambium, a thin layer just under the bark (see Fig. 1). These cells divide to produce wood (xylem) cells toward the inside of the tree and living bark cells (phloem) toward the outside. The cambium produces more wood than bark. Bark cells eventually collapse and die and some of the old outer bark is shed.

Because of this mode of growth, a tree's stem consists of annual increments of wood, one added on top of another. If you cut the tree in half from top to bottom you would see a series of overlapping cones (see Fig. 3).

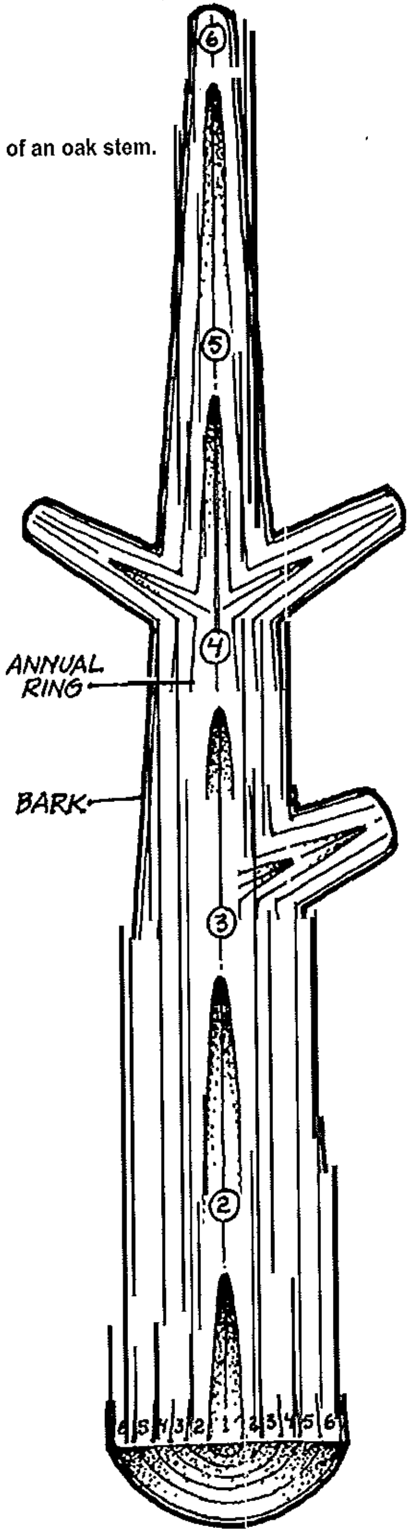


Figure 3.

Cross-section of an oak stem.

People often use annual rings as a way to determine the age of a tree. But a tree may appear to be different ages depending on where in the stem the rings are counted. There will be fewer rings higher on the tree than at its base. Trees sometimes grow more on one side than another. The annual rings of wood in a stem cross section result from variations in growth rate and differences in the kind of wood produced early and late in the growing season. Wood formed early, called *springwood* or *earlywood,* has cells of large diameter and is much less dense than wood formed late in the season, which is called *summerwood* or *latewood.* Annual rings are visible in stem cross sections because of the differences in density of the earlywood of one year and the adjacent latewood of the previous year.

Temperate zone trees usually produce one ring of wood each year. However, they may produce more than one in some years. Foresters can recognize "false" or "multiple" rings as well as "missing" ones. There also may be "discontinuous" rings, formed when the cambium is dormant on one side of a tree, as sometimes happens in trees with injured crowns and in very old trees. Frosts that occur after annual growth starts may injure a tree's cambium and cause "frost" rings, which are sometimes mistaken for annual rings. So ring counts do not always indicate a tree's true age.

Seasonal Duration of Diameter Growth

A tree's growth in diameter usually continues later into the summer than its growth in height does. However, the duration of diameter growth varies among species and crown classes and with weather and site. Diameter growth is very responsive to water supply and often slows during a drought and speeds up after a rain. Seasonal diameter growth in one year usually continues for a longer time in conifers than in deciduous trees because conifers retain their needles and continue to produce carbohydrates and growth regulating hormones later in the fall.

Dominant trees, whose crowns extend above the general level of the crown canopy, not only grow faster, but they continue to produce wood much later into the summer than suppressed trees do. Dominant trees may continue to grow in diameter throughout most of the growing season, whereas suppressed trees (whose crowns are completely below the general crown canopy) may increase in diameter during only a small part of the growing season. Dry weather can shorten the duration of diameter growth substantially, especially in suppressed trees.

Vertical Distribution of Diameter Growth

A tree does not grow in diameter at the same rate all along the stem. In fact, the rate of diameter growth varies consistently. The annual sheath of wood laid down by the cambium is quite thin near the top of the tree. It is thicker further down the stem, becoming thickest in deciduous trees at about the stem height where the number of leaves is greatest. In pines, the annual sheath is thickest somewhere between the middle and base of the crown.

How the thickness of the annual sheath varies with stem height depends on the tree's crown class (Fig 4). In dominant trees, the sheath becomes thinner below the crown and thickens again near the stem base. In suppressed trees, maximum sheath thickness occurs at a greater stem height and,

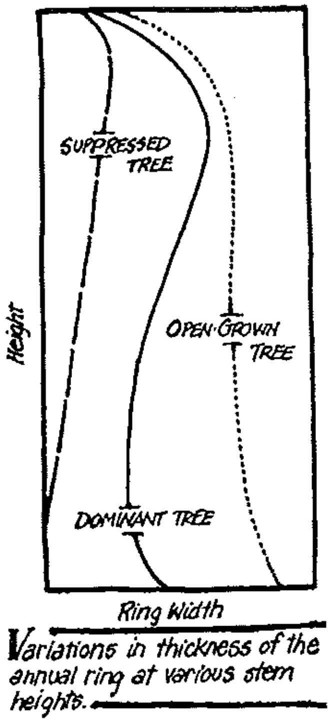


Figure 4. Thickness of the annual layer of wood produced at different stem heights in suppressed, dominant and open-grown trees. Suppressed trees are those with crowns completely below the general level of the crown canopy. They receive no direct sunlight from above or from the side. The crowns of dominant trees extend above the general level of the crown canopy and receive full sunlight from above, some from the side.

below the height of maximum thickness, the sheath becomes thinner and does not thicken near the base of the tree. The annual layer of new wood in suppressed trees is also thinner overall than in dominant trees. Stems of very suppressed trees which often lay down very little wood near the base are much less tapered than those of dominant trees. However, even though there is more diameter growth in the upper stem than in the lower stem of suppressed trees, the trees are still thicker toward the base where there are more annual rings of wood (see Fig. 3). Unlike dominant and suppressed trees, open-grown trees usually show a progressive increase in thickness of the annual sheath from the height of maximum crown width to the base of the stem.

In managed plantations, the annual increment of new wood changes in rather predictable ways. When the trees are young, the annual layer is progressively thicker from the top of the tree downward. As the trees grow older and the crowns grow together or "close," competition for light, water, and minerals intensifies among the trees, and the zone where the layer is thickest moves upward. Below this height, the thickness of the layer decreases toward the stem base. Removing some trees by thinning a stand stimulates cambial growth near the stem base of the remaining trees. As the trees subsequently become more crowded, the position of greatest layer thickness again moves upward. Therefore, to obtain optimum volume growth (and value) it is important to keep forest stands in an uncrowded condition.

Effects of Thinning and Pruning on Diameter Growth and Stem Form

There is much interest in cultural practices which stimulate diameter growth of trees. Although an increase in diameter growth by such practices increases stem taper, normal crown closure tends to keep these effects from becoming serious. Generally, thinning accelerates diameter growth and the greater wood volume combined with an increase in log grade more than compensate for change in stem form.

Thinning a stand of trees increases the growing space for the remaining trees and accelerates physiological activity in their crowns. As a result, the remaining trees grow faster in diameter, and the form of their stems changes. Thinning usually stimulates wood production most near the stem base, resulting in a more tapered stem. How much a tree responds to thinning of a stand depends among other things on its crown class. Dominant trees with large crowns often do not show much response to thinning. More suppressed trees show much greater response.

Pruning branches has just the opposite effect from thinning. Removing lower branches tends to slow diameter growth at the stem base, so more wood is produced in the upper stem after pruning. Pruning, in other words, tends to reduce stem taper. The extent to which tapering is reduced depends on the severity of the pruning and the crown class of the tree. Pruning affects diameter growth of open-grown trees more than stand-grown trees. Both the amount of wood formed and its distribution along the stem of a large-crowned tree vary with the intensity of pruning and the tree's age. Many pruning trials have not changed stem form appreciably because too few branches were removed or the trees were pruned too late.

Extreme taper is normally not a problem in forest-grown trees because they can be bucked into shorter logs, minimizing the impact of volume lost to taper. Nevertheless, using pruning and thinning to manage stem form can pay off in higher stumpage prices.

ROOT GROWTH

The most common types of roots are tap roots (found in oaks and hickories), and fibrous root systems, such as those in pines. However, for many species, rooting characteristics are not fixed because site conditions alter the pattern of root growth. Red maple, for example, has a very plastic root system. It develops many shallow laterals in swamps and a deep taproot in dry upland soils.

The root system of a tree consists of large perennial roots and many small ones that are short-lived. In many tree species, root hairs on the surface of these small roots increase their absorbing surface. Most of these hairs live only days or weeks. As old hairs die, new ones form behind the growing root tips. Many of the small roots normally die, mostly during winter, but also at other times from unfavorable environmental conditions or attacks by pests. Complete defoliation of a tree may induce death of most of these small "feeder" roots.

Roots usually begin to elongate earlier in the spring, and to continue longer, than shoot growth (Fig. 2). The rate of root growth varies during the growing season and in many species occurs in cycles regulated by environmental changes. Root growth rate varies at different soil depths because of differences in water and mineral supply, aeration, temperature and other factors. In woody roots, seasonal cambial growth begins near the soil surface, then the zone of growth moves downward like a wave. Cambial growth in roots is much more irregular than in stems. False and double rings are common in roots, as are roots that are eccentric in cross section.

Closely related species of trees often become joined by root grafts. When growing roots of related trees come into contact, their tissues often fuse in such a way that carbohydrates, growth hormones, water, minerals and disease agents such as fungus spores may pass from one tree to another. Sometimes stumps stay alive for many years because they receive carbohydrates and growth hormones through root grafts with another tree. Herbicides injected into one tree can move through grafted roots and kill other trees by "backlash."

REPRODUCTIVE GROWTH

To produce a large seed crop, a tree must go through several sequential stages. It must form flower buds and then flower. The flowers must be pollinated and female and male reproductive cells must unite (fertilization). The fruits and seeds must grow and ripen, and then the seeds must be shed. Poor seed years often result from a breakdown in one of these essential stages of reproductive growth.

Flowering

Flowers of most forest trees are small and inconspicuous. Some trees, such as birches and alders, have female and male flowers on the same plant. Poplars and willows have female and male flowers on separate plants. Only female trees of these species produce seeds.

Many broad-leaved trees form flower parts between late May and early June in the season preceding the spring in which the flowers open. Weather and site conditions influence the timing.

Flowers of most broad-leaved trees open sometime between March and mid-June, with the order of bloom varying among species. The usual order of flowering is as follows: silver maple, willows, red maple, American elm, birches, sugar maple, oaks, black cherry, and black locust. Unlike these early-flowering species, witch hazel does not flower until autumn. The actual date of flowering of a given species varies from year to year because of differences in weather, especially temperature (Table 1). Over a 48-year period the dates of first flowering of silver maple and black locust trees in southern Wisconsin varied by 43 and 26 days, respectively.

Table 1. Variation in dates of flowering of silver maple and black locust trees in Dane County, Wisconsin.

Year	Silver Maple	Black Locust
1945	March 7	May 31
1950	April 4	June 6
1955	March 15	May 20
1960	April 8	June 1
1965	April 11	May 25
1970	April 5	May 24
1975	April 11	May 24

Growth of Fruits and Cones

The time required for fruits and cones to grow and mature varies a lot. The fruits of elms, poplars, red maple and green ash ripen within 4-6 weeks after pollination. Fruits of most other broad-leaved species develop throughout the entire growing season. Acorns are exceptions and require two years to mature.

On most conifers—including firs, larch and spruce—cones ripen and shed their seeds during one season. Pines, however, require a much longer time to mature seeds. Red pines growing in central Wisconsin, for example, require three growing seasons to produce mature seeds. Cones begin to form in August of one year, but do not become visible until late May or early June of the next year. They grow little during this year, but grow rapidly in the third year, and the seeds ripen by early September.

Periodicity of Seed Production

It is important to know seed production intervals for seed collecting. If you expect to collect and sell seed or use it for your own tree regeneration you will need to know which species are likely to produce heavy seed crops. If you plan to depend on natural seed production for forest regeneration, knowing seed production cycles will help you develop forest management plans.

Forest trees go through a juvenile stage during which they do not produce any seeds. Once they reach adulthood, however, they may produce seeds for as long as they live, providing that environmental conditions are suitable. The length of the juvenile, non-flowering stage varies from 5-10 years for shade-intolerant species to 30-40 years for shade-tolerant species. Jack pine may produce cones by the third year. Slash pine usually takes about 10 years and does not produce many cones until about 20 years of age. The juvenile period may last 20-25 years in Norway spruce and 30-40 years in beech.

As trees age and lose vigor, both the size and quality of their seed crops decrease. Even after reaching adulthood, forest trees do not produce seeds every year because environmental conditions influence flowering. Open-grown trees and those on the edge of a stand usually produce more seeds—and at an earlier age—than do trees growing in a dense stand.

Irregular and unpredictable seed production by many forest trees is one of the most serious problems in forestry. The amount of seed produced by forest trees varies greatly among species and among trees of the same species. It also varies from year to year in the same tree. Some species produce good crops almost every year, while others have good crops irregularly and still others at regular intervals of several years.

Even closely related tree species show considerable variation in seed production. Red maple and silver maple have good seed crops almost every year, whereas sugar maple produces a good seed crop every 2-5 years. Black oak and bur oak tend to have good seed crops every 2-3 years; white oak has irregular heavy seed crops, at roughly 4- to 10-year intervals. Poplars also vary widely in seed production. Black poplar and cottonwood typically have good annual seed crops, but trembling aspen and big-tooth aspen have good crops at 4- to 5-year intervals. Poor seed crops seem to be due to blocking of one or more of the sequential reproductive phases. Each phase is necessary for a good seed crop.

Tree Vigor and Seed Production

Dominance and vigor are important factors in a tree's capacity to produce large seed crops. In the same forest stand, dominant trees of a given species produce much larger seed crops than trees of intermediate or suppressed crown classes do. In very dense stands, suppressed trees may not produce any seeds at all. Within a tree, variations in the vigor of branches also affect seed production. Red pines, for example, typically produce larger cones on the vigorous branches in the upper and middle part of the crown than on the less vigorous lower branches. Furthermore, the large cones contain more and higher-quality seeds than the small cones.

In conifers, pollen cones and seed cones form at different locations and at different times of the year. In pines, pollen cones form at the base of the current year's growth in the lower crown. The seed cones develop in the upper crown, sometimes forming clusters near the end of the current year's growth. In balsam fir, seed cones form mostly in the upper 4-5 feet of the crown, pollen cones much lower. In tamarack, pollen cones develop on 1- or 2-year-old branches; seed cones on older branches (usually 2-4 years old). Pollen cones usually form before seed cones.

Effect of Seed Production on Vegetative Growth

Trees do not grow as much in heavy seed years as they do in other years. Branches of flowering balsam firs elongate only about half as much as those of non-flowering trees. Furthermore, the shoots of flowering balsam firs have poorly developed needles.

Both conifers and broad-leaved trees grow less in diameter in years of abundant seed production. In beech, for example, the width of annual rings that form in good seed years may be only half as wide as those formed in years of low seed production. In fact, ring width may be reduced for two years after a good seed year. Apparently, the reproductive phase in trees monopolizes substances needed for growth. Reproductive growth and vegetative growth seem to compete for carbohydrates, and vegetative growth often loses out.

For More Reading

Physiology of Woody Plants by P. J. Kramer and T.T. Kozlowski. Academic Press, New York, 1979.

Table 2. Variations in Size, Growth Rate, and Longevity of North American Conifers

Common Name	Scientific Name	Maximum height (feet)	Maximum diameter (feet)	Growth Rate	Longevity (years)
Arbovitae (see Whitecedar)					
Douglas fir	*Pseudotsuga menziesii*	270	15	Rapid	—
Balsam fir	*Abies balsamea*	85	3	Rapid	100-150
Fraser fir	*A. fraseri*	65	2.5	Moderate	200-300
Grand fir	*A. grandis*	250	6	Moderate	200-400
White fir	*A. concolor*	200	6	Moderate	100-400
Hemlock (eastern)	*Tsuga canadensis*	160	6	Slow	300-600
Juniper (see Redcedar)					
Larch (see Tamarack)					
Jack pine	*Pinus banksiana*	90	2	Rapid	80-150
Jeffrey pine	*P. jeffreyii*	130	9	Moderate	300-500
Loblolly pine	*P. taeda*	190	5	Rapid	150-250
Lodgepole pine	*P. contorts*	150	3	Slow	120-300
Longleaf pine	*P. palustris*	150	4	Rapid	300-400
Pinon pine	*P. edulis*	50	3	Very slow	150-400
Pitch pine	*P. rigida*	100	3	Rapid	100-200
Ponderosa pine	*P. ponderosa*	235	9	Moderate	300-500
Shortleaf pine	*P. echinata*	150	4	Rapid	200-300
Slash pine	*P. elliottii*	130	3	Rapid	150-250
Sugar pine	*P. lambertiana*	250	10	Rapid	300-600
Virginia pine	*P. virginiana*	100	3	Moderate	100-200
White pine (eastern)	*P. strobus*	220	6	Rapid	300-500
White pine (western)	*P. monticola*	120	8	Rapid	200-500
Redcedar (eastern)	*Juniperus virginiana*	100	4	Slow	150-300
Redwood	*Sequoia sempervirens*	365	20	Rapid	800-1500
Giant Sequoia	*S. gigantea*	350	38	Rapid	2000-3000
Black spruce	*Picea mariana*	100	3	Slow	150-250
Red spruce	*P. rubens*	120	4	Slow	200-300
Sitka spruce	*P. sitchensis*	300	16	Rapid	400-750
White spruce	*P. glauca*	120	4	Slow	150-350
Tamarack	*Larix laricina*	100	3	Moderate	100-200
Whitecedar (northern)	*Thuja occidentals*	125	6	Slow	300-400

Table 3. Variations in Size, Growth Rate, and Longevity of North American Broadleaved Trees

Common Name	Scientific Name	Maximum height (feet)	Maximum diameter (feet)	Growth Rate	Longevity (years)
Black ash	*Fraxinus nigra*	90	5	Slow	—
Green ash	*F. pennsylvanica*	85	2.5	Rapid	—
White ash	*F. americana*	125	6	Rapid	260-300
Bigtooth aspen	*Populus grandidentata*	80	3	Rapid	70-100
Trembling aspen	*P. tremuloides*	120	4.5	Very rapid	70-100
Balsam poplar	*P. balsamifera*	100	5	Rapid	100-150
American basswood	*Tilia americana*	125	5	Rapid	100-140
American beech	*Fagus grandifolia*	120	4	Slow	300-400
Grey birch	*Betula populifolia*	60	1.5	Rapid	50
River birch	*B. nigra*	100	5	Rapid	—
White birch	*B. papyrifera*	120	5	Rapid	80-100
Yellow birch	*B. alleghaniensis*	100	4	Rapid	150-300
Blackgum	*Nyssa sylvatica*	100	4	Rapid	—
Yellow buckeye	*Aesculus octandra*	100	4	Rapid	60-80
Butternut	*Juglans cinerea*	110	3	Rapid	80
Catalpa	*Catalpa speciosa*	120	5	Rapid	100
Black cherry	*Prunus serotina*	100	5	Rapid	100-200
Cottonwood (eastern)	*Populus deltoides*	175	11	Very rapid	60-100
Black cottonwood	*Populus trichocarpa*	225	8	Rapid	150-200
Flowering dogwood	*Cornus florida*	50	1.5	Slow	125
American elm	*Ulmus americana*	120	11	Rapid	150-300
Red elm	*U. rubra*	90	4	Rapid	300
Hackberry	*Celtis occidentals*	130	5	Rapid	75-150
Bitternut hickory	*Carya cordiformis*	85	4	Slow	175
Mockernut hickory	*C. tomentosa*	100	3.5	Slow	200-300
Pecan (hickory)	*C. illinoensis*	180	6	Moderate	300
Pignut hickory	*C. glabra*	120	4	Slow	200-300
Shagbark hickory	*C. ovata*	120	4	Slow	250-300
American holly	*Ilex opaca*	140	4	Slow	100-150
Honeylocust	*Gleditsia triacanthos*	140	6	Rapid	120
Ironwood or Hophornbean	*Ostrya virginiana*	55	1.5	Slow	—
Black locust	*Robinia pseudoacacia*	100	5	Rapid	60-100
Red maple	*Acer rubrum*	120	5	Rapid	80-250
Silver maple	*A. saccharinum*	120	7	Rapid	50-125
Sugar maple	*A. saccharum*	135	5	Slow	200-300
Red mulberry	*Morus rubra*	50	1.5	Moderate	125
Black oak	*Quercus velutina*	55	7	Moderate	150-200
Blackjack oak	*Q. marilandica*	55	2	Slow	100
Bur oak	*Q. macrocarpa*	170	7	Slow	200-400
Northern red oak	*Q. rubra*	150	11	Rapid	200-400
Pin oak	*Q. palustris*	120	5	Rapid	125-150
Post oak	*Q. stellata*	100	4	Slow	250
Scarlet oak	*Q. coccinea*	110	4	Moderate	150
Southern red oak	*Q. falcata*	110	7	Moderate	200-275
Swamp white oak	*Q. bicolor*	100	7	Slow	300
Water oak	*Q. nigra*	125	5	Rapid	175
White oak	*Q. alba*	150	8	Slow	300-600
Persimmon	*Diospyros virginiana*	130	7	Slow	60-80
Sweetgum	*Liquidambar styraciflua*	200	6	Rapid	200-300
Sycamore	*Platanus occidentals*	175	14	Rapid	250-300
Black walnut	*Juglans nigra*	150	7	Rapid	150-250
Black willow	*Populus trichocarpa*	225	8	Rapid	150-200
Yellow popular	*Liriodendron tulipifera*	200	12	Rapid	200-250

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Extension FactSheet

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F-35-02

Measuring Standing Trees

Determining Diameter, Merchantable Height, and Volume

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Stephen M. Bratkovich
Former Extension Specialist, Forestry

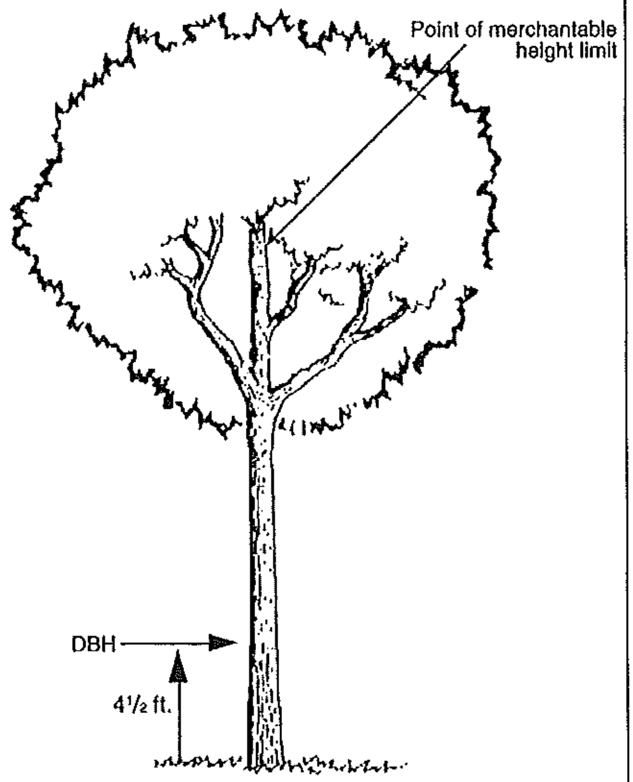
Woodland owners often need to measure the merchantable board-foot content (termed "volume") of certain trees in their woodland. In order to sell timber, for example, an estimate is needed of the quantity to be sold. If trees are to be cut to provide lumber, an estimate of volume is needed to determine what size and how many trees to cut. Using the methods described in this article, a woodland owner can estimate the board-foot volume in one or several trees. If an estimate is needed for several acres, however, it is recommended that the woodland owner engage the services of an Ohio Department of Natural Resources Division of Forestry Service Forester, a consulting forester, or an industry forester. Methods needed to accurately and efficiently inventory timber volume on large areas are beyond the scope of this publication.

Tree Volume Estimation

In the United States, the most common measure of lumber volume is the board foot, defined as a piece of wood containing 144 cubic inches. It can most easily be visualized as a board 12 inches square and one inch thick (12" x 12" x 1" = 144 cubic inches). However, any piece of wood containing 144 cubic inches is a board foot (e.g., 3" x 4" x 12"; 2" x 6" x 12"; etc). The board-foot content of any board may be determined by multiplying the length by the width by the thickness, all expressed in inches, and dividing by 144 cubic inches.

The board foot is also the most common volume measure for trees and logs to be used for lumber and veneer. The board-foot volume of a tree or log is an expression of the number of board feet of lumber that can be cut from that tree or log. The lumber volume that can be cut from a tree or a log depends on a great many variables, including how the tree is cut into logs, the dimensions of the lumber, how much of the log is lost in sawdust and waste, and the efficiency of the sawmill and workers. Because of these variables, the board-foot volume of a tree or log cannot be measured exactly but is estimated.

Numerous methods (called "rules") have been developed to estimate board-foot tree volume. Two board-foot volume rules are commonly used in Ohio, the Doyle and the International 1/4-Inch rules (Tables 1 and 2). Both of these rules provide an estimate of the board-foot content of a tree based on tree-trunk diameter breast high and merchantable tree height (discussed later). The Doyle rule is the most common rule in Ohio. It is used



Common reference points used to measure standing trees.

by the timber industry and many professional foresters. The International 1/4-Inch rule is used by state agencies and the U.S. Forest Service.

A comparison of these two volume tables will show that they are not identical. The International 1/4-Inch rule is generally considered to be the best estimate of the amount of lumber that can actually be sawn from a tree or a log under optimum conditions. The Doyle rule substantially underestimates the volume of trees in the smaller diameter classes. The International 1/4-Inch rule should, therefore, be used when the most accurate estimate of yield is important, as when determining how many trees to cut to obtain a specified amount of lumber. When marketing timber stumpage, however, the choice of volume rule is less critical. Confusion on quantity should not arise as long as both buyer and seller know which rule was used to estimate volumes. Timber stumpage prices are commonly adjusted based on which rule is used.

Measuring Tree Diameter

Tree-trunk diameters are measured at breast height (termed diameter at breast height or DBH), defined as the diameter of the tree 4-1/2 feet above ground on the uphill side of the tree. If a tree forks below breast height, each trunk is treated as a separate tree. DBH can be measured with a tree caliper, a Biltmore stick, a tree diameter tape, or a flexible measuring tape (e.g., cloth or steel). Tree calipers, Biltmore sticks, and tree-diameter tapes can be purchased through forestry equipment supply companies. The flexible measuring tape can be used to measure tree trunk circumference and circumference divided by 3.14 to determine diameter.

Measuring Merchantable Height

Merchantable height is the height of the tree (or the length of its trunk) up to which a particuar product may be obtained, usually minus a one-foot stump height. Merchantable tree heights for sawlogs and veneer are generally estimated to the height where the trunk diameter tapers to 10 inches, or until heavy branching or defects are encountered. The merchantable height of very valuable trees, such as veneer black walnut, may be measured to the nearest foot or two feet. The merchantable height of most other trees is measured in units of 16-foot logs and 8-foot half-logs. Merchantable height measurements are rounded to the nearest half-log. Thus, a tree with a merchantable height of 42 feet would be measured as having 2-1/2 logs of merchantable height.

Merchantable heights may be measured with a number of special instruments designed specifically for tree-height measurements such as clinometers, altimeters, relascopes, or hypsometers. These instruments are available through forestry equipment supply companies. Merchantable heights can also be measured with a long pole if only a few trees are being measured and they have relatively short merchantable heights. With some practice, merchantable heights in log and half-log units can be estimated quite accurately, particularly for trees with short merchantable heights.

Using the Tables to Estimate Merchantable Tree Volume

Once the diameter at breast height and the merchantable height of a tree have been measured, Table 1 or 2 may be used to estimate its volume in board feet. For example, a 20-inch DBH oak tree with a merchantable height of 2-1/2 logs contains 260 board feet Doyle rule or 350 board feet International 1/4-Inch rule.

When using these tables, it is important to remember that only that portion of the trunk that will produce a useable product should be measured. Portions of the trunk or entire trunks that are hollow, excessively crooked, rotten, etc., should not be measured. You may hear foresters or buyers talking about gross and net volume. Gross volume is the estimated tree volume without deduction for defects (i.e., the DBH and merchantable heights of all of the trees were measured ignoring defects, volumes were determined, and the volumes were added up). Net volume is the estimated tree volume with proper deductions made for defects.

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Table 1. Standing Tree Board Foot Volumes — Doyle Rule

Dbh (inches)	Number of 16-Foot Logs							
	1/2	1	1-1/2	2	2-1/2	3	3-1/2	4
	Board Feet							
12	20	30	40	50	60			
14	30	50	70	80	90	100		
16	40	70	100	120	40	160	180	190
18	60	100	130	160	200	220	40	160
20	80	130	180	220	260	300	320	360
22	100	170	230	280	340	380	420	460
24	130	220	290	360	430	490	540	600
26	160	260	360	440	520	590	660	740
28	190	320	430	520	620	710	800	880
30	230	380	510	630	740	840	940	1,040
32	270	440	590	730	860	990	1,120	1,220
34	300	510	680	850	1,000	1,140	1,300	1,440
36	350	580	780	970	1,140	1,310	1,480	1,640
38	390	660	880	1,100	1,290	1,480	1,680	1,860
40	430	740	990	1,230	1,450	1,660	1,880	2,080
42	470	830	1,100	1,370	1,620	1,860	2,100	2,320

From: Ashley, Burl S. 1980. *Reference handbook for foresters.* USDA NA-FR-15. 35 pp.

Table 2. Standing Tree Board Foot Volumes — International 1/4-Inch Rule

Dbh (inches)	Number of 16-Foot Logs							
	1/2	1	1-1/2	2	2-1/2	3	3-1/2	4
	Board Feet							
12	30	60	80	100	120			
14	40	80	110	140	160	180		
16	60	100	150	180	210	250	280	310
18	70	140	190	240	280	320	360	400
20	90	170	240	300	350	400	450	500
22	110	210	290	360	430	490	560	610
24	130	250	350	430	510	590	660	740
26	160	300	410	510	600	700	790	880
28	190	350	480	600	700	810	920	1,020
30	220	410	550	690	810	930	1,060	1,180
32	260	470	640	790	940	1,080	1,220	1,360
34	290	530	730	900	1,060	1,220	1,380	1,540
36	330	600	820	1,010	1,200	1,380	1,560	1,740
38	370	670	910	1,130	1,340	1,540	1,740	1,940
40	420	740	1,010	1,250	1,480	1,700	1,920	2,160
42	460	820	1,100	1,360	1,610	1,870	2,120	2,360

From: Ashley, Burl S. 1980. *Reference handbook for foresters.* USDA NA-FR-15. 35 pp.

FORESTRY
FACTS

UW Extension

COLLEGE OF
AGRICULTURAL & LIFE SCIENCES
UNIVERSITY OF WISCONSIN-MADISON

Department of Forest Ecology and Management • School of Natural Resources

No. 44 August, 1989

What Is A Cord?

A. Jeff Martin, Dept. of Forestry, UW-Madison

A cord is a unit of measure applied to stacked roundwood, usually pulpwood or firewood. With firewood, the pieces may be split before the cordwood stack is formed. Since a cord is a measure of a loose stack of wood, it contains air space as well as solid wood and bark, and is therefore more of an indication of space occupied than actual wood measure. A standard cord contains 128 cubic feet of wood, bark, and air space, often measuring 4 feet high, 4 feet wide, with pieces 8 feet in length, or 4 feet high, 8 feet wide, with pieces 4 feet in length. Although the dimensions can vary, depending on the length of the pieces, the cubic-foot content is constant for a standard cord.

To estimate the number of standard cords in a stack (or truckload) of roundwood, use the following formula:

$$\text{Cords} = \frac{\text{height x width x length}}{128}$$

Where: height, width, and length of the stack are in feet.

A stack with irregular height is best measured by a series of height measurements. These should be taken at even intervals at right angles to the ground or truck bed. The average height is then determined from the series of measurements.

Sometimes we are interested in the solid wood contents of a cord, excluding the bark and air space. Or, we may want to know the amount of wood and bark only. In the Lake States, the average values (based on many measurements for a variety of species and conditions) are shown in the table on page 2.

CONTENTS OF A STANDARD CORD:

Wood, bark and air space	**128 cu. ft.**
Wood and bark	**92 cu. ft.**
Solid wood	**79 cu. ft.**

Therefore, an average standard cord contains 62 percent solid wood, 28 percent air space, and 10 percent bark. Since these are average values, you should remember that some variability will be found, due to differences between species, diameter of the pieces, care in piling, and straightness of the pieces.

Sometimes the pieces are cut to very short lengths, as with firewood, and the face cord (or short cord) is used as the unit of measure. A face cord is 4 feet high, 8 feet wide, with pieces less than 4 feet in length. Firewood lengths are commonly 16 inches.

In the Lake States, pulpwood pieces or "sticks" are commonly cut to 100 inches in length. Therefore a pulpwood cord is 4 feet high, 4 feet wide, with pieces 100 inches long. The pulpwood cord actually contains 133 cubic feet of wood, bark, and air space.

Often we are interested in estimating the number of cords that we will obtain when standing trees are harvested. To do this we normally estimate the number of 8-foot sticks and the DBH (diameter at breast height) for each tree. These values are then used with a cordwood volume table to estimate the cords available. Numerous tables have been developed for this purpose. A table commonly used in the Lake States can be found in UW-Extension Bulletin G3332.

Sometimes we want to convert cordwood volumes to board feet and vice versa. This is often not very reliable because small trees suitable for pulpwood and firewood are not large enough to produce lumber. Therefore such a conversion should be viewed as an approximation only and used accordingly. It is probably safer to convert board feet of sawlog-sized wood to cords rather than converting cords to board feet, to avoid the problem with converting undersized wood. In the Lake States we often assume that 1000 board feet of sawtimber equals about 2.4 standard cords for softwoods (pines, spruce, fir, etc.), and 2.2 standard cords for hardwoods (oaks, maples, etc.)

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August, 1989

What Is A Chain?

A. Jeff Martin, Dept. of Forestry, UW-Madison

A chain is a unit of measure commonly used by foresters to determine horizontal distances. However, the chain is seldom used by others, being replaced by feet and other units. This is unfortunate because the chain, for many purposes, is a more convenient unit.

The chain has a history of use in early surveys. In fact the original tool for measuring distances in the woods of the United States and Canada was commonly the Gunter's Chain. This chain was 66 feet long and composed of 100 links of stout wire, each 7.92 inches long. Today's "chain," also 66 feet long, is actually a steel tape that is either coiled or retracted on a reel for carrying.

Why a unit of measure having such an odd length of 66 feet? This can best be explained by looking at some of the conversions that are possible with the chain. First, let's look at distance:

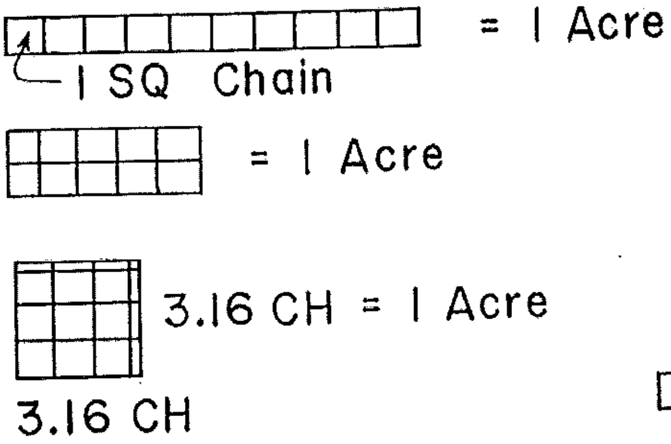
Since a rod equals 16 ½ feet, a chain contains exactly 4 rods; 66/16.5 = 4.0

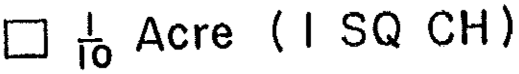
A mile is 5,280 feet long, therefore a mile contains exactly 80 chains; 5,280/66=80.

What really makes the chain a handy unit of measure is when it is used to measure areas:

One square chain (a square having sides that are each 1 chain, or 66 feet in length) contains 4,356 square feet; 66' x 66' = 4,356.

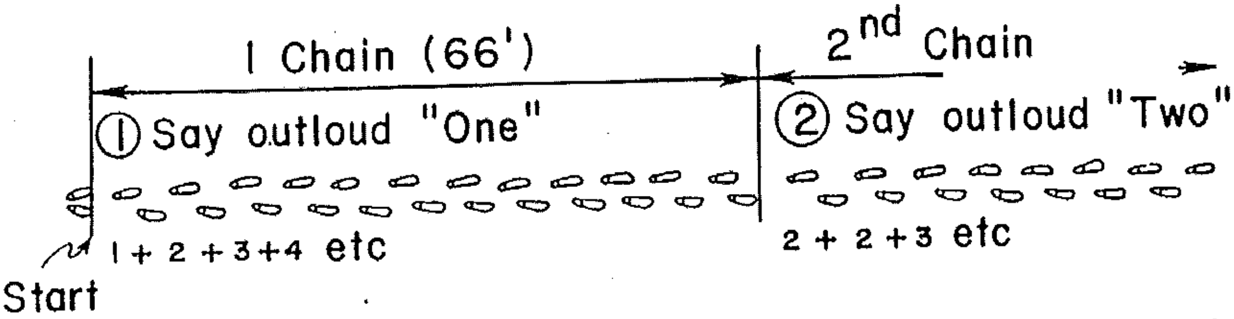
Since one acre contains 43,560 square feet, it also contains exactly 10 square chains; 43,560/4,356=10 (see diagram on page 2).





Therefore, with such useful conversions as 80 chains per mile and 10 square chains per acre, it's no wonder that this unit has survived over the years.

You can borrow or purchase a steel tape graduated in chains for use in determining distances and areas in your woodlot, or you can learn to pace the distances. The latter is less accurate, but may suffice for many purposes other than legal surveys. To learn pacing lay off a 66-foot distance in your woods and mark the ends with stakes. Then walk between the stakes, counting your paces (one pace equals two steps) as you go. You may want to repeat the process a few times and average the results. A word of caution, determine your pacing for a comfortable stride, not one that you normally don't use or can't maintain.



If your land is hilly, you'll want to practice this on steeper ground as well. In this case you must be sure to lay off the 66-foot distance horizontally and not along the slope. This may require measuring the 66 feet in several shorter horizontal segments - called "breaking chain" by surveyors.

Once you've determined the number of paces it takes for you to walk one chain, you're ready to measure distances and areas in the woodlot.

For example, suppose you're curious about the number of acres actually harvested during your last timber sale. If the area is roughly rectangular in shape you can pace the length and width and multiply the two to get the area. If in this example, the width is 12 chains and the length is 15 chains, you would multiply 12 x 15 and obtain 180 square chains in the harvested area. This can easily be converted to acres by dividing 180 by 10, resulting in 18 acres. The acreage of irregular shaped areas can be estimated by partitioning the area into smaller rectangles. Then, estimate the acres in each (as above) and add the results to get a total.

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What Is Basal Area?

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A tree's basal area is the cross-sectional area of the stem at 4 1/2 feet above ground - breast height (see drawing, page 2). Foresters report basal area as either square feet per tree or square feet per acre (see table, page 2).

If you are interested in the mathematics, you can estimate a tree's basal area (in square feet) with the following formula:

$$\textbf{Basal Area} = \frac{3.1416 \times DBH^2}{4 \times 144}$$

This formula simplifies to:

$$\textbf{Basal Area} = 0.005454 \times DBH^2$$

Where: DBH equals the diameter of a tree's stem, in inches, at 4 ½ feet above the ground.

Basal area per acre, the sum of each tree's basal area in your woodlot divided by the acres involved, is used to gauge whether your forestland is overstocked (too many trees), understocked (too few trees), or just right. For more on estimating and interpreting stocking information, the reader is referred to UW-Extension Bulletin No. G3362.

You could determine the basal area for your entire woodlot by actually summing the basal areas of each tree - after considerable effort was spent in obtaining the individual DBH measurements. Fortunately there are several ways of estimating basal area per acre without measuring every tree.

To determine basal area per acre, foresters use a special kind of prism or an angle gauge to obtain precise estimates. However, if you are interested only in a rough estimate to help decide if you need to thin your stand or call in a forester, there are other tools. For a gauge, glue a 1-inch wide target to the end of a 33-inch stick, or use a penny held 25 inches from the eye - about arm's length. If you use the stick/gauge combination, place the zero end under your eye and look toward the 1-inch target 33 inches away.

While standing over a single point, hold the gauge and look at each nearby tree as you rotate in a full circle. Don't miss any trees as you turn. Focus on each tree at breast height - 4 1/2 feet above ground. If the stem of any tree is wider than your target - sticks out past the sides of the penny, for example -- count the tree (see drawing). You don't have to measure anything, just count trees. When you've completed a 360-degree circle about the point, multiply the count by 10. The result is one estimate of basal area per acre. You should repeat this several times throughout your woodlot and average the results.

Table 1. Basal Area Per Tree

DBH	SQ. FT.	DBH	SQ. FT.	DBH	SQ. FT.
5	0.14	**12**	0.79	**19**	1.97
6	0.20	**13**	0.92	**20**	2.18
7	0.27	**14**	1.07	**21**	2.41
8	0.35	**15**	1.23	**22**	2.64
9	0.44	**16**	1.40	**23**	2.89
10	0.55	**17**	1.58	**24**	3.14
11	0.66	**18**	1.77	**25**	3.41

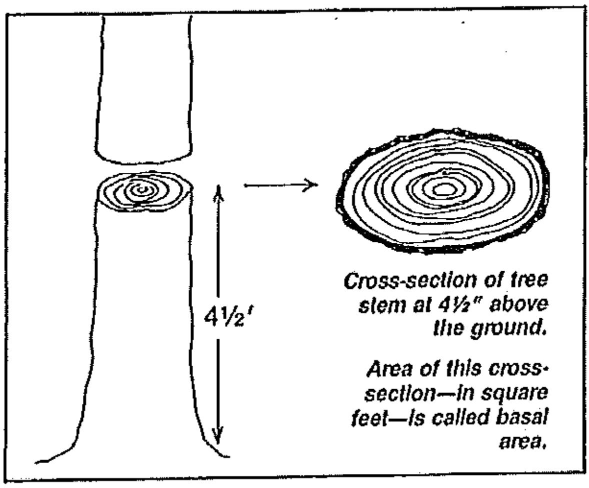

Figure 1....Basal Area Of An Individual Tree

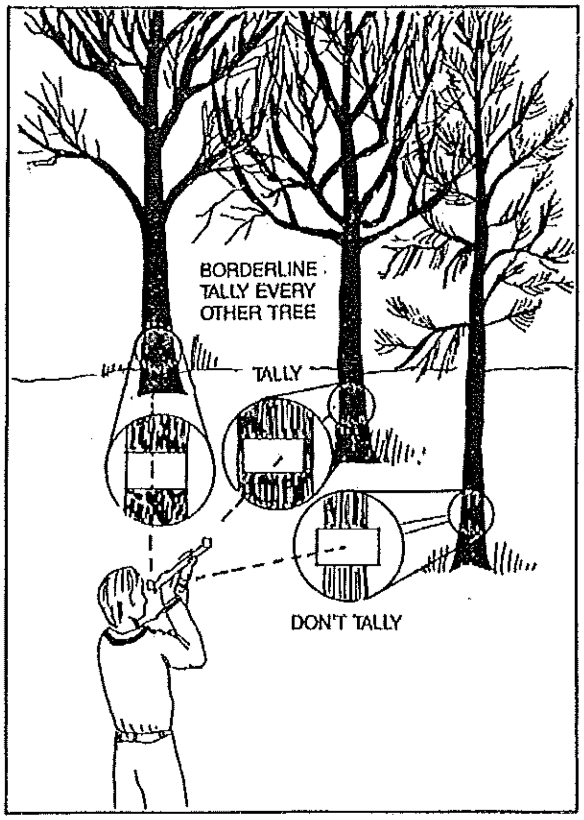

Figure 2....Point Sampling With An Angle Gauge